CHAPTER 1

Irrigation Management in the Fordwah Branch Command Area, Southeast Punjab, Pakistan

Marcel Kuper and Jacob W. Kijne

INTRODUCTION

IN 1989, IIMI-PAKISTAN started research under the Dutch-funded Waterlogging and Salinity Project at three sites in Pakistan's Punjab, where the International Irrigation Management Institute (IIMI) had previously carried out studies on equity of water distribution.

When IIMI started its research under the project, the authors were requested by the Secretaries of the Irrigation and Agriculture Departments to initiate further studies in the area of the Fordwah and Eastern Sadiqia canals in Southeast Punjab. The area is enclosed by the Sutlej River, the Indian border and the Cholistan Desert and is known to be severely affected by salinity and high water tables. Extensive surface and subsurface drainage schemes have been planned for the area, and one is now under construction in an area overlapping the site IIMI selected for its study. As the objectives of the project stipulate that research should be done in areas of incipient waterlogging and salinity, the selected sites are not among the worst affected by salinity or waterlogging in the entire service area of these two canals.

The research objective is to identify possible improvements in irrigation management which may lead to prevention of further land degradation and which could mitigate the effects of salinity on crop production. It is by no means certain that the underlying hypothesis, i.e., improved management can prevent further deterioration, can be demonstrated to be correct. In fact, much of irrigation history indicates otherwise; once water tables are high and secondary salinity has become a source of much reduced productivity, reversal of these trends can only be achieved through the installation of (subsurface) drains for lowering the water table. Salts in the root zone can be leached successfully when water tables have been lowered unless the salinization process proves to be (nearly) irreversible due to sodicity-induced loss of soil structure and very low infiltration rates.

However, soils in the research area are light textured and, over most of the area, capillary rise from water tables is not likely to reach the plant roots. Moreover, there is considerable tubewell development in parts of the area which may be sufficient to maintain the water table at the present depth. The tubewells in the area are mostly privately owned, as the area is not part of a Salinity Control and Reclamation Project (SCARP) which would have entailed the installation of public tubewells. The reason is that the quality of groundwater was judged too saline to justify the cost of installing public wells. This is undoubtedly true for much of the area under the command of the Fordwah and Eastern Sadiqia canals, but, as farmers have found out to their own benefit, it is not true for the riparian zone along the Sutlej, or for the areas close to main canals and distributaries where seepage provides a thin layer of "sweet" groundwater that can be tapped for irrigation.

The tremendous development of groundwater use in irrigated agriculture in the Punjab, through SCARPs and private tubewells, which was initiated to bring down water tables and hence contribute to mitigating problems of waterlogging and salinity, has contributed substantially to the development of secondary salinity, as recent research suggests (VanderVelde and Kijne 1992). Even in areas with low groundwater tables, a process of salinization has been observed to occur. Obviously, these environmental hazards impacting on agricultural production and related to irrigation practices are issues that cut across the traditional compartmentalized institutional structure of Provincial Irrigation and Agriculture Departments and the federal Water and Power Development Authority (WAPDA). This was recognized in the early twentieth century, when the Punjab authorities decided to establish multidisciplinary committees to investigate emerging problems of waterlogging and salinity.

However, at present, precious little information is shared by the various line and research agencies involved in irrigated agriculture on problems of waterlogging and salinity; an indication of the lack of coordination between these agencies on these issues. The present study focuses on the surface irrigation system and the agency directly responsible for operation and maintenance of the system (the Punjab Irrigation Department). The results of this study will, of course, have to be incorporated in a larger framework, linking irrigation management more clearly with problems of waterlogging and salinity that affect crop production.

The paper describes system performance at main-canal level (Fordwah Branch), distributary level (fourteen distributaries that take off from the Fordwah Branch) and eight sample watercourses offtaking from two distributaries in the tail reach of the subdivision. It does so in terms of performance parameters that allow the performance of the Fordwah Branch System to be compared with other systems. The paper also describes the rules and regulations of the engineers of the Irrigation Department who are in charge of system operation, and compares the reality of operation with the nominal rules. Analysis of the results obtained thus far lead to a number of (tentative) suggestions for improvement of the management of the system. These and possibly other management innovations need to be implemented through collaboration of the Irrigation Department and IIMI and their effects monitored, before an answer can be given to the research question posed above.

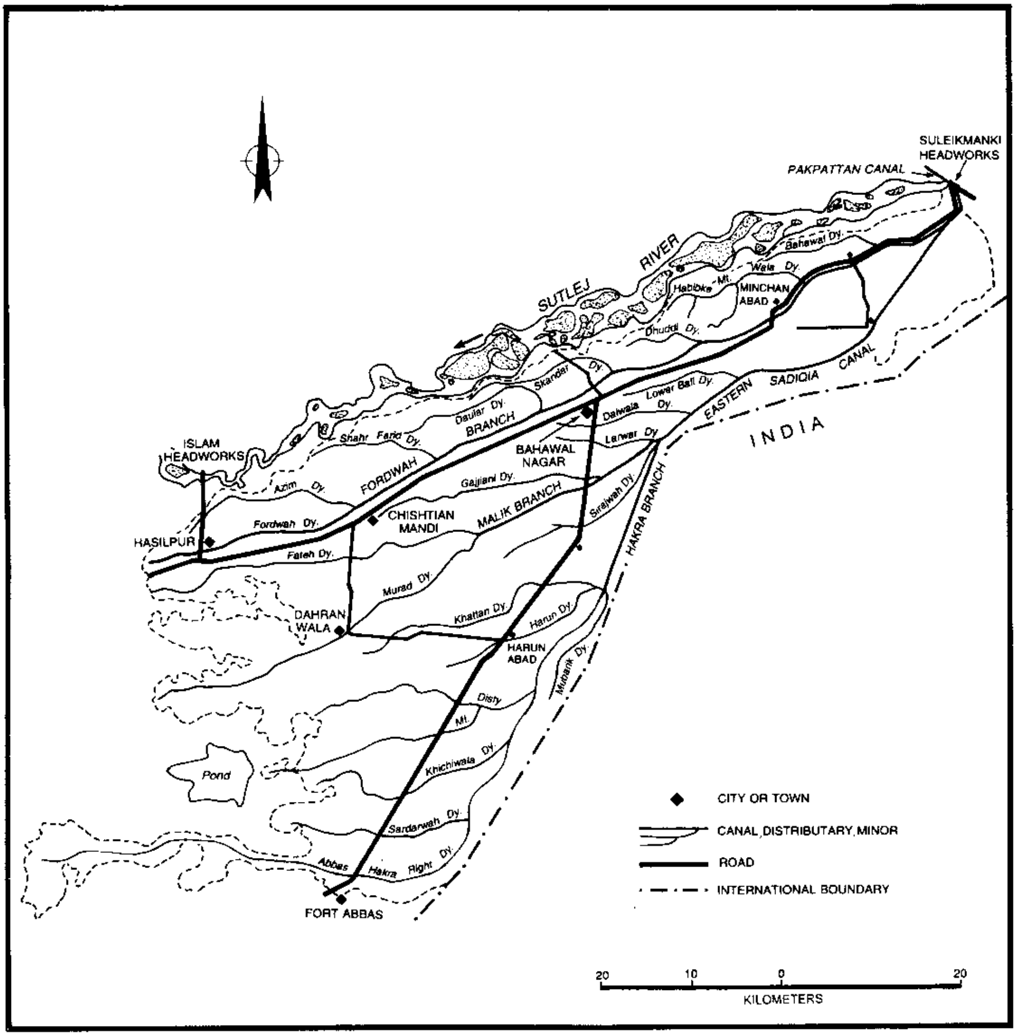
RESEARCH LOCALE

The Fordwah/Eastern Sadiqia area is located in Southeast Punjab and is confined by the Sutlej River in the northwest, the Indian border in the east and by the Cholistan Desert in the southeast (see Figure 1.1). It commands a gross area of 301,000 hectares (ha), of which 232,000 ha are culturable and commendable.

The climate is (semi)arid with the annual evaporation (2,400 mm) far in excess of the annual rainfall (260 mm). The area is part of the cotton-wheat agroecological zone of the Punjab, with cotton, rice and forage crops dominating in *kharif* (summer season), and wheat and forage crops in *rabi* (winter season). In the Fordwah Division, almost a quarter of the area is cropped with rice during kharif, mainly in the alluvial areas of the Sutlej. In contrast, the Eastern Sadiqia Division, not forming part of the riparian tract, is almost devoid of rice; only 5 percent of the area is cultivated to rice.

Fordwah Canal and Eastern Sadiqia Canal receive water from the Sutlej at the left abutment of Suleimanki Headworks (Figure 1.1). Both canal commands were developed under the Sutlej Valley Project of 1921, which was launched to increase the reliability of the water supply to low-lying areas along the Sutlej during kharif. These areas were previously irrigated by inundation canals. An additional objective of the project was to supply water to higher lands closer to the Cholistan Desert. The system derived its water originally from Beas, a pributary of the Sutlej, but since partition, when the link canals that connect the rivers of Punjab were constructed, it receives its supply through the link canals from other sources. In kharif, the supplies stem mainly from the Chenab and in rabi, they come from the Mangla Reservoir.

Figure 1.1. The Fordwah/Eastern Sadiqia area in Southeast Punjab, Pakistan.



To distribute the available, limited water supplies over the Fordwah/Eastern Sadiqia System, some areas, which are prone to waterlogging, were labelled non-perennial (i.e., they only receive water during kharif; April–October) and others perennial, with supplies the year round. The non-perennial canals would receive a maximum of 3 allocations per rabi season to "save the wheat crop" (Siddiqi 1991).

There are no public tubewells in this area. However, a large number of private tubewells have been installed, especially towards the river. Exploitation of groundwater in these command areas varies widely, being influenced by access to canal water supplies and limited by the quality of the groundwater.

The total extent of land affected by waterlogging was reported to be around 380 ha (0.2 % of the Culturable Command Area [CCA]) and that affected by salinity was 36,400 ha (16 % of CCA).[1] An increase in the waterlogged area was reported after the 1988 floods. Extensive surface drainage schemes have been planned, and one is now under construction in part of IIMI's research area.

The riparian tract, traditionally commanded by the inundation canals, was inhabited long before the implementation of the Sutlej Valley Project. The farmers in this area, often referred to as "locals," usually have larger landholdings (see Table 1.3 on page 7), make more use of external labor and tend to have a wheat-cotton farming system. The general perception about these locals is that they are uncooperative (Van Waayjen 1991).

By contrast, the farmers in the higher areas that were developed after the introduction of irrigation are locally known as "settlers," and are considered cooperative and more "progressive."

New Developments

During the annual closure period of 1992, a highly publicized province-wide desiltation campaign was launched by the Chief Minister of Punjab. Canals that had been poorly maintained for years were to be upgraded during closure, larger distributaries were to be cleaned by contractors and the smaller distributaries and minors were to be desilted by farmers on a "self-help basis" (Van Waayjen and Bandaragoda 1992). In the Fordwah Division, a large portion of the canal system was actually desilted during the closure period. In addition to this, a number of head-end outlets in distributaries were remodeled to restore their dimensions to the design values.

Research Area

Part of the Fordwah/Eastern Sadiqia Irrigation System, combining perennial and non-perennial canals in its command, was chosen for the study. A distinct hydraulic (sub)unit (Chishtian Subdivision) was selected starting at RD[2] 199 of Fordwah Branch (offtaking from Fordwah Canal) and going down to the tail at RD 371; it includes the 14 offtaking distributaries. The total length of this stretch of main canal is 52.4 km with 24 direct outlets, and it commands a total CCA of 67,597 ha. The design discharge of Fordwah Branch where it enters the study area is 33 m^3/s. In Table 1.1, the main characteristics of the 14 distributaries are presented.

The study area forms part of the Fordwah Division, which falls under the administrative control of the Executive Engineer (XEN), Fordwah Division. The Division is divided into three subdivisions. The study area is located in the tail subdivision, Chishtian, headed by a Subdivisional Officer (SDO), a qualified engineer who is responsible for the operation and maintenance (O&M) of the canals in his charge.

1 Letter from Superintending Engineer, Bahawalnagar to Chief Engineer, Bahawalpur on 31 January, 1984.

2 RD = Reduced Distance from the head of a canal (in 1,000 feet).

The Chishtian Subdivision is further divided into five sections, each headed by a subengineer who is responsible for the day-to-day O&M of a portion of the main canal and its offtaking distributaries (see Table 1.2).

Table 1.1. Characteristics of distributaries in Chishtian Subdivision.

Name of distributary	Offtake at RD (feet)	CCA (ha)	Status	Design discharge (m^3/s)	Water allocation (l/s/ha)
Daulat	245+600	13,570	NP	5.9	0.38
Mohar	245+600	1,446	NP	1.1	0.49
3 L	245+600	1,166	NP	0.7	0.49
Phogan	267+700	949	NP	0.5	0.49
Khemgargh	281+000	2,032	NP	0.8	0.38
4 L	281+000	877	NP	0.5	0.49
Jagir	297+500	1,604	P	1.1	0.42
Shahar Farid	316+400	10,255	NP	4.3	0.38
Masood	316+400	3,295	P	1.0	0.25
Soda Minor	334+000	4,093	NP	2.2	0.49
5 L	348+800	357	P	0.1	0.25
Azim	371+600	12,199	NP	6.9	0.49
Mehmud	371+600	813	P	0.2	0.25
Fordwah	371+600	14,941	P	4.5	0.25

Notes: P= Perennial
NP= Non-Perennial

Table 1.2. Sections of Chishtian Subdivision.

Section	Area of authority, Fordwah Branch (RD)	Area of authority, distributaries (RD)
Takhat Mal	199–281	Mohar, Daulat (0–63), 3L, 4L, Phogan
Chak Abdullah	281–334	Jagir, Masood, Shahar Farid (0–47), Soda
Chishtian	334–371	5L, Mehmud, Forwah (0–64), Azim (0–52)
Khemgarh	—	Daulat (63-tail), Shahar Farid (47-tail)
Hasilpur	—	Fordwah (64-tail), Azim (52-tail)

The Fordwah Branch has six control points (cross-regulators) in the Chishtian Subdivision (see Figure 1.2), with distributaries offtaking just upstream of five of these regulators (RD 199, RD 245, RD 281, RD 316 and RD 371). The remaining cross-regulator at RD 353 controls the water level in the Fordwah Branch itself with only a very small distributary (5 L) offtaking upstream of this control point.

Gauge Readers observe the water levels twice daily at all these control points and the data are transmitted through signalers to the SDO and/or to the XEN via telegraph, and on the basis of these data, the irrigation officers are supposed to take decisions regarding the operation of the irrigation system in their (sub)division.

Two major distributaries offtaking at the tail of Fordwah Branch were studied in more detail to assess the impact of main system performance on the water distribution at secondary level. Eight sample watercourses were selected along the distributaries to study the effects of the operation of the irrigation system at field level. The main characteristics of the eight watercourses are presented in Table 1.3.

Figure 1.2. Layout of Fordwah Branch.

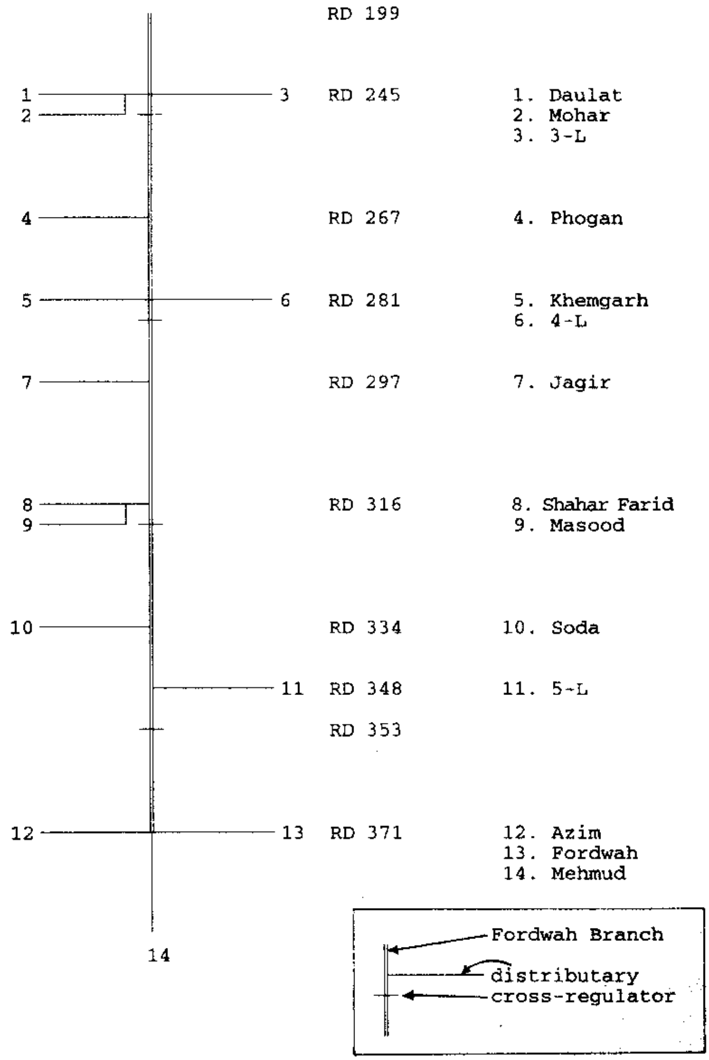


Table 1.3. Characteristics of sample watercourses.

Watercourse	CCA (ha)	Number of landowners	Design discharge (l/s)
Azim 20610 L	119	10	45.9
Azim 43260 L	66	6	26.3
Azim 63620 L	121	14	59.2
Azim 111770 L	119	19	45.9
Fordwah 14320 R	196	46	49.3
Fordwah 46725 R	172	14	44.7
Fordwah 62085 R	133	45	33.4
Fordwah 130100 R	256	42	64.6

Research Methodology

A comprehensive set of primary data was collected from June 1991 to October 1992, focusing especially on rabi 1991/1992 and kharif 1992. To study the performance of the main system, discharges were monitored daily by recording water levels and gate settings at all control points in the Branch Canal and at the inlets to the distributaries downstream of RD 199. This was complemented by interviews with the operating staff using a formal questionnaire.

As part of the study at secondary level, discharges were measured daily along the two sample distributaries, Fordwah and Azim, during kharif 1991 and readings of tail gauges in both distributaries were recorded daily from rabi 1991/1992 onwards. In addition to this, the daily water intakes of sample watercourses were determined.

The operation of tubewells in the command areas of sample watercourses was also monitored daily from June 1991 onwards. Basic socioeconomic data for the sample watercourses, and the status of the *warabandi* ("fixed turns") were obtained through formal questionnaires.

SYSTEM REGULATION — OFFICIAL DIRECTIVES

The Fordwah Canal System, as previously mentioned, is part of the Sutlej Valley Project, which was designed in the 1920s and has been in operation since 1927. The operational objectives, no different from the rest of the Indus Basin Irrigation System, were to allocate and distribute water within as large an area as feasible and as equitably as possible (Bandaragoda and Firdousi 1992), after which farmers would share the water among themselves through a flexible roster of turns called *kacha warabandi*[3]. This warabandi was agreed upon by the farmers themselves, with the Irrigation Department (ID) interfering only when disputes arose. About 20–30 years ago, an increasing occurrence of disputes over the distribution of water in watercourses led the ID to

3 kacha = informal, wahr = turn, and bandi = fixed.

intervene in the vast majority of watercourses and fix an official roster of water turns, *pacca warabandi* (*pacca* = official).

In the design, the area to be irrigated annually was based on the availability of water and the total Culturable Command Area (CCA) with fixed design cropping intensities. In the Fordwah Division, the non-perennial canals have a cropping intensity of 70 percent (35% in kharif and 35% in rabi), whereas the perennial canals have a cropping intensity of 80 percent (32% in kharif and 48% in rabi). The capacities of canals were subsequently determined by multiplying the CCA with the design duty (usually presented in cfs/1,000 acres), and the expected conveyance losses were added. The duty for most perennial-canal distributaries in the Fordwah Branch is 0.25 l/s/ha CCA (3.5 cfs/1,000 acres), while the non-perennial distributaries have a duty of 0.4–0.5 l/s/ha CCA (5.5–7.0 cfs/1,000 acres).

According to the Public Works Department (PWD) Manual (1963), it is customary to treat non-perennial areas more generously in the matter of water allowances during kharif as a kind of compensation for the deprivation of water during rabi. The duties are supposedly, to some extent, based also on the type of soil in the command area, the prevailing climate and the dominant crop. Hence, a second reason for the higher water duties in the non-perennial canals in the Fordwah Division is their location in the rice-cropped, pre-project irrigated, riparian tract.

The implication of fixing the cropping intensities at less than 100 percent in each season is that the actual water allowances for the crops are much higher than the official duties determined for the CCA. When the cropping intensities are taken into account, the water allowances work out to be 0.8 l/s/ha (11.3 cfs/1,000 acres) for perennial and 1.1–1.4 l/s/ha (15.7–20.0 cfs/1,000 acres) for non-perennial canals. Nowadays, however, actual cropping intensities in Punjab are much higher; the Fordwah Division, for instance, achieves an annual cropping intensity of 108 percent, rendering canal water supplies insufficient to cover crop water requirements.

The irrigation system, however, allows some flexibility in the delivery of water. The canal officers (XEN, SDO) can reduce or increase the water supply to main canals and to distributaries according to the (perceived) demand in the command areas. To effect a change in the supply to the system, the ID has established a peer-based communication system wherein the SDOs of the subdivisions of a canal command, starting from the tail of the system, pass on a request, the *indent*, for the desired quantity of water in their subdivisions. In the Fordwah Division, the SDO, Chishtian indicates the desired discharge for his subdivision, through telegraph, to the SDO, Bahawalnagar who places the combined indent of Chishtian and his own division with the SDO, Minchinabad. The SDO of this subdivision, because of its location at the head of Fordwah Canal, is the indenting officer of Fordwah Division who submits the combined indent of Fordwah Division to the XEN in charge of Suleimanki Headworks. The XEN, Suleimanki then tries to match the indents received from all main canals that take off from Suleimanki with the water allowances (for 10-day periods) indicated by the Director, Regulation, based in Lahore. In case of a shortage of water at Head Suleimanki, the shortfall will be shared equally by all divisions. The decision taken by the XEN, Suleimanki is conveyed to XENs and SDOs of the affected divisions.

An indent can be fixed for a definite period, say for a month, or for an indefinite period. Indents are sometimes frequently changed in case of emergencies; for instance, when a breach has occurred in a distributary. The new indent is then quickly passed on via upstream subdivision(s) to the XEN, Suleimanki, who takes action accordingly.

An indent point is fixed usually at the head of each subdivision. In the Chishtian subdivision, it is at RD 199.

Increased cropping intensities and the development of previously unirrigated lands have strengthened the general perception that canal water supplies are insufficient to feed all distributaries simultaneously. Hence, over the past 15–20 years, the ID has introduced rotational programmes within divisions, with subdivisions being given preference with 8–10-day rotations.

In the Fordwah Branch, 3.3 m^3/s (116 cfs) or almost 5 percent of the total design discharge of 73.7 m^3/s (2,603 cfs) is allocated to direct outlets of the Fordwah Branch, all of which were sanctioned during the last 10–20 years. The larger distributaries of the Fordwah Branch are known to be run at an average discharge which is higher than the design discharge in order to feed the tails. The tail reaches receive less than their share because of several intra-distributary distribution problems, such as water theft, siltation, etc. (Kuper and Strosser 1992).

The XEN, Fordwah Division has introduced an 8-day rotation between the 3 subdivisions of his division, during kharif. Within this 8-day period, first, second and third preferences are given to the three subdivisions. The subdivision that has first preference takes all the water it requires according to its indent, enabling its main distributaries to run at full supply level. Only the requirements of smaller distributaries can be met when the subdivision is in second or third preference. After the subdivision in first preference has taken its full share, the remaining water may be used by the subdivision that has second preference, with the subdivision in third preference taking all the water that is left.

This rotational programme does not apply to water allocation during rabi when only 6 perennial canals in the division, all of which are located towards the tail of Fordwah Branch, draw water. In rabi, water is supplied to Fordwah Branch through the Sadiq-Ford Feeder, which takes off at RD 189 in Eastern Sadiqia Canal and discharges into Fordwah Branch at RD 129. The supply through this feeder is subject to a rotational programme in the Eastern Sadiqia Division, during rabi.

Some 10 years ago, it was felt that available supplies were not sufficient to distribute water simultaneously to all divisions. At Head Suleimanki, a rotational programme was therefore implemented between the divisions under the responsibility of the Superintendent Engineer, Bahawalnagar Circle. First, second and third preferences were allotted to each of the three divisions in 10-day rotation periods, similar to the already ongoing programme of rotations between subdivisions.

The Chishtian Subdivision generally faces a severe water shortage when it is in the third preference. It is left to the discretion of the SDO to distribute the water as equitable as possible. A rotation within the subdivision is, therefore, implemented as the water supply to the tertiary units cannot be regulated. This informal programme is effected between 3 sections of the main canal, i.e., Takhat Mal (RD 245–281), Chak Abdullah (RD 282–316), and Chishtian (RD 316–371) with their offtaking distributaries. Execution of this rotation, which is not documented, is subject to the judgment of the SDO and subordinate regulating staff, who take into consideration the amount of water certain distributaries have received so far during the season in comparison with other distributaries in the subdivision.

Execution of operational orders issued by the canal officers (XEN, SDO) is carried out by gauge readers, who also inform these officers of the water levels, discharges and tail-gauge readings on a daily basis. In the Fordwah Branch, a gauge reader is generally made responsible for the operation of a cross-regulator and one to three secondary intakes just upstream of the regulator.

PERFORMANCE OF THE FORDWAH BRANCH — RESULTS AND DISCUSSION

A first step in the analysis of the performance of an irrigation system in an attempt to identify bottlenecks that affect the performance adversely is to quantify water delivery to different parts of the system. Following Molden and Gates (1990), a number of performance parameters were calculated for the 14 secondary canals in Chishtian Subdivision. Three performance parameters were calculated: adequacy, dependability and equity. During analysis, a question that arose was how the performance of Fordwah Branch compared with that of canals that have been reported on in previous IIMI-Pakistan research. Much of the research work reported so far was carried out in the command area of Upper and Lower Gugera Branches of Lower Chenab Circle East, Mananwala and Lagar Distributary in the upper reaches, and Khikhi and Pir Mahal in the lower reach of the system. The parameter used in these studies to indicate the degree of (in)equity of the system at secondary level is the amount of water delivered as a fraction of the design discharge. Therefore, a comparison was attempted with the data of the Upper and Lower Gugera distributaries reported earlier (Bhutta 1990, Bhutta et al. 1991).

Adequacy

Generally, a fundamental objective of irrigation systems is to deliver the amount of water required to adequately irrigate crops. However, this was never the stated objective of irrigation systems in the Indus Basin, where the intention at the time of the design of the systems — for the Fordwah Eastern Sadiqia System, some sixty years ago — was to spread the water equitably among the farmers. It has been argued before that the aim of equity of distribution is no longer attained partly as a result of physical shortcomings of the systems (deferred maintenance, siltation), and partly due to the sociopolitical situation where water (and other resources) is distributed on the basis of power and influence rather than in equitable shares among the users. A comparison of the degree of adequacy of the delivered amount among distributaries within a system, and between sets of distributaries in different systems allows a ranking of system performance in terms of adequacy of delivery.

The amount of water required is a function of the area of land that is cropped and irrigated, the crop water requirements of the crops grown on the land, application losses, and cultural practices such as irrigation for land preparation and leaching. Adequacy of delivery depends on water supply, specified delivery schedules, the capacity of the hydraulic structures to deliver irrigation water according to the schedules and the operation and maintenance of the delivery system.

Cropping intensities in the Fordwah Division, originally designed to be 70–80 percent annually, have gone up to 108 percent,[4] affecting the adequacy of canal water supplies.

Considering the relative service areas of perennial and non-perennial distributaries, and the actual recorded cropping intensities in the command areas of the sample watercourses, the value of the cropping intensity for the command areas of perennial and non-perennial distributaries was taken as 67 percent for the calculation of crop water requirements for kharif 1992. Actual crop water requirements were calculated from the relative areas planted with the main kharif crops, i.e., cotton, rice, sugarcane, fodder and an oil crop (sarson), making use of the FAO program, CROPWAT. Conveyance efficiency was assumed to be 60 percent and no allowance was made for leaching (Van Essen and Van der Feltz 1992).

4 According to official ID (Khasra) data (average for 10 years). IIMI data suggest even higher values, with sample watercourses attaining cropping intensities of 150 percent (Kuper and Strosser 1992).

The performance parameter for adequacy, according to Molden and Gates (1990), is :

$$P_A = \frac{1}{T}\sum_T \left(\frac{1}{R}\sum_R \frac{Q_D}{Q_R}\right)$$

where Q_D/Q_R is the ratio of water supply over water demand.

The equation indicates that the values of Q_D and Q_R are defined for discrete locations where water is delivered within the region R, and for finite times within the period T. Ratios of weekly averages of daily values of Q_D and Q_R were calculated and used in the above equation. The performance parameter for adequacy, P_A, for kharif is the arithmetic mean of those ratios for the period of 20 May-12 October. A similar value, P'_A, can be calculated for the ratio Q_D/Q_S, where Q_S stands for the design discharge. As Q_D/Q_S equals the delivery performance ratio, comparison with published values of other systems is possible.

Molden and Gates (1990) present a tentative performance standard in which a P_A value of more than 0.9 is assumed to be good, a value between 0.8 and 0.9 to be fair, and that below 0.8 to be poor.

Dependability

Dependability is defined as uniformity over time of the ratio of the delivered amount, Q_D, to the required amount, Q_R. A system that performs in a consistent manner is considered dependable. The value of this parameter is based on the hypothesis that farmers prefer a system that delivers water in a predictable way, even though it may be inadequate in amount, over a system that is unpredictable but delivers adequately over the entire season. Unpredictability prevents farmers from planning optimal cropping patterns and planting intensities. A farmer can plan for a dependable delivery of an inadequate supply of water by planting less area or growing different crops. Farmers in the Punjab have reacted to the perceived inadequacy/unreliability of canal water supplies by installing large-scale, self-controlled tubewells. Molden and Gates (1990) proposed as a measure of dependability of water delivery the temporal variability in the ratio of Q_D over Q_R, supply over demand. It is expressed as:

$$P_D = \frac{1}{R}\sum_R \mathrm{CV}_T\left(\frac{Q_D}{Q_R}\right)$$

where $CV_T(Q_D/Q_R)$ is the temporal coefficient of variation (i.e., the ratio of standard deviation to the mean) of the ratio Q_D/Q_R for one specific location within the region R, over the time period T.

A corresponding value, P'_D, represents the temporal variability in the ratio of Q_D over Q_S.

The closer the value of P_D is to zero, the greater the degree of dependability of water delivery. Molden and Gates (1990) suggest that performance is good if P_D falls between 0 and 0.1, fair for P_D values between 0.11 and 0.2, and poor for P_D values above 0.2.

Equity

Equity of water distribution can be defined as the delivery of a fair share of water to users throughout the system. The fairness of a share may be based on legal rights for water, as in a prior appropriation system, or on the delivery of a fixed proportion of a water supply based on the extent of the irrigated lands served by each outlet. The latter, of course, is done in many rotational schemes, and is the stated objective of water delivery in Pakistan's systems. Molden and Gates (1990) mention that equity of water delivery is a difficult objective to measure because there are many factors that determine the meaning of a "fair share." As was pointed out before in other publications (see e.g., Bandaragoda and Firdousi 1992), fair shares are often interpreted subjectively and have become to depend on the (political) power of the recipient. Measurement of equity of distribution is important as it is used in Pakistan as an indication of the need for management changes required to sustain irrigated agriculture in view of salt accumulation where farmers are irrigating with marginal quality groundwater because of the inequity in the delivery of canal water.

Following Molden and Gates (1990), we define the equity parameter as the spatial uniformity of the ratio of the delivered amount to the required amount (Q_D/Q_R), as in:

$$P_E = \frac{1}{T}\sum_T CV_R\left(\frac{Q_D}{Q_R}\right)$$

$CV_R(Q_D/Q_R)$ is the spatial coefficient of variation of the ratio Q_D/Q_R for a specific time over the region R. This measure describes the degree of variability in relative water delivery from point to point over the region. To assess the equity with reference to the design discharge, a value P'_E is introduced.

The closer the value of P_E is to zero, the greater the degree of equity (spatial uniformity) in delivery. Molden and Gates (1990) suggest as boundaries between good, fair and poor performance in terms of equity, P_E values of 0.1 and 0.2.

Results

Values of the indicators for the secondary canals in the Fordwah Branch downstream of RD 245, calculated as described above, quantify how well the system performs and permit comparison with previously reported results for the Gugera Canal System. The sets of values for the Fordwah Branch and Gugera systems are shown in Table 1.4.

Evidently, the performance of the Fordwah Canal System leaves much to be desired when all three indicators, with respect to the crop water requirements and the design discharges, are rated as "poor." The difference in calculated values between Fordwah and Gugera canal systems is substantial, even though the difference in rating is not. The delivery of water during kharif to Gugera's distributaries is comparatively better, though not significantly, than to Fordwah's, with Gugera rated fair and Fordwah poor. The differences between the two systems are even greater in terms of the variation in discharge delivered to secondary canals, and in the equity of water delivery to these canals, Gugera performing significantly better (at a 5% significance level) than Fordwah. The inflow in both systems is not taken into consideration here. However, available supplies are distributed significantly better (more equitably) in Gugera than in Fordwah, as evidenced by the equity parameter.

Table 1.4. Performance Indicators for Fordwah and Gugera Canal systems during kharif.

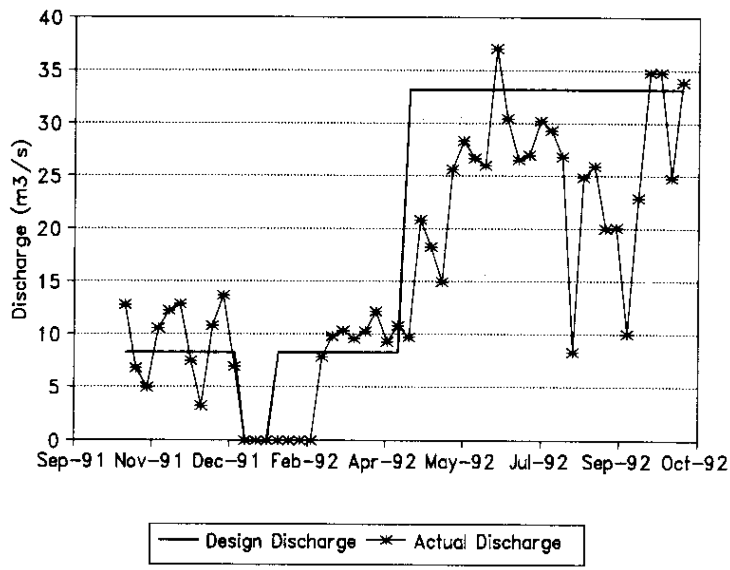
Indicators	Fordwah Branch	Rating	Gugera Branch	Rating
Adequacy (P_A)	0.67	Poor		
DPR (P'_A)	0.76	Poor	0.81	Fair
Dependability (P_D)	0.47	Poor		
Temporal CV (P'_D)	0.41	Poor	0.24	Poor
Equity (P_E)	0.63	Poor		
Spatial CV (P'_E)	0.56	Poor	0.38	Poor

Canal Operations

What are the causes of the poor performance of distributary canals in the Chishtian Subdivision? Performance of the canal system in this subdivision, which forms the lower part of the Fordwah Branch, while being affected by operations/regulations in the subdivision itself, is governed to a large extent by the amount of water that flows into the subsystem, which in turn is a function of the inflow into the Fordwah Canal system and operations/regulations in upstream subdivisions.

The inflow into the subdivision was evaluated at RD 245, upstream of the cross-regulator, where the first distributaries are offtaking, and the results are presented in Figure 1.3. In rabi, the peaks and valleys are a result of the rotation in Eastern Sadiqia Division in which the Sadiq-Ford feeder also participates. The annual closure was prolonged in 1992 from the originally envisaged three weeks to a period of seven weeks, partly due to a unusually heavy desiltation campaign.

Figure 1.3. Inflow in the Chishtian Subdivision at RD 245 (weekly averages, 1991/1992).



Supplies at the start of the kharif season (April to the beginning of June) were well below design, due mainly to a shortage in the supply to the Fordwah Canal. Ten-year averages of water supply to the Fordwah Branch (data provided by the Irrigation Department) show an average deficit in supply of 77 percent and 27 percent for April and May respectively, whereas for June, the situation improves markedly with a deficit of only 8 percent compared to design. The shortage in supply occurs before the rainy season when water levels in the River Chenab, the main source of irrigation water for the Fordwah system during kharif, are low.

Supplies improved during June and this level was fairly well sustained throughout August, September and October. Two steep valleys can be discerned in Figure 1.3 during this period, showing disturbances in the supplies to the subdivision and having an adverse effect on system performance. The first valley, which occurred in the last week of July, was caused by a temporary closure of the link canal feeding the Suleimanki Headworks, forcing the Fordwah System to close for four days. The second valley, which took place in the first week of September, was due to floods in the River Sutlej combined with heavy rains in the Fordwah Division, resulting in the closure of Fordwah Canal for five days. Observations made during 1991 suggest that these types of events occur frequently.

An analysis of the performance of the canal system in the subdivision itself can be made by comparing the three sections between which an informal rotation exists. In Table 1.5, the results are summarized. The calculated values indicate a marked difference in performance between the three sections. P'_A, an indicator of the total volume of water delivered, is rapidly decreasing towards the tail of the Fordwah Branch from a level of 0.79, almost a fair performance according to Molden and Gates (1990), to 0.45 in the tail section. The variation in discharge (P'_D values) does not change towards the tail, indicating that even though the volume of water may be inadequate in the tail section, the delivery of water is no more variable than in the head reach. The distribution of water between the distributaries, however, appears to be worse in the tail section than in the two upstream sections (*vide* the values under the heading "Equity" in the Table).

Table 1.5. Performance of sections of Chishtian Subdivision during kharif 1992.

Section	Equity (P'_E)	Dependability (P'_D)	Adequacy (P'_A)
Takhat Mal	0.52	0.26	0.79
Chak Abdullah	0.46	0.26	0.57
Chishtian	0.65	0.25	0.45

When comparing perennial and non-perennial canals, which officially receive equal shares of water in kharif, it appears that non-perennial canals receive a relatively larger amount of water (at a 5% significance level), with P'_A of 0.75 for non-perennial canals, and a P'_A of 0.52 for perennial canals. In terms of variability, perennial canals are slightly better off, though not significantly so.

Discussion

The inflow into the Chishtian Subdivision, which was found to be both inadequate and unreliable, affects the performance of the canal system in this subdivision. However, the performance deteriorates towards the tail of the subdivision, implying a negative effect of operations in the Chishtian Subdivision on the performance of the 14 secondary canals.

Three rotations coexist at different levels of the system with the rotation at subdivision level being informal and based on the judgment of the SDO or operating staff. While this may be hardly ideal in terms of transparency, both for the implementing personnel and for the beneficiaries, the situation is further aggravated by a series of contradicting operational objectives and system restrictions with different actors across the canal system.

While, officially, all secondary canals should receive an equal share of water during kharif, different actors have different operational preferences. The argument of good quality groundwater is used when commenting on the apparent poor delivery to Azim and the argument of waterlogging is used when indicating a preference for the Fordwah Distributary as compared to Azim.

Gauge readers have been found to give preference to the distributaries offtaking at their own control points and thus reduce the share that is passed on to downstream sections of Fordwah Branch. During interviews, all nine gauge readers in the study area expressed priority for keeping the supply to offtaking distributaries constant at an adequate supply level (keeping in mind the indent) when water levels upstream of their control point in the Fordwah Branch were changing.

Changes in water levels (and discharges) in Fordwah Branch are substantial, with discharges downstream of RD 245 fluctuating more than 3 m^3/s (more than 10%) within a day (van Essen and van der Feltz 1992). IIMI's automatic stage recorders indicate that fluctuations in discharge are more pronounced during rabi. This is confirmed by gauge readers who indicate that days with large fluctuations in discharge generally occur two and four days out of seven for kharif and rabi, respectively. Gauge readers responsible for smaller distributaries reported that they would keep their distributaries fully open even when the discharge in the main branch would drop substantially below normal supply level. An explanation for this is that farmers from offtaking distributaries exert more pressure on gauge readers than that by farmers in downstream command areas. When checking the performance of smaller distributaries in comparison to larger ones (with the dividing point arbitrarily taken at 2 m^3/s), it appears that the average volume of water delivered to small distributaries is significantly better (at a 5% significance level) with P'_A equal to 0.74, when the P'_A for larger distributaries is 0.54. In terms of dependability, both groups have approximately the same value with 0.44 and 0.48 for large and smaller distributaries, respectively (difference is not significant).

Gauge readers appear to be quite independent in the operation of structures under their control, as is shown by the fact that the number of adjustments in gate settings (resulting in changes in discharge) far exceeds the number of instructions from canal officers (a ratio of about 25:1). This makes the operational preference of gauge readers an important issue in the distribution of water.

When comparing the number of operational instructions from SDO/XEN (Table 1.6), it appears that the attention is focused on RD 199 (handover point for tha Chishtian Subdivision) and RD 316. An explanation for the attention to RD 316 could be that it is the only control point in the subdivision with a telegraph that is in working order, other control points relying on messages being taken by *baildars* (Irrigation Department labourers), etc. Similarly, it appears that control points are very rarely visited by (sub)divisional officers, whereas the high number of visits to RD 199 again attract attention.

In contrast, we have the cross-regulator at RD 354 about which little or nothing is heard, which is rarely visited by canal officers, and from where even gauge readings are not relayed anymore. The presence of only one very small distributary upstream of this structure may be an explanation for the apparent lack of interest in this control point.

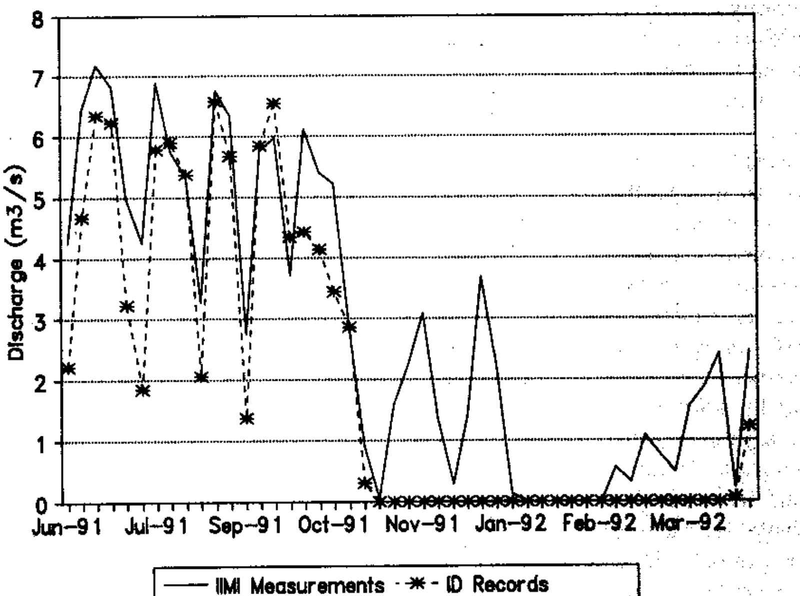
Another cause for the confusion of operating staff is the (non)perenniality of distributaries. Although officially entitled to three allocations of water per rabi season (Siddiqi 1991), when the water supply permits, operating staff are generally under the impression that non-perennial canals are not to be operated. When they are operated, as frequently occurs, personnel often consider this as illegal and records indicate no discharge (see Figure 1.4).

Table 1.6. Operatiknal practices of gauge readers in the Fordwah Branch.

Location	Number and type of structure	Operational orders received per month	Visits (of SDO) per month	Manipulations per day
RD 199	CR, Ds (3)	12	10	0– 5
RD 245	CR, Ds (3)	2	2	2–10
RD 267	Ds (1)	1	1	0– 3
RD 281	CR, Ds (2)	1	1	4–10
RD 297	Ds (1)	3	1	0– 5
RD 316	CR, Ds (2)	15	2	10–15
RD 334	Ds (1)	2	1	0–10
RD 354	CR, (1)	1	0	6–10
RD 371	Ds (3)	4	1	12–20

Notes: CR = cross-regulator
D = distributary

Figure 1.4. IIMI and ID discharges in Azim Distributary — a comparison.



At a number of the smaller distributaries, temporary gauge readers or even (regulation) *baildars* are appointed to monitor the gauges and to adjust the gates. Their experience/training and formal education is generally of a lower level than that of the gauge readers at the more important control points. Usually, the operating staff at smaller distributaries have no concepts of Full Supply Levels (FSL), discharges or rating tables. In most cases, they do not even report the gauge readings to the gauge readers at the main control points, who are supposed to relay the data to the SDO through the signaller. But these, usually experienced, gauge readers estimate the gauges of the smaller distributaries without having seen them, and convey this data accordingly. The same practice exists at the tail gauges. When such a gauge reader makes a mistake by sending, for instance, a value of 0.3 m (1.0 foot) for a distributary that is officially closed, the signaller intimates to the concerned gauge reader that the tail gauge reading should be zero, upon which this is entered into the gauge register at the site.

Some physical constraints also affect the operation of the system. The flexibility to deal with sudden increases in water levels or discharges in the Chishtian Subdivision, as a result of operations in an upstream subdivision, has been impeded after the existing escape at the very tail of Fordwah Branch ceased to function. This escape, originally intended as a feeder channel for the Bahawal Canal, but used in later years as an escape, has been encroached upon as the frequency with which water was passed through this feeder decreased. Since 1986, it is no longer functional as an escape and irrigation officials therefore deem it undesirable to supply the tail of Fordwah Branch to its FSL. To cope with unexpected rises in water levels in the tail due to upstream operations, an extra safety margin is imposed by supplying less than the design discharge to the tail, and by rotating supplies between Fordwah and Azim Distributary. However, these sudden rises have not been completely eliminated. During kharif 1992, a total number of 22 breaches were observed in distributaries of Chishtian Subdivision, all occurring at times when water levels in these secondary canals were exceptionally high. Out of this total number of breaches, 16 occurred in distributaries in the tail section of the subdivision, indicating that not only water shortfalls are unevenly distributed in the subdivision, as argued previously, but that excesses in supply are also passed down the system. During rabi, these problems are less severe when the non-perennial canals are used to drain excess water.

Finally, an inventory showed that out of 14 distributaries, 8 did not have a rating table for the head structures, whereas 6 did have one, rendering the estimation of the discharge upon which the kacha rotation in the subdivision is based even more questionable. The existing rating tables for 6 distributaries are generally more than ten-years old. Hydraulic conditions of structures have changed over time, with siltation in the Fordwah Branch amounting to 0.2 to 1.5 m when comparing design and actual bed levels (van Essen and van der Feltz 1992). As a result, a number of structures in the canal system are operated under different (submerged) hydraulic conditions than envisaged in the rating tables.

CANAL PERFORMANCE AT SECONDARY AND TERTIARY LEVELS

Flow measurements were carried out on a routine basis by IIMI field staff at the distributary outlets (moghas) of 8 sample watercourses, 4 offtaking from the Azim and 4 from the Fordwah Distributary. In addition, tail gauges in both distributaries were observed daily, providing an opportunity to study the impact of main system performance on the distribution of water at lower levels of the system. The delivery of water to the secondary canals differs substantially in terms of adequacy and dependability, with Fordwah performing better than Azim Distributary (see Table 1.7).[5]

5 A high degree of performance is associated with high values of the adequacy parameter and low values of the dependability parameter (temporal variability in watrer delivery).

Table 1.7. Water delivery to Fordwah and Azim distributaries during kharif 1992.

Distributary	Dependability (P'D)	Adequacy (P'A)
Azim	0.66	0.39
Fordwah	0.37	0.57
Average of Chishtian Subdivision	0.41	0.76

The measurements of water supply to 4 sample watercourses, expressed as millimeters (mm) of water supplied to the service areas of the watercourses, are presented in Table 1.8. The same Table presents data of the amounts of water, in mm, derived by pumping from groundwater, and from rainfall. The total amounts of water received are also given in the Table as relative water supplies (ratio of amount supplied to that required, according to the calculated crop water needs).

It is clear from the figures presented in Table 1.8 that tubewells are an important source of water, and more so when the canal water supply is perceived to be inadequate and unreliable (Azim 111). Utilization of groundwater enables farmers to adequately meet crop water requirements for a cropping intensity that is much higher than originally envisaged, and provides farmers with an opportunity for flexibility in their irrigation application (Kuper and Strosser 1992).

The existence of highly active water trading is further evidence of farmers' need for flexibility in the supply of irrigation water. It was found that farmers purchase or exchange parts, or even entire canal turns, as well as tubewell water (Kuper and Strosser 1992). Sixty farmers who were interviewed in the command areas of the sample watercourses all said that they participated in transactions of water.

The two kharif seasons differed substantially in the amount of rainfall received; the rainfall during kharif 1992 was 3 times that during kharif 1991. Canal supplies were also more for two watercourse command areas, Fordwah 130 and Azim 111. During the annual closure of 1992, the sill level of the orifice structure (the *moghas* are all adjustable proportional modules) of Fordwah 62 was raised by 12 cm (0.4 foot), reducing the actual discharge. Although the dimensions of the structure were restored to what they were before the annual closure, the total amount of canal water received in the watercourse command area during kharif 1992 was about 18 percent less than what was received the year before. Also, during the annual closure of 1992, the sill of the mogha of Fordwah 130 was lowered by 12 cm thus increasing the design discharge, which is apparent from the increased canal supply (20% more than the year before).

Table 1.8. Sources of irrigation water and Relative Water Supply (RWS) for sample watercourses during kharif.

Watercourse	Canal (mm)		Tubewell (mm)		Rainfall (mm)		RWS	
	1991	1992	1991	1992	1991	1992	1991	1992
Azim 63	295	256	377	248	50	165	0.82	0.91
Azim 111	77	120	658	671	47	88	0.73	1.05
Fordwah 62	522	413	126	78	44	121	0.73	0.74
Fordwah 130	387	482	318	165	42	127	0.76	0.93

The changes in canal supplies for the two watercourses offtaking from Azim reflect the effect of the substantial desiltation that took place in these and many other distributaries during the annual closure of 1992. The watercourses in head reach and middle reach receive less water after the cleaning of the canal while the tail watercourses, such as Azim 111, receive more than they did earlier.

Pumping of groundwater in three of the four command areas was markedly less in kharif 1992 than in kharif 1991, showing that farmers reacted (in the management of their tubewells) to the higher rainfall in the area during 1992 (and to a higher canal supply as in the case of Fordwah 130). The reaction to rainfall is even more apparent when monthly figures, rather than the seasonal figures of Table 1.8, are compared. An arbitrary example is given by the data for Azim 63, where the tubewell water supply was 56 mm in June 1992 when there was no rainfall, and 9 mm in July when rainfall was 67 mm, while canal supplies were the same in both months and crop water requirements were similar for both months. As cotton is the main crop in the command area, it shows good water management when farmers reduce the supplies during rains.

The smallest change in groundwater extraction occurred in Azim 111, where tubewell pumpage actually increased by a small amount. Total water supplies for the command area of this watercourse increased by 28 percent resulting in a rise in relative water supply to a value in excess of 1. The situation was confounded by a decrease in crop water requirements of about 11 percent due to a decrease in area irrigated in 1992 compared to that for 1991.

Total water supplies in 1992 were also more than that for 1991 in Fordwah 130 (11%), and (by a smaller amount) in Fordwah 62 (3%). The corresponding values of the relative water supplies increased accordingly. The increase in RWS in Azim 63 is due to a decrease in irrigated area (11%) rather than to an increase in total supply of water received, which remained the same for this watercourse command.

The extent of equity of distribution and dependability of water delivery (that were identified in an earlier paragraph) at main and secondary levels were also evaluated at tertiary level from the discharge values at the outlets (moghas) of the eight sample watercourses. Weekly average discharges, which IIMI field staff calculated from head readings of the calibrated moghas as fractions of the design discharge of the mogha formed the basis of the evaluation. The temporal coefficients of variability of these weekly averages over the kharif season of 1992 are listed in Table 1.9.

Table 1.9. Performance indicators for water intake of sample watercourses in kharif 1992.

Watercourse	**Adequacy (P'_A)**	**Dependability (P'_D)**	**Watercourse**	**Adequacy (P'_A)**	**Dependability (P'_D)**
Azim 20	1.08	0.40	Fordwah 14	0.98	0.41
Azim 43	0.77	0.51	Fordwah 46	1.17	0.34
Azim 63	0.50	0.55	Fordwah 62	1.27	0.31
Azim 111	0.29	0.74	Fordwah 130	0.79	0.42

The values of these coefficients of variability give an indication of the dependability of water delivery at the heads of the sample watercourses. Dependability of supply at these distributary outlets is poor, according to the performance classes suggested by Molden and Gates (1990) and, not surprisingly, becomes poorer down the distributary, particularly in the case of Azim.

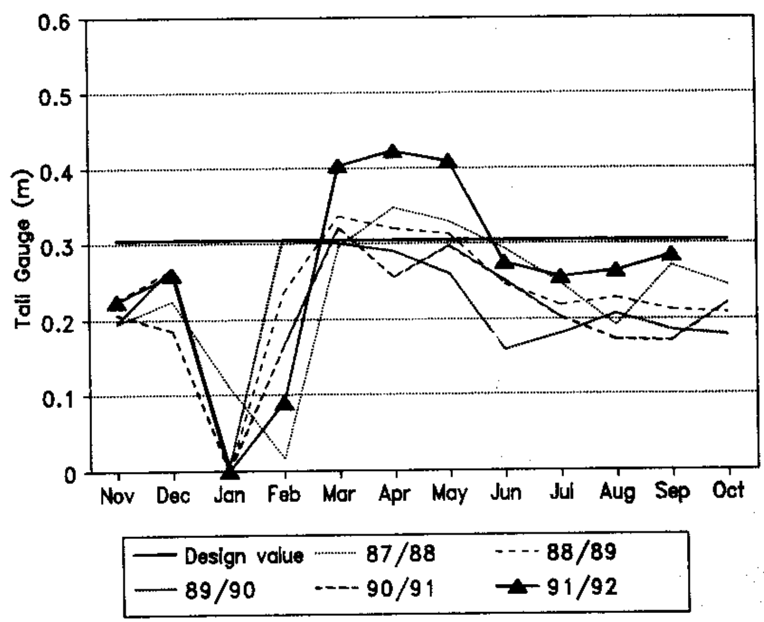
Equity of water delivery, at watercourse level, down the distributaries was also calculated from the weekly average discharges. The average spatial coefficient of variation of delivered flow over design discharge for kharif 1992 was 0.23 for the four watercourses offtaking from Fordwah Distributary, and 0.62 for those offtaking from Azim. Performance in terms of equity at tertiary level is obviously not very good in both cases, but considerably worse for Azim than for Fordwah (see also the calculated values for P'_A). Using the criteria of Molden and Gates (1990) once again, the value for Fordwah would be classified as fair.

The performance of both distributaries appears to have improved in kharif 1992, compared with kharif 1991 as evidenced by Table 1.10, where values of performance parameters are given for the two seasons, i.e., the amounts of water delivered (adequacy), and the temporal variability (dependability parameter).

Table 1.10. Performance of four sample watercourses in Azim and Fordwah distributaries — a comparison between kharif 1991 and kharif 1992.

Watercourse	**Adequacy**		**Dependability**	
	1991	**1992**	**1991**	**1992**
Azim 63 L	0.58	0.50	0.39	0.55
Azim 111 L	0.17	0.29	0.96	0.64
Fordwah 62 R	1.46	1.21	0.17	0.33
Fordwah 130 R	0.61	0.79	0.52	0.43

Figure 1.5. Tail-guage readings of Fordwah Distributary (1987–92).



The difference between the parameter values of head-reach and tail-reach watercourses is smaller in 1992 than in 1991. In large measure, this is due to the desiltation and mogha remodeling that were carried out during the annual closure of 1992, as was mentioned before.

Monitoring of the water level at a tail gauge of the distributary provides an indication of whether equity of distribution has been attained within the distributary or not. According to the design, the water level at the tail gauge should be 0.3 m to have equitable conditions along the distributary. Taking Fordwah as an example (Figure 1.5), it is clear that the tail conditions have improved substantially in 1992, although the discharge at the head of the distributary was lower in 1992 than in 1991.

Towards the latter part of the kharif, tail-gauge levels tended to come down to the levels of previous years. This may be attributed in part to siltation occurring during kharif when silt loads are high, but the fact that, under pressure from farmers, the recently remodeled moghas in the head reach were again brought back to the size they had before the remodeling has certainly contributed to the reduction in tail water levels, and hence to reduced equity of distribution. For example, 22 percent of the remodeled outlets of Fordwah Distributary were reverted to the original size, compared to only 10 percent in Azim. The lower degree of cooperation and organization among farmers in the Azim command area (Van Waaijjen 1991), mentioned earlier, may have played a role here.

CONCLUSIONS AND RECOMMENDATIONS

On the basis of the analysis of flow data and current operational practices in the Fordwah System, as discussed in this paper, a set of practical recommendations are discussed below. It would not be difficult to suggest more and more far-reaching changes, but the authors feel that implementation of this initial set would test the desire of Irrigation Department staff to improve and sustain irrigation in the area. Monitoring of the effects of implementing this set of recommendations would provide the bench mark against which further, and probably more expensive, management changes and technical improvements, including the expected impact of the construction of surface and/or subsurface drainage systems in the area, could be measured. The authors feel that it would be irrational to suggest now that lining of canals or the construction of drainage systems is required to sustain irrigated agriculture in the area. Once this set of recommendations has been implemented and their effects monitored, other technological and managerial improvements could ne considered.

1. Presently, the quality of the daily readings that are relayed from the control structures to the office of the (sub)system manager leaves much to be desired. Tail gauges and water levels at the head of smaller distributaries are fictitious and gauge readings are generally reported in such a way that they are in agreement with the official policy rather than reflecting the actual situation in the system. This is mainly caused by the fact that these data, considered to be of vital importance at the time of design and at earlier stages of operation, are no longer used by the system managers to make decisions on operation and maintenance of the system. The system manager is not confronted with the consequences of operational decisions on the water distribution other than through remonstrations of farmers. It is recommended that IIMI starts collaborating with the Punjab Irrigation Department in a pilot activity to emphasize the importance of information in an irrigation system and to quantify the impact of operational decisions on the distribution of canal water supplies.

2. Three different rotations occurring simultaneously at different levels of the irrigation system, coupled with a number of individually conceived operational rules that are followed within the system make it difficult — if not impossible — to assess the actual discharges in comparison to the intended discharges at any given point in the system. Visualizing of irrigation operations in the Fordwah Division by displaying actual and intended water levels and discharges in the office of the system manager is recommended. This should aim at making the process of water allocation and actual distribution of water more transparent both for operators and end-users.

3. The performance assessment carried out in this study clearly indicates that present operational objectives are not attained and that there is certainly scope for improvement, when all performance indicators with respect to the design discharges are rated as "poor." It is recommended that the information generated by such assessments be made available to the system manager on a regular basis through a set of institutionalized indicators that would quantify irrigation operations in a straightforward, comprehensible way.

4. Operating staff, such as gauge readers, have been observed to adjust the gates of their control structures frequently without any instructions to that effect, and with limited (localized) objectives as, for example, to keep the discharge in an offtaking distributary canal constant. Through these frequent interferences in the system, gauge readers exert a substantial influence on the performance of the system. These interferences take place in the absence of a clear operational plan and in a situation where operational guidelines are not available. It is recommended that a study be carried out on the impact of gauge readers' operations on system performance through mathematical modeling. The objective of the study would be to derive a comprehensive decision-tree for all levels of the system, and to identify the minimum information required to make rational decisions at the various levels.

5. More than half of the secondary canals in the Chishtian Subdivision do not have rating tables for their head structures, whereas the tables for the other distributaries have been established more than 10 years ago and have never been revised. Quantification of the flow of water in the subdivision has therefore become nearly impossible with any acceptable degree of precision. It is recommended that the ID should recalibrate all head structures in due time, and set priorities for this activity based on an assessment of control points which need recalibration most.

6. Farmers reportedly exert pressure on operating staff, either directly or through influential people, to gain operational advantages. It is recommended that the ID should recognize the presence of this phenomenon and start making use of the informally organized farmers' groups to tackle previously intractable problems such as water theft and distributary maintenance (e.g., desiltation and berm cutting).

7. Formal operational rules dating back to the design of the system and informal operational practices have led to a rigid supply-based operation of the system. The flexibility that farmers require in the management of their irrigation applications in order to respond to changes in crop water requirements over a season has led them to develop tubewells even in areas where groundwater is at best marginally suitable for irrigation. Flexibility in water supplies is also enhanced by the trading of canal and tubewell water between farmers. It is recommended that the ID should take cognizance of these developments and attempt to maximize the benefits of the groundwater resource for farmers by adjusting canal supplies in a way that would stimulate the development of successful patterns of

conjunctive management of surface water and groundwater wherever that is possible. In the allocation of canal supplies between rotating distributaries, the ID staff have to take into account the effects of their decisions on the average irrigation water quality over time that results from using canal and tubewell water in each command area.

8. Relative water supplies are maintained around 0.8-0.9 by *de facto* conjunctive management of groundwater by farmers to suit the availability of canal supplies and rainfall, which goes to show that farmers operate the only source presently under their control in such a way that water is applied near optimally in an economic sense. The inbuilt danger of these irrigation practices is the emergence of salinity, even in areas where water tables are low, through under-irrigation and the absence of leaching practices of farmers. It is recommended that further research be carried out to ascertain current field irrigation practices of farmers, with a view to evaluating the (potential) role of the surface irrigation system in managing problems of waterlogging and salinity to avoid land degradation and to mitigate the effects on agricultural production.

ACKNOWLEDGMENTS

The authors wish to express their appreciation to Shahid Sarwar, Fiaz Hanif Sendhu and the field team of Hasilpur for their able and effective work in collecting data and information on the Fordwah Irrigation System. M. Saleem Malik and M. Samee Ullah Goraya have been instrumental in the development and execution of field interviews and data entry, respectively.

Bibliography

Bandaragoda, D. Jayatissa and G.R. Firdousi. 1992. Institutional factors affecting irrigation performance in Pakistan: Research and policy priorities. Colombo, Sri Lanka: International Irrigation Management Institute.

Essen, Anton van and Casper F.C. van der Feltz. 1992. Alternative water management systems in the Punjab. MSc. Thesis, Technical University, Delft, the Netherlands.

Kuper, Marcel and Pierre Strosser. 1992. The appropriateness of canal water supplies: The response of the farmers — A case study in the Fordwah/Eastern Sadiqia Area, Punjab, Pakistan. Lahore, Pakistan: International Irrigation Management Institute (IIMI-Pakistan Discussion Paper 6).

Molden, David J. and Timothy K. Gates. 1990. Performance measures for evaluation of irrigation-water-delivery systems. *In* Journal of Irrigation and Drainage Engineering, Volume 116, No. 6.

Nazir, Ahmed and Ghulam Rasul. 1988. Irrigated Agriculture of Pakistan. Lahore, Pakistan.

PWD. 1963. Hundred years of PWD. Lahore, Pakistan: Public Works Department, Punjab.

Siddiqi, Mehmood u.H. 1991. Regulation of river waters and equitable distribution of canal supplies. Lecture Notes, Punjab Engineering Academy, Lahore, Pakistan.

VanderVelde, Edward J. and Jacob W. Kijne. 1992. Salinity and irrigation operations in Punjab, Pakistan: Are there management options? Lahore, Pakistan: International Irrigation Management Institute (IIMI-Pakistan Discussion Paper 2).

Waaijjen, Erik G. van. 1991. Some relations between irrigation, agriculture, and socioeconomic context for five watercourses near Hasilpur. Lahore, Pakistan: International Irrigation Management Institute.

Waaijjen, Erik G. van and Bandaragoda D. Jayatissa. 1992. The Punjab desiltation campaign during 1992 canal closure period — report of a process documentation study. Lahore, Pakistan: International Irrigation Management Institute (IIMI-Pakistan Discussion Paper 7).