CHAPTER 11

# Performance of Secondary Canals in Pakistan Punjab: Research on Equity and Variability at the Distributary Level

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IIMI RESEARCH IN Pakistan on distributary channels is primarily concerned with how irrigation agencies can be effectively assisted to improve irrigation system performance at the secondary level, in order to achieve and sustain higher output from irrigated agriculture. Specifically, the research objective is to identify management options with the potential to increase equity and reduce variability in irrigation water deliveries, improving the performance of irrigated agriculture. This research is predicated upon two key observations. The first is that, so long as the irrigation environment is characterized by inequitable and unpredictable water deliveries, Pakistani farmers are unlikely to invest in improved farm management practices. Much research on farmer adoption of new or improved farm inputs and farming practices suggests that this assumption is not unreasonable. The second observation is that Pakistan irrigation agencies continue to cite distributional equity and the provision of adequate amounts of water at appropriate times — "so far as is possible" — as performance objectives for the public irrigation infrastructure that serves farmers.

Begun in 1987, this research has focused principally upon an analysis and understanding of the actual conditions of secondary canal operations in one major Punjab canal command, the Lower Chenab Canal (LCC) system.[59]

Field studies have been carried out over several successive agricultural seasons to determine the relationship between existing water distribution conditions and design norms. Field research has also sought to identify the forms and extent of management activities currently practiced in representative areas of the LCC system, keeping in mind that in so large a system substantial spatial diversity is the norm.

Preliminary findings on the equity and variability of water deliveries between different distributaries, as well as among watercourses along Lagar Distributary in the

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[59] Perhaps a sense of scale of the LCC is best communicated by the following: its irrigable command area is more than 1.2 million ha, served by 176 distributary channels (excluding minors and sub-minors), the total length of which exceeds 2,800 km. Design full supply discharge for the system at head exceeds 310 cu.m/s.

LCC, were reported internally by IIMI Pakistan in November 1987. That report was based upon the analysis of primary water supply measurement data collected by IIMI Pakistan for the period August-October 1987, and of several years of secondary data provided by the Punjab Irrigation Department. Subsequently, summaries of additional findings have been presented in periodic research progress reports prepared by IIMI Pakistan for its Consultative Committee, donors, and internal institutional programs.

## THE DISTRIBUTARIES OF THE STUDY

The following discussion is based upon primary measurement data covering both a much longer period of field research activity and an increased number of distributary channels. In the case of Lagar Distributary in Farooqabad Sub-Division, Upper Gugera Division, primary data are now available for nearly two years, from August 1987 through June 1989. Primary and secondary data are also available for three additional distributary channels in the LCC system where IIMI Pakistan field staff have been measuring and monitoring irrigation operations for the past three agricultural seasons. Table 11.1 provides basic information about the distributaries currently being studied in this research.

*Table 11.1. Distributary characteristics.*

| Distributary | Design discharge ($m^3/s$) | CCA (ha) | No. of minors & sub-minors | No. of outlets | Design intensity (%) |
|---|---|---|---|---|---|
| Mananwala | 5.24 | 27,159 | 4 (1) | 125 | 50 & 75 |
| Lagar | 1.08 | 6,578 | 1 | 30 | 50 & 75 |
| Pir Mahal | 4.67 | 14,891 | 4 | 90 | 75 |
| Khikhi | 9.66 | 33,119 | 6 (3) | 158 | 75 |

In April 1988, IIMI Pakistan expanded daily measurement activities of water conditions to include a set of locations along the primary channel of Mananwala Distributary, also in Farooqabad Sub-Division. In size and service area, Mananwala Distributary is arguably a "more typical" distributary of the LCC than is Lagar. There also appears to be an important incipient soil and groundwater salinity condition in its tail-reach command area.

Regular field observations and measurement activities had already been extended to a limited number of survey locations along both Pir Mahal and Khikhi distributaries in Bhagat Sub-Division, Lower Gugera Division, in November 1987. The choice of Bhagat Sub-Division for these activities was conditioned by the need to maintain system contiguity, by the desirability of including a known contrasting hydrologic environment in this research, and by the cooperation offered by the Punjab Irrigation Department.

Bhagat Sub-Division comprises the command of six distributaries in the southwestern portion of LCC (East) Circle, including four that offtake at the tail of Lower Gugera Branch canal. Surface water supplies here are rather less reliable than in sub-divisions served by Upper Gugera Branch canal. Unlike Farooqabad Sub-Division, public tubewell systems are largely absent; moreover, groundwater is often too saline for irrigation purposes unless it is mixed with canal water. Finally, rotational operations both between distributaries and within distributaries are commonly practiced in Bhagat Sub-Division.

Mananwala Distributary is 45 km in length, and surface flow observations and measurements are carried out at 20 points confined to the main distribution channel; no watercourse observations have been made along its minor channels. Monthly crop surveys of sample fields in five watercourse commands, and daily monitoring of public and private tubewell operations in these same commands, supplement IIMI surface water data.

Lagar Distributary is a much shorter channel (19 km). Surface flow conditions were measured and observed daily at 28 locations along the distributary and its minor until the end of rabi season 1988-89. These data are now generated from the hydraulic model, MISTRAL, adapted for Punjab canal applications and thus far calibrated only for Lagar. Additional data collected in Lagar command include detailed monthly crop surveys in 3 watercourse commands and daily logs of all public and private tubewell operations in 13 watercourse commands.

Pir Mahal Distributary is slightly longer than Mananwala at 48 km but its service area is a good deal smaller because of a higher design water allocation. Along Pir Mahal, beginning in late 1987, surface water conditions were measured at 30 locations through rabi season 1988-89, after which the observation points were reduced to 23. Irrigated agriculture activities, as well as private tubewell operations are monitored in six watercourse commands.

Khikhi Distributary is the largest on which IIMI is conducting research, although it is only 43.5 km long. Regular observations and measurements of surface water distribution are presently confined to its head and the offtakes of its principal minors. This is because the phased rehabilitation program of canal lining — the primary reason for Khikhi's selection as a study channel — underway since early 1988, means flow conditions are unstable for about six months per year.

In summary, IIMI Pakistan's detailed field observations of secondary-level irrigation operations in the head reach and the tail reach of a very large Punjab canal system now cover a range of conditions of management actions by, and options available to, Sub-Divisional Officers and Executive Engineers, the agency officers primarily responsible for day-to-day canal operations. It is perhaps significant that the LCC system has also been considered by many agency and government officials to be one of the better operating systems in Punjab, although the sociopolitical environment dominant in the command area of Upper Gugera Branch is reckoned to be possibly the most difficult and violent in the province.

## PUNJAB CANAL SYSTEMS AND EQUITY

The equity principle that the Punjab Irrigation Department has sought to maintain in canal operations was originally established as a design parameter for Punjab canal systems. An amount of water was to be made available at the head of each *mogha* (watercourse outlet) for its command area based upon a preset "duty" or water allowance per unit area. Two standards were followed in the design of the LCC system. Outlets that served preexisting settlements and their agricultural lands were allocated 1.9 cusecs (53.8 l/s) of water per 1,000 acres (405 ha) of culturable commanded area (CCA, the physically irrigable agricultural area commanded by the outlet) or about 1 l/s per 7.5 ha. Moghas serving the agricultural lands of new villages were designed to deliver water at the rate of 2.84 cusecs (80.4 l/s) per 1,000 acres CCA (about 1 l/s per 5 ha). Design discharge at the outlet is therefore directly related to irrigable area commanded by the outlet, and each unit of irrigable area within the outlet command is allocated an equal share of surface water. Since the amounts of water allotted to area units in perennial canal systems were very low (at the turn of the 20th Century, the irrigation development objective was to protect maximum spatial extent from rainfall failure and famine, not to maximize productivity per unit of land), it was further envisaged that the actual area irrigated by farmers in any year of two agricultural seasons would not exceed 50 percent of the CCA in the former instance or 75 percent of the CCA in the latter case.

Furthermore, the large Punjab canal systems were designed and constructed with a minimum of adjustable control structures throughout the main and secondary system. For example, below Sagar Head, the Upper and Lower Gugera Branch system of the LCC, designed to carry about 170 cu.m/s at full supply, has only a single movable crossregulator in its 250 km length. Below the distributary head gate, water is distributed to the watercourses through fixed structures or moghas, either an orifice or flume, at their heads.

Unquestionably, there have been many changes in the 90 or so years since the LCC system began operations. By no means the least of these was the introduction, in the early 1960s, of an extensive large capacity public tubewell infrastructure (SCARP I) in the upper half of its command area, which often tripled or even quadrupled water supplies at the watercourse head. Nevertheless, the water allocation principle for the surface system remained as originally designed, and the performance objective for canal operations continues to be the delivery to each outlet of its sanctioned share of the distributary's full discharge. Since the outlets are fixed structures, the relationship between its design discharge and the water supplied to each watercourse head along the distributary is governed primarily by hydraulic principles.

If the performance objective is to be achieved, then stable distributary water levels at, or very close to, design levels are required, because departures from design levels will cause differences in outlet discharges. The standard and most widely used orifice outlet, the APM, maintains a proportional head-discharge relationship to about 70 percent of channel design discharge. Rotational operations between distributaries are planned for use when system water supplies are insufficient to maintain canal discharges above 70 percent of design. Although routinely drawn up, rotational programs are rarely adopted, perhaps because it is widely assumed or perceived that Punjab canal systems operate continuously at, or near to, full supply levels throughout the main and secondary channels.

## DISTRIBUTARY PERFORMANCE: WATER DISTRIBUTION EQUITY

An early research finding on Lagar Distributary was that the degree of maintenance required to keep channel conditions reasonably close to design was not being achieved. Not only was the distributary significantly silted, particularly in the head reach and downstream of Jhinda Minor offtake, but its cross-section was substantially enlarged in many reaches and the embankments severely eroded in numerous locations throughout its length, despite having been rehabilitated in 1985 when the tail one-third of the channel was lined. Figures 11.1 and 11.2 illustrate the difference between design and existing physical conditions for Lagar in late 1988.

Consequently, the existing full supply water level was substantially above the design level for nearly the upper two-thirds of the channel. Subsequent field survey work on Pir Mahal and Mananwala distributaries revealed very similar physical conditions for these channels, too. The implication is that the inability to sustain required levels of channel maintenance has led to an increasingly widespread deterioration in the

*Figure 11.1. Lagar Distributary: Longitudinal section (RD 0 to RD 32).*

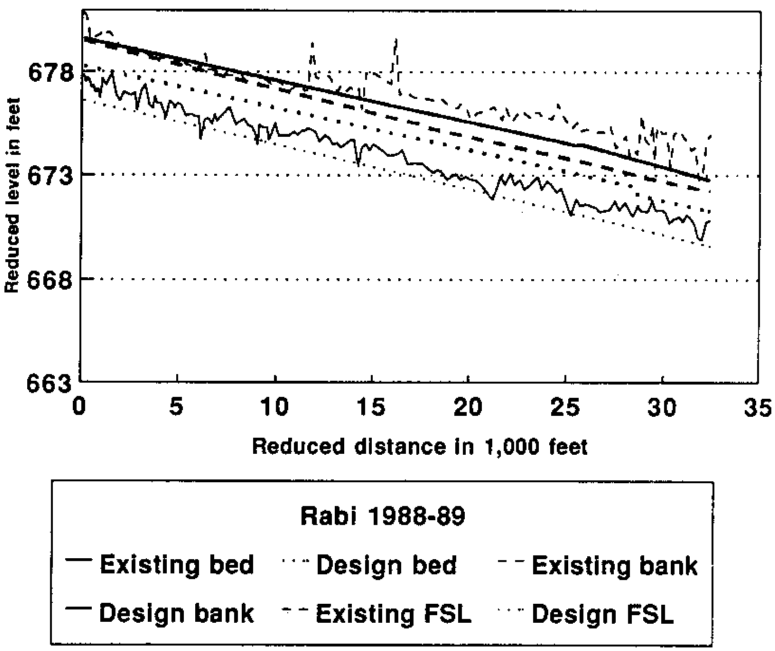
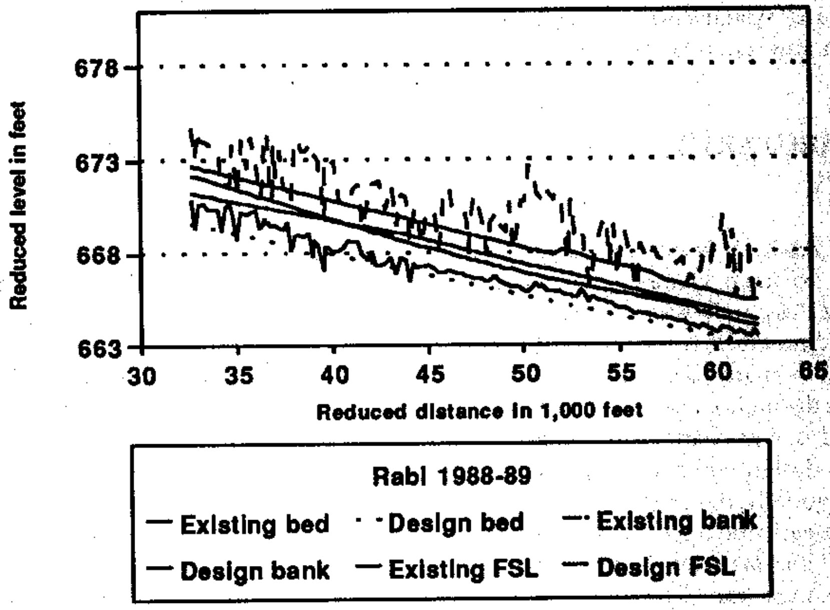


*Figure 11.2. Lagar Distributary: Longitudinal section (RD 32 to RD 62).*




physical conditions of distributaries throughout the LCC and, quite likely, in other Punjab canal systems as well.

One consequence of continuing low levels of maintenance inputs to secondary channels is that the relationship between design and actual discharge conditions at the heads of watercourse outlets is dominantly a function of the physical distance between an outlet and the distributary head gate. This is illustrated by the markedly similar patterns of water distribution equity among outlets for Lagar (Figure 11.3) and Pir Mahal (Figure 11.4) distributaries under near-design discharge conditions. The term used here to describe this relationship, Delivery Performance Ratio (DPR), is the ratio of actual discharge to design discharge. When the relative distance measure developed by Murray-Rust (IIMI Review Vol.2 No.1 April 1988, pp 17-18) ("Equivalent Distance" — a measure which combines actual distance and the locational opportunity of an outlet vis-a-vis channel discharge) is applied, the difference between actual and design conditions is even more strongly related to an outlet's location along the channel (Figure 11.5).

When distributary head discharges fall below 70 percent of design, DPR for the last quarter to one-third of watercourse outlets rapidly approaches zero. At discharges below 50 percent of design, most outlets in the lower half of distributaries do not draw any water at all (Figure 11.6). These relationships have been known for decades, and the management option of rotational operation of distributaries was framed partly to minimize inequity in water distribution under such low water supply conditions. Interestingly, however, a rotational delivery program between and within distributaries has so far been implemented only in Bhagat Sub-Division, despite the fact that head

*Figure 11.3. Lagar Distributary: Water distribution equity.*

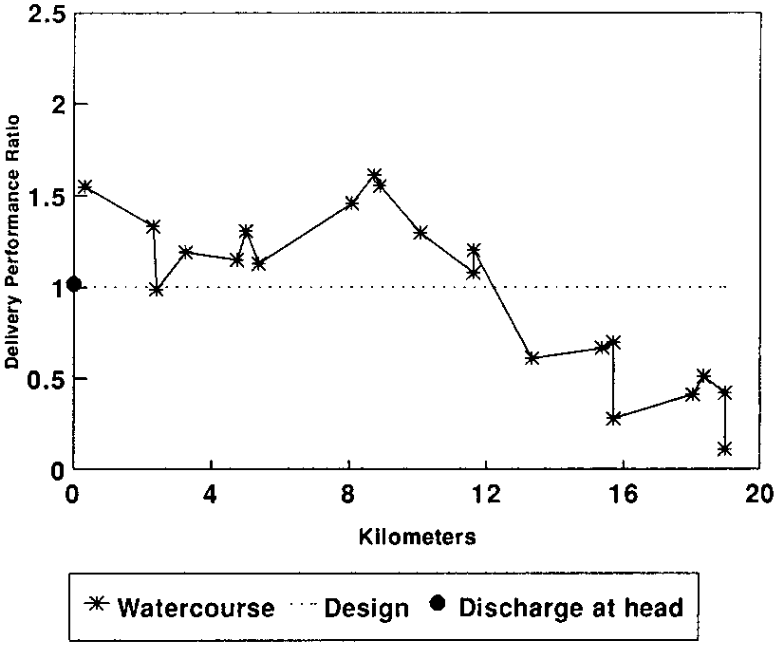



*Figure 11.4. Pir Mahal Distributary: Water distribution equity.*

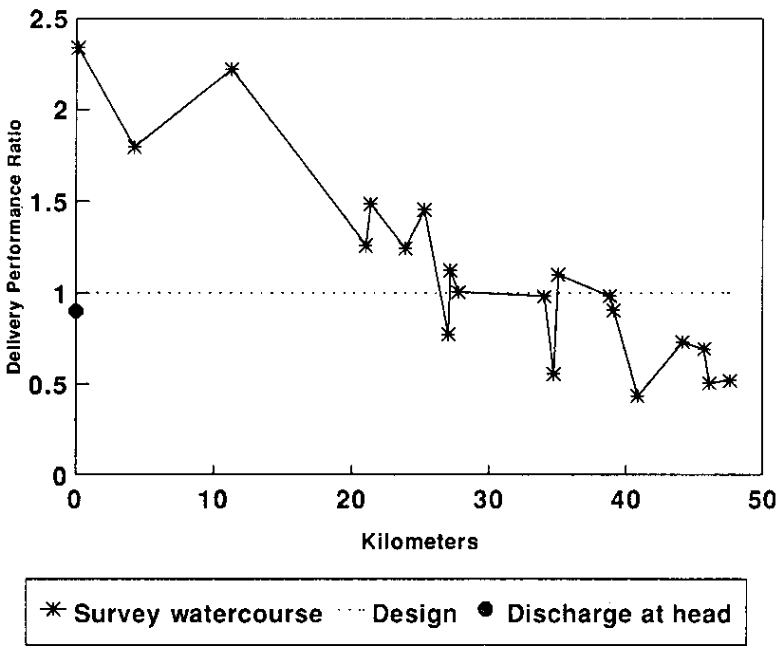


*Figure 11.5. Lagar Distributary: DPR and equivalent distance.*

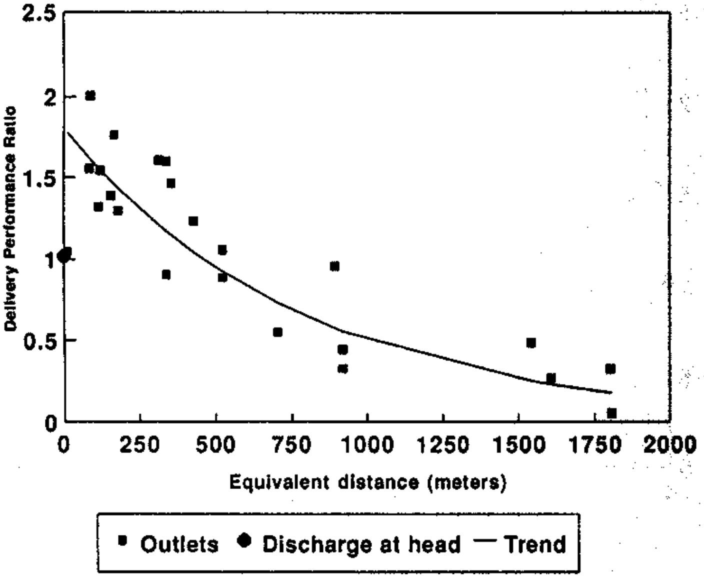
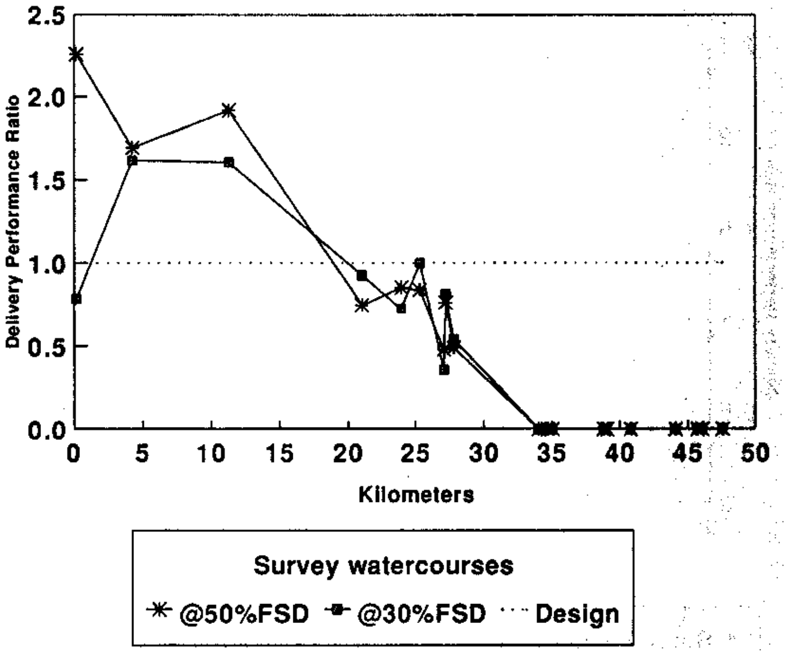



*Figure 11.6. Pir Mahal Distributary: Water distribution equity, low Qs.*



discharges of less than 70 percent commonly occur among distributaries in Farooqabad Sub-Division, too.

It is obvious that, on average, outlets in the tail reaches of distributaries draw only a fraction of their intended discharges, while those watercourses located in the upper half of the channel commonly obtain 25 percent to 50 percent more water than originally planned. The resulting pattern of water distribution inequity between watercourses along distributaries is both persistent and severe. Moreover, there appears to be relatively little variation in this pattern in terms of distributary location in the system. The long-term mean monthly DPR for Lagar (Figure 11.7), a distributary in the upper LCC, is little different from the long-term mean monthly DPR of Pir Mahal (Figure 11.8), a tail-end distributary in the system.

The degree of inequity experienced by irrigators is perhaps most readily demonstrated through the interquartile ratio (IQR), a measure suggested by Abernethy in 1986, that compares the performance of the poorest performing quartile of watercourse outlets to the top quartile along a channel. The measure has been modified and used here both for all outlets in each quartile length of a distributary (e.g., Lagar) and for all sample outlets in each distance quartile (e.g., Pir Mahal). IIMI data suggest that the DPR of upper quartile outlets is generally at least 4 times better than those in the lowest quartile (Figure 11.9 and Figure 11.10). This level of inequity largely explains the intensity and near-continuous frequency of complaints of tail-end Punjab farmers that they do not receive their fair share of canal water.

*Figure 11.7. Lagar Distributary: Water distribution equity.*

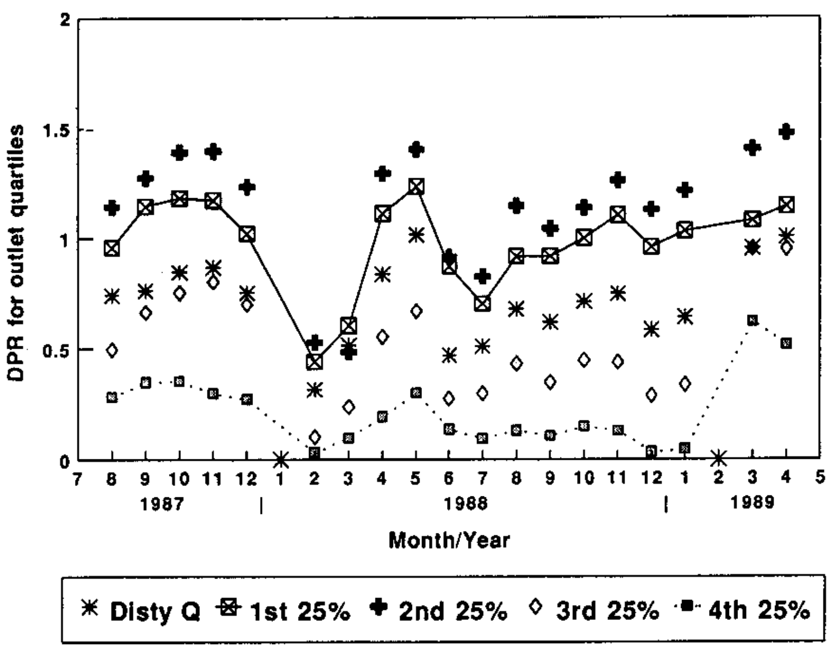


*Figure 11.8. Pir Mahal Distributary: Water distribution equity.*

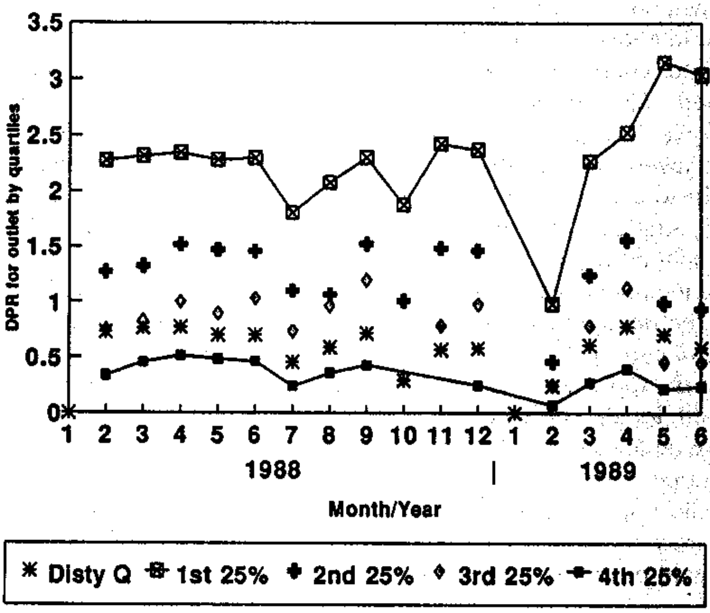



*Figure 11.9. Lagar Distributary: Water distribution equity.*

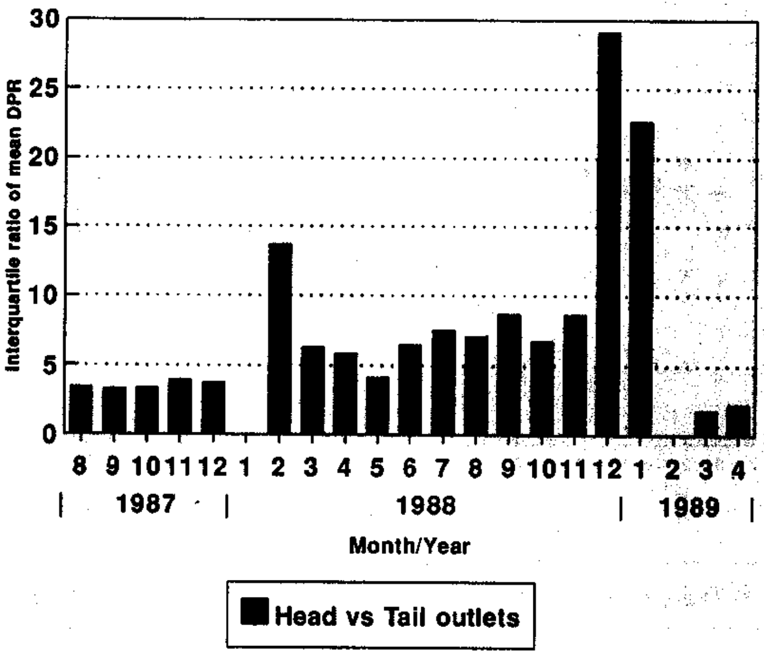
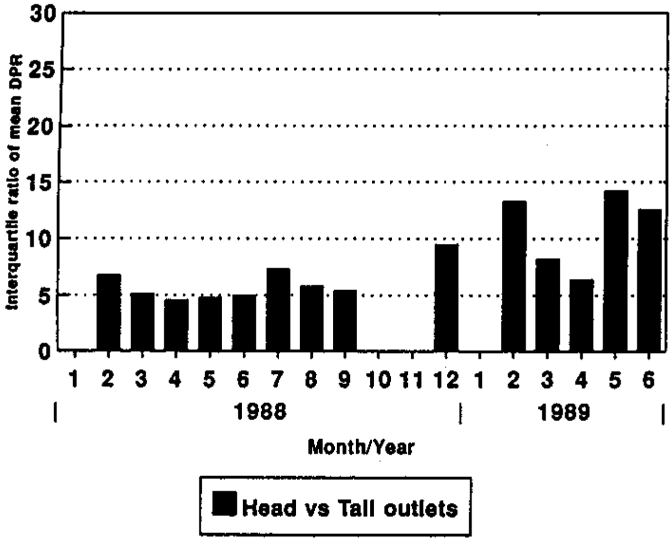


*Figure 11.10. Pir Mahal Distributary: Water distribution equity.*

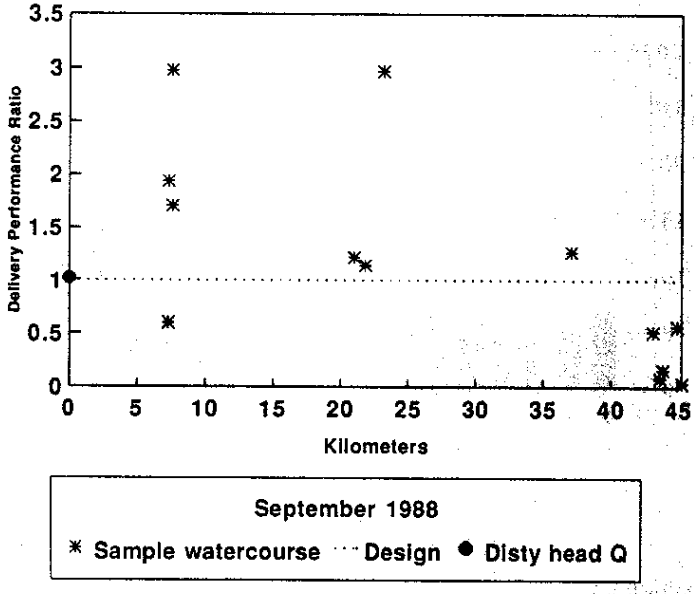



No ratio for October-November, 1988
as floods closed tail outlets

Although distributary-level inequity in water distribution is substantially accounted for by high rates of channel sedimentation and concomitant low levels of maintenance inputs, there are at least four other factors that interact to exacerbate this condition. The best known and most widely acknowledged of these variables are "outlet tampering," activities that result in a physical modification of the outlet structure so that it will draw more than its design or fair share discharge, and water theft, often through semi-permanent and/or quasi-sanctioned pipes and siphons. These interventions are widespread (increasingly so according to both agency officers and farmers), invariably concentrated in the upper two-thirds of distributaries, and are difficult, though not impossible, to track. It is not uncommon for farmers and agency field staff to be jointly involved in activities, and for both to benefit from them.

The impact of these factors is revealed on Mananwala Distributary where such interventions have been more commonly observed by IIMI field staff than elsewhere in the LCC (Figure 11.11). This graph, a summary performance "profile" showing mean DPR for IIMI sample watercourses of Mananwala, covers a two-week period in late September 1988. In the upper reach of the distributary, a semipermanent, quasi-sanctioned tampered outlet is shown drawing nearly three times its design discharge under full supply conditions, a performance level consistently observed there since studies began on this distributary. A second outlet about half-way downstream has recently been illegally tampered with; it too draws about three times its design discharge, much more than previously observed under similar distributary discharge conditions. A third intervention can be inferred from the virtual collapse of tail outlet

*Figure 11.11. Mananwala Distributary: Mean DPR for sample water courses.*




DPR for the period. Field observations and interviews, however, revealed that at several locations about 30 kilometers down the channel farmers had intervened at night during these two weeks to redirect much of the distributary flow through embankment cuts into a temporary network of nine watercourses to irrigate fields of rice!

A third contributing factor to distributary-level water distribution inequity is, ironically, the watercourse improvement program of the Directorate of On-Farm Water Management (OFWM) which has as a principal objective the enhancement of water distribution equity within the watercourse command. Certainly the impact thus far observed is unintended, but it is significant nevertheless and is in large measure a consequence of the pronounced bias in the spatial distribution of watercourse improvement within distributary commands. A primary component of the OFWM program is watercourse lining, which frequently involves the restoration of an appropriate bed slope to the channel. In many instances the result is an improved watercourse discharge, usually because the flow condition at the mogha is changed from non-modular to modular, which is, of course, the design outlet flow condition. However, when this occurs for watercourses in the upper reach of a poorly maintained distributary, the frequent result is an outlet discharge greater than sanctioned (because of a higher than design water level in the distributary), and a concomitant reduction in downstream distributary discharges.

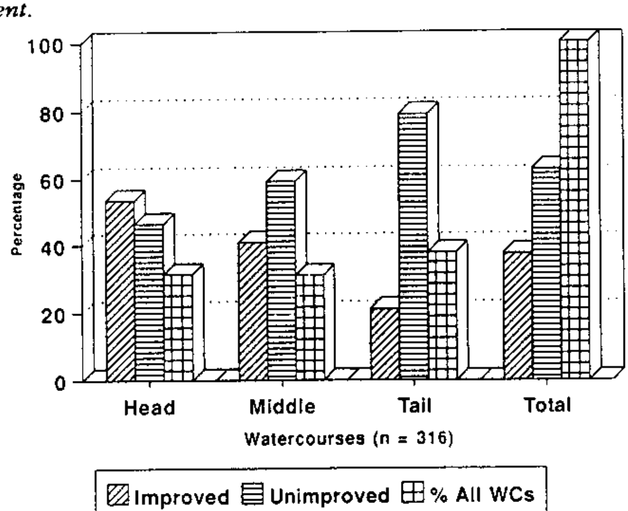
Unfortunately for distributary water distribution equity, there has been a very strong "top-end" orientation to the implementation of the OFWM watercourse improvement program. A survey of all watercourses of distributaries in Farooqabad Sub-Division, done in 1988-89, showed that just under 40 percent of the total had been partially lined through the OFWM program (Figure 11.12). More than one-half of the watercourses in the head reaches of these distributaries had been improved as had slightly more than 40 percent of the watercourses in the middle reaches. By contrast, nearly 80 percent of tail-reach watercourses had not been improved, despite the fact that more watercourses are located in the tail than in either the head or middle reaches of Farooqabad distributaries.[60] A comparable pattern of spatial bias is found among the 131 watercourses in the command of Khikhi and Pir Mahal Distributaries of Bhagat Sub-Division, even though this locale was one of the first to be targeted when the watercourse improvement program was initiated province-wide in the late 1970s.

Every lined (i.e., "improved") watercourse on Lagar Distributary typically has a DPR 25 percent to 50 percent greater than the corresponding DPR at distributary head; all are located within the upper two-thirds of the channel. Lined watercourses among IIMI survey outlets in the top two-thirds of Mananwala and Pir Mahal distributaries exhibit a similar DPR relationship.

The last, though by no means least, contributing factor is the frequency of distributary operations under low discharge conditions. Operational data for 1988 and 1989 confirm that the distributaries under study typically operate at less than 75 percent of design discharge for between 70 and 160 days per year, excluding the annual maintenance closure period of 3 to 6 weeks. There are a variety of reasons for this operational mode, some of which are generic, others more channel-specific, and still others remain to be clarified.

When Upper Gugera Branch canal operates at or below 75 percent of full supply, Mananwala and, particularly, Lagar operate at less than 50 percent of their design

*Figure 11.12. Farooqabad Sub-Division distributaries: Distribution of watercourse improvement.*

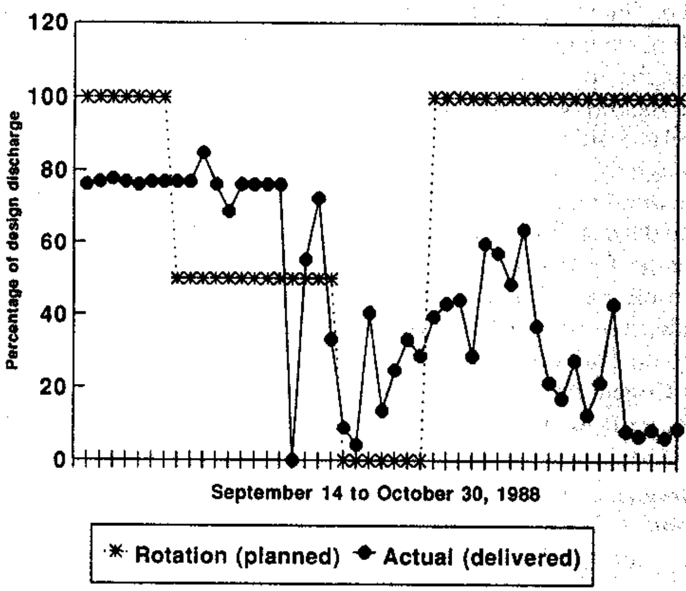



Field Survey Data, 1988-89

[60] The probability of such a pattern having emerged by chance is less than 0.001.

discharges. The lower half of Pir Mahal was severely damaged by river flooding in early October 1988, and it took an unusually long time for repairs to the channel to be effected. It therefore operated for about 60 days at a greatly reduced head. Moreover, for another 62 days, discharge into the distributary was reduced or stopped as part of the rotational program between distributaries in Bhagat Sub-Division. The resulting pattern of low discharges for Pir Mahal is partially illustrated in Figure 11.13.

*Figure 11.13. Pir Mahal Distributary: Rotational program at head.*




In all distributaries, flows are diminished or terminated for brief periods to carry out urgent maintenance, to repair breaches in the channel, or because farmers have indicated that they do not need water for their crops. No gatekeeper/gauge observer has a reliable, up-to-date rating table to guide him in gate adjustments, so there is some lag in their responses to changing main channel flow conditions. Only Mananwala Distributary is equipped with a readily adjustable mechanical gate in any case. What is not known, because of the relatively short time span for which data are available and the limited sample size of four distributaries from a single system, is just how widespread and persistent this operational pattern is in the Punjab.

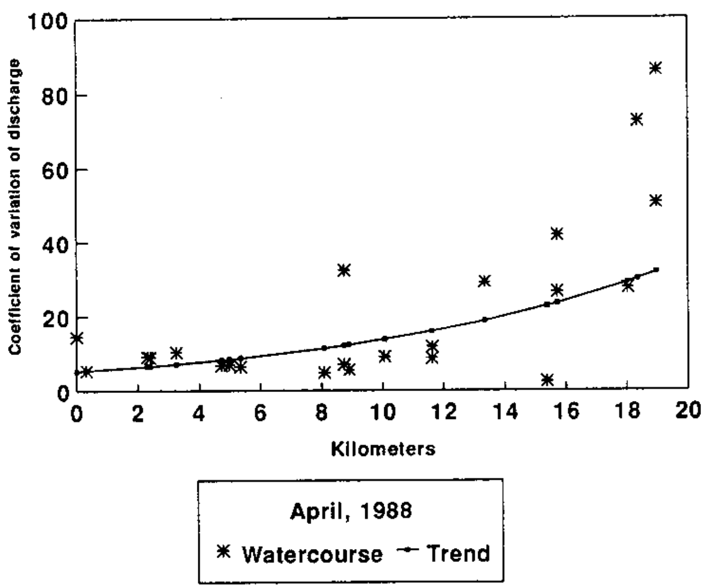
## DISTRIBUTARY PERFORMANCE: VARIABILITY IN WATER DISTRIBUTION

Variability of surface water supplied to the heads of outlets along distributaries exhibits a general spatial pattern that parallels that of equity in water distribution. Distributary conditions that produce serious inequity in water distribution between head and tail also tend to magnify water supply variability between these locations. The close correlation with distance, in this case increased variability of discharge to outlets with increasing distance from the distributary head, is generally pronounced for all distributaries, whether at the head of the LCC system or the tail. Distributary profiles of outlet discharge variability for the same month and similar head discharge conditions for Lagar (Figure 11.14) and Pir Mahal (Figure 11.15) illustrate this pattern.[61]

Certainly this relationship is logical and consistent with expectations, especially given the hydraulic conditions of channel flows previously described. As the amount of discharge in the channel diminishes toward the tail reach, relatively modest fluctuations in water supplies at the distributary head that are uncontrolled and transmitted downstream in a rigidly designed system become a significantly larger fraction of the remaining discharge.

However, there are also important and rather distinctive differences in water distribution variability among the distributaries studied, apparently related to more site-specific operational conditions. These include the presence or absence of a readily adjustable head gate and the activities of gatekeepers. As was noted previously in IIMI Pakistan's 1987 reporting of preliminary research results, it is common to encounter outlets where water flows fluctuate between modular and non-modular conditions,

*Figure 11.14. Lagar Distributary: Variability in outlet discharge.*

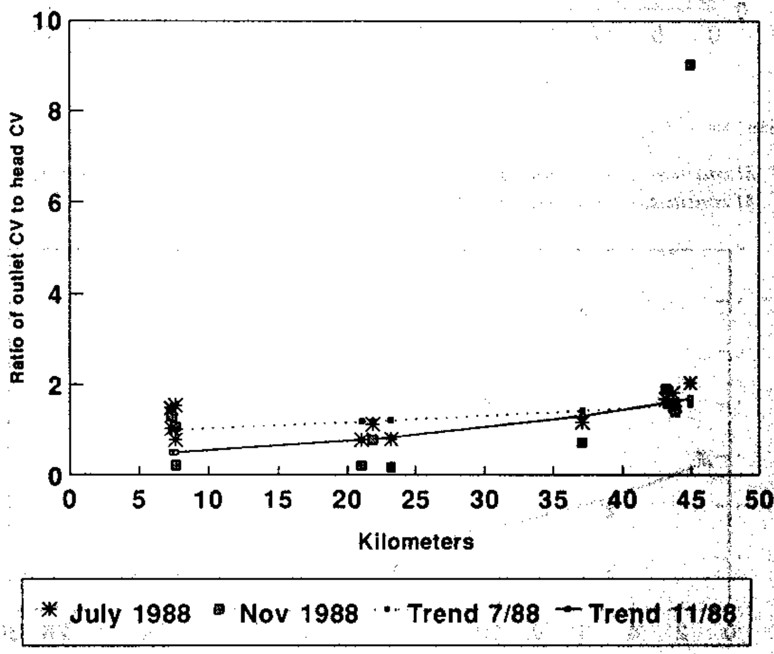



[61] Here and elsewhere in the discussion that follows, the coefficient of variation, a measure of relative variability or dispersion around a mean condition, has been used to ascertain variability in water distribution.

The likely consequences of such gate management can be inferred from Figure 11.18. The month of July 1988 was the month of maximum variability in Upper Gugera Branch flows, as well as of maximum head gate adjustments. In November 1988, variability in Upper Gugera Branch flow was less than 5 percent, although variability of Mananwala discharges at head was nearly 30 percent, about 50 percent less than that of July 1988. Overall, the condition of relative discharge variability at watercourse heads down Mananwala for these two months was roughly the same, as indicated by the computed trend lines for these two months. This would suggest that variability in main channel flow was managed rather effectively in July, and was not passed into the distributary to further exacerbate flow conditions.

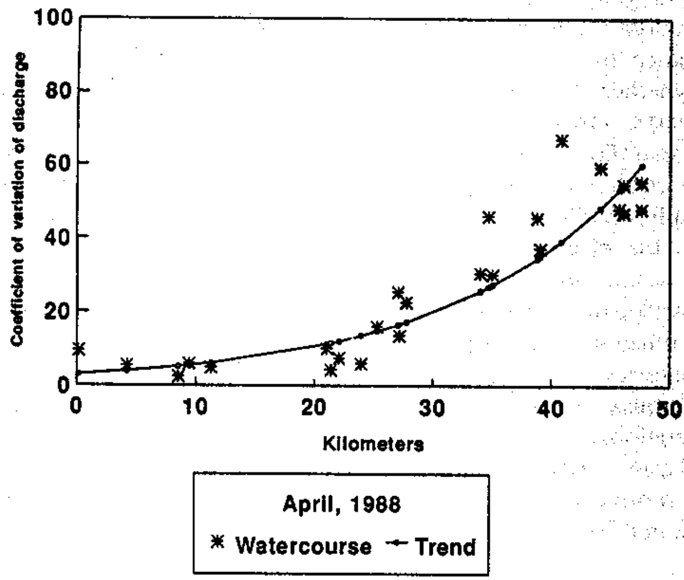
Analysis of daily discharge conditions for Lagar Distributary outlets during 1988 indicates that there may be a significant diurnal pattern to distributary discharge variability that compounds the problems of surface water supply reliability to which farmers must adjust. Water supply variability for Fridays at the head and along the distributary (Figure 11.19) during kharif season, 1988, for example, was consistently about 50 percent greater than variability on Mondays.[62] Concomitantly, DPR for

*Figure 11.18. Mananwala Distributary: Gate operations and outlet Q variability.*




[62] Although a "Friday effect" on operations of Pakistan's canal systems has been speculated about by some observers, this is the first firm evidence that such a condition may indeed exist. Fridays, as well as half of Thursday, are the "weekend" in Pakistan and thus a time when agency officers and staff are normally not at work.

*Figure 11.15. Pir Mahal Distributary: Variability in outlet discharge.*

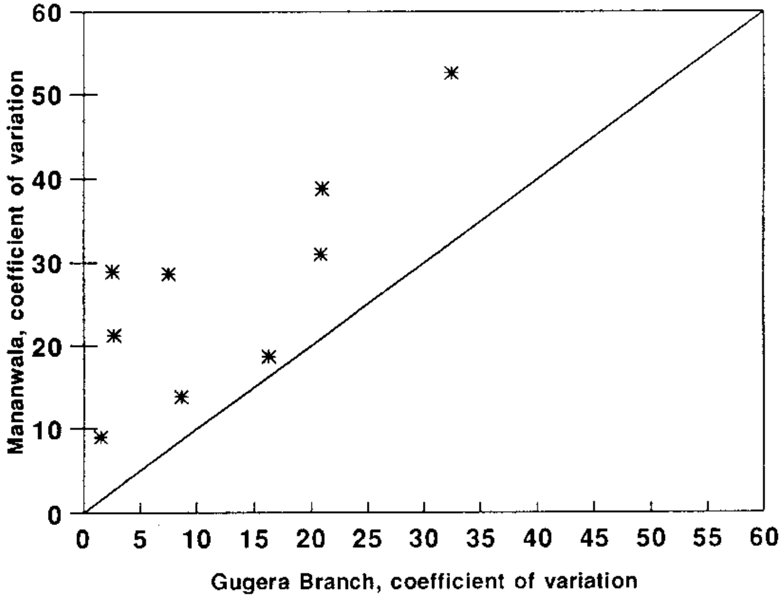



particularly in the upper reaches of distributaries. In addition to changing distributary water supply levels, the presence of a large public tubewell discharging into the watercourse head can be a cause of this condition. Farmer activities below the outlet, such as irrigating higher fields during their warabandi (roster) turn along the watercourse, poor watercoûrse maintenance, or improperly designed or implemented watercourse improvements, have also been observed as factors contributing to water distribution variability.

Mananwala Distributary is the only distributary currently being studied that has a mechanical head gate. Lagar's head gate is comprised of stop-logs (horizontal karries) and at Bhagat (the tail of Lower Gugera Branch), vertical karries are used to regulate discharges through the proportional dividing head structure into Pir Mahal Distributary. In neither of the latter two cases is it as easy to adjust the head gate to respond promptly to main channel flow fluctuations as it is in the former.

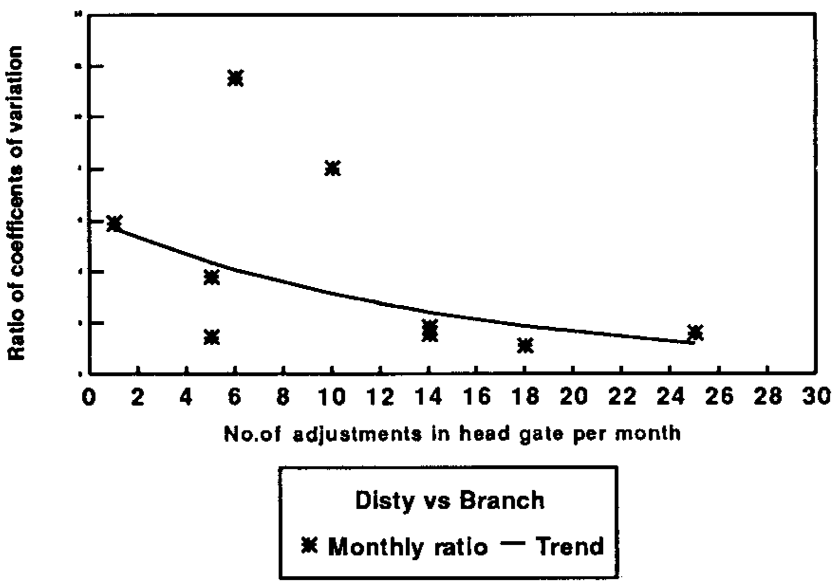
Analysis of a limited set of discharge and gate operation data for Mananwala Distributary reveals that with careful and frequent head gate adjustments, variability in distributary head discharges relative to the variability of main channel discharges can be successfully managed. This is shown in Figures 11.16 and 11.17 where the coefficients of variation of monthly main channel and distributary head discharges are plotted, and then the ratio between Mananwala variability and Upper Gugera Branch variability is compared to the number of adjustments made monthly in the distributary head gate. The kinds of information used by the gatekeeper to make the adjustments, as well as the reasons for many adjustments being made in some months but not in others (thereby resulting in more variable distributary flow conditions), remain to be identified.

*Figure 11.16. Mananwala Distributary and Gugera Branch: Monthly discharge variability at head.*



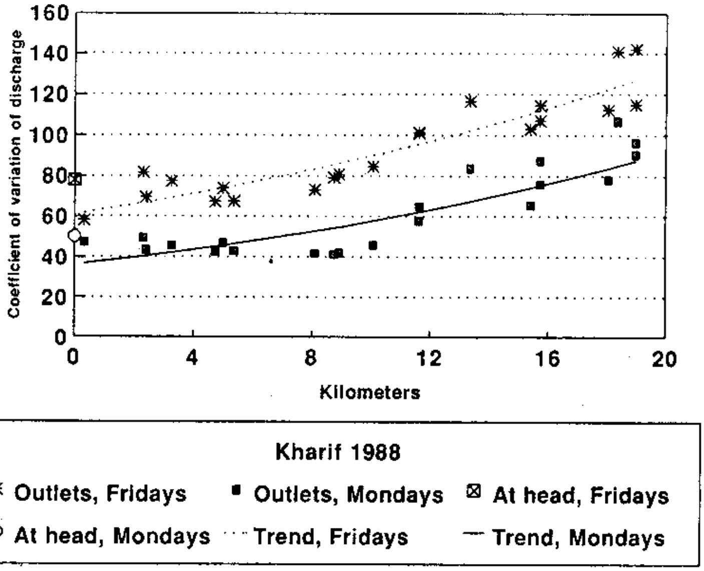

April - December 1988

*Figure 11.17. Mananwala Distributary: Head gate operations vs discharge variability of Mananwala and Upper Gugera Branch*




IIMI data, April- December 1988

*Figure 11.19. Lagar Distributary variability: Discharge at outlets on selected days.*




Mondays equalled or exceeded that of Fridays for about 85 percent of the season, a period of maximum crop water requirement and, correspondingly, of maximum water demand by farmers.

Such a pattern of discharge variability interpenetrating the pattern of water distribution equity has important implications for actual surface water supply conditions encountered by farmers in their watercourses where farmers' irrigation turns are governed by the common 7-day warabandi[63]. Typically, the warabandi cycle begins on Monday mornings with the irrigation turns of farmers whose lands are at the watercourse head. In this roster of irrigation turns, farmers whose turns come on Fridays are commonly those whose lands are more than half-way down the length of the main watercourse. The extremes in the diurnal pattern of DPR variability at watercourse head encountered by farmers in mid-kharif 1988 in two watercourse commands, one a head outlet and the other a tail outlet, on Lagar Distributary are depicted in Figures 11.20 and 11.21, respectively (note the difference in DPR scale used in each figure).

Clearly, farmers whose irrigation turn comes on Mondays can anticipate both a greater likelihood of flows and a better flow condition than can those with Friday turns, just as all farmers served by head-end outlets can expect a better overall delivery performance by the channel than can those supplied by tail-end outlets. The cause(s)

[63] The 7-day warabandi is followed in the commands of 17 of the 23 watercourse outlets along Lagar Distributary's main channel.

*Figure 11.20. DPR variability in Head Outlet 2R, for selected weekdays.*

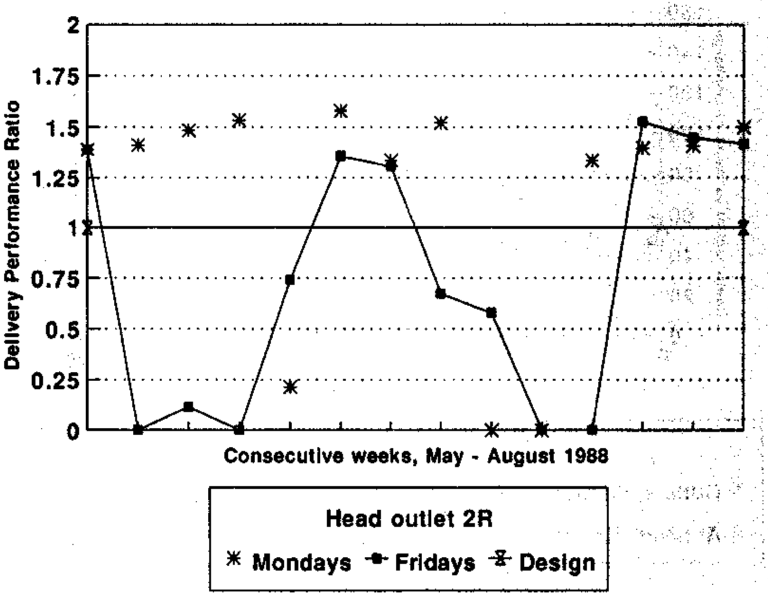
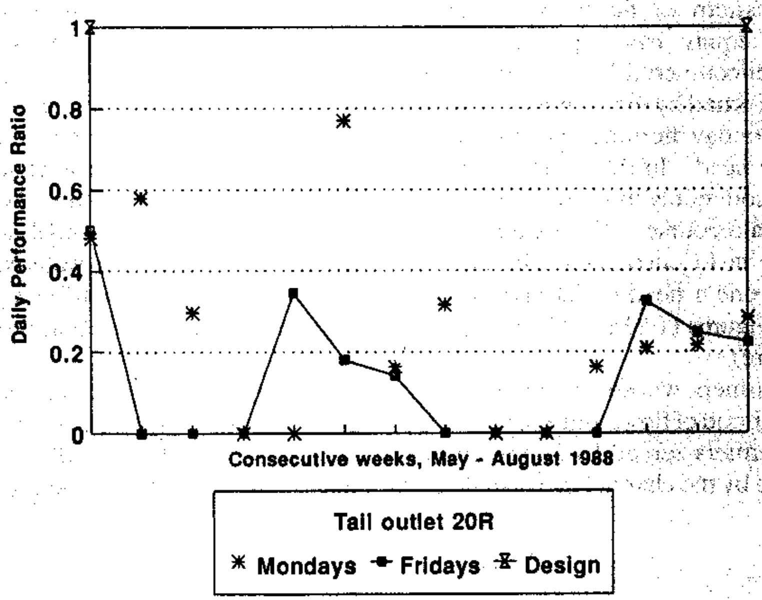


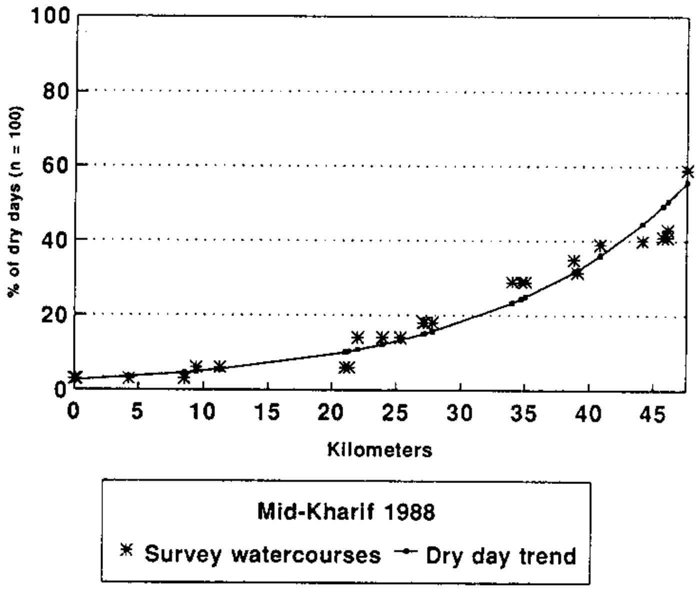

*Figure 11.21. DPR variability in Tail Outlet 2OR, for selected weekdays.*



of this diurnal pattern in Lagar, and whether or not it is common to other distributaries (and in other systems) can only be speculated about at this juncture. It has not, as yet, been identified for Mananwala Distributary in the same sub-division.

Neither has such a pattern been observed in the operations of Pir Mahal, where the interaction of both between-distributary and within-distributary rotations, currently being studied there, may mask its occurrence. In any case, rotational operations complicate the determination and analysis of variability in distributary water deliveries, insofar as low water or no water conditions are certain to be present periodically. Undoubtedly the within-distributary rotation practiced on Pir Mahal is a contributing factor to the disproportionately greater frequency of dry days at tail outlets than at middle or head outlets (Figure 11.22).

*Figure 11.22. Pir Mahal Distributary: Dry days (percent).*




## MANAGEMENT OPTIONS TO IMPROVE WATER DISTRIBUTION EQUITY AND VARIABILITY

The primary objective of research on water distribution equity and variability at the distributary-level has not merely been to define the current condition and its causes in different canal systems in different agro-ecologic and hydrologic environments in Pakistan, but rather to identify appropriate management solutions to such problems that can be used by irrigation agencies. In the discussion that follows, some promising management opportunities to improve water distribution equity and lower water supply variability in distributaries are identified.

## Improving Water Distribution Equity

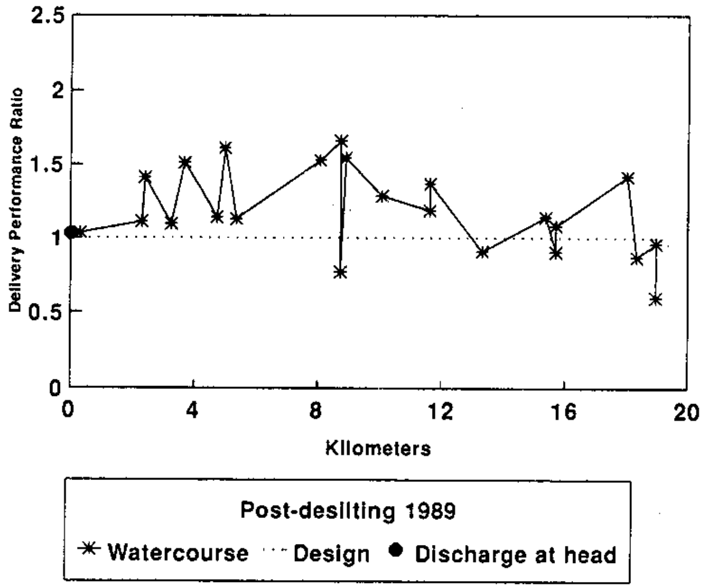
Formerly, when regular monitoring of watercourse outlets revealed that discharges had changed significantly, primarily in response to the changing physical condition of the distributary, a responsible officer (usually the Executive Engineer), would initiate procedures to remodel the channel and the outlets so that the existing distributary full supply water level resulted in a discharge that again met the design equity condition. Of course, if inspection showed that increased outlet discharges resulted from physical tampering with the structure, the outlet would be immediately restored to its former design and legal procedures would be initiated to identify and prosecute those responsible. It is widely admitted, however, that neither procedure to restore design water distribution equity conditions is — or can any longer be — practically followed by irrigation officers.

Consequently, improved management of regular maintenance inputs to distributaries is now the principal method whereby the Irrigation Department can readily redress serious water distribution inequity between watercourse outlets. The potential gains, as well as subsequent problems, of doing so were demonstrated on Lagar Distributary during the 1989 annual closure maintenance period. In a jointly planned and implemented "action" project, the Irrigation Department used survey and measurement data provided by IIMI to target channel desiltation and other channel maintenance activities to specific reaches of Lagar Distributary. The maintenance objective, of course, was to improve distributary performance, particularly in terms of increasing water distribution equity.

The performance profile for Lagar (Figure 11.23) after its annual closure confirms that when maintenance inputs are targeted to the primary locational sources of problems, rather than to the locational source of problem complaints, as had been done in previous years, the result is a very substantial improvement in water distribution equity. The distinctive linear correlation between lower DPR and outlet distance from the distributary head was markedly weaker. In Figure 11.7, it can be seen that mean DPR for tail quartile outlets for March and April 1989 was much greater than it ever had been for any two-month period since mid-1987. Even under a flow condition of less than 70 percent of design, there was a greater degree of equity in water distribution to outlets than had been previously observed. Moreover, under full supply conditions, at least initially, the IQR of delivery performance between head-end and tail-end outlets had been reduced from more than 5:1 to about 1.5:1. Farmers served by tail outlets claimed that surface water supply conditions were better than they had experienced at anytime in the previous ten years, although such claims could not be independently confirmed by reliable data.

It is clear that by targeting, as well as prioritizing, maintenance inputs at the distributary level, it is possible for the Punjab Irrigation Department to meet, at least partially, two important irrigation management objectives. On the one hand, it can obtain significant improvement in the degree to which it meets the existing canal operations objective of water distribution equity. On the other hand, it can demonstrate

*Figure 11.23. Lagar Distributary: Water distribution equity.*




a responsible management of the admittedly meager resources available to it for the maintenance of canal system physical infrastructure.[64]

Unfortunately, at this juncture, there is no firm evidence that either management objective is being achieved at a satisfactory or desirable level. In fact, the interquartile ratios of mean DPR for both Lagar and Pir Mahal distributaries (Figures 11.9 and 11.10) suggest that the failure to manage maintenance inputs more carefully, can contribute to a worsening pattern of water distribution equity. In the case of Pir Mahal Distributary, the IQR of head to tail outlets since October-November 1988 (when major work was done to repair damage to the lower half of the canal caused by river flooding), has been much worse than it was for the preceding eight months. The DPR for Lagar tail outlets in the twelve months after substantial maintenance inputs during the January 1988 annual closure followed a similar pattern.

Equally problematic is the current level of management of maintenance resources, and this has important consequences for how long improvements in water distribution

[64] The 1989 budget said to have been available to the Executive Engineer, Upper Gugera Division (which includes Farooqabad Sub-Division) for maintenance activities during the annual closure period was Rs 300,000 or about $15,000 at that time. This amount was so small, relative to the needs of some 27 distributaries commanding more than 230,000 hectares (575,000 acres), that the Executive Engineer chose to simply divide it evenly among the three subdivisions comprising Upper Gugera Division. The ID-IMMI "action" maintenance activity was financed separately from funds directly controlled by the Chief Engineer, Faisalabad Zone. Slightly more than Rs 65,000 was budgeted for it.

equity can be sustained. Further developments in Lagar command have not provided much of a basis for optimism here. Within slightly more than four months from completion of the joint "action" maintenance project on Lagar, water supplies to outlets in the last quarter of the distributary had deteriorated so badly that farmers there filled in a 20-m length of channel in protest. IIMI field observations and measurements permit at least a preliminary identification of two crucial reasons for this development that have significant implications for similar management interventions designed to improve secondary canal performance. First, targeted maintenance was not implemented and completed as planned and approved, and second, initial improvements in water supply conditions led directly to illegal interventions by farmers and ID field staff in order to appropriate improved supplies at points of locational advantage on the channel.

Comparative analysis of longitudinal and cross-sectional survey data of "before" and "after" channel conditions, done as part of IIMI's commitment to the "action" project, indicate that only a modest fraction of the earthworks — desilting and berm cutting — that were planned and said to have been done, was actually carried out.

There can be little doubt that this was a major factor in the non-sustainability of the initial improvement in water distribution equity. It is not clear whether this result reflects local conditions of maintenance resource management or whether it is part of a more widespread pattern. However, there would seem to be at least an implied need for more effective supervision and management of contracted ID maintenance activities at both sub-divisional and divisional levels.

A spatial refocusing of the watercourse improvement program of the Punjab Department of Agriculture, implemented by the Directorate of On-Farm Water Management, is also likely to enhance conditions for achieving a more fair distribution of distributary water supplies. If priority emphasis were given to improving watercourses offtaking from the tail reaches of distributaries before improving those in the middle or head-end reaches, there would be less chance of improved outlet flow conditions actually intensifying inequity in distributary operations. Action research to test the efficacy of this approach could be readily designed and implemented with agency cooperation and collaboration. It is already clear that a management initiative that deliberately focused and encouraged improvement of tail-end watercourses would have the additional benefit of conserving surface water supplies in the genuinely water deficit areas of distributary commands.

Initial canal operations simulation research using the hydraulic model, MISTRAL, calibrated by empirical data obtained for LCC distributaries has included a comparison of the management option of rotational operations at the distributary level with existing operational practices for Lagar Distributary. Preliminary results indicate that there was a modest decrease in the discharges of offtakes in the upper two-thirds of the distributary, although most continued to draw more than their design or sanctioned amounts. More important, however, was the prediction of a very considerable (two to three-fold) increase in supplies to outlets in the lower one-third of the channel. Given that distributary hydraulic conditions do not vary substantially among Farooqabad Sub-Division channels, the tentative conclusion from this work is that equity in surface water distribution could be significantly improved by implementing carefully planned and rigorously followed rotational operations at distributary heads in the sub-division during low discharge periods in the main Upper Gugera Branch channel.

## Reducing Variability in Water Distribution

Research results confirm that careful management of head gate structures is necessary if distributary discharge variability is to be reduced to, and maintained at, the lowest practical levels consistent with the rigid hydraulic design conditions of the secondary canal system. This is neither new nor surprising. However, the efficiency of the gatekeeper is substantially a function of the hardware and software available to him. It does not appear likely that the hardware of existing distributary gate structures is going to be replaced or modernized on a major scale in Punjab in the foreseeable future, although individual, localized improvements are bound to occur. More realistically, if information were made more reliable, then better head-gate management could be reasonably expected from gatekeepers.

Sufficient distributary discharge measurement data are now available to conclude that there are significant differences between the amounts of water recorded as being discharged into distributary channels and actual discharges. Comparisons between official records and IIMI measurement data for Mananwala, Lagar and Pir Mahal distributaries are shown in Figures 11.24, 11.25 and 11.26 respectively. A major reason for this gap is that all gatekeepers (or gauge observers) in the two sub-divisions

*Figure 11.24. Mananwala Distributary discharge: Comparison of ID records and IIMI data, August-September 1988.*

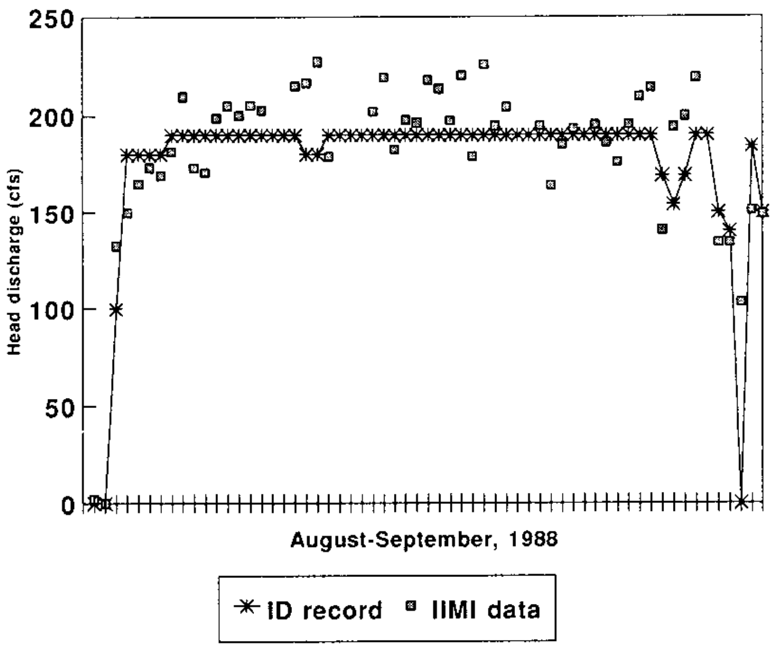


*Figure 11.25. Lagar Distributary discharge: ID records and IIMI data, August-September 1988.*

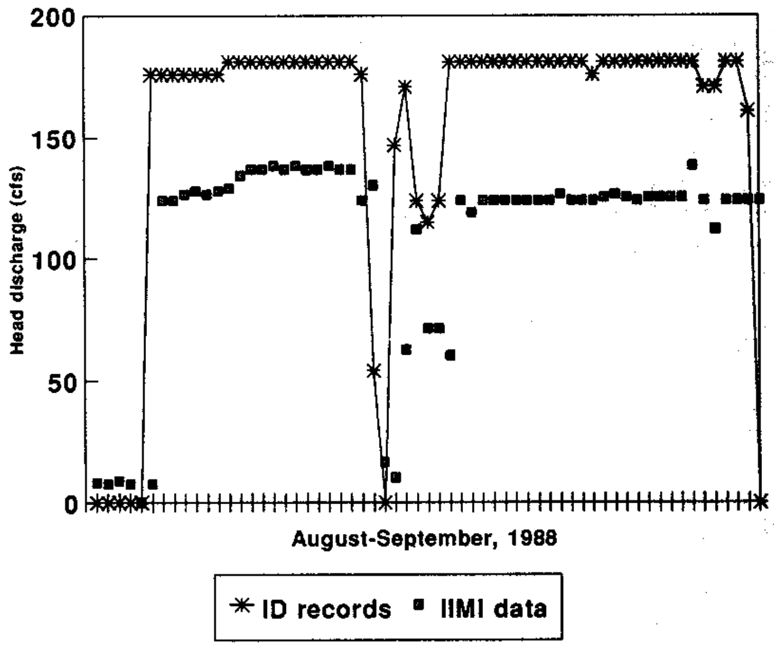
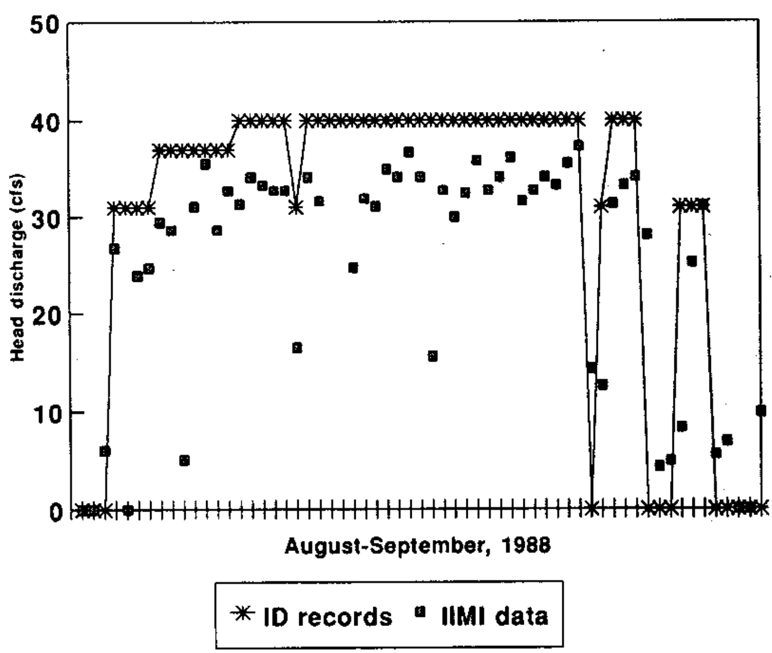



*Figure 11.26. Pir Mahal Distributary discharge: Comparison of ID records and IIMI data.*



where research is underway are using discharge tables for their structures that are often more than 20 years old. When this condition is combined with the absence of gauges at many distributary heads (none of the three distributaries discussed here have functioning downstream gauges), regulation of head discharge becomes a matter of guesswork or an "art." Accumulated experience is certainly helpful. So, too, is the presence of a readily adjustable mechanical gate, as at Mananwala head where comparative data suggest that the information gap between measured and recorded discharge is often within the range of the accepted measurement error. However, even in the absence of the latter condition, it seems certain that if gatekeepers were able to use their accumulated experience in conjunction with reliable information, variability in distributary discharge could be better controlled than being done now.

## CONCLUSION

Although the research activities and results reported here are limited in their geographic scope relative to the size of Pakistan's canal irrigation environment, at least one broad, general conclusion seems inescapable. If a more productive and sustainable irrigated agriculture is a system performance objective, then the results thus far from research on distributaries in the LCC system point to the need for a more reliable, precise and disaggregated view of within-system canal performance than has so far been available. This is an important, perhaps essential, first step in developing appropriate and effective management interventions. Although a productive start has been made in this direction in a single large Punjab canal system, there remain substantial gaps in our understanding of distributary-level canal performance. An especially important gap concerns actual main system operations and their impact upon distributaries in the LCC.

There has been sufficient research progress to begin actively considering management options to improve both the equity and reliability of water distribution to farmers at the distributary level. Several initiatives to do just that in a more "action research" mode, involving irrigation agency cooperation and collaboration with IIMI Pakistan, are already underway or are being planned for implementation.

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