CHAPTER 4

Impacts of Physical and Managerial Interventions on Canal Performance in Pakistan: A Review of Five Years of Field Research Studies

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INTRODUCTION

THE OBJECTIVE OF this paper is to review the results obtained from a set of related research activities that assessed the impacts of physical and management interventions in various distributary canals in the Lower Chenab Canal (LCC) system, Punjab, Pakistan, over the past five years (Vander Velde 1991, Bhutta and Vander Velde 1992). The locations of these various research sites are shown in Figure 4.1.

A key facet of the research in the LCC system reviewed here is that a comparison of three contrasting approaches to secondary canal performance improvement is now possible:

- **Physical improvement** of the conveyance system, primarily through canal lining.
- **Focused desilting** of existing canal infrastructure that aims to restore, as far as possible, designed conveyance conditions.
- **Operational management** to ensure that available water is distributed as efficiently as possible to meet the stated operational objectives of irrigation agencies.

Overall, there is a significant opportunity to go beyond studies that simply describe improvements based on a single intervention but do not address the relative merit of one approach over another, or the possible synergistic impact of undertaking two or more interventions in parallel. Furthermore, the findings justify making some specific recommendations for policies aimed at improving the performance of canal systems in Pakistan. Definition of a set of activities that will form the basis of practical options for irrigation managers is also possible.

Short of completely overhauling the canal system in Pakistan, an impossibly expensive task, the three interventions identified above represent the only realistic approaches that can be adopted under present conditions to improve the performance of the secondary canal system. There well may be different interventions possible in the main canal system, including provision of more cross-regulation capacity than that currently exists, but to date IIMI has had neither the resources nor the technical capacity to undertake studies in this portion of the irrigation system in Pakistan.

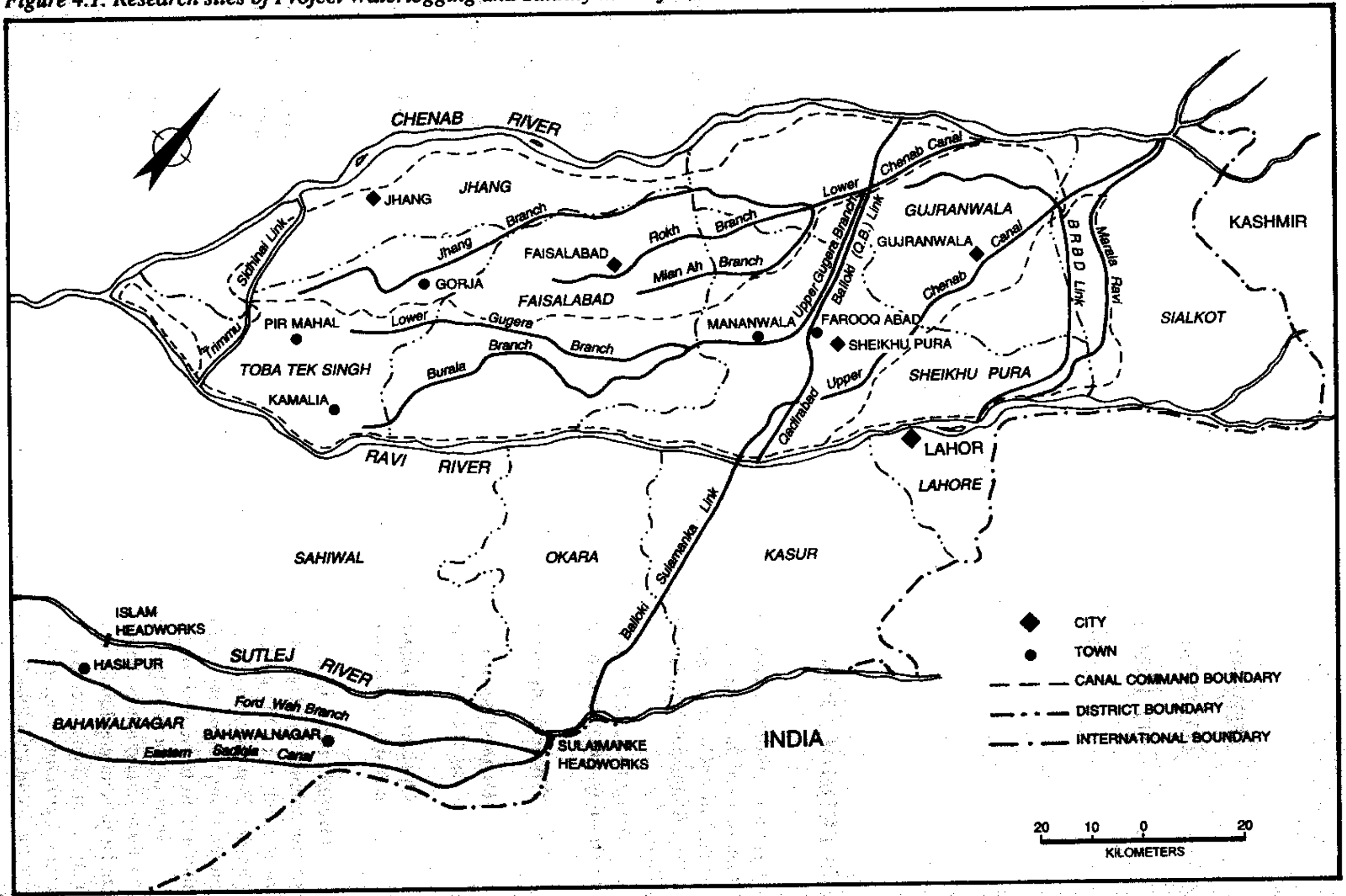

Figure 4.1. Research sites of Project Waterlogging and Salinity in Punjab, Pakistan.

Finally, before proceeding further, it may be appropriate to strike a cautionary note. Despite the relative success of this work as a research program, both as an example of how to conduct such research and in transforming results into practical options for irrigation agencies, institutional conditions in Pakistan simply do not yet favor a performance-oriented approach to irrigation management. Concerns with personal advancement frequently outweigh rational use of resources for either construction or maintenance; moreover, both the increasing frequency of political interference in canal systems and the declining law and order situation over much of the rural countryside makes it hard for irrigation-agency staff to implement operational plans effectively.

ESTABLISHMENT OF THE CANAL RESEARCH PROGRAM

In common with the experiences of other field offices, IIMI-Pakistan initially found it difficult to clearly identify research issues that were both feasible and of interest to line agency staff. This was partly a consequence of the relatively low level of resources and facilities available when the office was established, and partly because IIMI came to Pakistan with no proven track record. It is not unreasonable to expect a country to be cautious in opening its offices, data records and irrigation systems to researchers from an unknown institution.

An additional impediment was posed by prevailing conventional wisdom. In the early discussions on nearly every possible research topic, agency staff were convinced they not only knew the true nature of things at field level, but also believed that canal systems in Punjab were really performing quite well. Under such conditions, it was difficult to obtain concurrence with research proposals to undertake field studies, which implicitly questioned this conventional wisdom.

One notable bias among irrigation agency staff was that studies of canal operations were unlikely to be particularly useful. It was repeatedly stated that the main and secondary canal system in Pakistan provided little opportunity for management intervention since canals were run more or less at full supply level for eleven months of the year. Because actual discharges were believed to be always at, near or even above actual designed discharges, it was assumed there was no further flexibility in the system that could form the focus for managerial interventions. While observations during the first field trips (and on the daily drive to work along Lahore Branch Canal) indicated that water levels did (and do) fluctuate, and over a significant range during quite short time periods, no window of opportunity soon appeared for initiating a structured research program.

Whenever interest was expressed by staff of various provincial or federal irrigation, agriculture and water resource agencies, it commonly was oriented to tertiary and farm-level issues. This partially was a reflection of the high public profile of the On-Farm Water Management Program in Pakistan, with IIMI being perceived as having a role not dissimilar to that played by other foreign research consultants in the past. But, it also served to perpetuate the myth that the problems of irrigated agriculture in Pakistan basically are a consequence of farmer ignorance. It has long been the ethic of agency staff to place the blame for the comparatively poor performance of irrigated agriculture at the door of farmers, and to advocate training and organizational activities as the solution to problems of farmer inefficiency and low production.

Interest in Canal Lining

The first opportunity to undertake research in the main and secondary canal system finally emerged when the Punjab Irrigation Department (PID) asked whether IIMI would be interested in undertaking an evaluation of the benefits of canal lining in two canals near Lahore. The provincial irrigation departments had watched with some envy the substantial flow of resources into the watercourse lining component of the On-Farm Water Management Program that had been managed through provincial agriculture departments. There was also some professional pique that agriculturalists were involved in irrigation-related lining programs, albeit at the watercourse level. Although substantial resources to improve canal-system infrastructure had been made available to the irrigation departments through the World Bank/USAID co-financed Irrigation System Rehabilitation Project (ISRP), there was strong PID interest in developing a wider lining program in secondary and minor canals. While this first research activity was comparatively modest, it was to provide the basis for a sustained and increasingly complex research focus on the assessment of canal performance in Pakistan.

The two canals in question, Lagar and Ghordaur distributaries, offtake from Upper Gugera Branch of the LCC system. They had been selected for the PID's lining experiment because they were "problem" channels, the "problem" being that water supplies at the tails were well below design and had been so for extended periods. It was hoped that lining would make it possible to get more water to the tails and thereby reduce or eliminate the continuing complaints of farmers in tail watercourses about the lack of surface water. Lagar and Ghordaur distributaries also proved to be conveniently located for inclusion in IIMI's research program; they were readily accessible from Lahore during the initial stages of establishment of IIMI-Pakistan, and were within easy distance of the first IIMI Field Station being established at Farooqabad in Sheikhupura District. In retrospect, it is hard to conceive a more suitable starting location for the research program.

The Lessons of Lagar and Ghordaur Distributaries

As reported in the first *IIMI Review*, the results of this first study were inconclusive (Murray-Rust 1987). The only data sets arailable were secondary information from the PID's subdivisional records, consisting of water level data at the head of each canal and water levels at the tail gauges. Both sets comprised data reputedly measured and collected on a daily basis. However, it was impossible to realistically assess the impact of lining on subsequent canal performance because there were considerable doubts about the veracity of the tail gauge data, and because there had been a major increase in actual discharges into both canals following lining.

Despite the inconclusiveness of that first study, several important lessons were learned in relation to design and implementation of subsequent research activities. They include the following:

- **Data available from official sources could not be used as a basis for intensive research studies.**

  Data from agency records are patchy, often inaccurate and insufficiently documented to form the basis for research. In some cases, they may be indicative of actual conditions, but they should not form the basis for detailed research studies unless they can be verified through parallel field measurement programs.

- **Physical and hydraulic conditions along distributaries appeared to deteriorate about two-thirds down the channel.**

  The field observations made along both Lagar and Ghordaur suggested that water conditions in the upper half of the secondary canal were reasonably good, but that somewhere after about half way down the channel, discharges became inadequate even though discharge at the head was at or close to the designed value. This observation could not be substantiated initially by available data, but clearly lining could not be effective if there were inadequate water conditions upstream of the lined section.

- **Canal operations greatly influence canal performance in both lined and unlined conditions.**

  The PID data clearly indicated that there were fluctuations in discharge into secondary canals resulting both from water level fluctuations in the main canal and operation of secondary canal head gates. This finding contrasted sharply with the conventional view that there was little or no opportunity for management in the main and secondary canal system.

As a consequence of these findings, field-based activities on a number of topics were added to the emerging research program. There were:

- ***Continued interest in performance resulting from canal lining***

  It was agreed to continue research into the impact of lining, but only where it could be conducted in more controlled conditions: a baseline study of water supply conditions prior to intervention, and a similar set of readings once the intervention had occurred.

- ***Studies on changes in hydraulic performance along canals***

  The apparent deterioration in hydraulic performance resulting in major differences in water distribution equity between head and tail watercourses even when discharges into the canals were at or close to designed levels provided a significant research opportunity to examine how these canals actually function, and what could be done to address the obvious conditions of inequity.

- ***Studies on the operation of secondary canal head gates***

  In an environment where the number of locations for management intervention are limited, it is obvious that the level of management applied at these locations must be of high quality. Frequent fluctuations in discharges into secondary canals, and evidence of extended periods of operation at discharges well below design limits presented opportunities for operational improvements, but required more data before recommendations could be developed.

Although the results of each of these three activities are reported separately here for purposes of clarity, in reality, there was considerable complementarity and linkage in implementation of the components of the research program and the subsequent reporting of results.

Finally, in this first stage of research, one overall guiding principle was adopted:

> **Before rushing in with action-research programs that might only yield ephemeral improvements, it was necessary to first have a clear description and understanding of current levels of canal performance, and to then try to deduce what would be the most effective management strategies that could be adopted on a lasting basis by irrigation agencies.**

THE IMPACT OF LINING ON CANAL PERFORMANCE: KHIKHI DISTRIBUTARY

IIMI's research had already established that official records of water conditions were inadequate below the head of secondary canals, although they were reasonably reliable for many locations along the main system. Therefore, undertaking a reliable and scientific evaluation of the impact of lining on canal performance would require a long-term commitment to repeated measurements under controlled or known conditions at many locations along a distributary.

Surprisingly enough, selecting a suitable site for such a study proved remarkably difficult. Although several minor distributary canals were being lined through the Command Water Management Project, no data of sufficient quality were available for the before-lining condition or, in most cases, for conditions following improvement.[6] From the perspective of research, the data environment was no better than the conditions encountered in Lagar or Ghordaur. A few other canals were lined during 1988 but either because IIMI did not have enough lead time to undertake the pre-lining survey or because the locations were too difficult to access from existing research sites, none of these canals could be included.

Eventually an opportunity arose at Khikhi Distributary. This canal is located in the Lower Gugera Division of the Lower Chenab Canal. IIMI had for some time been interested in working in the tail-end portion of a major canal to provide a contrast with upper-end conditions studied in the Farooqabad area, and Khikhi provided sufficient interest for IIMI to establish a second field station in Bhagat Subdivision. In addition, it removed some criticism IIMI had encountered for working only in small canals: Ghordaur has a design discharge of 1.4 m^3/sec, Lagar only 1.1 m^3/sec, while Khikhi has a design discharge of almost 10 m^3/sec and irrigates some 42,000 ha.

Khikhi Distributary was well-known as a "problem canal" with chronic and long-standing water shortages at the tail end. In addition, Khikhi supplies drinking water to several areas where the groundwater is of unsuitable quality for human consumption. These problems were of sufficient magnitude that they aroused the attention of the late President of Pakistan, General Zia. In response to complaints, he eventually sanctioned the use of special Presidential Funds to be released to the Irrigation Department to undertake various remedial measures.

On receipt of these funds the Punjab Irrigation Department developed a two-stage strategy. The first activity involved a program of desilting, in 1986, using mechanical and manual inputs to clean out much of the upper two thirds of the distributary. The second activity involved lining, but this could not be started immediately due to the time required for developing detailed designs and submitting the final estimates for approval.

The delay in actually implementing the lining program enabled IIMI to undertake a complete baseline survey of hydraulic performance along Khikhi Distributary in the period between desilting and the commencement of lining. As it turned out, the lining program itself extended over a three-year period in order, it was stated, to minimize disruption in irrigation supplies to farmers. Because work was divided into several phases, with construction proceeding slowly upstream from the tail, IIMI was able to undertake a further three sets of readings over the first two stages of lining. The last phase of lining was completed in late 1990, and a final set of measurements were taken in late 1992 to complete this study. These readings had been deliberately delayed in order to make sure the hydraulic conditions at the head of Khikhi would be essentially the same as those for previous measurement sets.

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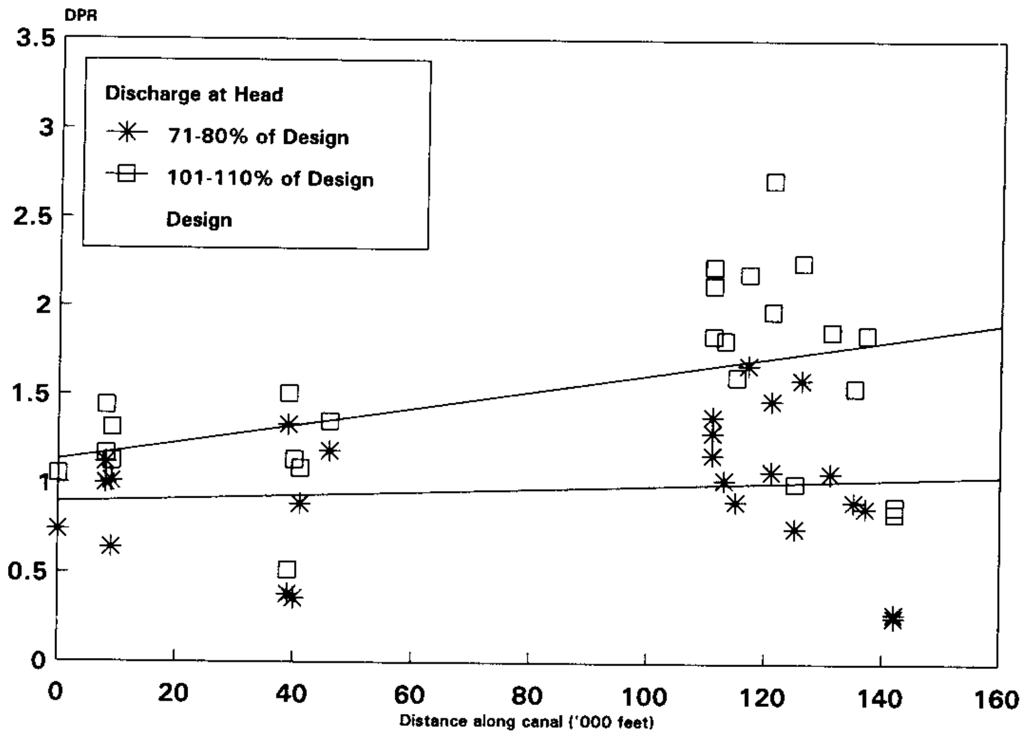
6 Given the magnitude of the costs associated with these lining activities, it is disturbing that such financial decisions continue to be made without a careful examination of pre-lining conditions, an assessient of the likely benefits to accrue from such an intervention and a rigorous evaluation of the results actually achieved.

The main results of the research can be summarized as follows:

- **Tail-end water conditions did not improve following the desilting of the canals**

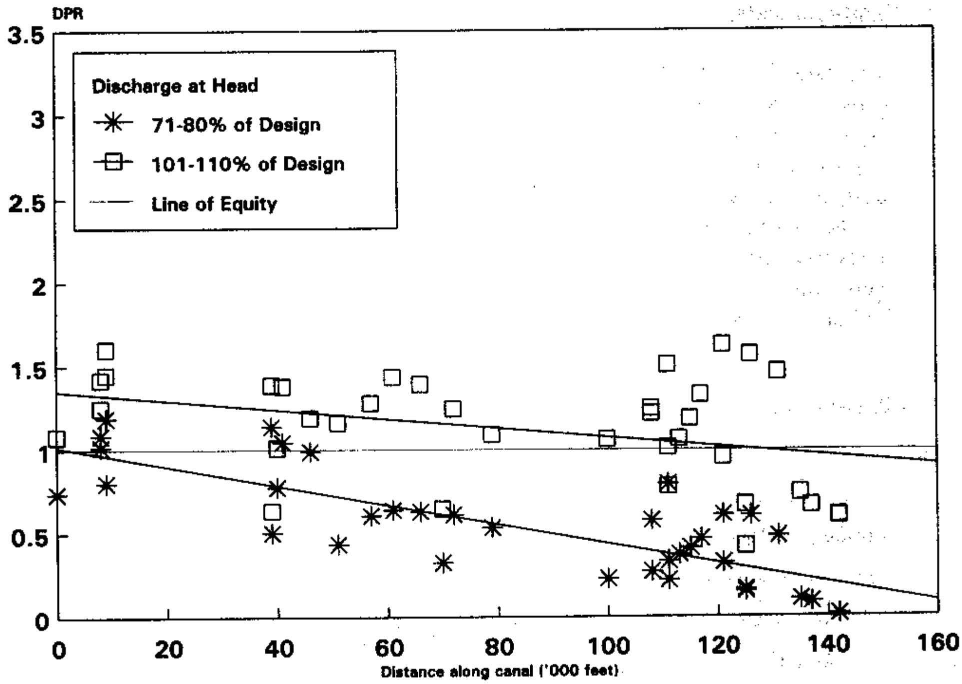
  The data show no significant change in water conditions at the tail end of the canal between the different measurement periods. The immediate reason for this is quite obvious: the desilting, taken as a contingency measure prior to lining, appears to have improved things so much that the Delivery Performance Ratio (DPR) in tail-end watercourses was not significantly different from those at the head. At high discharge levels, for example, the DPR of tail-end watercourses was better than those in head-end areas and more or less the same along the distributary when discharges into head of Khikhi were about 75 percent of design (Figure 4.2). Consequently, there was little room for hydraulic improvement as a result of the lining.

Figure 4.2. DPR, Khikhi Distributary, after desilting, before lining.



To make matters worse, there is evidence that tail-end water conditions have declined since the onset of the lining program. Examination of the conditions prior to the penultimate phase of lining show that tail-end areas only receive their fair share when the discharge is above design at Khikhi head, and the conditions deteriorate rapidly when discharges drop below design (Figure 4.3).

Figure 4.3. DPR, Khikhi Distributary, after lining.



- **Volume of water delivered to the tail has not increased.**

  Although the lining of Khikhi was not explicitly intended to save water, lining is frequently promoted as one way of saving water. Using data from sample watercourses only, it is difficult to be definitive about water savings. However, the average DPR of the sample watercourses was highest in the period prior to lining, and had deteriorated steadily since that time (Table 4.1).

Table 4.1. Delivery performance ratios for Khikhi Distributary after each stage of the lining program.

Location	Phase			
	I	II	III	IV
Khikhi Head	0.99	0.98	0.89	0.99
First Quartile	1.04	1.36	1.30	1.34
Second Quartile	0.90	1.07	1.00	1.07
Third Quartile	1.68	1.12	0.75	1.04
Fourth Quartile	1.27	1.16	0.71	0.86
IQR (First/Fourth)	0.82	1.17	1.84	1.55

Note: IQR = Interquartile Ratio.

The magnitude of these changes suggest that there may be other factors involved, such as illegal tampering with outlets during the lining process (such tampering was rampant), that distort the basic changes in hydraulic conditions along the canal. However, if such illegal practices are systematically associated with a lining program, the water savings will not result in improved tail-end water conditions.

Variability of water deliveries to the tail end increased following lining.

The coefficient of variability of daily discharges at the tail has also increased following lining. Following the desilting but before lining commenced, the coefficient of variation of daily discharges during each month were at modest levels (Figure 4.4); following the penultimate stage of lining they are significantly higher at the tail end, and significantly higher when there are substantial discharge fluctuations at Khikhi Head (Figure 4.5).

This may be a reflection of the greater hydraulic efficiency of a lined canal that allows perturbations in discharge at tha head to be transmitted more rapidly and effectively along the canal. If total volume increased, then an increase in variability might be of little concern but in a situation where total volume decreases, increased variability is an added constraint to good performance.

The sanctioned cost of this lining activity was approximately Rs 27 million (US$1.25 million). For a culturable command area (CCA) of 33,500 ha, the capital cost was in the order of Rs 933/ha (US$37.33/ha).

Figure 4.4. Coefficient of Variation, Khikhi, after desilting, before lining.

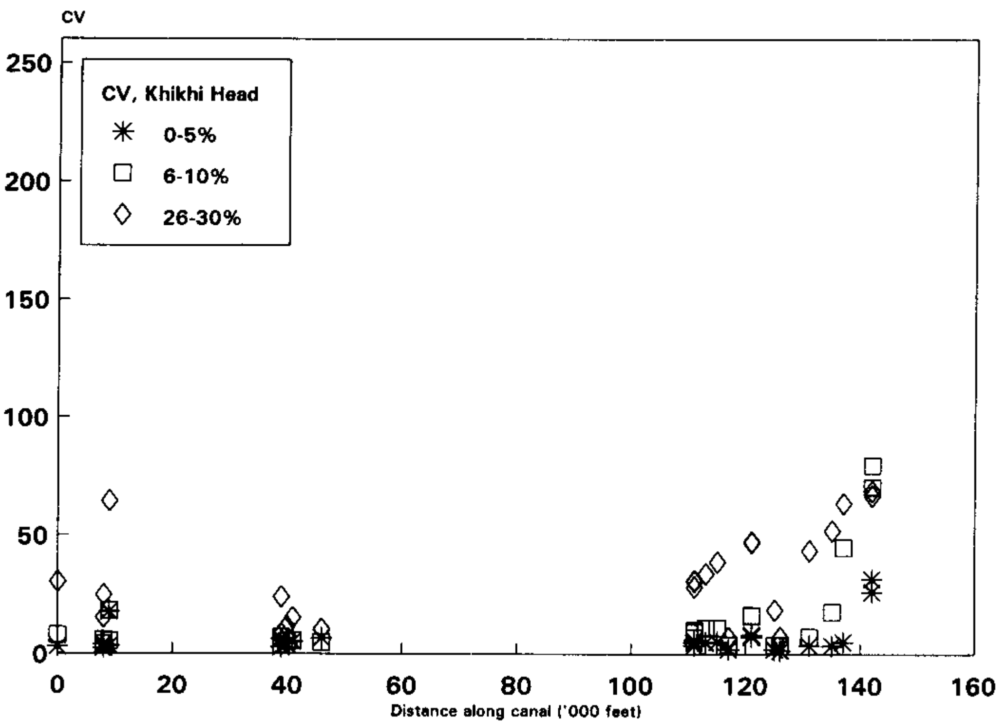
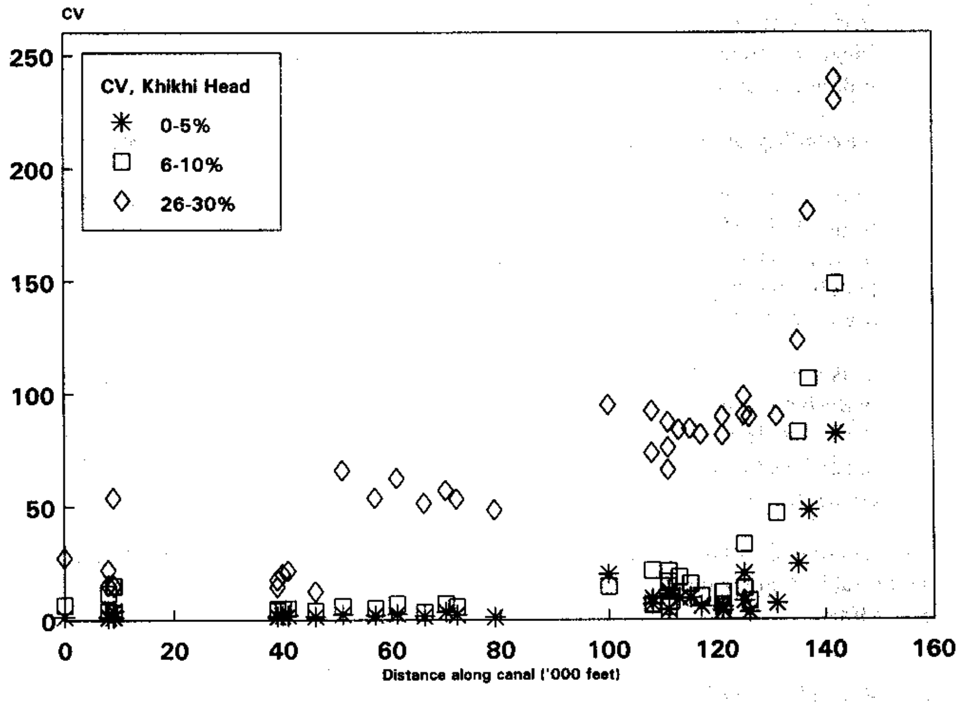


Figure 4.5. Coefficient of Variation, Khikhi, after lining.



One final footnote (which followed the collection of data presented here) to the Khikhi story needs to be reported. By late 1991, following the penultimate lining activity, the portion of Khikhi Distributary that lies on the southern side of the Trimmu-Sidhnai Link Canal and the Haveli Canal were receiving so little water that farmers were successful in getting the Irrigation Department to provide an alternative source of water supply. A special outlet was constructed in the Haveli Canal to deliver water into a specially constructed outlet box which serves the tail bifurcation structure of Khikhi Distributary that lies on the southern side of the link canal. A new tail structure was then constructed at RD 135000, dividing water between watercourses RD 135 and RD 137. This intervention cost about Rs 100,000 (US$4,000) and utilized funds provided from the discretionary budget of the local Member of the National Assembly, not Irrigation Department funds.

The tail end of Bachrianwala Minor, which is a minor off Khikhi and crosses both Haveli and Trimmu-Sidhnai link canals, was also abandoned, and a new outlet constructed in Haveli Canal. The total cost of these additional changes was Rs 1.2 million (US$ 45,000).

To put it bluntly, the net result of the activity was the loss of the tails of both Khikhi and Bachrianwala when the very purpose of the lining was to eliminate tail-end water problems.

The primary conclusions of this research are:

- **Lining the tail end of a canal does not seem to solve the problem of water deliveries at the tail.**

If the conclusion that the desilting of the upper half of the canal resulted in favorable tail-end water conditions is correct, then it seems equally logical to focus lining on the upper portion and try to establish highly reliable and dependable water conditions at the end of the lined section.

- **There is no evidence of water saving as a result of lining.**

  Investments in lining are frequently justified because of water savings. The data do not indicate any such savings, but it is possible that benefits form savings, if they exist, have been overshadowed by additional water extraction by head and middle outlets.

- **Implementation of the lining program was disruptive.**

  Because it was decided to maintain water deliveries along the entire length of the canal during the lining program, except during the period of annual closure of the entire Gugera Canal System, temporary parallel canals had to be constructed. These temporary sections were highly unstable: innumerable breaches were reported. In addition, it was clear that quality of construction was not up to design standards and this was obvious to farmers. They became increasingly dissatisfied with the work in progress and felt more than justified in making their own illegal interventions.

  Further, temporary outlets had to be constructed to serve watercourses while the main canal was closed. There is substantial evidence to show that many farmers took advantage of the disruption to install larger outlets, and even to add additional ones. The effect of these changes, some of which were encouraged by local staff of the Irrigation Department in return for financial considerations, is to further threaten the tail-end supply of water.

- **The desilting program appears to have more impact than the lining.**

  The pattern of water deliveries along the Khikhi Distributary measured in the first set of readings is similar to that of both Lagar Distributary and Pir Mahal following desilting (see section on "Maintenance and Desilting" below). It therefore appears that most of the improvements in performance at Khikhi resulted from the desilting program undertaken before lining commenced, and that subsequent lining had no subsequent impact on performance.

- **The total cost is significant in comparison to the apparent benefits.**

  The virtual lack of any improvement in performance between desilting and the end of the lining program cannot justify the money expended. In addition, it should be noted that the design adopted for Khikhi was comparatively low-cost. The lining consists of a single layer of bricks placed on a hand-compacted earth foundation with a mortar finish on both side walls and bed. More solid lining would undoubtedly be significantly more expensive and would have to result in improved performance for long periods of time to be cost-effective.

Despite these negative results, it is not possible to merely dismiss lining as a potential solution to the water delivery problems currently encountered in Pakistan. Experiences from many countries suggest that lining, while not resulting in significant savings of water for extended periods of time, does provide an effective datum for maintenance activities. Reestablishing the correct cross section is frequently a hit-or-miss-activity in an unlined canal: it is difficult, if not impkssible, to dig out just the right amount of material, not too much so as to maintain effective water depths in the canal, not too little so as to be of marginal benefit.

The lining at Lagar and Ghordaur, although broken in many places after only a few seasons due to back pressure, poor construction, and damage by tractors and buffaloes, nevertheless provides a better overall canal cross-section than in comparable canals that have not been lined.

What is required at Khikhi is a continued set of surveys over the next few years to see whether these potential benefits are achieved. If the canal silts up as rapidly in lined as in unlined sections, and if the lining rapidly deteriorates, then the argument for lining canals in the manner and to the design used at Khikhi is unlikely to provide any economically justified performance improvement.

Further, there has not yet been an opportunity to evaluate the impact of lining of the upper half of a secondary canal. It is highly probable that the results would be better than those reported here, but how much better remains a matter for speculation until a proper evaluation can be conducted.

MAINTENANCE AND DESILTING: LAGAR AND PIR MAHAL DISTRIBUTARIES

One observation made during the initial studies in Lagar Distributary was that water conditions at the head of the lined section were inadequate even though the water conditions at the distributary head were adequate. This observation led to two conclusions:

- However effective lining is, it cannot compensate for poor water conditions upstream of the lined section.

- Further studies are required to understand the hydraulic changes that occurred in the upper two thirds of the canal.

The first set of readings of discharges at every watercourse along Lagar, taken as part of the first phase of intensive field activities, revealed that there was a serious problem of water distribution equity: the tail was almost dry while head-end outlets received in excess of 150 percent of their allocation.

Analyses of these data and surveys of outlet dimensions confirmed that the excess head-end deliveries resulted from higher than designed bed levels in the upper half of the canal, and not from any significant interference by farmers: unless the outlet dimensions are illegally altered, the only way to increase discharge through an ungated structure is to raise the water surface elevation on the upstream side of the orifice. There was little sign at that time that farmers were interfering to any significant extent in terms of building temporary checks.

It was clear that the sediment problem was intense but there was no definitive evidence to indicate what the results of an effective desilting program would be on canal performance. The initial observations in Lagar and the first comparative data sets from Khikhi and Pir Mahal were considered insufficient to come to definitive conclusions concerning the actual benefits of maintenance: comparing poor water distribution in a badly maintained canal with good water distribution performance in a desilted canal 300 km away is hardly good research methodology.

As a result, it was decided to approach the maintenance and desilting issue in a careful and controlled manner in two selected locations:

Lagar distributary was selected because there was already a well-established program for collecting water readings at each outlet every day; because it was adjacent to the IIMI

Field Station at Farooqabad, it was possible to envisage close control over interventions in an action-research phase.

Khikhi could not be used because it was already desilted, but the adjacent **Pir Mahal distributary** proved an ideal alternative. The first set of data from Pir Mahal showed severe water distribution problems, and these were reported to be of similar magnitude to those of Khikhi prior to desilting.

The results of both of these studies are discussed below.

Maintenance Studies in Lagar

Using the hydraulic model developed by Dr. M. Nawaz Bhutta when working with IIMI to undertake his fieldwork for his Ph.D., a proposal was developed in collaboration with the Punjab Irrigation Department to undertake a selective program of maintenance in those locations where desilting appeared to have the greatest potential for performance improvement (Bhutta 1990). This activity was carried out during the annual closure of January and February 1988, allowing IIMI to undertake a comprehensive analysis of water delivery performance before and after the intervention. The full story of maintenance impacts in Lagar has been reported elsewhere (Murray-Rust, Vander Velde and Bhutta 1992).

Despite some evidence to suggest that not as much sediment was actually removed as planned, the results were dramatic. In summary, the selective maintenance had the following impacts:

- **The effects of desilting in the upper reaches of a distributary have a dramatic beneficial impact on water distribution equity.**

  Following desilting, the conditions at the tail end improved dramatically: the ratio of head-tail inequity dropped from 4.20 to 1.29 (Table 4.2), a condition never previously recorded from IIMI's own research or from the less reliable but longer term Irrigation Department records.

Table 4.2. Delivery performance ratios for Lagar Distributary, before and after desilting.

Location	Before	After
First Quartile	1.32	1.23
Second Quartile	1.32	1.38
Third Quartile	0.86	1.16
Fourth Quartile	0.31	0.95
IQR (First/Fourth)	4.20	1.29

- **Inequity between head and tail of the distributary was less than inequity among watercourses.**

  The changed spatial distribution of water deliveries (Figure 4.6) indicates that following desilting there was greater variability among adjacent watercourses than between head and tail of the distributary. These localized deviations from design conditions result from deviations from designed elevation or dimension of individual outlet structures. This finding means that the maintenance inputs were more than sufficient to overcome the problems caused by excess sedimentation.

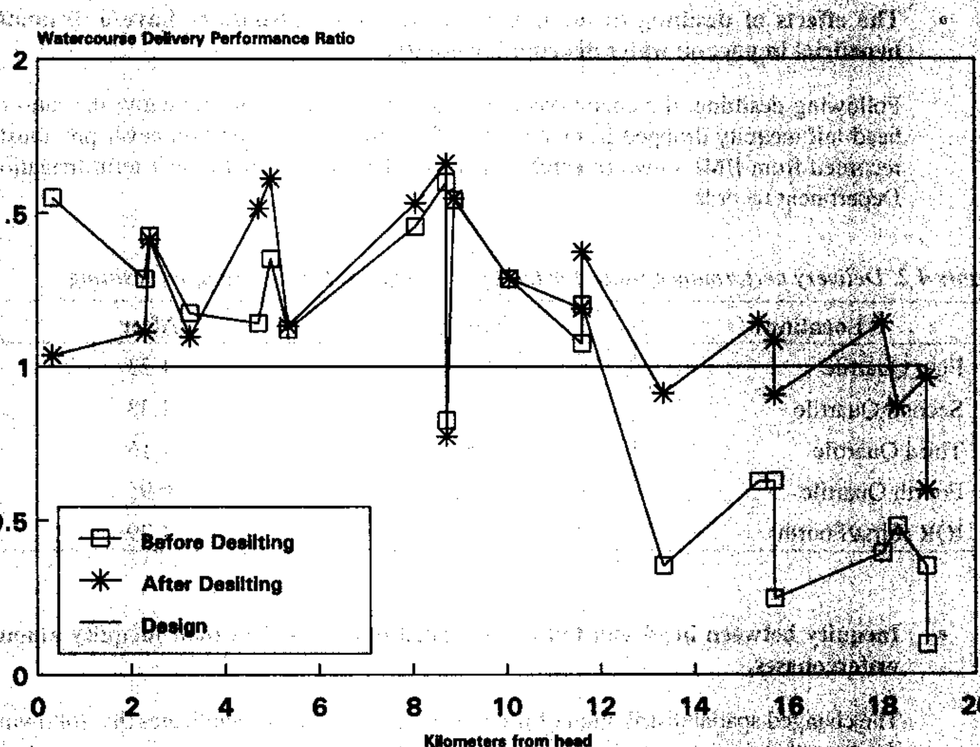
- **The economic benefits of desilting are significant.**

  Although the desilting intervention was treated as a special case, the actual cost per hectare of command area was so small that under the most conservative scenario it would likely pay for itself within three years on irrigation charges ("*abiana*") alone. The estimated cost of intervention was US$3,600, or US$0.52 per hectare of CCA, a cost that could probably be recouped within a single year through increased cropping intensity in tail-end areas.

- **Computer-based simulation models are effective as a management tool.**

  The hydraulic conditions following changes to canal cross sections and long profile were predicted with a high degree of accuracy by computer simulation. Such predictions enable managers to assess, with considerable confidence, the impact of desilting different portions of a canal and find the most cost-effective way to improve canal performance, if they wish to do so.

Figure 4.6. Lagar Distributary, water distribution equity.



- **Performance improvements following maintenance require parallel operational management.**

The improvements in performance following the maintenance activity only lasted for a few months. The cause for subsequent decline was not physical change but operational reasons. Tail-end farmers who had experienced the best water conditions for as long as anyone could recall found that when the subsequent rice season commenced, upper and middle farmers stole so much water that the tail again started to experienced severe water deficits. As a protest, the last quarter of the canal was blocked by farmers in an effort to demonstrate the ineffectiveness of the Irrigation Department in managing water equitably. The problems of water theft are discussed in more detail later (see page 103, "Operations Along Secondary Canals").

Desilting in Pir Mahal

Pir Mahal Distributary and its associated set of minors were in a sorry state of affairs prior to desilting: the ratio between head-end and tail-end DPRs was over 6.0, much higher than those of Lagar. Although it had been targeted for desilting for several years, resources for this purpose could not be mobilized by the Irrigation Department. However, a program for a thorough desilting was eventually implemented in early 1992. In preparation for the evaluation, IIMI undertook a set of measurements during June-August 1991 to determine actual conditions prior to desilting, and a second set of readings for June-August 1992 following desilting. A total of 20 watercourses along the full length of Pir Mahal Distributary were included in the measurement program, with daily readings of discharge taken at each location. In addition, automatic water level recorders were installed at the canal head and at the bifurcation at Junejwala Minor.

A comparison of canal performance before and after desilting shows that there were indeed significant improvements in performance as a result of the intervention. The primary benefits can be summarized as follows:

Canal Capacity

Before desilting, it was only possible only to deliver design discharge into the canal by using the full freeboard: under these conditions the canal is liable to breaching and it greatly favors the upper-end outlets because the operating water surface elevation is higher than designed. Following desilting, it is possible to deliver the design discharge more or less at designed water surface elevations, and to deliver 30 percent more than design discharge by using the full freeboard. The differences in actual discharge delivered into Pir Mahal is shown in Figure 4.7, while the frequency distribution is shown in Figure 4.8.

Measurement Capacity

Before desilting, it was not possible to use the official discharge rating curve for the drop structure immediately downstream of Bhagat Head. This drop structure was drowned out because of backwater effects created by higher than designed bed levels. Following desilting, this drop structure now functions normally, with an effective hydraulic jump downstream making it relatively easy to determine actual discharges into the canal.

Figure 4.7. Discharge into Pir Mahal at Bhagat Head.

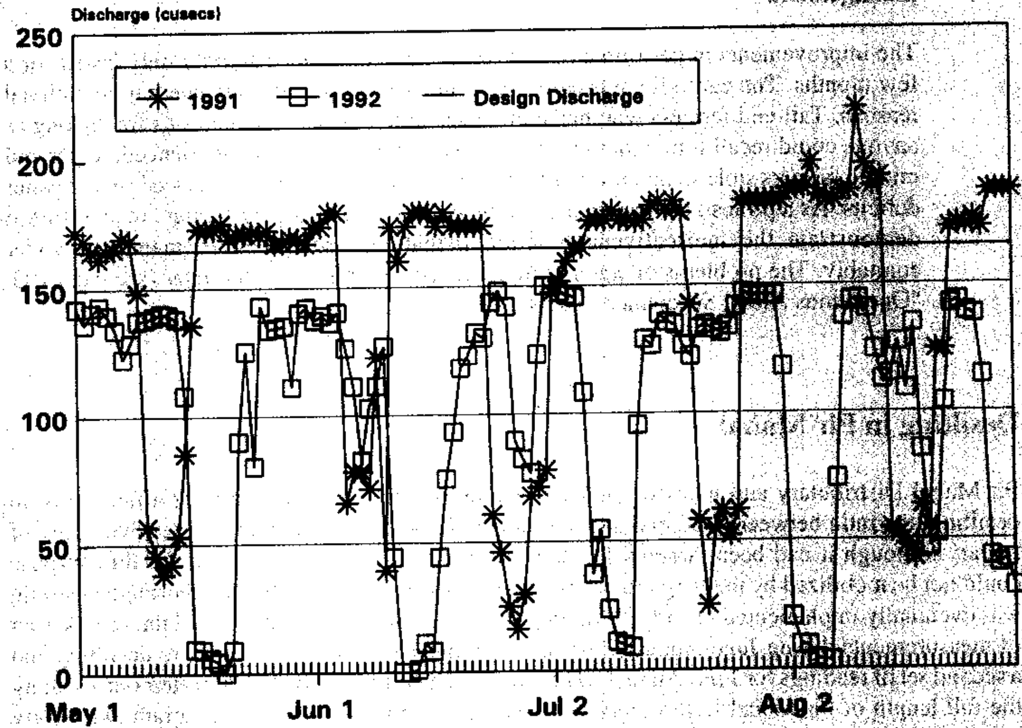
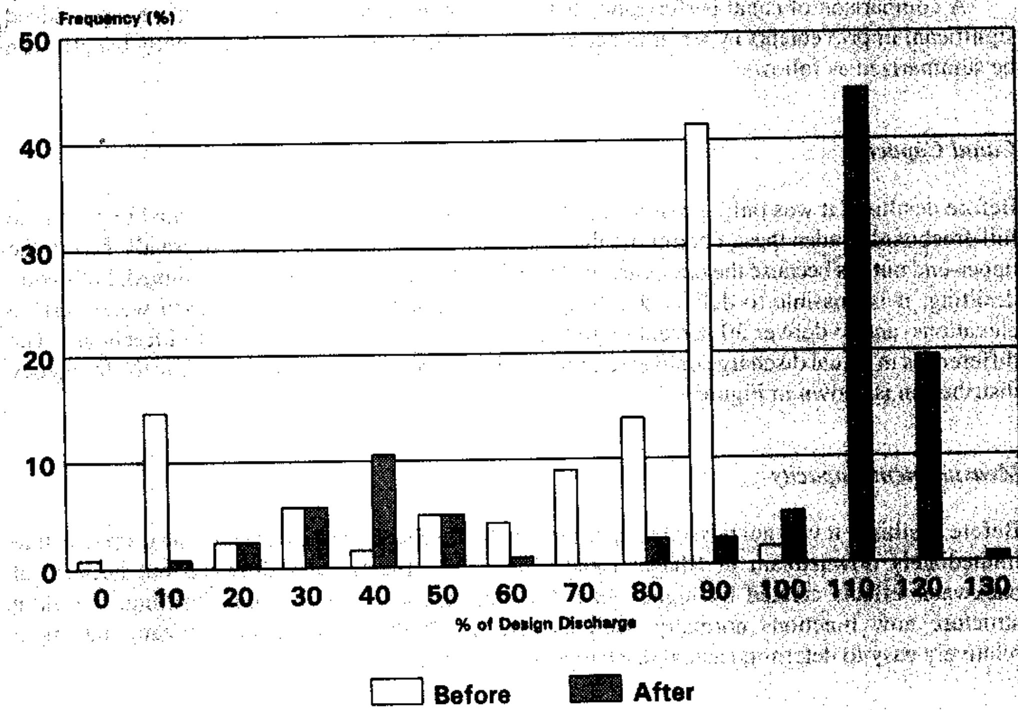


Figure 4.8. Distribution of inflow into Pir Mahal before and after desilting.



Equity of Water Deliveries

Before desilting, the average discharge into the canal was two thirds that of design, with a DPR of 0.67 (Table 4.3). The upper-end watercourses, however, received more than design with a DPR of 1.16, while water deliveries to tail-end watercourses had a DPR of 0.19. This gives an interquartile ratio (IQR) of 6.11. After desilting, the interquartile ratio declined dramatically. With an average DPR of 0.99 in the canal, head-end outlets had a DPR of 1.19 while tail-end areas had a DPR of 0.46.

Table 4.3. Delivery performance ratios in Pir Mahal Distributary before and after desilting.

Location	Before	After
Pir Mahal Head	0.67	0.99
First Quartile	1.16	1.19
Second Quartile	0.94	1.28
Third Quartile	0.49	0.84
Fourth Quartile	0.19	0.46
IQR (First/Fourth)	6.11	2.59

A fairer evaluation of performance can be obtained by comparing the DPRs when the head DPR was more or less the same. For periods when the inflow into the canal was at or close to design discharge, the interquartile ratio improved from 4.42 to 2.03.

However, when discharges were significantly below design, desilting did not result in such high levels of improvement. When the DPR is between 0.3 and 0.5 at the head, water did not reach the tail either before or after desilting. However, it was able to reach well into the third quarter of the canal following desilting, whereas it only reached half way down the canal before desilting.

Internal Rotations

For several years, it has been necessary to implement rotations at Bhagat Head due to lack of water in Lower Gugera Branch. However, due to sedimentation problems along Pir Mahal a secondary rotation had to be implemented at the bifurcation between Junejwala Minor and the tail-end section of Pir Mahal. In the worst conditions, when Pir Mahal was in third of fourth priority, no water would reach the bifurcation, with areas below the bifurcation only guaranteed to receive water during one week in four. Following desilting, the rotations at Bhagat Head still have to be implemented, but rotations are no longer required at Junejwala bifurcation (Figure 4.9). The change in flow distribution at Junejwala Minor before and after desilting show similar improvements (Figure 4.10).

Figure 4.9. Rotations between Junejwala Minor and tail half of Pir Mahal.

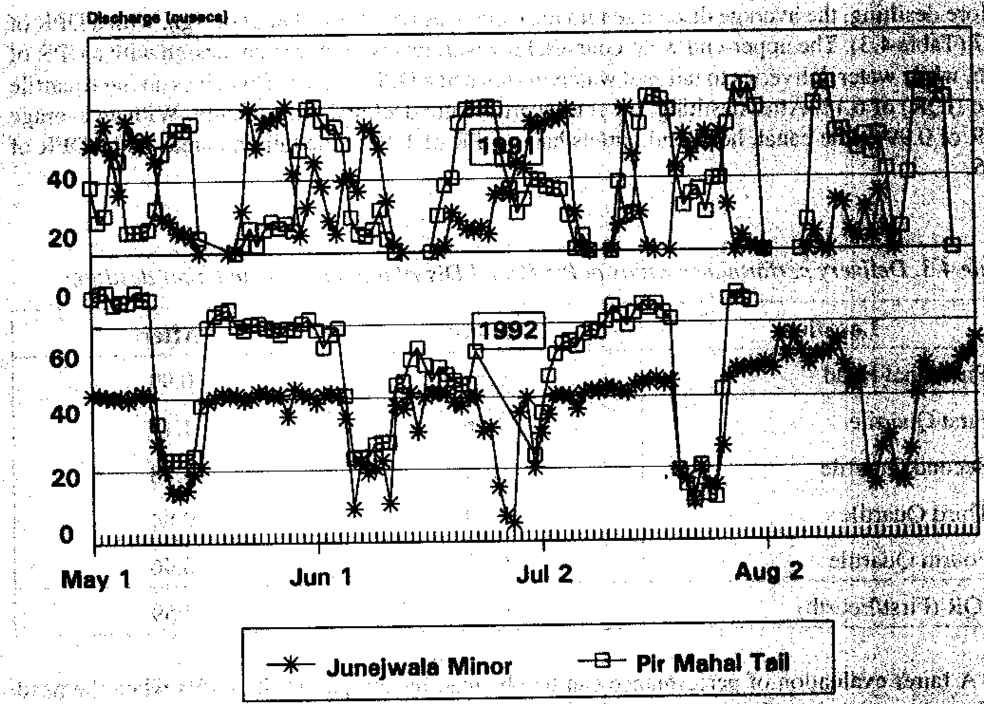
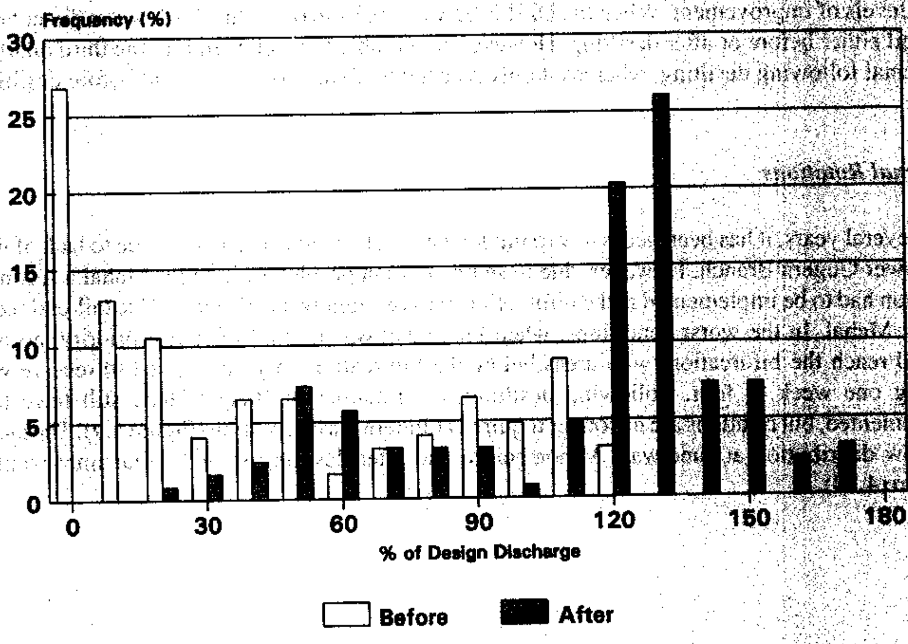


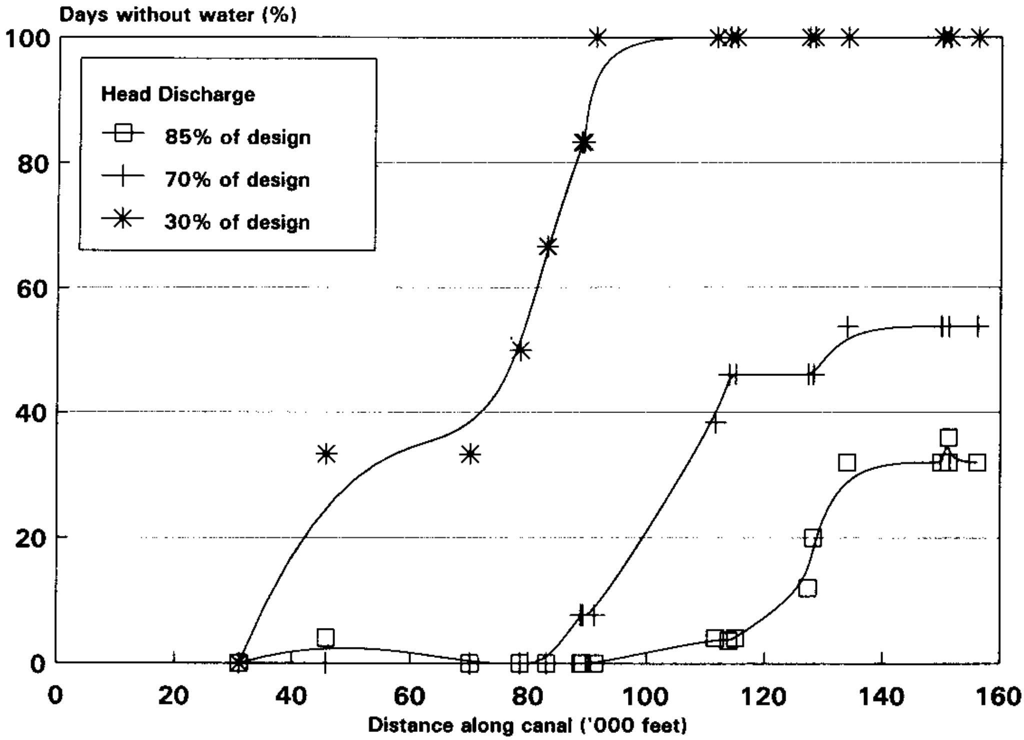
Figure 4.10. Distribution of inflow, Junejwala Minor, before and after desilting in Pir Mahal.



Number of Days without Water

Before desilting, the number of days without water was a major concern. Because of the rotation implemented at Bhagat Head between the different distributaries due to lack of water in Lower Gugera Branch, Pir Mahal did not receive water for about 15 percent of the time. However, due to excess withdrawals at the head, the lower portions of the canal received progressively less water, reaching 45 percent at the bifurcation of Junejwala and the tail of Pir Mahal. Because of the second rotation imposed at this location due to lack of adequate discharge, tail-end areas suffered even more, with watercourses dry 67 percent of the time (Figure 4.11).

Figure 4.11. Number of days without water at different discharges, Pir Mahal, 1991.



Following desilting, this picture changed dramatically. The number of days when water was not delivered to Pir Mahal dropped to 2 percent, rising to 13 percent at the Junejwala bifurcation (Figure 4.12). The improved discharges at the bifurcation meant that the rotation at that bifurcation was no longer required, and tail-end areas were deprived of water only for 33 percent of the time. In other words, following desilting, the tail-end watercourses received water on twice as many days as that before desilting.

Variability of Water Deliveries

Before desilting, the coefficient of variation (CV) of daily discharges over the three-month observation period was 50 percent at the head of Pir Mahal. Upper-end outlets had a CV averaging

Figure 4.12. Number of days without water at discharges, Pir Mahal, 1992.

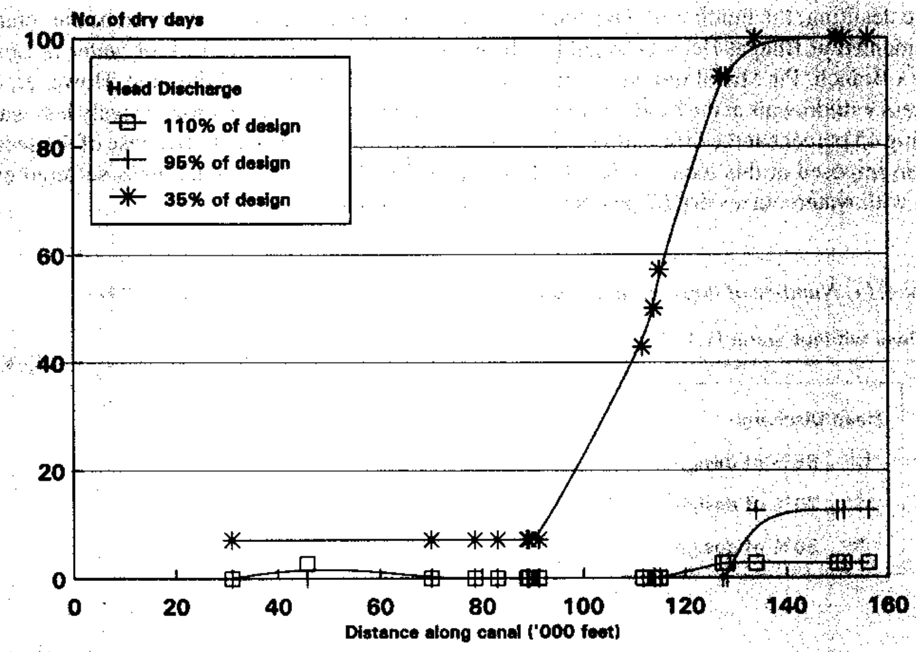
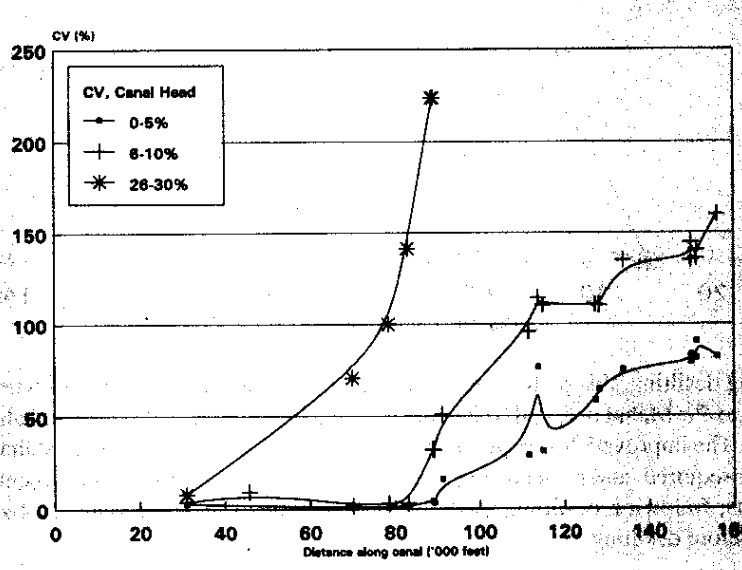


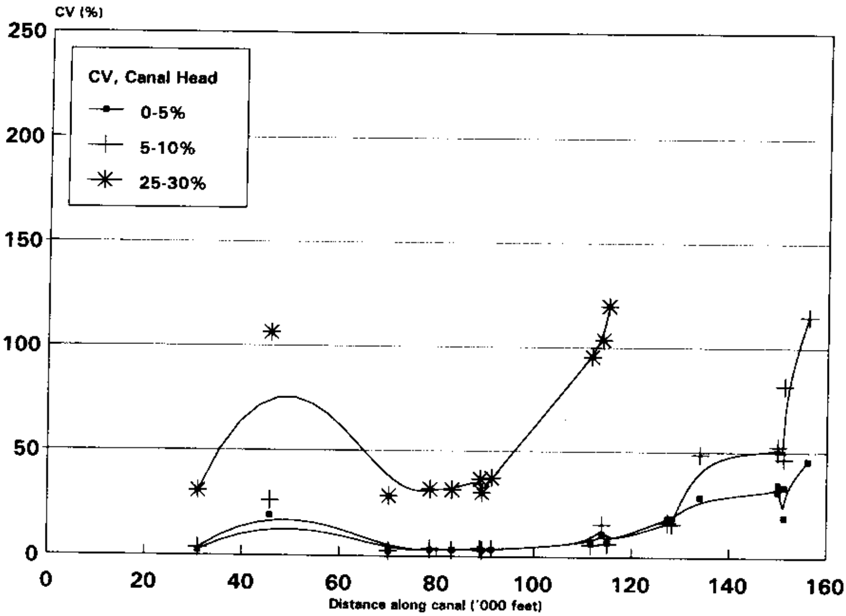
Figure 4.13. Coefficient of Variation of Discharge, Pir Mahal watercourses, before desilting.



60 percent, and increasing to 75 percent by the Junejwala bifurcation. Below the bifurcation, the CV increased rapidly to over 150 percent (Figure 4.13).

Following desilting, the coefficient of variation at the head dropped to 35 percent, and this level of variability remained unchanged down to the Junejwala bifurcation (Figure 4.14). Below

Figure 4.14. Coefficient of Variation of Discharge, Pir Mahal watercourses, after desilting.



the bifurcation, the CV increased but only reached 80 percent by the tail, thus halving the uncertainty in daily water deliveries.

Costs

The total cost was Rs 1.1 million for 18,300 ha, a capital investment rate of Rs 60 (US$ 2.40) per hectare of CCA. This level of expenditure is approximately 12 times less than that for lining, and yet the benefits are far superior.

These results dramatically justify the massive campaign for desilting that occurred throughout much of Punjab during the closure period of 1992. Tens of thousands of people, including government servants, farmers and, particularly, school children, were mobilized for desilting; massive publicity was given to these actions with political support form the highest levels. Although the reality is that less silt was removed than advertized, there can be no doubt that based on the Lagar and Pir Mahal experiences, water conditions must have improved dramatically.

OPERATIONAL MANAGEMENT AND THE EFFECT ON CANAL PERFORMANCE

The performance of canals, particular those where most water control is achieved by passive water division structures, depend heavily on the proper operation of the few control structures that exist. It is clear that the benefits of either canal lining or desilting will occur only if there is effective operational management.

In this section, two particular aspects of operational management are addressed: those undertaken by the Irrigation Department, and those undertaken by farmers along distributary canals. The combined action of both groups results in sub-optimal canal performance even when the physical condition of canals is satisfactory.

Operations by the Irrigation Department

The operation of long canals with few gated structures should, in many respects, be a relative straightforward matter: canals were designed to run more or less at full design discharge for months at a time. This means that, in comparison to systems in the humid tropics with much denser control infrastructure, the management opportunities in Pakistan are limited in both space and time.

Over the years since the initial phase of construction of canals of this type of design, a set of operating rules and regulations have been developed by the Punjab Irrigation Department for application in the main and secondary portions of the canal system. Among the more important facets of these operating regulations are those dealing with collection of field data to monitor canal performance:

- ***Daily water levels at the head end of every canal***

  Most secondary and some minor canals have some facility for measurement of water levels, either a stilling well constructed just downstream of the head regulator, or staff gauges. In a limited number of locations, there are control sections (normally drop structures) that have been installed to permit direct discharge readings to be made, but the topography in most locations does not provide sufficient elevation. These data are entered daily into the records at the Subdivision office and, later, sent on to the Executive Engineer.

- ***Daily readings of water levels at the tail of every secondary and minor***

  The tail-end structure of virtually every secondary and minor is a bifurcation or trifurcation consisting of open flumes. Design rules call for a set water surface elevation to be maintained at the tail, frequently 0.7 feet (21.5 cm), sometimes 1.0 feet (30.5 cm). A gauge is almost always installed in the structure. These data are also entered in the daily register.

- ***Monthly readings of water surface elevation in the secondary canal at every outlet structure***

  Regulations call for the regular checking of water surface elevations at every outlet structure to ensure that the actual water surface elevation is within the tolerance laid down in design guidelines. These data are collected in the "H" Register.

- ***Discharge calibration***

  Periodical measurements of canal velocities are required in order to check whether discharge tables for the head of every main and secondary canal, and some minors, are accurate. These velocity readings, which are intended to be done at several different water levels (actually not easy if canals are to be operated close to design discharge), are to be determined either by current meter or the use of floats, commonly in the form of velocity rods.

These four pieces of information are sufficient to tell the system manager whether things are operating more or less as intended. To oversimplify matters, the manager needs to know, on a daily basis, that the discharge into the canal is within tolerance and that the tail has adequate water: if both conditions are true, then no action need be taken.

The periodic checking of water levels along the canal ensures that water levels are not higher than the designed level either due to sedimentation or blocking of the canal by farmers. The inflow discharge information is required to determine, in the event the tail is short of water, whether the cause is inadequate discharge into the canal or some problem along the canal. It also ensures that the water allocation into each canal is adhered to.

The final operating rule that is of direct relevance is that discharge into canals should never drop below 70 percent of the designed discharge. This rule makes sound engineering sense: if discharges fall below this level, it becomes impossible to maintain acceptable levels of equity between head and tail of a canal that has no intermediate control structures. If discharges in main canals are not sufficient to meet the 70 percent minimum requirement, then rotations have to be implemented between secondary canals.

Observations made during the past six years merely confirm the worst case scenario:

- Water data are no longer collected systematically at the head of every secondary: although records exist for most canals, the data are not reliable and show increasing deviations from reality. Further, even where data are collected, the canal telegraph system has more or less collapsed and time lags in obtaining data at the managers office are increasing.

- There are hardly any locations where tail-gauge readings are now collected: the data that do exist can be considered completely unreliable.

- No "H" Registers have been filled in since the 1960s: data are not collected.

- There is no evidence that any velocity readings have been taken by the Department (except in connection with research components of special projects such as Command Water Management, Irrigation System Rehabilitation Project, etc.).

- No set of velocity rods has ever been seen by any IIMI staff in any office, although requests to see them are made as a matter of principle.

- Discharge rating curves are decades out-of-date, most are inaccurate at best, wrong at worst.

The result of these conditions is obvious: system managers do not know what is going on in their areas of responsibility. They clearly do not care about canal performance. The consequences are, however, very serious. A single example will demonstrate this.

From the very outset of IIMI's work, analyses using the daily observations from Lagar Distributary showed that the canal was being operated for substantial periods well below the 70 percent limit. There is a clear relationship between the actual discharge into Pir Mahal (as a percent of design discharge) and the inequity along the canal (Figures 4.15 and 4.16). Identical trends are found in Khikhi and Lagar despite the very great differenca in their design discharges.

Figure 4.15. Delivery performance ratios, Pir Mahal samphe watercourses, before desilting.

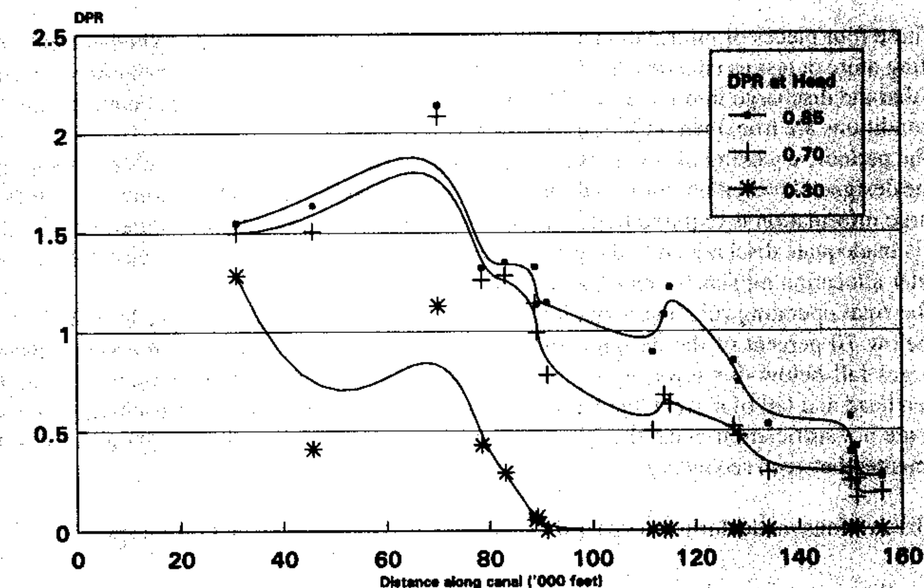
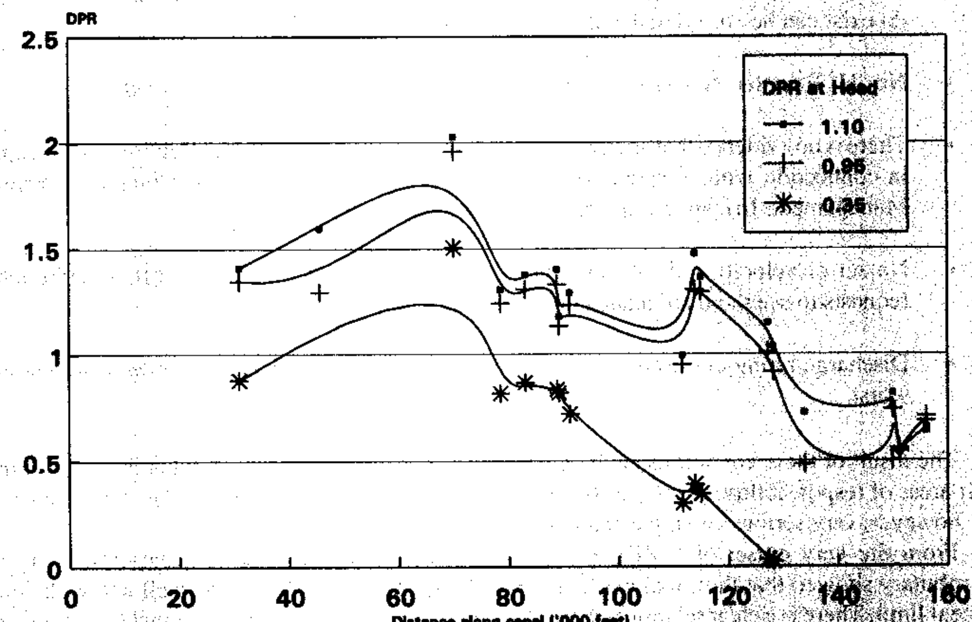


Figure 4.16. Delivery performance ratios, Pir Mahal sample watercourses, after desilting.



Whenever canals are operated below the design limit, water conditions at tail-end outlets deteriorate rapidly to the point where tail outlets dry up while upper-end outlets still receive supplies close to the design discharges. These empirical observations were subsequently confirmed through simulation analysis.

The data presented here appear to be representative: almost identical results have been obtained from all canals studied under the IIMI program. This is hardly surprising because the inequity measured can be calculated using hydraulic principles, which, after all, are the basis of the design of the entire Indus Basin canal network. What was known 100 years ago has been forgotten or just ignored.

It would be possible to describe at length the deficiencies in the actual operation of canals observed over the past six years. It is perhaps easier merely to express it all along the following lines:

> **The capacity to measure water in a canal system, particularly where water is the scarce resource, is fundamental to irrigation. It is inconceivable that major corporations would operate without knowledge about sales, markets, profits and losses, but this is precisely what most irrigation agencies, including those in Pakistan, are doing at the moment (Murray-Rust and Merrey 1992). They do not know how much water they put into the system, they do not know where it goes within the system, and they are care-less. To even imagine that irrigation departments respond to agricultural performance when they cannot measure water is unrealistic.**

Until this attitude changes, there is really little reason to believe that performance will improve. It matters little whether canals are lined or unlined, maintained or allowed to deteriorate, if there is no capacity to operate the system and measure water. All evidence, albeit unscientific, suggests that the rate of deterioration of repaired, rehabilitated, or even new canals is so rapid that any performance improvements are bound to be short-lived.

In short, the issue is primarily an institutional one rather than a technical one. Although technical competence may not be as high as might be desired now, any change there without an improvement in the current institutional setting and attitudes is unlikely to result in any significant benefits. At the same time, it is fair to say that irrigation agency staff are only half of the problem. Farmers too contribute their fair share to undermining canal management.

Operations Along Secondary Canals

It remains conventional wisdom that once water has entered into a canal, distribution is controlled by passive structures. Farmers have long been assumed to have only a capacity to manage water within the watercourse although reports of illegal tampering of outlets have occurred for decades. It is apparent that at more or less the same time the Irrigation Department began to lose control over the secondary canal system, farmers started to have a more direct impact upon distributary-level water distribution. Which came first is hard to tell, since there are records available of water thefts and outlet tampering from the earliest days of canal operations.

What is clear is that the capacity to prosecute farmers who tamper with outlets or are engaged in water theft has been lost now. Such activities can be done with little risk of prosecution because agency staff will sell immunity and sanction illegal activities for various considerations, or politicians and other influentials will provide protection. In these matters, of course, farmers themselves are not necessarily any more altruistic than government officials. What is of research interest to IIMI is to try to determine the relative magnitude of farmer interference in comparison to the operational failings of the irrigation agency.

Field observations along many distributaries over several years have confirmed that from late February through April there is relatively litthe stress on the canal system in Punjab. Evapotranspiration rates are fairly low, though slowly rising, and rainfall prospects are reasonable. Wheat, the dominant winter crop, is approaching maturity and ripening for harvest or else is sufficiently mature not to require significant irrigation. The other important crop at this time, various fodders, occupies a comparatively small percentage of the total command area. Thus, farmers in head-end watercourses do not need excessive amounts of water and there are frequent instances when one or more outlets are fully or partially closed for two or three days, often in response to rainfall.

Following this period of relative peace and harmony, from late May onwards, observations along selected canals show a marked upsurge in interventions undertaken by farmers to appropriate additional water in the upper two thirds of the channel, peaking in number from late July to early September. These events include direct cuts, breaches, the installation of both illegal and sanctioned pipes, blocks in the distributary, siphons, and so forth. Parallel field observations in the bottom one third of these canals reveal a simultaneous "collapse of the tail," whereby water no longer reaches the end of the distributary.[7] Once the rice crop has become established and water requirements begin declining with reduced evapotranspiration demand toward late September, the frequency of such interventions also decreases. IIMI's initial analyses of these conditions were mainly subjective, providing further anecdotal evidence of distributary head-tail differences.

What was required was a more careful and incontrovertible analysis of the location, magnitude and timing of the effects of such interventions. A promising methodology has been developed that permits expected discharges to be calculated for all measurement points along a secondary canal based on the discharge at the distributary head and other key upstream locations as may be required. This methodology relies on the use of running averages, required to smooth the variability introduced by discharge fluctuations in main canals and to eliminate the effects of hydraulic travel time along canals, and regression techniques. The resulting analysis follows a somewhat different approach to those previously undertaken in the IIMI-Pakistan program because it is possible to relate measured performance at selected locations with predicted values.

During the quiescent March-April period, when canal hydraulic conditions are as free of external interventions as they ever are, running averages of discharges into canals and into selected watercourse outlets along the canal are calculated.[8] The resulting values are converted to delivery performance ratios (DPRs) to permit locational comparisons. The entire set of daily DPR values for a watercourse for this period are then regressed against the corresponding set of independent distributary-head values. The correlation coefficients of these comparisons, even between head-end and tail-end discharges along longer canals, are remarkable high, rarely falling below the r-squared value of 0.8, and almost inevitably significant at the 1 percent level.

Assuming the relationship as hydraulically valid, it is then possible to use the regression results to calculate the DPR for each watercourse for the rest of the year if external interventions to appropriate water from the canal remain at the March-April minimum. These predicted values then can be compared directly with actual DPRs calculated from daily field measurements. The results of these analyses are briefly summarized below for one year, 1990, for one canal, Mananwala distributary, in Farooqabad Subdivision, Upper Gugera Division, of the LCC system. Similar

7 It has been officially acknowledged during the past year that 40 percent of all secondary canals in Punjab have, like the "three blind mice," "lost their tails."

8 A fifteen-day running average (seven days before and seven days after the date of observation) was found to give the most satisfactory results.

results have been obtained for other years and for other distributaries, strongly implying that the findings describe here are not merely an example of a special case.

The results obtained by this approach demonstrate the near catastrophic impact of upstream water theft, whether or not "sanctioned," on tail-end water conditions in Mananwala distributary.

MANANWALA DISTRIBUTARY: INTERVENTIONS AND PERFORMANCE

- The head-end watercourses do not reflect the just inflow pattern at the distributary head; their DPR values clearly show a substantial and systematic increase in water deliveries into head-end outlets. Such changes in DPR cannot be explained solely by hydraulics; it also involves deliberate enlargement of offtakes through several means and/or the partial blocking of the distributary. The variety of head-end interventions in Mananwala command have now been well documented over a several-year period (Figure 4.17).

- Middle-reach watercourses, as well as those at the upper end of the canal tail reach, appear to pretty much hold their own with interventions here largely compensating for the impacts of those upstream. Field data indicate that various interventions *between* watercourse outlets here are numerous during the peak water theft period, July–September, but their effects on outlet DPRs are not really experienced here (Figures 4.18 and 4.19).

Figure 4.17. Mananwala Distributary performance, Outlet 23R: Actual and predicted DPRs.

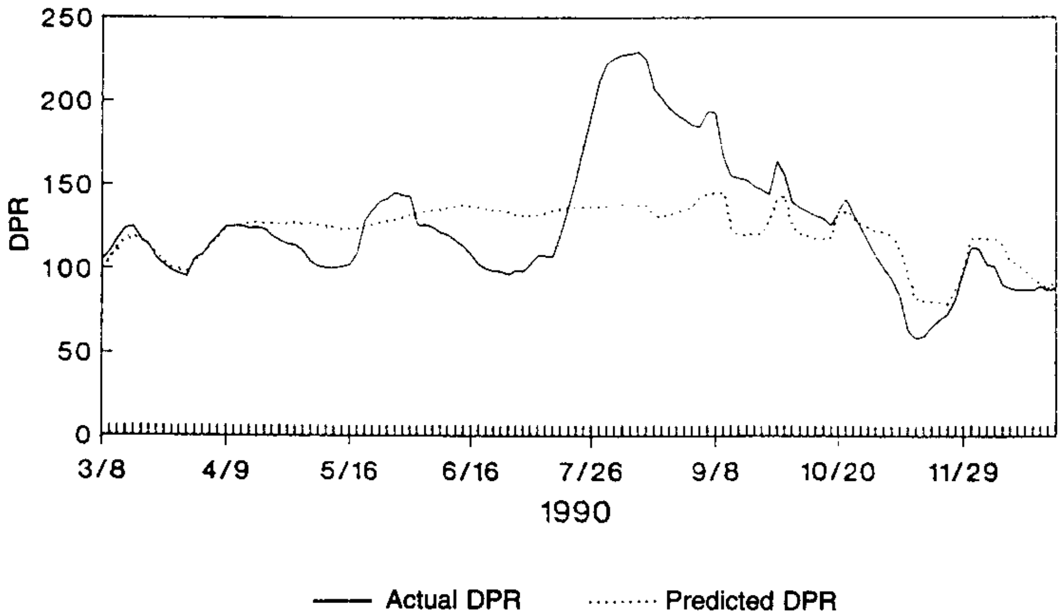


Figure 4.18. Mananwala Distributary performance, Outlet 121R: Actual and predicted DPRs.

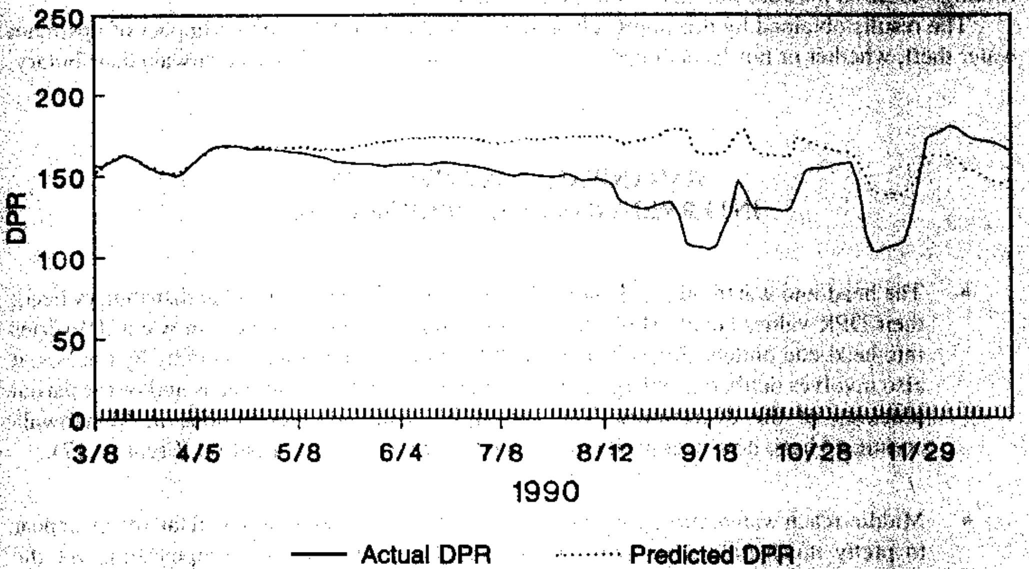
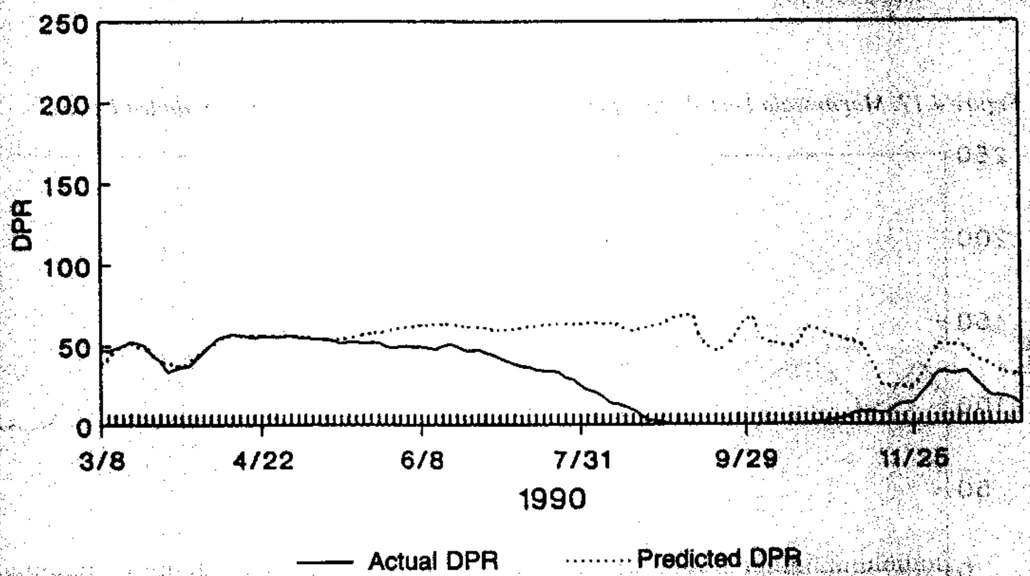
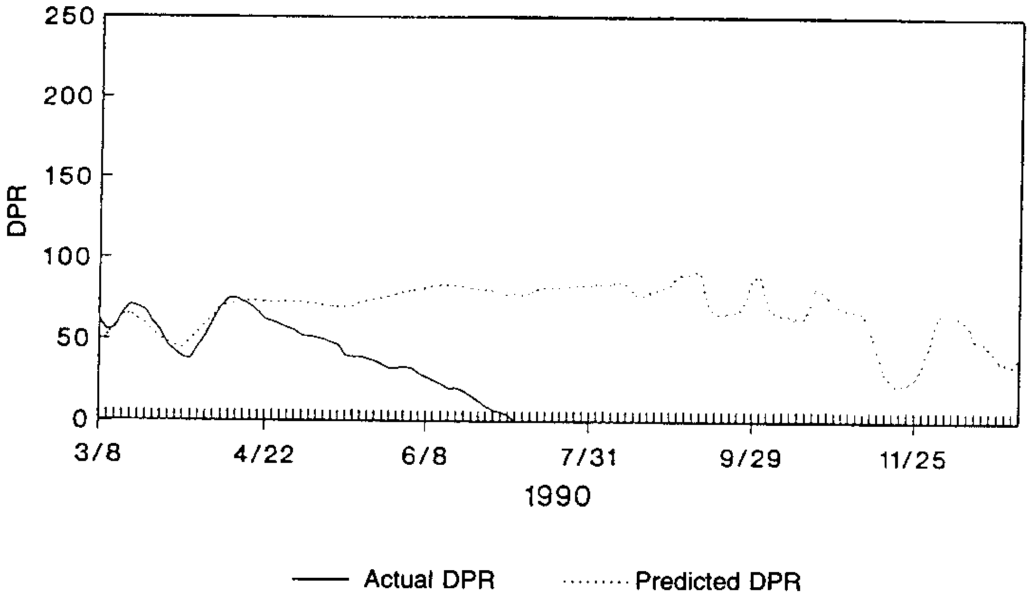


Figure 4.19. Mananwala Distributary performance, Outlet 141R: Actual and predicted DPRs.



- The distributary tail disappears. Watercourses in the last half of the tail reach have virtually no surface water throughout the entire summer season. Whatever the farmers grow must be irrigated with tubewell water only, and this is, as will be clearly demonstrated in Chapter 8, of sufficiently poor quality to induce rapid increases in substantial secondary soil salinity to levels that will inevitably reduce crop yields (Figure 4.20).

Figure 4.20. Mananwala Distributary performance, Outlet 148TR: Actual and predicted DPRs.



In some respects, it is amazing that tail-end farmers do not protest more strongly than they currently do. Everybody knows that water theft goes on, either independently or in connivance with irrigation agency staff. Reclamation and "Grow More Food" shoots, kharif season outlets that can be legally sanctioned *only* when it is certain that their discharges will not reduce water supplies at the tail, are sold to high bidders and other influentials by the Irrigation Department at the explicit expense of tail-end farmers.

ECONOMIC EVALUATION

Perhaps the most dramatic analysis of the results is that relating to the economic benefits of the different approaches. The cost of each intervention is presented in Table 4.4: the benefits have been calculated on the percentage improvement of the Interquartile Ratio following the intervention. The poor performance of lining is obvious, with a negative rate of return. For the two desilting interventions, the results suggest that minor desilting at frequent intervals may be the most efficient solution but this conclusion requires data on the return period of less intense desilting in comparison to more extensive but less frequent desilting.

The choice between different interventions depends on both hydraulic performance improvements and the cost of the intervention. Data exist for each intervention that allow an economic evaluation to be made, using an assumed interest rate of 10 percent.

Table 4.4. Comparative costs of different interventions.

		Interquartile Ratio (IQR)		Cost		Change in IQR	
Canal	**Activity**	**Before**	**After**	**US$ '000**	**$/ha**	**%**	**%/$/ha**
Khikhi	Tail-end lining	0.82	1.55	1,250	37.33	– 57	–1.5
Pir Mahal	Major desilting	6.11	2.59	42	2.40	+144	+60
Lagar	Minor desilting	4.20	1.29	3.6	0.52	+225	+433

Focused Desilting in Lagar Distributary cost US$3,600, an average investment of US$0.52/ha. Incomplete observations suggest that the silt excavated was equivalent to three-years accumulation (Murray-Rust et al. 1993). The net annual cost is therefore US$0.21/ha. For Pir Mahal, the total cost of the major desilting was US$42,000, or US$2.54/ha. This is equivalent to US$0.40/ha if the benefit of such an activity is 10 years, or US$0.33 if the benefits last as long as 15 years.

For the lining at Khikhi, the total cost was US$1,250,000, or US$37.73/ha. If, in line with normal project assumptions, the lining were to last 30 years, the net annual cost would be US$4.00, roughly 20 times more expensive per ha than the focused desilting at Lagar and ten times more expensive than major desilting at Pir Mahal.

There are no accurate data available on either the rate of sedimentation in secondary canals or the relative life length of each type of intervention studied. Annual monitoring of conditions continues in order to quantify more precisely the assumptions made in this paper. If the focused desilting at Lagar were required annually, then it would cost the same to desilt Pir Mahal every 6 years. Lining, as undertaken at Khikhi, would be eight times again as expensive, if it had a life length of 30 years.

Field observations of the lined sections of canal in Lagar and Khikhi suggest that life lengths are far less than 30 years. In both cases, a decision was made to go for a relatively inexpensive lining consisting of a single brick surface on both beds and banks covered by a thin cement plaster coat. This type of construction is susceptible to back pressure, collapse and damage by both animals and agricultural equipment. A more durable lining is inevitably more expensive; however, given the results of this study, it would not appear to be warranted.

It is also relevant to note that the lining process in both Lagar and Khikhi lacked rigorous quality control, resulting in a substandard lining because of substantial wasted expenditures on labor and materials. Furthermore, extensive tampering with outlets in both lined and unlined sections of Khikhi was tolerated so that many watercourses now receive more than their design discharge.

CONCLUSIONS

Several conclusions have been drawn in the main text of this paper and will only be referred to here in summary.

Improving Performance

There are three components of any effort to improve performance in the secondary canal system in Pakistan: physical upgrading, effective maintenance and focused operations. The results of this study strongly suggest the following:

- Lining of the tail ends of canals fails to lead to any noticeable improvement in canal performance, and cannot be seriously considered as a development strategy.
- Lining of upper portions of canals is likely to prove more effective, but only where sedimentation is not going to recur within a time frame dictated by the economics of the lining program. No data exist on rates of sedimentation in lined canals: they need to be collected.
- There is no evidence that brick and mortar lining leads to significant savings in water along canals. Savings are low due to leakage or due to water theft along canals exceeding any potential savings.
- It is possible to calibrate computer models of the hydraulics along secondary canals relatively quickly and easily, and use these models to identify locations which should be given priority in maintenance using the limited resources available.
- The benefits of maintenance and periodic heavy desilting appear to far outweigh lining, both in terms of hydraulic performance and in terms of cost-effectiveness.
- Operational discipline is essential irrespective of canal conditions: failure to observe basic design principles will inevitably lead to reduced canal performance.
- The institutional capacity to operate canals according to design guidelines is inadequate: routine data collection has broken down, and the data collected is virtually useless due to inaccuracies.
- The ideal combination of activities for improving canal performance is likely to be the maintenance of canals coupled with disciplined operations: physical interventions such as lining should only be resorted to when there is clear evidence of specific technical conditions that will be guaranteed to be overcome by physical changes to the canal system.
- Changes in the institutional setting are a precondition for changes in canal performance. It is impossible to imagine that any technical improvements, adoption of new methods such as computer modelling, etc., have any chance of becoming part of regular activities within the settings provided by irrigation agencies in Pakistan.

Research Implications

The results presented in this report, together with other research activities referred to herein, represent the culmination of a long-term program. While it is true that at various times within the life length of these activities there were specific projects that received external support, there has been a consistent and common thread throughout. This contrasts distinctly with the conditions that have occurred in project-dominated activities: sites change sufficiently frequently that no long-term records are built up, data collection programs in different sites are different and comparisons extremely hard to make.

This common thread enables the following conditions to be met and achievements accomplished:

- The capacity to measure the same parameters in the same location over a sufficiently long time frame to make sure that results are consistent and representative.

- The capacity to measure precisely the same parameters in other locations under the same conditions to facilitate comparison between locations.

- The capacity to be able to return to documented and stable locations to make repeat measurements after extended periods of absence.

- The capacity to review results periodically with the same researchers irrespective of whether they are based in Pakistan or not, and thus design the next stage of the program in a coordinated fashion.

- A coordinated and systematic data retrieval and storage program that enables access to past data sets by researchers other than those who originally designed or collected the data.

- A significant element of this research program is that there is an ever-increasing capacity to accurately predict the consequences of interventions. There is always a place for action-research programs that foster an intervention and then record the results; there is also a place for somewhat more classical scientific research that can effectively predict results.

- Because results are consistent, because the research methodology is consistent, and because the objectives are consistent, it becomes possible to slowly but surely get the message across. It is inconceivable that the recognition of "missing tails" would have occurred as the result of several projects spread over the same time period using the same resources (after all, USAID had spent millions of dollars for research on irrigation, and there had been no change institutionally except an increased desire to get even more resources).

Policy Implications

The policy implications of this study are clear. Lining of canals carried out in the manner observed in Khikhi would be a complete waste of resources. As it is, the Punjab Irrigation Department has proposed borrowing US$1.0 billion to undertake the lining of canals as part of the Provincial Water Sharing Accord. The Khikhi experience was a failure for three primary reasons: lining was almost certainly carried out in the wrong location, the quality of construction was very poor with large amounts of money disappearing during construction, and there was active and passive connivance in modifying the size of outlets during lining at the expense of tail-end farmers.

If each of these three conditions could be significantly improved (i.e., lining of upper reaches first, good quality construction with minimal financial leakage, and strict prohibition of tampering of outlets by farmers and agency staff alike) then there is probably a good case for lining. Data from the Indian Punjab (Upton and Chancellor-Weale 1988) suggests that lining does not result in significant improvements unless groundwater is already saline:

> "The general conclusion that must be drawn is that further expenditure on canal and watercourse lining in the Indian Punjab would be difficult to justify in economic terms.
>
> Watercourse lining over 75% or more of the length does not appear to yield an economic return .... No attempt was made to estimate the returns to lining a small proportion of the length, say 30%, but it seems doubtful whether even this level of lining could be justified economically."

The alternative is to reestablish a proper program of desilting with work focused on areas where performance is least satisfactory. This requires two conditions: sufficient data on actual performance to identify locations where conditions are particularly bad, and a capacity to determine the appropriate intensity of desilting to achieve an acceptable level of performance. Both these conditions could be met if the institutional will is rejuvenated. The collection of performance data (tail-gauge readings and "H" Registers) has lapsed; the computer model developed by IIMI allows desilting impacts to be assessed prior to actual intervention. These would form a substantial element of a Decision Support Package for irrigation managers but to date institutional interest is marked more by reluctance or apathy than active interest.

The same is true for operational improvements. Much of the water theft observed is institutionalized by the sanctioning of additional pipes in blatant contravention of the stipulation that such pipes can only be installed if tail-end farmers do not lose access to their water.

One thing is sure, however. The present management of the canal system in Pakistan is leading to rapid decline in irrigation infrastructure and contributing to the rapid increase in secondary salinization in areas where surface water supplies are inadequate (Kijne and Vander Velde 1991; Kijne and Vander Velde 1992; Vander Velde and Johnson 1992; Murray-Rust and Vander Velde 1992). If policymakers at the highest levels of government and the senior members of the provincial irrigation departments do not act to improve matters, then there is a very distinct possibility of a rapid and irreversible collapse of a highly productive irrigated agricultural system.

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