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EVALUATION OF THE IMPACT OF CANAL REHABILITATION ON HYDRAULIC AND AGRICULTURAL ECOONOMICS INDICATORS

by

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Report on Impact Evaluation of Hydraulic and Agricultural Economics Indicators

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SUMMARY

The ISM-II pre-rehabilitation impact study has been completed. The Alluvial Channels Observation Project (ACOP) in Lahore has finished collection of all data on hydraulic indicators in seven canal subsystems. ACOP has prepared or is in the process of finishing reports on each canal subsystem. The Watercourse Monitoring and Evaluation Directorate (WMED) and the Punjab Economic Research Institute (PERI) have completed data collection and draft reports on the pre-rehabilitation status of the agricultural economics indicators.

Following are the salient features resulting from the data collection and analysis activities.

Pre-Rehabilitation Hydraulic Indicators

ACOP has completed the pre-rehabilitation data collection on all canal subsystems in the impact study. Draft reports have been prepared and reviewed. The results of the pre-rehabilitation data collection and analysis confirm that water delivery of all systems is inequitable. Two systems, Chowky and Killianwala exhibit severe inequity in water delivery, and in two systems, Puran and Nari, tail-end watercourses receive more water than those at the head end, an unusual inequitable situation attributable wo an oversupply of water to the canals.

With regard to reliability, flow in the tail is generally less reliable, with three subsystems, Chowky, Killianwala and Nagnah showing marked deterioration in reliability from the head to the tail. Two subsystems, Venoi and Nari show little difference in reliability between head and tail reaches. Conveyance losses during the pre-rehabilitation period were small, seldom more than 10 percent of the incoming discharge to the distributary head.

Outlet performance and outlet geometry are important measures of the equity and reliability of the irrigation system. A high percentage of outlets in Nagnah (45 percent), Pakpattan (35 percent), and Puran (48 percent) drew at least 150 percent of sanctioned discharge. While the percentages of excessively drawing outlets are lower in other subsystems, there are nevertheless significant percentages of outlets drawing too much, thus contributing to the inequitable distribution of water. All subsystems had significant numbers of moghas with areas that exceeded design specifications.

The general conclusion of the pre-rehabilitation work is that the seven canal subsystems show significant problems with equity and reliability of water delivery.

Pre-Rehabilitation Agricultural Economics Indicators

WMED and PERI have completed their draft reports of the agricultural economics indicators. These indicators have been summarized in the body of this report, because the WMED and PERI reports do not report pre-rehabilitation on an indicator basis.

The watercourse sample selected for the agricultural economics work was biased in that, in general, they exhibited very high outlet performance. Twenty-seven of 32 watercourses had measured discharge exceeding sanctioned discharge. Three water short watercourses were in Chowky and two in Killianwala, and the two in Killianwala had measured discharges that far exceeded the average for tail end watercourses. Thus, the watercourses are not representative of the range of characteristics typical of the individual canal subsystems.

The agricultural economics indicators are, however, closely related to the hydraulic indicators outlet performance and reliability. Four regression analyses relating outlet performance and reliability to four agricultural economics indicators, cropping intensity, crop yields, input use and value of agricultural output showed that hydraulic indicators are statistically significant in determining the levels of the agricultural economics variables. The conclusion of these four analyses is that if canal rehabilitation improves the water delivery in terms of outlet performance and reliability, one can expect and improvement in the agricultural economy.

It is unfortunate that the sample of watercourses were skewed towards those with good outlet performance, because it will be difficult to measure the extent to which canal improvements have a positive impact on the agricultural economy. It is important to emphasize that in the process of achieving equity, supplies to some watercourses will be reduced, with a corresponding reduction in the level of the agricultural economics indicators.

Chowky Pre- and Post-Rehabilitation

Rehabilitation works carried out on Chowky did not have the desired impact on hydraulic indicators. Average monthly flow to tail watercourses did not increase. Although some tampered outlets were restored to design conditions, others have flow areas well in excess of design. As a consequence, the performance of outlets in the middle and tail reaches has deteriorated slightly, and equity has worsened. Another factor contributing to inequitable water supply is the location of the Chowky Distributary. Being located at the very tail of the Upper Swat Canal, Chowky receives a water supply generally less than 7 percent of design full supply. At these low discharges, it is

not possible to maintain equity among watercourse outlets, regardless of rehabilitation.

Reliability, calculated as the coefficient of variation of outlet performance, has improved in the tail reach of the distributary, but overall reliability suffers because inflow to the head is insufficient and erratic. Conveyance losses and freeboard conditions have also improved.

The agricultural indicators from pre- and post-rehabilitation Kharif seasons, in general, show improvement in the five sample watercourses. Cropping intensities increased in all but one watercourse, average maize yields increased, though fertilizer applications on maize were reduced. Cropping patterns were altered also. A greater percentage of total cultivated area was allocated to tobacco and sugar cane, or tobacco or sugar cane. Higher value crops were more prevalent in Kharif 1992 than Kharif 1990.

Changes in outlet performance and reliability for the five watercourses were not uniform. Apart from one watercourse, which had little change between the two seasons, the other four watercourses had improvement in outlet performance or reliability, but not both.

The non-uniform changes in hydraulic parameters leads to ambiguous conclusions regarding the impact of canal rehabilitation on the agricultural economy. There is little doubt that water supply and reliability are important for crop production, but it is difficult at this time to conclude that the changes in agricultural economics indicators are an impact of changes in hydraulic variables.

Recommendations for Post-Rehabilitation

Hydraulic data

Recommendation 1: ACOP should collect post-rehabilitation data during the 12 months immediately following completion of rehabilitation works. It is recommended that ACOP publish reports comparing pre- and post-rehabilitation status, and draw conclusions regarding the impact of rehabilitation works on project goals.

Recommendation 2: Two years after the post-rehabilitation data are collected and analyzed, ACOP should carry out another similar study to track the rate of deterioration of the rehabilitation works.

Agricultural economics data

Recommendation 1: WMED should complete the post-rehabilitation of Chowky Distributary and finish a report comparing pre- and post-rehabilitation agricultural economics indicators. The completion of two seasons of data will provide a clearer picture of potential changes in the agricultural economy resulting from canal rehabilitation.

Recommendation 2: Post-rehabilitation data collection for other canal subsystems should not be initiated. The atypical characteristics exhibited the sample watercourses will not provide the type of information necessary to determine the impact of canal rehabilitation on the agricultural economy. In future, it is recommended that a purposive sampling procedure be utilized in order to guarantee that a full range of watercourses are selected.

Chapter One

INTRODUCTION AND SCOPE OF STUDY

The goals of the Irrigation Systems Management Project II (ISMII) are to improve the safety, equity and reliability of selected canal systems in Pakistan. This USAID project and the parallel World Bank Project, ISRP-II, are designed to rehabilitate irrigation works which have deteriorated due to deferred maintenance.

One project task is to establish an impact evaluation system to track changes in hydraulic and agricultural economics indicators achieved by rehabilitation. The impact evaluation should answer two basic questions:

1) Has the rehabilitation improved safety, reliability and equity of water supply in canal subsystems? and

2) Does canal rehabilitation have an affect on the agricultural economy of the canal subsystem?

The impact evaluation is thus organized along two separate but related lines, issues relating to hydraulic changes which may occur because of rehabilitation; and issues related to agricultural economics. Two separate sets of indicators have been developed to track the impact of rehabilitation, and two separate data collection procedures established.

Seven canal subsystems were chosen for the impact evaluation system. Three are located in Punjab Province, Venoi, Killianwala, and 11-L Pakpattan, two in Sindh, Puran and Nagnah, one in NWFP, Chowky, and the last subsystem, Nari, is located in Balochistan.

The impact evaluation program includes seven hydraulic indicators: outlet performance, modularity, freeboard, equity, reliability, conveyance losses, and outlet flow area (or outlet geometry). The Alluvial Channels Observation Project (ACOP), located in Lahore was responsible for collecting and analyzing the hydraulic data. ACOP has produced, or is in the process of producing, separate reports, with both narrative and a full data set, on all seven canal subsystems.

There are five agricultural economics indicators: cropping intensity, cropping pattern, average yields of the major crops, average input use (particularly fertilizer applications), and value of agricultural output. Between four and seven sample watercourses in each canal subsystem were selected for data collection, and approximately 20 farm families were interviewed in each watercourse. The Punjab Economics Research Institute

(PERI) was responsible for data collection and analysis in the three Punjab canal subsystems. The Watercourse Monitoring and Evaluation Directorate (WMED) conducted the evaluation activities in the balance of canal subsystems. Both agencies have supplied complete data sets on the pre-rehabilitation status of the five indicators. WMED has submitted a report on its pre-rehabilitation baseline survey, and PERI has provided a draft report.

This paper reports on the pre-rehabilitation status of both the hydraulic and agricultural economics indicators in the seven canal subsystems, and offers comments on the validity and credibility of the impact evaluation program. This report is organized as follows: the balance of Chapter One contains short introductions to the seven canal subsystems, indicating general features of each irrigation system and characteristics of the local agricultural economy. The last part of Chapter One contains comments on the relationship of hydraulic and agricultural economics indicators to project objectives.

Chapter Two provides the pre-rehabilitation status of each indicator in each canal subsystem. The agricultural economics data are presented in greater detail than the hydraulic data. This is because ACOP's reports comprehensively summarize the hydraulic indicators, thus eliminating the need to repeat it here. WMED and PERI reports, on the other hand, are not organized according to the five agricultural economics indicators, thus necessitating a full presentation of these data in this report.

Chapter Three establishes statistical relationships between the hydraulic indicators, outlet performance and reliability, and four of the agricultural economics indicators, cropping intensity, crop yields, average input use, and average value of agricultural output. Chapter Four documents the rehabilitation work that actually occurred or is planned for each canal subsystem, and comments on the relevance of these works to the project goals of safety, equity and reliability.

Chapter Five is the pre- and post-rehabilitation summary for Chowky. A full set of hydraulic data are available for both pre- and post-rehabilitation on Chowky. With regard to the agricultural economics indicators, the post-rehabilitation Kharif season data are available. The post-rehabilitation Rabi season data are currently being collected. Chapter six provides recommendations for further work on the impact evaluation program.

Description of Canal Subsystems

Chowky, NWFP

Chowky Distributary is the smallest of the canal sub-systems monitored under the ISM II Project. Data exist on both its pre- and post-rehabilitation status. Average discharge to the head of the distributary was 56 percent of full supply during the pre-rehabilitation period, and 49 percent during the post-rehabilitation period. Lack of water led to an unusually large number of tampered outlets, particularly those in head reaches. This created a significant inequity condition between head and tail outlets in the system. Chowky is the sub-system with the most variability in flow and the least reliability.

To cope with water shortage and inequitable water distribution, farmers have installed private tubewells. Cropping intensity (CI) is 207 at the head and 111 at the tail of selected sample watercourses. Major crops are wheat, maize, sugar cane, with smaller cultivated areas of tobacco, and sesame. Tree crops are not evenly distributed throughout the five sample watercourses selected for agricultural economics data collection. In two watercourses, over 30 percent of the cultivated area was devoted to orchards, while in the other three, no tree crops were grown. The highest valued crop in the canal subsystem is tobacco, particularly Virginia tobacco. Tobacco is grown on a contract basis. In two sample watercourses with reliable and adequate water supplies, tobacco accounts for 20 and 10 percent of the cultivated area during the post-rehabilitation Kharif season.

Rehabilitation works included lining of minors. repairs to stone pitching in the distributary, silt removal, and restoration of 17 outlets to original design.

Killianwala, Punjab

Serving the largest area of the sub-systems monitored, Killianwala Distributary has the poorest water endowment. One cfs serves 425 acres, and the distributary receives only 78 percent of design discharge. Of all the sub-systems, equity is the worst on Killianwala. Farmers at the head end have over three times greater access to surface irrigation supplies than that of tail-enders. Almost one outlet in four located in tail sections receives no water. Because of chronic water shortage at the tail and to Minors 7 and 8, farmers on some outlets have chosen to close off the moghas, electing instead to rely on private wells to avoid payment of abiana for a deficient and unreliable surface source.

Despite water shortage and inequitable surface supply, cropping intensity averages 144 percent and is nearly the same at the head and the tail. Main crops are wheat, fodder, sugar cane, cotton and maize.

It is unfortunate that the agricultural economics data acquired from Killianwala are biased towards watercourses with relatively abundant water supplies, and information on crop production must therefore be used cautiously. For example, the two tail end watercourses have outlet performance of over 75 percent, far higher than most tail enders. Because no formal data collection was done on more typical watershort watercourses at the tail, it is not clear to what extent lack of surface irrigation affects cropping intensity, cropping patterns or other agricultural economics variables. Site visits to Killianwala gave the impression that there are in fact large differences between head and tail agriculture. Unfortunately, the available data cannot provide an accurate portrait.

The rehabilitation program included:

a) Lining of 73,401 feet of the distributary and minors. Prior to rehabilitation, conveyance losses, at 12 percent, were the largest for any of the sub-systems.

b) Bank strengthening, road repair, compaction, and freeboard restoration.

c) Repairs to nearly all the outlets.

Nagnah, Sindh

At 146 percent of full supply, Nagnah Distributary, along with Pakpattan 11-L, and Puran, receives more than its fair share of water. Almost two-thirds of the moghas function in a non-modular mode. Equity in water supply appears to be adequate, though several outlets at the tail receive no water.

The average cropping intensity is low, a mere 78 percent, reflectsing strong inequity in water supply. At the head, CI averages 106 percent, and at the tail, only 51 percent. The main crops are wheat, sugar cane, and tree crops. In most of the sample watercourses, the cropping pattern, with its high level of orchards and sugar cane, reflects adequate and fairly reliable water supply. Farmers in four of the five watercourses are confident that water will be available as exemplified by their cultivation of a high percentage of land to high value and high input crops. These four watercourses have good reliability indices. The fifth watercourse has a poor reliability index (CV of outlet performance is 64 percent), causing these sample

farmers to place most of their land in cotton and wheat, avoiding tree crops or sugar cane.

Rehabilitation works included:

a) Bank strengthening, road repair, clearance of vegetation, compaction, freeboard restoration.

b) Construction of groynes for bank protection and control of erosion.

c) Repair of 45 outlets.

d) Repairs to minor structures.

Nari, Balochistan

On average, Nari Distributary receives 101 percent of its design flow. The distributary has the most abundant water supply, with one cfs serving 122 acres. Except for Municipal Minor, equity conditions are very good and moghas at the tail of the distributary have more access to water than head-end outlets. Two moghas each have sanctioned flow in excess of 10 cfs.

Rehabilitation works will include:

a) Lining of 71,600 feet of the distributary and minors.

b) Silt removal, canal bank strengthening and other forms of earthwork.

c) Construction and repairs to an aqueduct, siphons and bridges.

Pakpattan 11-L, Punjab

Pakpattan 11-L receives 161 percent of full supply giving 11-L farmers a generous water supply (one cfs for 158 acres). Equity is good.

Cropping intensity averages 153 percent, with somewhat more intensive cultivation in head chaks than in those at the tail. The main crops are wheat and cotton. It is surprising that very little of the land is devoted to sugar cane or orchards, though this could reflect market conditions. The cropping pattern of Pakpattan 11-L illustrates typical lower Punjab agriculture.

Rehabilitation works included:

a) Lining of 33,486 feet of the distributary and minors.

b) Side protection: killabushing, bank repair.

c) Bank strengthening, road repair, compaction, freeboard restoration.

d) Installation of outlet templates.

Puran, Sindh

As one of three sub-systems in this study with overabundant canal supplies, Puran Distributary received 141 percent of full supply. In spite of water overabundance, or rather because of it, cropping intensity is the lowest of the systems monitored, averaging 60 percent at the head and 39 percent at the tail. Puran is the only sub-system of the seven which is characterized by an equity coefficient less than unity and indication that farmers at the head routinely pass on water to tail reaches. As a result, the area is severely waterlogged. Similar to 11-L Pakpattan, the principal crops are wheat and cotton. Orchards, sugar cane and vegetables are also cultivated, but on small areas in relation to cotton and wheat. The average value of agricultural output per hectare is lower in Puran than all other canal subsystems.

Rehabilitation works included:

a) Bank strengthening, road repair, compaction, freeboard restoration.

b) Construction of groynes for bank protection and control of erosion.

c) Repair to 112 outlets.

It is noteworthy that Puran, and only one other system, Nagnah, are the only systems in which no canal lining was done.

Venoi, Punjab

Venoi's water supply is near design flow, in this case 109 percent. It is the distributary with the fewest number of tampered outlets. The equity coefficient is 1.35, which is similar to Nagnah or Puran although those distributaries receive greater percentages of design flow. This indicates that even

with normal (not excess) flows, some semblance of equity can be maintained.

Average cropping intensity is 167 percent with little differences between watercourses. The main crops are wheat, fodder and cotton. Due to the cropping intensity, the value of output per hectare in Venoi is very high, more than double that of Puran. Venoi also has higher than average yields of cotton and wheat.

Rehabilitation works included:

a) Lining of 43,772 feet of the main distributary and minors.

b) De-siltation, cleaning canal prism, bank strengthening, road widening, and compaction. Prior to rehabilitation, average freeboard was 0.82 feet, the smallest of any of the canal sub-systems.

c) Side protection in the form of killabushing, and canal side lining was provided to 28,290 feet of canal.

d) Repairs were made to 49 outlets, many of which drew excessive flow.

Discussion of Indicators and Project Goals

Hydraulic indicators

As mentioned above, the ISM-II Project goals are to rehabilitate canals for the purpose of improving safety, equity and reliability of water supply. The seven hydraulic indicators are direct measures of these goals. Freeboard and modularity are measures of safety, outlet performance, outlet geometry, conveyance losses and the equity coefficient are measures of equity, and the reliability index is a direct measure of the reliability of water supply.

As these seven indicators are direct measures of project goals, it is important that the project should be evaluated against changes in these measures. Evaluation of the project progress against these measures is the most direct way of determining the extent to which project activities are accomplishing Project goals.

Agricultural economics indicators

The five agricultural economics indicators were chosen for the following reasons: 1) they mirror the impact on the agricultural economy of changes in water reliability and equity, which may occur due to rehabilitation, and 2) they are simple to compute and do not require large sets of data. However, it is important to make clear that these indicators are not direct measures of Project goals, and cannot be used to track Project progress, nor the success or failure of the ISM-II Project. The agricultural economics indicators are limited to measuring the changes in the agricultural economy that may have occurred due to canal rehabilitation.

Comparisons of the levels of the agricultural economics indicators before and after rehabilitation should be done with caution. It is particularly important that changes in the agricultural economics indicators of a given canal system are correlated to actual changes in water supply as measured by the hydraulic indicators. If canal improvements have not resulted in changes in water supply, changes in the level of agricultural economics indicators cannot be ascribed to rehabilition. They may be the result in changes of relative prices or an increase or decrease in input prices.

Conversely, changes in water supply may cause changes in the agricultural economy, but not necessarily. We should view the agricultural environment in which farmers operate as a set of constraints on land, labor, capital and water. Any or all of these constraints may affect crop decision making. Improved water supply alters one of the constraints and enhances the agricultural economic environment, especially at tail reaches of canals. However, it is very important to note that altering only one of the numerous factors constraining farmers may or may not be sufficient to cause significant changes in the agricultural economics indicators.

Thus, for meaningful evaluation, it is necessary to isolate as much as possible the impact that changes in water supply will have on the agricultural economy. While these five indicators are unfortunately also related to other independent variables, such as output prices, input availability and prices, market access and others, as a group, they are closely tied to water supply and reliability (see Chapter Three). For all the potential caveats surrounding use of these variables, they are nevertheless, the best possible choice.

Chapter Two

PRE-REHABILITATION STATUS
HYDRAULIC AND AGRICULTURAL ECONOMICS INDICATORS
SEVEN CANAL SUBSYSTEMS

The purpose of this chapter is to provide information on the pre-rehabilitation status of each monitored canal subsystem. The first part of this chapter discusses the hydraulic indicators, and part two provides the agricultural economics indicators. Each indicator is briefly described and the results of data collection for each indicator are given.

In this chapter, there is no attempt to correlate the hydraulic and agricultural economics indicator levels. Discussion on the relationship between hydraulic and agricultural economics indicators is found in Chapter Three.

Hydraulic Indicators

The impact of rehabilitation on water availability (hydraulic impact) was determined through monitoring seven indicator parameters. Those indicators are 1) outlet flow area; 2) outlet performance; 3) modularity; 4) conveyance losses; 5) freeboard; 6) equity; and 7) reliability. Following is a summary of the detailed results presented in ACOP reports for each indicator for the seven canal sub-systems.

In addition to the seven indicators, there is a discussion of possible changes in inflow to the head of a distributary. Variation in inflow to the head has a direct affect on the hydraulic indicators used to measure canal rehabilitation impact, and it is thus necessary to report possible changes in inflow during the period between pre- and post-rehabilitation data collection.

Inflow to the head of the distributaries

Daily readings of staff gauges at the head of each distributary were used together with ACOP-determined stage-discharge relationships to determine daily inflow to the head of each canal sub-system. No-flow periods (during scheduled canal closures) are excluded from the computations. Average inflow (cfs) and percentage of full supply are shown in Table 1. Both pre- and post-rehabilitation data are presented for Chowky. Nari Distributary (122 ac/cfs) and Pakpattan Distributary (158 ac/cfs) have the most abundant supplies of surface irrigation water, three to four times the supply that is furnished to Killianwala (425 ac/cfs). This is shown in Figure 1.

Table 1. Average Inflow; seven canal subsystems

Sub-System	Inflow (cfs) Pre	Inflow (cfs) Post	% Full Supply Pre	% Full Supply Post	Ac/CFS[1]
Chowky	29.2[2]	25.3[2]	56	49	213
Killianwala	165.5		78		425
Nagnah	141.5		146		250
Nari	120.9[3]		101		122
Pakpattan	338.1		161		256
Puran	243.2		141		186
Venoi	212.7[4]		109		158

Outlet Flow Area

Outlet flow area was calculated through measurements of geometry, height, and width. Data were collected monthly, generally over a one-year period to characterize pre- and post-rehabilitation conditions. The observed outlet flow area was compared to the sanctioned/design area and has been expressed as a percentage of design.

$$\frac{Ao}{As} \times 100$$

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[1] At pre-rehabilitation.

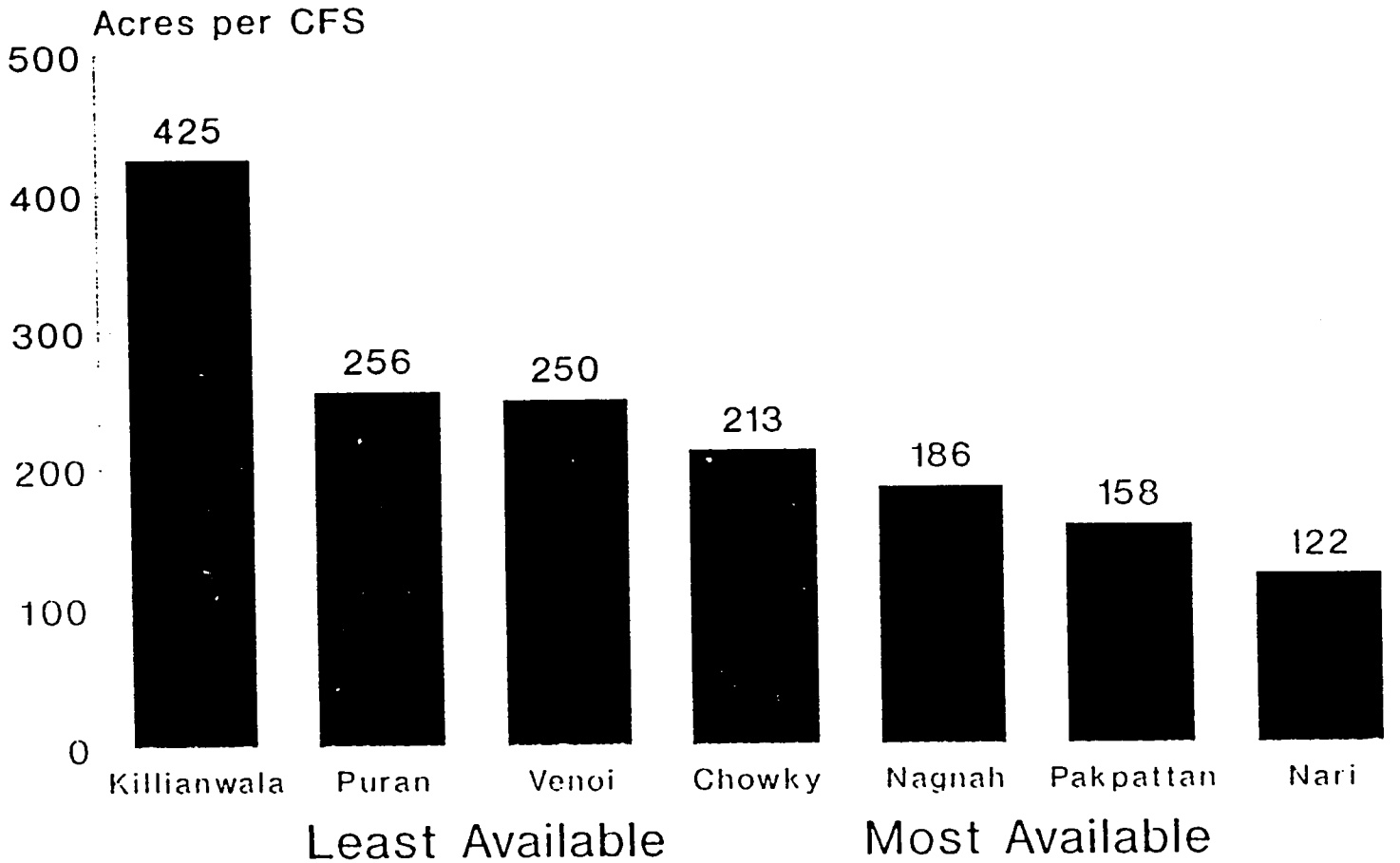
[2] Four months, September through December.

[3] Five months, January through May.

[4] Nine months, October through June.

WATER AVAILABILITY

Acres Served by One CFS



Pre-rehabilitation

Given in Table 2 is the percentage of outlets having an area 150 percent or more than design.

Table 2. Outlet geometry; Percent of outets with area exceeding 150 percent of design.

Sub-System	-------%----- Pre	Post
Chowky	15	8
Killianwala	9	
Nagnah	38	
Nari		
Pakpattan	14	
Puran	49	
Venoi	3	

Outlet performance

Outlet performance is the observed discharge (Q_o) through the mogha expressed as a percentage of sanctioned discharge (Q_s).

$$\frac{(Q_o)}{Q_s} \times 100$$

For all moghas in each canal sub-system, up to 12 discharge measurements were taken throughout the year using velocity meters. Table 3 shows the percentage of outlets drawing at least 150 percent of sanctioned flow.

Outlets drawing a large percentage above sanctioned flow deprive other outlets of their fair share. Table 4 shows outlets which draw no flow. Killianwala Distributary has the largest percentage of no-flow moghas, all located in the tail reach of the system. Nearly one-quarter of the tail outlets on Killianwala draw no flow. In some cases these include outlets where farmers have elected to draw no canal flow and instead rely solely on groundwater. These farmers prefer irrigation from tubewells to an inadequate and unreliable surface water source.

Table 3. Outlet performance; Percentage of outlets drawing at least 150 percent of sanctioned discharge

Sub-System	Pre	Post
Chowky	10	7[5]
Killianwala	17	
Nagnah	45	
Nari	22	
Pakpattan	35	
Puran	48	
Venoi	21	

Table 4. Outlets that draw no flow

Sub-System	--------%------- Pre	Post
Chowky	0	0
Killianwala	8	
Nagnah	2	
Nari	0	
Pakpattan	0	
Puran	0	
Venoi	0	

Modularity

When flow through watercourse outlets is controlled exclusively by the upstream head, the outlet performance is said to be modular. Strictly defined, "a semi-modular outlet is an outlet in which the discharge depends upon the water level in the distributary only and is independent of the water level in the watercourse. This is achieved by producing a hydraulic jump

[5] All are head outlets.

within the flume length".[6] The majority of the moghas in Pakistan were designed to be characterized by semi-modular flow.

Non-modular flow occurs when there is no hydraulic jump, and downstream and upstream head both affect flow. This flow regime, also called "submerged flow", impedes flow through the outlet. Non-modular flow can be caused by: 1) insufficient head in the parent channel; 2) too much head on the downstream side; and 3) a tampered outlet so that flow constriction does not occur.

Modularity was determined monthly over a one-year period. A mogha which was had non-modular flow for one-third of the observations was labeled as "non-modular". The percentage of outlets which were characterized by non-modular flow is shown in Table 5.

Table 5. Non-modularity; Percent of outlets with non-modular flow

Sub-System	Pre	Post
Chowky	need data	31
Killianwala	31	
Nagnah	67	
Nari		
Pakpattan	32	
Puran	51	
Venoi	41	

Conveyance Losses

Conveyance losses occur due to seepage, percolation, and evaporation. Losses should be reduced, and conveyance efficiency increased, through rehabilitation.

Conveyance losses were determined by:

a) measuring the inflow to the head of the distributary system;

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[6] Ali, Iqbal, Irrigation Engineering, Oxford University Press, 1975, p 279.

b) measuring the outflow at each of the moghas;

c) subtracting the summation of outflow at all moghas from inflow. The difference is conveyance loss.

Conveyance losses in the distributary have been expressed in Table 6 as a percentage of incoming discharge to the distributary head.

Table 6. Conveyance Losses (%)

Sub-System	Pre	Post
Chowky	10	8
Killianwala	12	
Nagnah	9	
Nari		
Pakpattan	8	
Puran	9	
Venoi	10	

Freeboard

Freeboard is the vertical distance between the surface of water in the canal at peak flow, and the top of the canal bank. Well designed and well maintained canals should have freeboard on the order of two feet for safety in operations. Rehabilitation during the ISM/ISRP project was designed to improve canal banks and to provide adequate freeboard.

Freeboard was determined at regular intervals along each canal sub-system. Average freeboard and the percentage of full supply at which measurements were taken are presented in Table 7. While calculation of average freeboard as shown in Table 7 indicates the general adequacy of canal bank maintenance, it also obscures the possibility that certain canal reaches may have insufficient freeboard. Even a small portion of a canal with insufficient freeboard can ultimately result in a breach.

Table 7. Average freeboard (feet)

Sub-System	Pre		Post	
	Free'brd (feet)	% Full Supply	Free'brd (feet)	% Full Supply
Chowky	2.78	56	2.78	49
Killianwala	1.50	111		
Nagnah	3.43	172		
Nari				
Pakpattan	0.93	161		
Puran		174		
Venoi	0.82	134		

Equity and reliability

Equity is a measure of variation in access to water between locations at a particular time. Reliability is a measure of variation in flow with time at a particular location.

Equity: Equity measures the difference in access to irrigation water by farmers in differing reaches of a canal system. If all moghas located along a distributary share equally in excess or deficient supplies, water distribution is said to be equitable; if there is differential access to irrigation water, canal operations are not equitable.

To determine the degree of equity in canal sub-systems, outlets were stratified into "head", "middle", or "tail" based on their distance from the head of the distributary in relation to all other outlets. That is, the first one-third outlets are classified as head, the second one-third, middle, and the last one-third are said to be tails, irrespective of the actual distance from the head of the distributary. An equity coefficient was used to determine the relative degree to which water is evenly distributed throughout the reaches of the canal sub-system.

The equity coefficient was defined as the ratio of measured or observed flow to sanctioned flow of head and tail outlets. It is the ratio of average outlet performance in the head to average outlet performance in tail.

$$\frac{(\text{Observed Flow/Sanctioned Flow})_{\text{head outlets}}}{(\text{Observed Flow/Sanctioned Flow})_{\text{tail outlets}}}$$

Equity coefficients shown in Table 8 were calculated using observed (measured) and sanctioned flow data for all of the head and tail outlets on a distributary. Generally, data represent an average of all observations taken over a period of 12 months. A value of unity would indicate perfect equity. Equity coefficients in excess of unity indicate that head-end moghas obtain a larger relative share of water than tail-end moghas.

Rehabilitation works which:

a) restore outlet flow areas to meet design specifications;
b) improve conveyance efficiency;
c) restore modularity in tail moghas;
d) reduce breaches; and/or
e) reduce canal operating conditions to full supply level

can improve water delivery to tail sections and should lead to greater equity and to improved agricultural productivity. Among the works listed above, restoration of outlet flow area to design specifications is likely to have the most impact on equity.

Table 8. Equity coefficients

Sub-System	Pre	Post
Chowky	2.25	2.64
Killianwala	3.03	
Nagnah	1.20	
Nari	0.65[7]	
Pakpattan	1.19	
Puran	0.83[8]	
Venoi	1.35	

Reliability: Reliability is a measure of the regularity or dependability of water supplied over time at a particular location. If flow is variable and reliability is poor, farmers will respond by reducing cropping intensity and cultivating a larger percentage of land to low value crops. Conversely, if reliability can be improved farmers will be encouraged to increase plantings and shift to higher value crops.

The reliability index is the coefficient of variation (CV)[9] of outlet performance (flow) for each mogha. If CV is low in the head reach, say 10 percent, head watercourses will receive the average percentage of full supply plus or minus 10 percent, 68 percent of the time, irrespective of the mean. This would be a reliable water supply. On the other hand, if the CV is high in the tail reach, say 50 percent, tail watercourses receive the average percentage of full supply plus or minus 50 percent, 68 percent of the time. Even if the mean is high, this must be

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[7] Prior to rehabilitation, most head moghas received close to their sanctioned flow. Moghas located on Municipal Minor, all of which are located near the middle of the sub-system, drew less than sanctioned flow. The difference between flow to head moghas and that taken by Municipal Minor flowed to tail moghas. As a consequence, tail portions of Nari drew more than sanctioned flow and equity is less than unity.

[8] Puran is badly waterlogged. Excess water flows to tail outlets and contributes to the waterlogging problem.

[9] Coefficient of variation of water supply is computed as the standard deviation of the percentage of outlet performance (Q_o/Q_s x 100) divided by its mean times one hundred.

considered an unreliable water supply. CVs for the canal sub-systems are presented in Table 9.

Table 9. Coefficient of variation (%) in outlet performance

Sub-System	Head	Middle	Tail
Chowky	18.4	32.0	34.3
Killianwala	22.0	20.4	65.6
Nagnah	26.6	25.3	47.8
Nari	12.6	10.5	11.9
Pakpattan	34.0	30.0	24.0
Puran	30.6	32.1	39.9
Venoi	23.2	19.4	26.2

Generally, flow is less reliable to tail moghas. Chowky is the one sub-system in which there is a marked deterioration in reliability between head and middle. The poor reliability of the Killianwala tail reflects the fact that ten moghas in that reach are often closed. Reliability is best on Nari.

Rehabilitation improvements resulting in fewer periods of unscheduled canal closure will have a positive impact upon reliability. Improvements such as bank strengthening to restore freeboard and to reduce the number of breaches will result in better flow reliability.

Agricultural Economics Indicators

Agricultural economics indicators are used to determine the impact of canal rehabilitation on the local agricultural economy. The impact evaluation using agricultural economic indicators will answer the question: Do changes in water delivery as reflected in equity of distribution among watercourses and reliability of water delivery make an impact on the local agricultural economy?

The data presented in this section of the report were collected and assembled by the Watercourse Monitoring and Evaluation Directorate (WMED) and the Punjab Economics Research Institute (PERI). Both agencies are located in Lahore. WMED collected data from four canal subsystems: Chowky, in NWFP, Puran and Nagnah in Sindh Province and Nari in Balochistan. PERI

data come from three canal subsystems in Punjab: Venoi, 11-L Pakpattan, and Venoi.

Five indicators have been developed to measure the impact on the agricultural economy: 1) cropping intensity; 2) cropping pattern; 3) crop yields; 4) level of input use; and 5) value of agricultural output. These indicators are defined in the following pages.[10]

These indicators were chosen because they best reflect the impact on the agricultural economy resulting from changes in water reliability and equity. However, it is very important to underscore the fact that agricultural economics indicators are not direct measures of the impact of canal improvements. While the indicators are doubtless related to irrigation, water supply is only one factor which determines the level of each indicator. Other important exogenous variables, such as output prices, input availability and prices, market access and others also govern farmers' crop decision making.

It was originally planned to present the agricultural economics indicators on a canal reach basis, that is, showing the various levels of each indicator as averages of the head, middle and tail watercourses. Such presentation would show how changes in equity, for example, within the canal subsystem affected each of the three reaches in relation to each other. Meaningful comparisons of indicators by canal reach require that the levels of the indicators in the pre-rehabilition data set vary from reach to reach, or that head and tail watercourses exhibit charateristics typical of the agricultural economy in the head and tail reaches.

Compilation of the data from PERI and WMED shows that there are few differences between the indicator levels in what are nominally head, middle or tail reach watercourses. In some canal subsystems, there was no variation in outlet performance between head and tail watercourses chosen by the two agencies and tail watercourses received as much water as head watercourses. Under these conditions it is not likely that agricultural economics variables would show any variation, and there would be little if any affect of canal rehabilitation on these particular watercourses.

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[10] The socio-economic impact study on the Left Bank Outfall Drain Project identified indicators very similar to these five for agricultural economics evaluation. See 1991. LBOD Project, Socio-economic Impact Evaluation Study; Baseline Report; Volume 1; Main Report. Published by Sindh Development Studies Centre, University of Sindh, Jamshoro, in association with ITAD Ltd. and Wye College (University of London), UK.

To accommodate this problem with the data set, the indicators will be presented on a watercourse basis, not a canal reach basis. By showing the data on a watercourse basis, it is possible to show statistical relationships between the hydraulic and agricultural economics variables, irrespective of position in the canal subsystem. Statistical relationships are given in Chapter 3. In this section, the purpose is to present indicator levels of 32 watercourses.[11]

Cropping intensity

Cropping intensity is total cultivated area within a watercourse given as a percentage of total farm size. This indicator can be given on a yearly or a seasonal basis. If for example, one hundred hectares of land are cultivated during the year, and total farm size is one hundred hectares, cropping intensity is 100.

In the absence of a reliable and equitable distribution of water, cropping intensity is most likely to be the highest in watercourses which are supplied with high levels of water. In general, insufficient water supply is likely to be a tighter constraint to crop cultivation in the tail of the canal system than in the upper reaches. Canal improvements should ease the water constraint in watercourses which are currently short of water, and cropping intensities across all watercourses of the canal system should converge.

More equitable distribution of water may lower cropping intensities in watercourses which are well-endowed with water. This should not be deemed as a negative impact of canal improvements. While an increase in overall cropping intensity is a desirable impact resulting from canal rehabilitation a positive impact will be determined by the a reduction in the difference between intensities across watercourses.

Table 10 lists the cropping intensities of all 32 watercourses. In all but a few watercourses, cropping intensity is greater than that estimated to correspond to the design capacity of the irrigation system (estimated to be about 50 percent per season or 100 percent in any given year). Only five watercourses (15.6 percent) have cropping intensities below 100 percent (or 50 percent per season) and only 10 or one-third have cropping intensities below 125 percent. Thus we can conclude that as a group these watercourses have abundant water supplies.

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[11] In this section, Nari data are excluded. Though WMED has supplied agricultural economics data on Nari, a complete set of hydraulic data are not available.

Table 10. Cropping intensity (CI) by watercourse

Watercourse number	CI (%)	Average CI by system	Outlet performance (%)
Chowky 6750-L	207		151
Chowky 17912-R	135		52
Chowky 25000-TL	98		45
Chowky 3500-L	193		72
Chowky 8000-TF	186	164	105
Nagnah 3-R	102		176
Nagnah 1-AL	123		218
Nagnah 7-R	125		118
Nagnah 9-L	108		195
Nagnah 14-AL	51	102	112
Puran 2-R	101		175
Puran 1-R	62		145
Puran 2-AL	96		168
Puran 2-T	51	78	161
Pakpattan 11000-L	153		184
Pakpattan 38774-L	187		169
Pakpattan 4000-L	191		149
Pakpattan 14966-L	111		159
Pakpattan 127055-L	138	156	166
Venoi 3108-L	154		123
Venoi 10783-L	148		110
Venoi 79660-L	160		174
Venoi 75302	185		200
Venoi 6068-L	175		140
Venoi 32558-R	179	167	131
Killianwala 7136-L	136		155
Killianwala 12500-L	132		191
Killianwala 15063-L	156		123
Killianwala 11361-L	143		142
Killianwala 17600	145		169
Killianwala 136506-L	174		84
Killianwala 136780-L	142	147	74

Cropping intensities are graphically shown in Annex A of this chapter.

Cropping pattern

The second agricultural economics indicator is cropping pattern. Cropping pattern is defined as the amount of land allocated to cultivation of each crop as a percent of total cultivated area. The use of this indicator illustrates the relative amounts and percentages of land allocated to the various crops in the farming system.

An unreliable and inequitable distribution of irrigation water results in a reduction of the amount of land allocated to high value and high risk crops. Farmers' crop cultivation decisions are in part determined by perceptions of the reliability of water supply. Farmers are more likely to plant high value and high input crops if water is supplied reliably. Conversely, they will plant lower input and lower valued crops if they are faced with the risk of irregular water supplies. It is important to note that other factors, both physical factors such as soil type and salinity, and economic factors such as market access, also are important in determining cropping patterns.

Thus, before canal improvements, watercourses with an abundance of water should have a greater percentage of land placed in high value crops than watercourses which have a poor water endowment. After canal improvements, farmers who were formerly watershort should allocate a larger percentage of land in high value crops, while the farmers who originally had abundant water may lower their allocation of land to high value crops. Similar to the cropping intensity indicator, canal improvements may have an adverse effect on the cropping patterns of water abundant farms. This adverse impact on should not be considered a negative impact of canal improvements.

The pre-rehabilition status for the cropping pattern indicator is given in Table 11.

Chowky watercourses are in general more diversified than watercourses of other canal sub-systems. They contain a high percentage of maize during Kharif, with lower percentages of sugar cane, tobacco and orchards. Diversification is generally a risk management measure taken by farmers who face significant production risk, and may explain why such as small percentage of land is allotted to tobacco, a high value crop with little marketing risk. Chowky watercourses are the most watershort of the seven canal subsystems, as it is the tail end of a larger canal system.[12]

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[12] The average outlet performance of the sample watercourses in Chowky is lower than those in all other canal subsystems. However, Killianwala is the most watershort canal subsystem if

The Nagnah sub-system watercourses have a much higher percentage of land allocated to sugar cane and orchards, all relatively high valued crops. Generally, Nagnah watercourses reflect good outlet performance (adequate water supplies) and reliable water. Only one watercourse, 14-L, with a relatively low outlet performance level, 112 percent, and low reliability, CV of 64 percent, has no production of sugar cane or orchards. Ninety-three percent of the land is allocated to cotton in Kharif, and 92 percent to wheat in Rabi.

Puran has unusual cropping patterns especially with reference to its level of water availability. The cropping patterns in Puran are generally diverse, indicating risk aversion, and low percentages are placed in sugar cane and orchards. Its low cropping intensity and lowered value cropping pattern could be the results of waterlogging and perhaps saline soils. No well water is applied to agriculture in the four watercourses of Puran.

Pakpattan watercourses have typical lower Punjab cropping patterns dominated by cotton in Kharif and wheat in Rabi. Small areas of sugar cane, fodder, orchards and other crops are intermixed with the two main crops. The cropping patterns reflects adequate water supplies, and are typical for the area. One would expect that good water supplies would results in higher valued crop cultivation, but other factors such as marketing or input supply may restrict inclusion of other higher valued crops.

The cropping patterns in Venoi are similar to those in Pakpattan and differ in degree only. There is slightly more diversification in Venoi and a higher percentage of land placed into fodder than found in Pakpattan. As with Pakpattan, the cropping pattern reflects adequate water supplies from both surface irrigation and wells.

Killianwala watercourses are very diverse, including cultivated areas of rice, cotton, maize, fodder, vegetables, oilseeds and sugar cane, during Kharif and wheat, fodder, vegetables and orchards during Rabi. The sample watercourses are relatively well-endowed with surface irrigation, and there is a high density of wells in those watercourses with outlet performance below 100 percent.

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one is considering average outlet performance of all watercourses in the monitored subsystems.

Table 11. Cropping patterns for 6 canal subsystems.

Chowky; Kharif

Watercourse	Maize	Veg	Tobacco	Sugar cane	Orchard	Fodder	Rice
6750-L	40	4	9	14	31	0	0
17912-R	34	3	0	1	41	20	0
25000-TL	80	0	0	20	0	0	0
3500-L	66	1	2	29	0	2	0
8000-TF	38	48	0	1	0	8	5

Chowky; Rabi

Watercourse	Wheat	Oilseed	Fodder	Sugar cane	Orchard	Minor crops
6750-L	49	1	8	14	31	5
17912-R	70	1	4	1	23	2
25000-TL	70	0	9	16	0	5
3500-L	60	0	1	34	1	4
8000-TF	41	0	14	38	1	6

Nagnah; Kharif

Watercourse	Bajra	Cotton	Janter	Fodder	Veg	Minor crops	Sugar cane	Orchard
3-R	14	8	3	7	5	7	19	37
1-AL	0	0	0	0	0	0	70	30
7-R	0	0	0	0	0	0	2	98
9-L	0	8	1	3	18	0	0	70
14-AL	0	93	4	0	3	0	0	0

Table 11. cont.

Nagnah; Rabi

Watercourse	Wheat	Fodder	Sugar cane	Veg	Orchard
3-R	36	1	18	16	29
1-AL	30	1	49	0	20
7-R	10	1	3	0	86
9-L	41	0	0	0	59
14-AL	92	0	0	8	0

Puran; Kharif

Watercourse	Cotton	Janter	Fodder	Veg	Sugar cane	Orchard	Rice
2-R	69	3	1	18	9	0	0
1-R	48	6	0	40	2	4	0
2-AL	56	7	0	0	13	24	0
2-T	55	14	0	5	0	21	5

Puran; Kharif

Watercourse	Wheat	Fodder	Sugar cane	Veg	Orchard
2-R	92	3	4	1	0
1-R	86	5	1	5	2
2-AL	49	21	10	2	18
2-T	64	16	0	5	15

Table 11. cont.

Pakpattan; Kharif

Watercourse	Cotton	Sugar cane	Fodder
11000-L	83	2	17
38774-L	77	3	19
4000-L	89	0	11
14966-L	89	0	11
127055-L	84	1	14

Pakpattan; Rabi

Watercourse	Wheat	Fodder	Orchard	Melon	Minor crops
11000-L	76	14	1	8	1
38774-L	81	19	0	0	0
4000-L	88	12	0	0	0
14966-L	92	8	0	0	0
127055-L	90	10	0	0	0

Venoi; Kharif

Watercourse	Cotton	Rice	Fodder	Sugar cane	Veg	Maize
3108-L	68	16	14	3	0	0
10783-L	67	4	22	6	0	0
79660-L	87	0	12	0	1	0
75302-R	68	0	30	1	1	0
6068-L	77	0	23	0	0	0
32558-R	77	4	0	3	0	16

Table 11. cont.

Venoi; Rabi

Watercourse	Wheat	Fodder	Melon	Orchard	Veg	Pu
3108-L	86	14	0	0	0	
10783-L	71	24	5	0	0	
79660-L	82	16	0	2	0	
75302-R	69	31	0	0	0	
6068-L	73	0	0	0	27	
32558-R	86	1	0	0	0	

Killianwala; Kharif

Watercourse	Rice	Cotton	Maize	Fodder	Veg	S
7136-L	4	24	11	24	2	
12500-L	4	20	20	25	1	
15063-L	1	44	7	26	0	
11361-L	2	23	35	24	0	
17600	0	28	36	20	0	
136506-L	0	69	1	26	0	
136780-L	0	68	0	16	0	

Killianwala; Rabi

Watercourse	Wheat	Fodder	Veg	Orchard
7136-L	78	17	1	4
12500-L	80	18	1	1
15063-L	79	19	0	2
11361-L	79	20	0	1
17600	80	16	0	4
136506-L	79	21	0	0
136780-L	82	18	0	0

It is unfortunate that a true "tail end" watercourse, in the sense of low outlet performance, was not chosen in Killianwala. The two tail end watercourses, 136506-L and 136780-L, have outlet performance measures that far exceed those of average watercourses.[13] Thus the cropping pattern is probably not reflective of a true watershort watercourse.

Crop yields

Crop yields should be positively correlated with reliable water supply and with good outlet performance. Before rehabilitation, therefore, farms in well-endowed watercourses should have higher yields than watershort watercourses, unless too much water results in waterlogged soil conditions. In addition, unreliable water supply should also be partly responsible for yield variation, as unreliable water supply increases the probability of crop failure.

It is important to note that crop yields are also closely related to factors other than water, for example, soil type or rainfall. Changes in crop yields after rehabilitation should be considered in light of other factors which are beyond the scope of this work. Annex B of this chapter contains charts of average wheat yields for six canal subsystems.

Crop yields for the major crops in each canal subsystem are given in Table 12.

Table 12. Crop yields in the 6 canal subsystems.

Chowky subsystem

Watercourse	Maize (kg/ha)	Sugar cane (kg/ha)	Wheat (kg/ha)
6750-R	1401	34045	1949
17912-R	821	27654	1267
25000-TL	767	17619	1281
3500-L	1216	33367	1051
8000-TF	1408	39323	1231
Average yield[14]	1123	30401	1356

[13] ACOP data show that the average tail end outlet performance in Killianwala was 52.75 percent. However, it is noteworthy that about one-third of the Killianwala watercourses received no surface irrigation during the period of measurement.

Table 12. Continued

Nagnah subsystem

Watercourse	Wheat (kg/ha)
3-R	1477
1-AL	1700
7-R	1288
9-L	2173
14-AL	1806
Average yield	1689

Puran subsystem

Watercourse	Wheat (kg/ha)	Cotton (kg/ha)
2-R	1910	856
1-R	1454	694
2-AL	1365	487
2-T	1986	642
Average yield	1679	670

[14] Average yield in this case is the average across watercourses, not the average of all farmers within the distributary.

Pakpattan subsystem

Watercourse	Wheat (kg/ha)	Cotton (kg/ha)
11000-L	1985	1821
38774-L	2051	2027
4000-L	1867	1967
14966-L	1698	1460
127055-L	1884	1208
Average yield	1897	1697

Venoi subsystem

Watercourse	Wheat (kg/ha)	Cotton (kg/ha)
3108-L	2061	1922
10783	1820	1434
79660	1801	1953
15302	2351	2055
6068-L	2021	2078
32558-R	1988	1739
Average yield	2007	1864

Killianwala subsystem

Watercourse	Wheat (kg/ha)	Cotton (kg/ha)
7136-L	2473	1182
12500-L	2104	1517
15063-L	2210	1716
11361-L	2387	1203
17600	2353	1166
136506-L	2001	1958
136780-L	2482	2273
Average yield	2287	1574

Wheat yields are highest in Killianwala averaging over two tons per hectare. This is very high considering that Killianwala is also the most watershort of all canal subsystem. The high incidence of tubewell water and the fact that the sample watercourses had higher than average outlet performance is the reason for this unexpected result. Venoi and Pakpattan had the next highest wheat yields, followed by Puran and Nagnah. Chowky had the lowest average yield across watercourses only 1.3 tons per hectare.

Level of inputs

This indicator measures the average level of inputs applied to the major crops in each of the sample watercourses. Since water availability and reliability are factors partially governing farmers' decision making regarding input use, changes in the level of application of inputs before and after rehabilitation may be partially the result of changes in water availability. As the risk of insufficient water supply diminishes, farmers are apt to increase input use.

Before rehabilitation, one would expect that input use would be greater in water abundant watercourses, where water supply is generally more reliable. After rehabilitation, levels of input use among watercourses should converge. Levels of inputs in the water abundant watercourses should not be negatively affected by a more equitable water distribution. As mentioned above, equity improvements should have its greatest effect on cropping intensity and cropping pattern. Thus, with greater reliability, input use may increase in water abundant watercourses though the most dramatic affect should be found in water short watercourses.

Details of the input use indicator are given in Annex E-1 through Annex E-6, attached to Chapter two. Graphs showing total cost of fertilizer applied to wheat in each watercourse is given in Annex C. Wheat is used for comparison as it common to all watercourses.

Value of agricultural output

The value of agricultural output is the fifth and final agricultural economics indicator. It is defined in two ways: 1) the average gross value of agricultural output per farm hectare (the summation of price times output of each crop divided by farm size); and 2) the average gross value of agricultural output per cultivated hectare. Watercourses with high cropping intensity will have high value per farm hectare relative to value of cultivated hectare. On the other hand, the value of agricultural output per cultivated hectare will be higher than that of farm hectare in watercourses with low cropping intensity.

The absence of a reliable and equitable distribution of irrigation water will cause farmers in watershort watercourses to cultivate their lands less intensively, will result in lower yields and will prompt farmers to allocate a larger percentage of land to lower valued crops than farmers with abundant water supplies.

With canal improvements, farmers in formerly watershort watercourses should have greater opportunities to do any or all

of the following: alter cropping patterns to include a greater percentage of higher value crops, improve crop yields with more reliable water supply or more intensive application of inputs, or more intensively cultivate their land holdings. Any or all of these changes will result in greater value of agricultural output per hectare. As with other indicators, there should be a convergence of the value of agricultural output among watercourses in the canal subsystem provided that agronomic and market conditions are constant across reaches of the system.

Table 13 gives the two measurements for value of output by watercourse. A set of graphs showing value of output is located in Annex D.

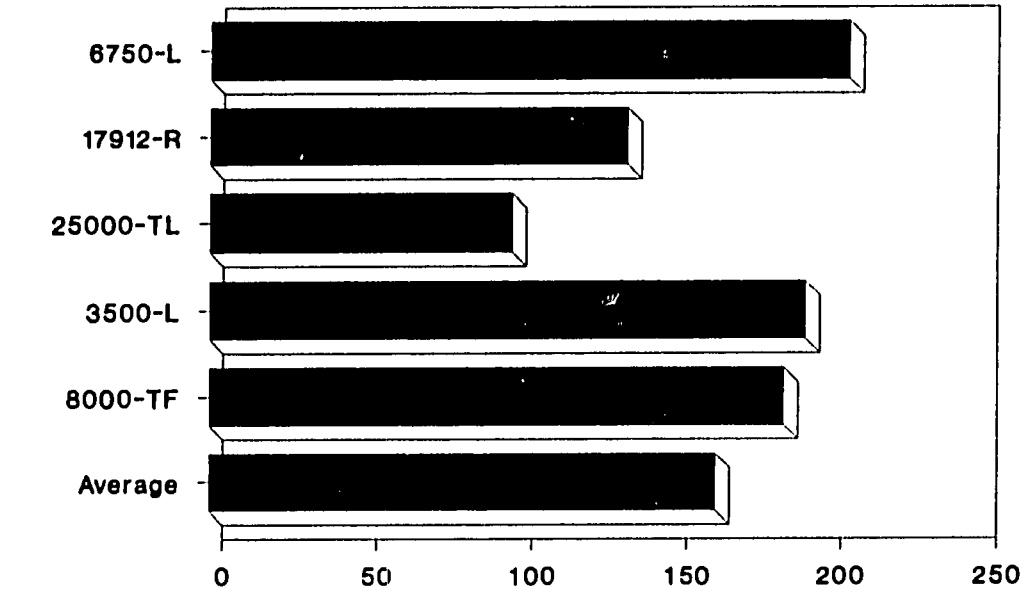
The value of agricultural output per farm hectare is the highest in Venoi, Pakpattan and Killianwala. This stems from high cropping intensities and relatively good yields in comparison to other canal subsystems. These three canal subsystems also have the highest value of output per cultivated hectare. Nagnah has the lowest average value of output per farm hectare, and Chowky has the lowest average value per cultivated hectare.

Table 13. Value of agricultural output per farm hectares and per cultivated hectare, by watercourse.

Watercourse number	Value of output per farm hectare (Rs/ha)	Value of output per cultivated hectare (Rs/ha)	Outlet performance (%)
Chowky 6750-L	15313	9454	151
Chowky 17912-R	4755	4783	52
Chowky 25000-TL	4877	4590	45
Chowky 3500-L	9652	5671	72
Chowky 8000-TF	10955	7342	105
Average	9110.4	6368	
Nagnah 3-R	5440	6621	176
Nagnah 1-AL	11742	16655	218
Nagnah 7-R	1315	1327	118
Nagnah 9-L	6387	6387	195
Nagnah 14-AL	3357	4602	112
Average	5648.2	7118.4	
Puran 2-R	7558	6278	175
Puran 1-R	6615	8576	145
Puran 2-AL	11063	11502	168
Puran 2-T	3524	5825	161
Average	7190	8045.25	
Pakpattan 11000-L	17005	10036	184
Pakpattan 38774-L	19409	10466	169
Pakpattan 4000-L	18125	9592	149
Pakpattan 14966-L	11300	8190	159
Pakpattan 127055-L	8857	7335	166
Average	14939.2	9123.8	
Venoi 3108-L	16440	9882	123
Venoi 10783-L	12400	7745	110
Venoi 79660-L	18268	11085	174
Venoi 75302	18685	9890	200
Venoi 6068-L	19345	11839	140
Venoi 32558-R	15491	8853	131
Average	16771.5	9682.3	
Killianwala 7136-L	10783	7643	155
Killianwala 12500-L	11540	8075	191
Killianwala 15063-L	13798	9293	123
Killianwala 11361-L	9920	6768	142
Killianwala 17600-L	12250	6743	169
Killianwala 136506-L	9693	17181	84
Killianwala 36780-L	17708	12430	74
Average	12241.7	9733.3	

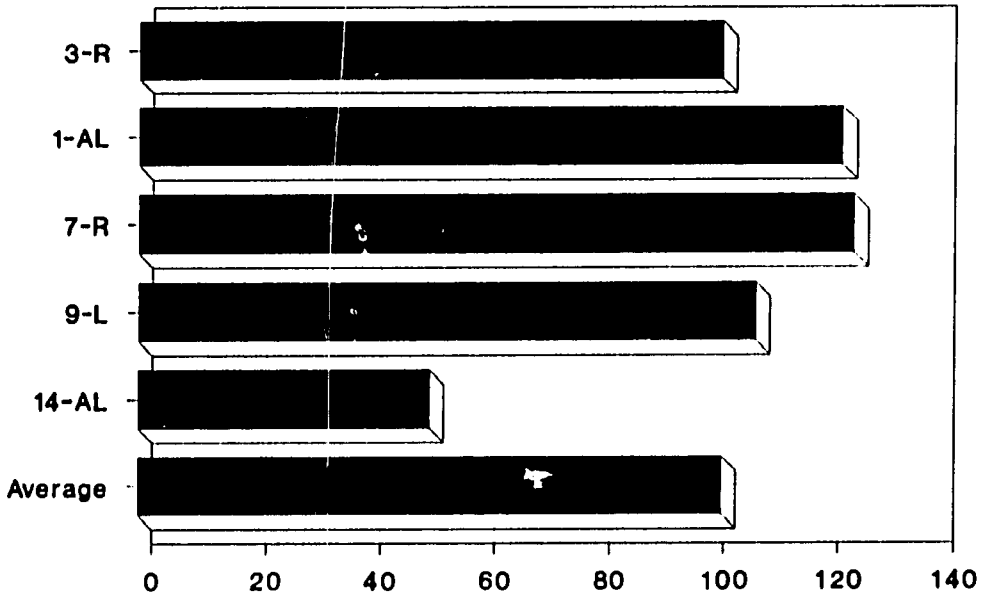
Annex A
Cropping Intensity
Watercourses on Six Canal Subsystems

Cropping Intensity
Chowky Watercourses



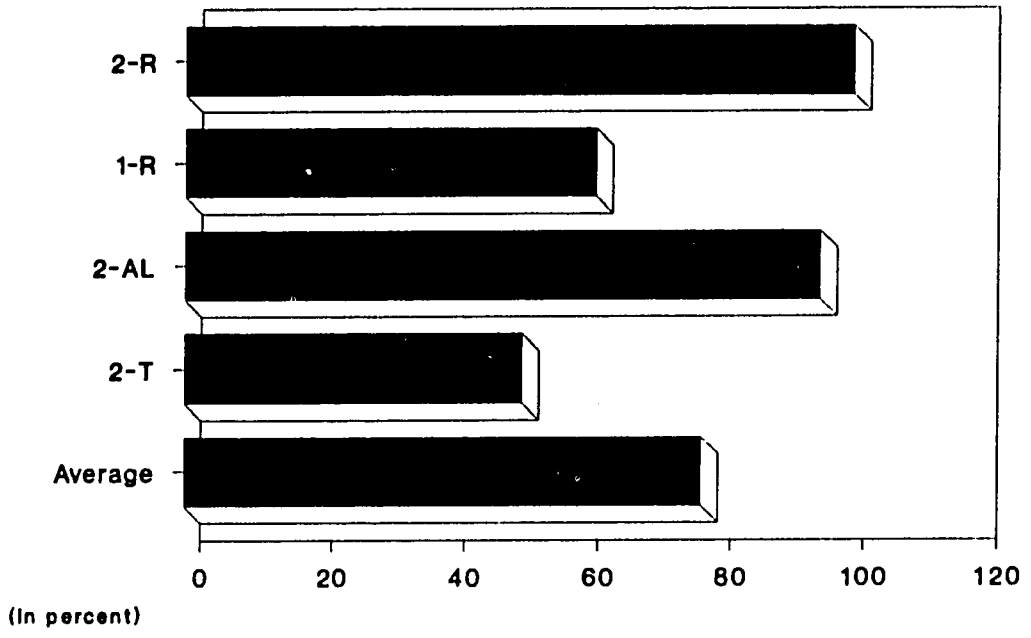
(In percent)

Cropping Intensity
Nagnah Watercourses

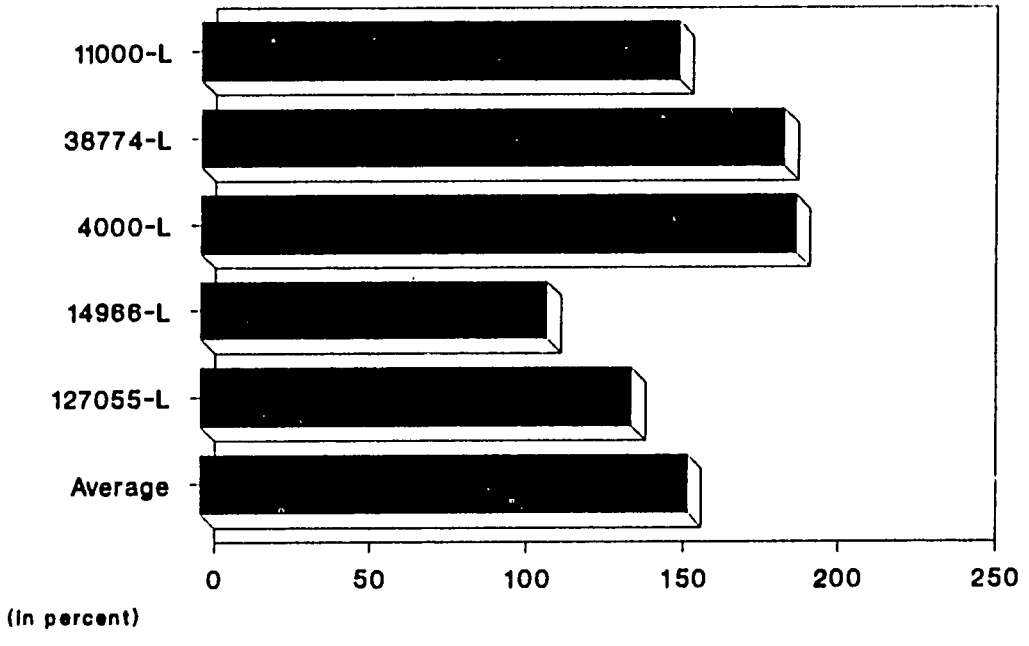


(In percent)

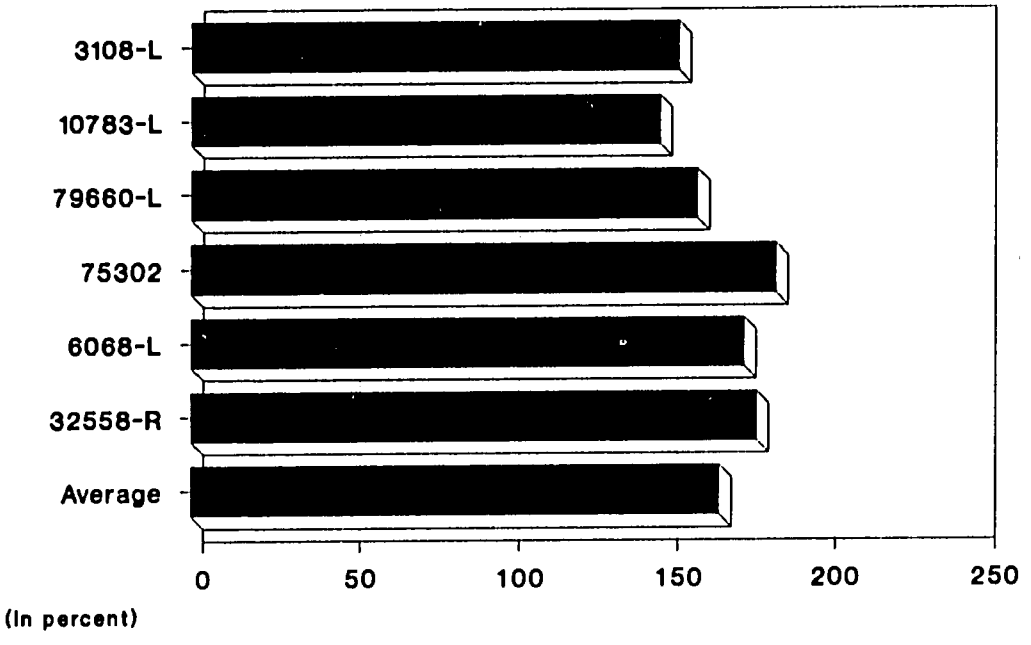
Cropping Intensity
Puran Watercourses



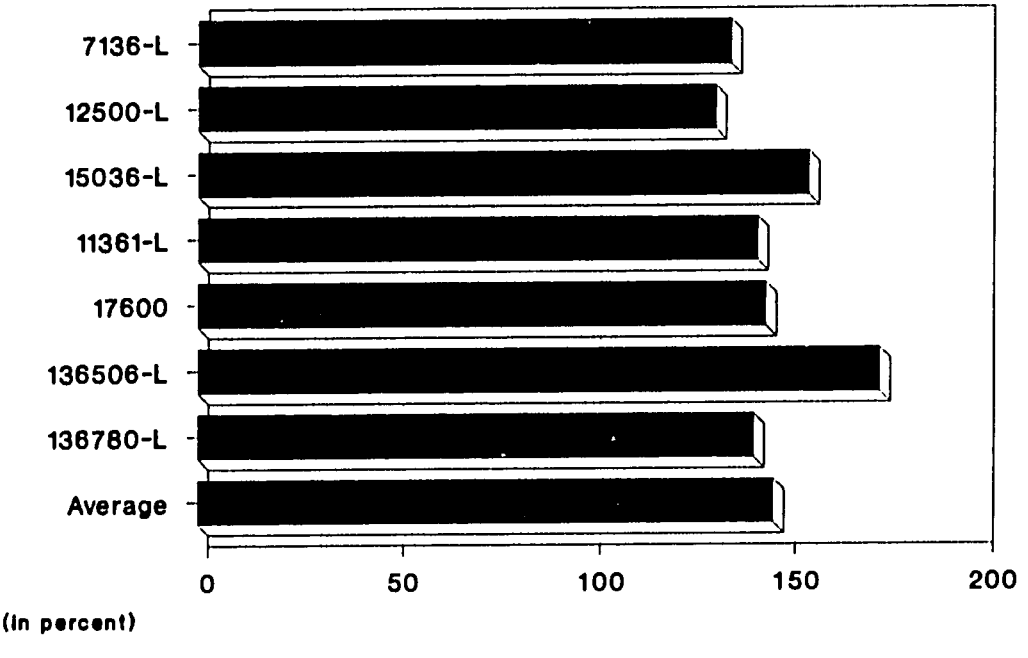
Cropping Intensity
Pakpattan Watercourses



Cropping Intensity
Venoi Watercourses

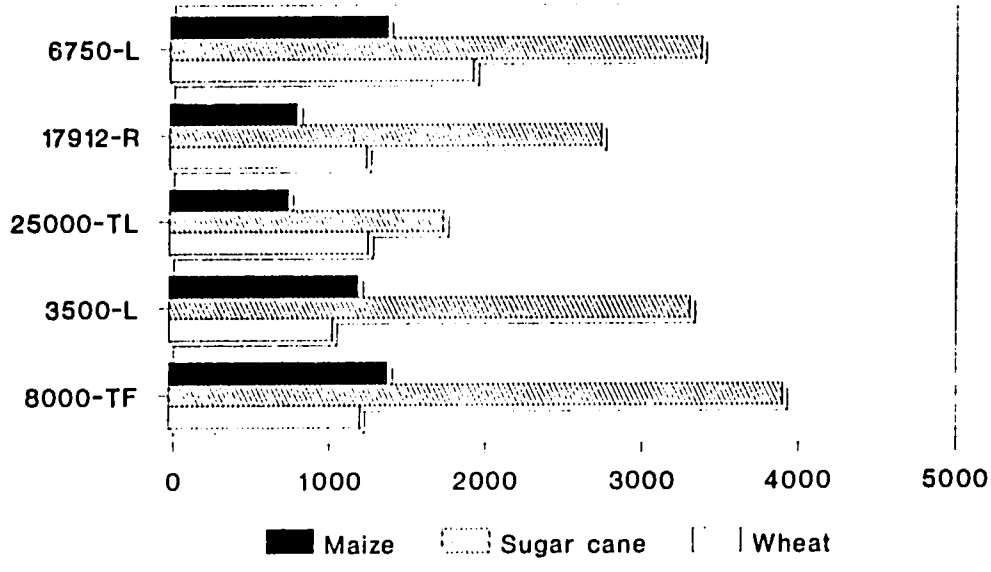


Cropping Intensity
Killianwala Watercourses



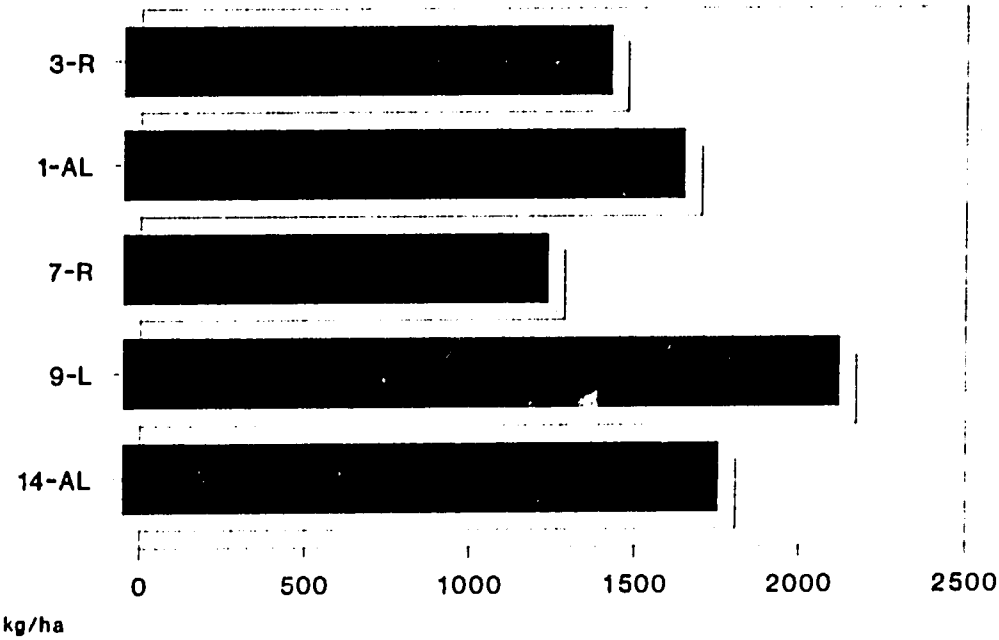
Annex B
Average Crop Yields
Watercourses on Six Canal Subsystems

Yields of Maize, Sugar Cane and Wheat
Chowky Watercourses



Maize and wheat in kg, cane in 10's kg

Yields of Wheat
Naghna Watercourses

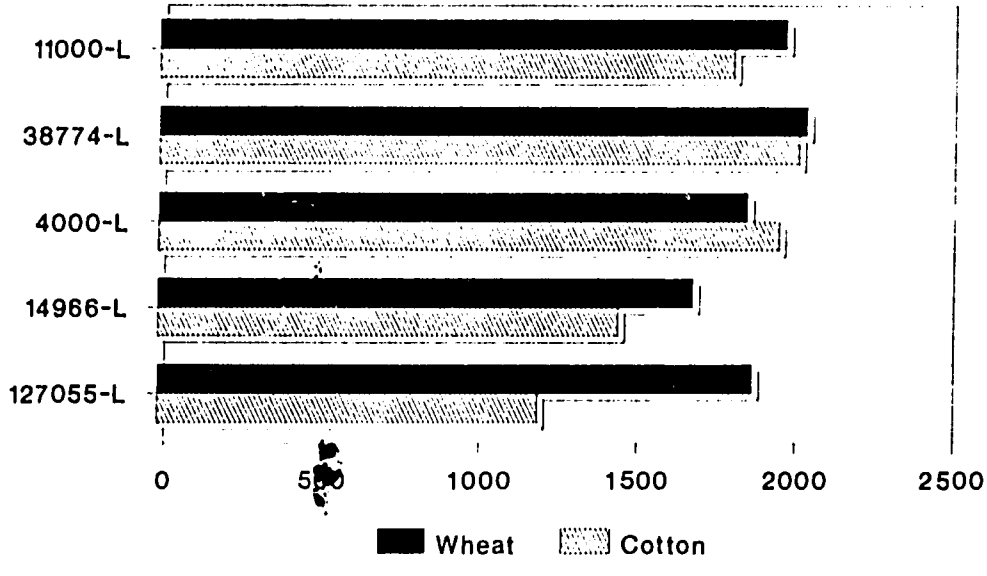


in kg/ha

Yields of Wheat and Cotton
Puran Watercourses

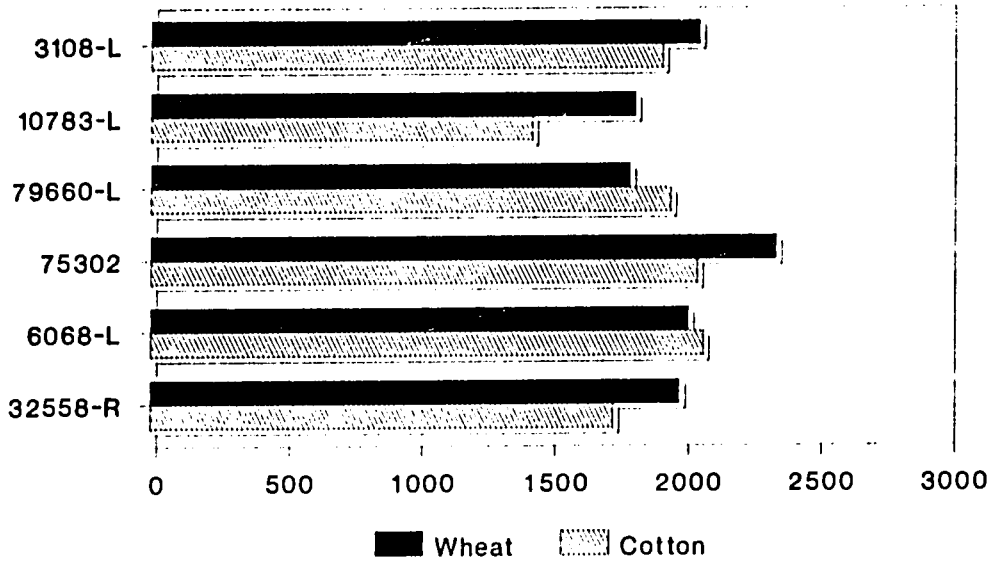
In kg/ha

Yields of Wheat and Cotton
Pakpattan Watercourses



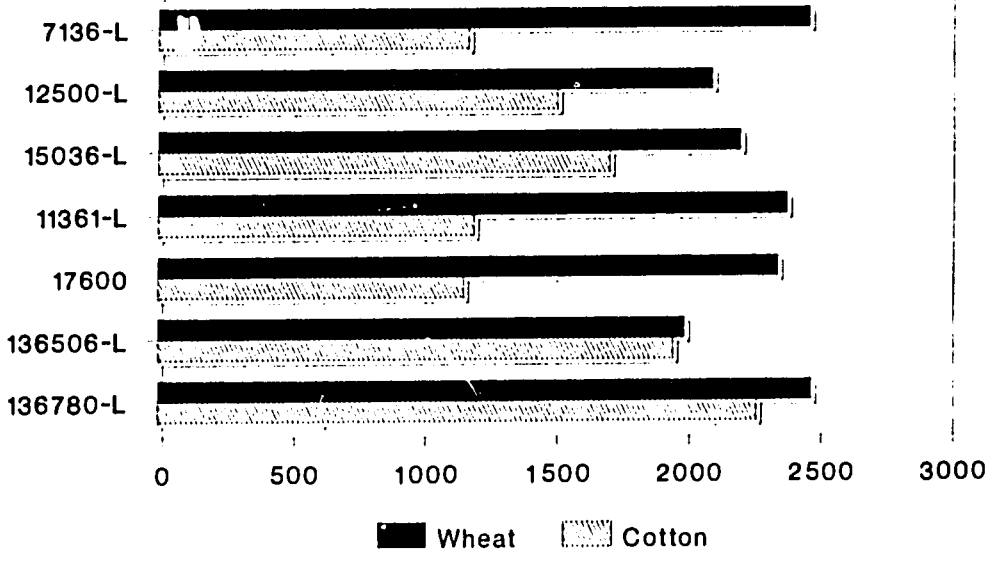
In kg/ha

Yields of Wheat and Cotton
Venoi Watercourses



In kg/ha

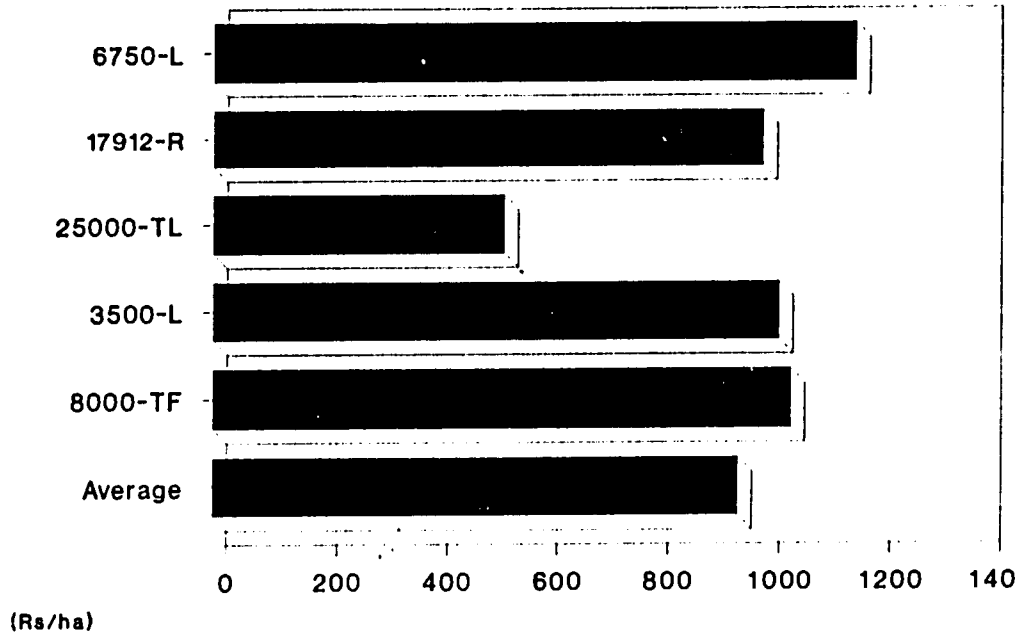
Yields of Wheat and Cotton
Killianwala Watercourses



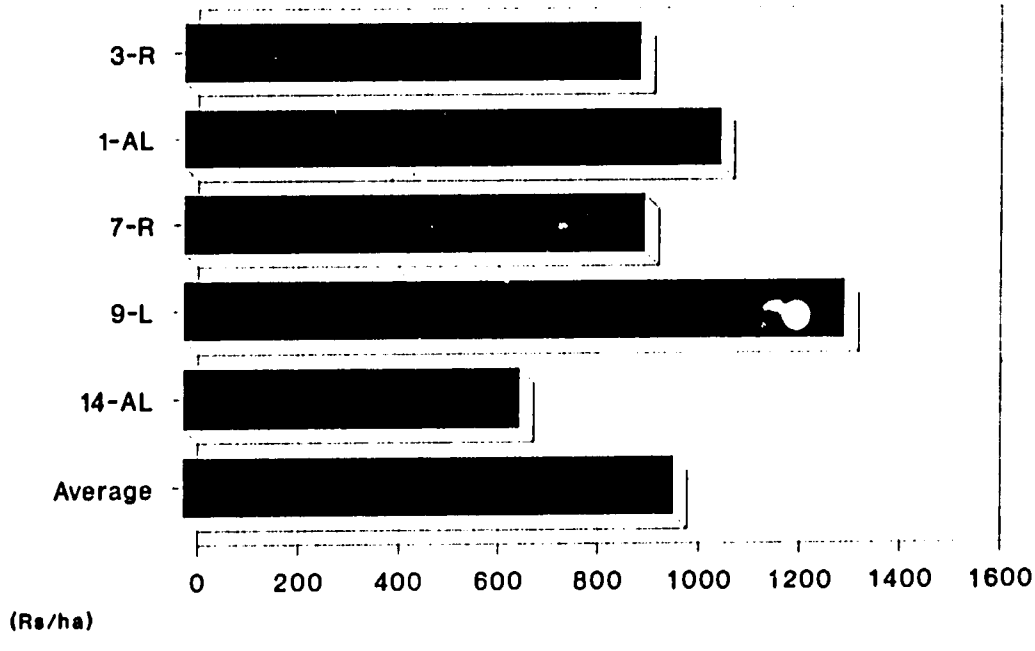
In kg/ha

Annex C
Average Input Use
Watercourses on Six Canal Subsystems

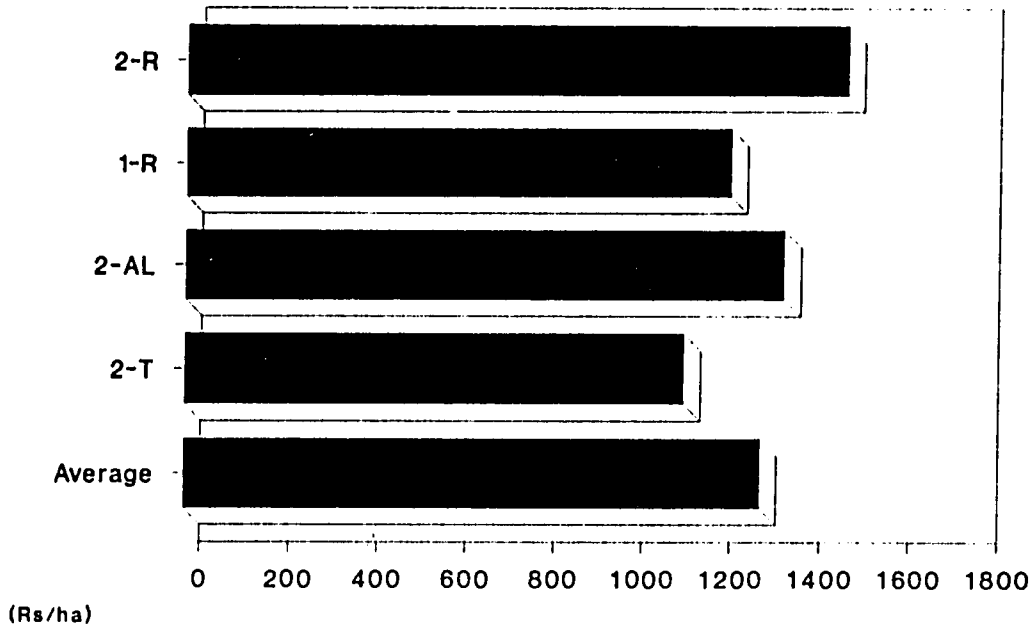
Value of Fertilizer on Wheat
Chowky Watercourses



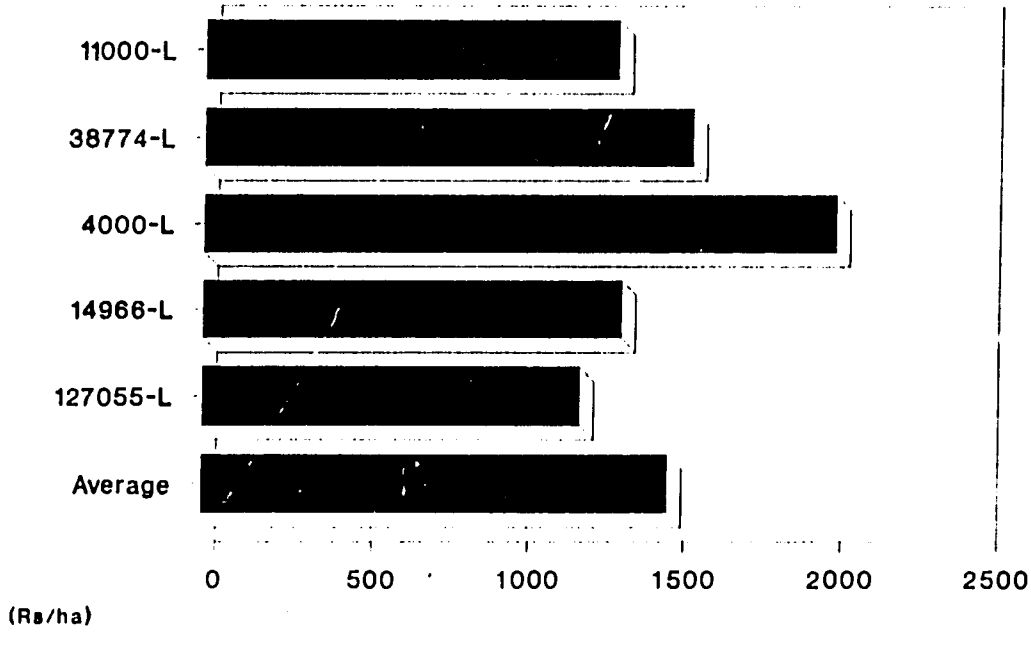
Value of Fertilizer on Wheat
Nagnah Watercourses



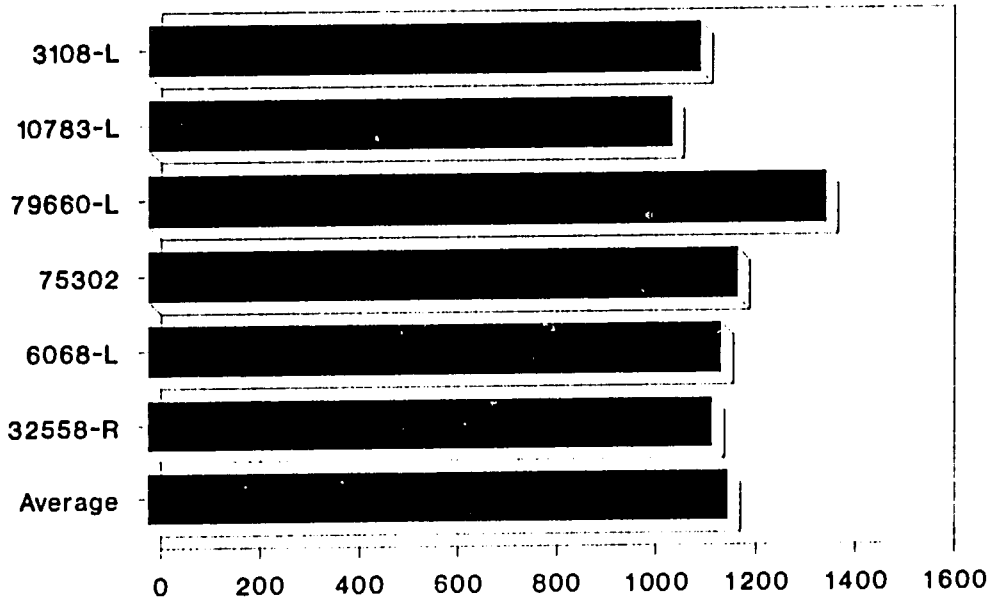
Value of Fertilizer on Wheat
Puran Watercourses



Value of Fertilizer on Wheat
Pakpattan Watercourses

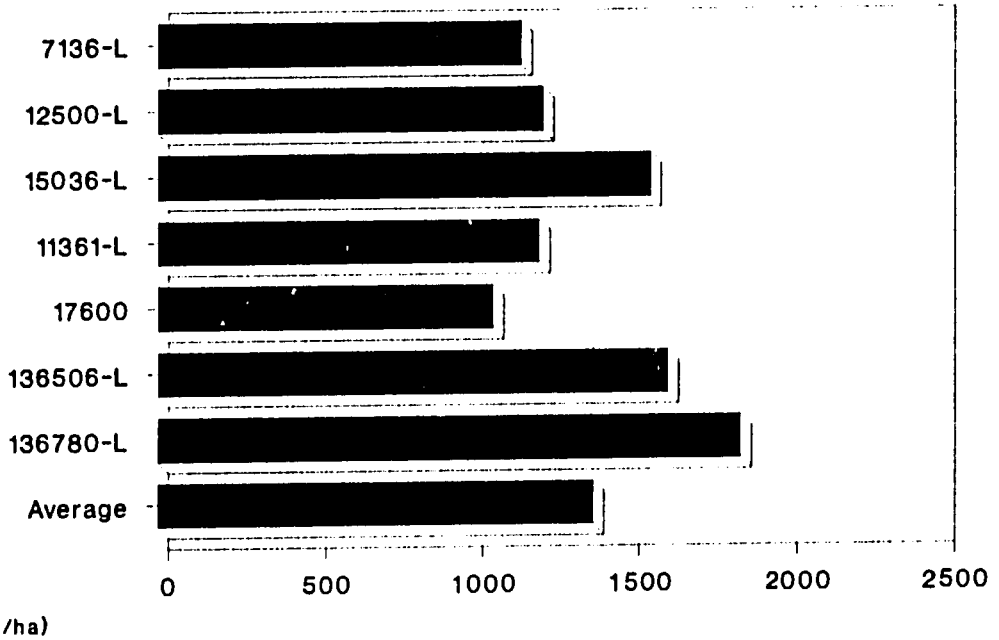


Value of Fertilizer on Wheat
Venoi Watercourses



(Rs/ha)

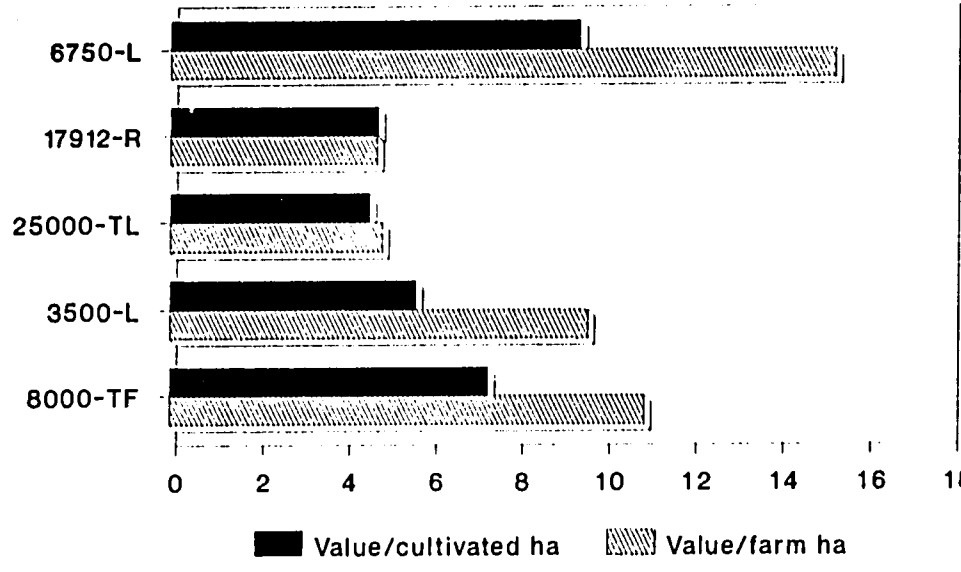
Value of Fertilizer on Wheat
Killianwala Watercourses



(Rs/ha)

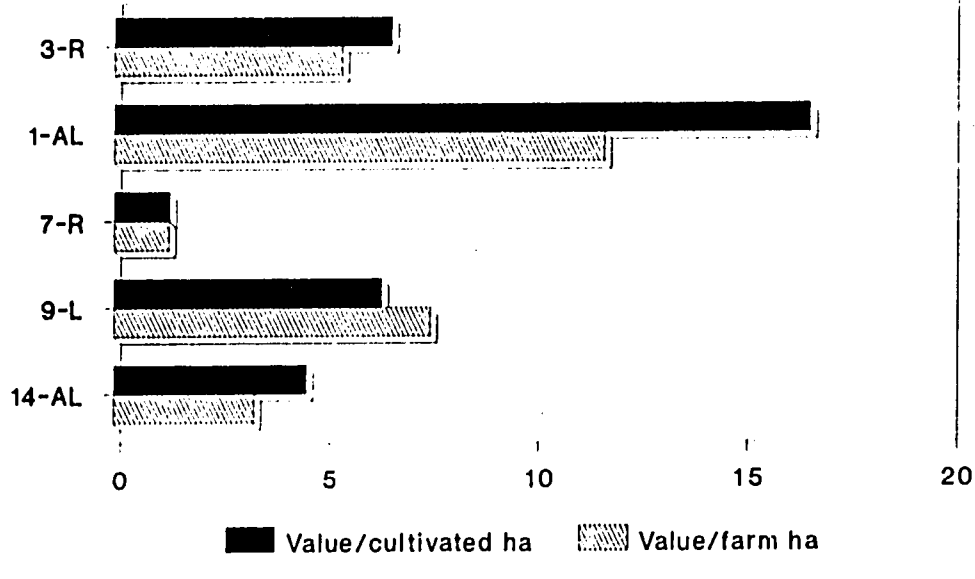
Annex D
Average Value of Agricultural Output
Watercourses on Six Canal Subsystems

Value of Agricultural Output
Chowky Watercourses



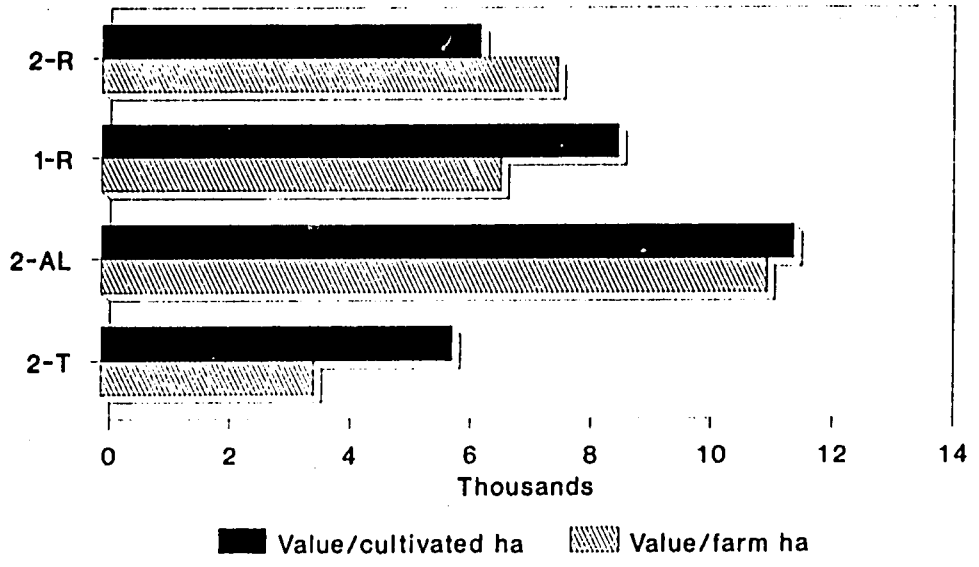
(Rs '000s/ha)

Value of Agricultural Output
Nagnah Watercourses



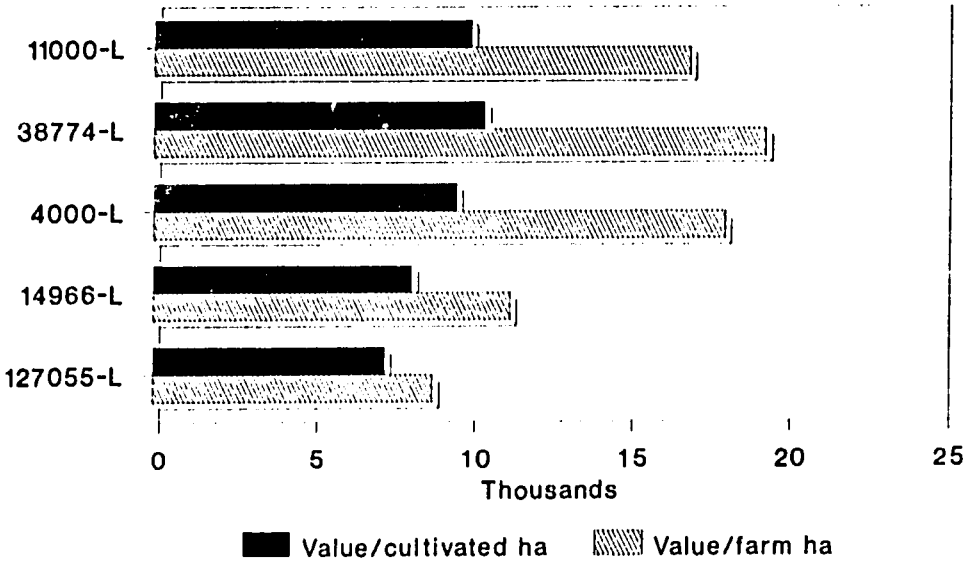
(Rs'000/ha)

Value of Agricultural Output
Puran Watercourses



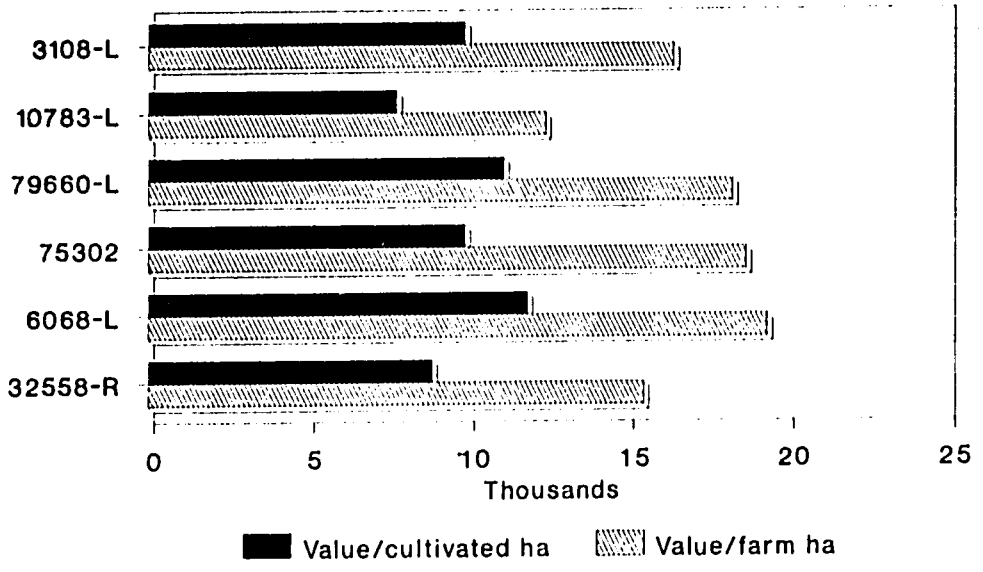
(Rs '000s/ha)

Value of Agricultural Output
Pakpattan Watercourses



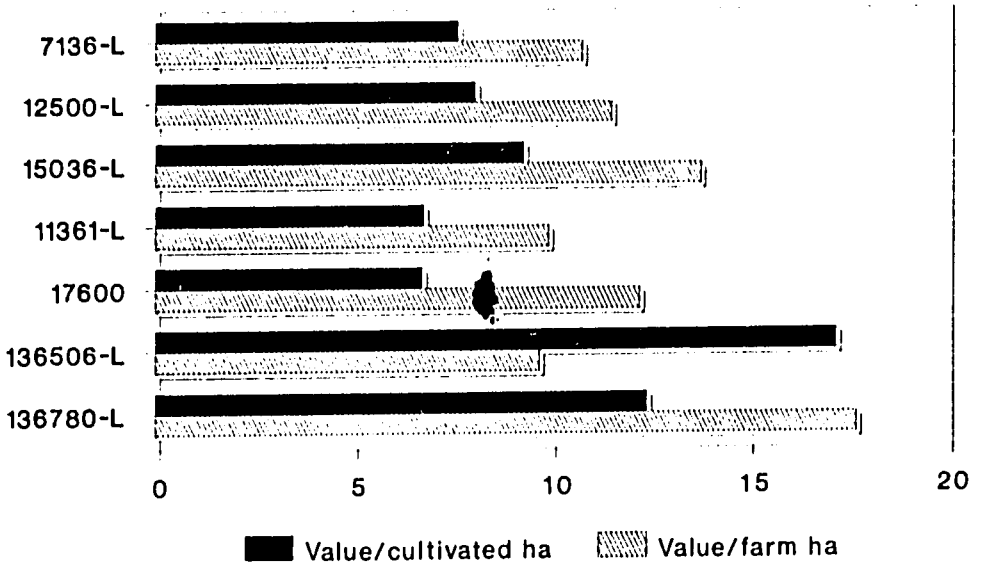
(Rs '000s/ha)

Value of Agricultural Output
Venoi Watercourses



(Rs '000s/ha)

Value of Agricultural Output
Killianwala Watercourses



(Rs '000s/ha)

Chowky watercourses

6750-L Indicators

Performance (%)	151
Reliability (%)	19.7
Wells/hectare	0
Cropping intensity (%)	207

Cropping Pattern

Kharif (%)		Rabi (%)	
Maize	40	Wheat	49
Vegetables	4	Oilseed	1
Tobacco	9	Fodder	8
Sugar Cane	14	Sugar cane	14
Orchard	31	Orchard	31
		Minor crops	5

Yields

Maize (kg/ha)	1401
Sugar cane (kg/ha)	34045
Wheat (kg/ha)	1949

Input use

	Maize	Sugar cane	Wheat
Seed (kg/ha)	34	6232	97
N (kg/ha)	84	112	90
P (kg/ha)	53	69	54
Total fertilizer cost (Rs/ha)	1109	1442	1162

Value of Agricultural Output

Rs/ha of cultivated land	9454
Rs/ha of farm area	15313

Chowky watercourses

17912-R Indicators

Performance (%)	52
Reliability (%)	33.5
Wells/hectare	0.040983
Cropping intensity (%)	135

Cropping Pattern

Kharif (%)		Rabi (%)	
Maize	34	Wheat	70
Fodder	20	Oilseed	1
Vegetables	3	Fodder	4
Sugar Cane	1	Sugar cane	1
Orchard	41	Orchard	23
		Minor crops	2

Yields

Maize (kg/ha)	821
Sugar cane (kg/ha)	27654
Wheat (kg/ha)	1267

Input use

	Maize	Wheat
Seed (kg/ha)	43	99
N (kg/ha)	48	73
P (kg/ha)	27	48
Total fertilizer cost (Rs/ha)	599	995

Value of Agricultural Output

Rs/ha of cultivated land	4783
Rs/ha of farm area	4755

Chowky watercourses

25000-TL Indicators

Performance (%)	45
Reliability (%)	31.4
Wells/hectare	0.112359
Cropping intensity (%)	98

Cropping Pattern

Kharif (%)		Rabi (%)	
Maize	80	Wheat	70
Sugar Cane	20	Fodder	9
		Sugar cane	9
		Ratoon cane	7
		Minor crops	5

Yields

Maize (kg/ha)	767
Sugar cane (kg/ha)	17619
Wheat (kg/ha)	1281

Input use

	Maize	Sugar cane	Wheat
Seed (kg/ha)	49	4908	99
N (kg/ha)	53	153	55
P (kg/ha)	0	0	10
Total fertilizer cost (Rs/ha)	465	1460	527

Value of Agricultural Output

Rs/ha of cultivated land	4590
Rs/ha of farm area	4878

Chowky watercourses

3500-L Indicators

Performance (%)	72
Reliability (%)	34
Wells/hectare	0.056497
Cropping intensity (%)	193

Cropping Pattern

Kharif (%)		Rabi (%)	
Maize	66	Wheat	60
Fodder	2	Fodder	0.5
Sugar cane	29	Sugar cane	10
Vegetable	1	Ratoon cane	24
Tobacco	2	Orchard	0.5
		Minor crops	4

Yields

Maize (kg/ha)	1216
Sugar cane (kg/ha)	33367
Wheat (kg/ha)	1051

Input use

	Maize	Sugar cane	Wheat
Seed (kg/ha)	30	5928	99
N (kg/ha)	80	93	79
P (kg/ha)	50	53	48
Total fertilizer cost (Rs/ha)	1037	1178	1024

Value of Agricultural Output

Rs/ha of cultivated land	5670
Rs/ha of farm area	7153

Chowky watercourses

8000-TF Indicators

Performance (%)	105
Reliability (%)	58
Wells/hectare	0.285714
Cropping intensity (%)	186

Cropping Pattern

Kharif (%)		Rabi (%)	
Rice	5	Wheat	41
Maize	38	Fodder	14
Fodder	8	Sugar cane	38
Sugar cane	1	Vegetable	0.5
Vegetable	48	Minor crops	6.5

Yields

Maize (kg/ha)	1408
Sugar cane (kg/ha)	39323
Wheat (kg/ha)	1231

Input use

	Maize	Sugar cane	Wheat
Seed (kg/ha)	30	5957	104
N (kg/ha)	84	82	77
P (kg/ha)	60	59	52
Total fertilizer cost (Rs/ha)	1157	1127	1046

Value of Agricultural Output

Rs/ha of cultivated land	7343
Rs/ha of farm area	10955

Nagnah Watercourses

3-R	Indicators			
	Performance (%)	176		
	Reliability (%)	27.7		
	Wells/hectare	0.006858		
	Cropping intensity (%)	102		
	Cropping Pattern			
	Kharif (%)		Rabi (%)	
	Bajra	14	Wheat	36
	Cotton	8	Fodder	0.01
	Janter	3	Sugar cane	15
	Fodder	7	Vegetable	16
	Vegetables	5	Ratoon cane	3
	Minor	7	Orchard	29
	Sugar cane	19		
	Orchards	37		
	Yields			
	Wheat (kg/ha)	1477		
	Input use			
		Wheat		
	Seed (kg/ha)	141		
	N (kg/ha)	121		
	P (kg/ha)	32		
	Total fertilizer cost (Rs/ha)	911		
	Value of Agricultural Output			
	Rs/ha of cultivated land	6620		
	Rs/ha of farm area	5440		

Nagnah Watercourses

1-AL	Indicators			
	Performance (%)	218		
	Reliability (%)	38.9		
	Wells/hectare	0.068965		
	Cropping intensity (%)	123		
	Cropping Pattern			
	Kharif (%)		Rabi (%)	
	Sugar cane	70	Wheat	30
	Orchards	30	Fodder	0.5
			Sugar cane	49
			Orchard	20.5
	Yields			
	Wheat (kg/ha)	1700		
	Input use			
		Wheat		
	Seed (kg/ha)	148		
	N (kg/ha)	84		
	P (kg/ha)	56		
	Total fertilizer cost (Rs/ha)	1071		
	Value of Agricultural Output			
	Rs/ha of cultivated land	16655		
	Rs/ha of farm area	11743		

Nagnah Watercourses

7-R	Indicators			
	Performance (%)	118		
	Reliability (%)	17.5		
	Wells/hectare	0		
	Cropping intensity (%)	125		
	Cropping Pattern			
	Kharif (%)		Rabi (%)	
	Sugar cane	2	Wheat	10
	Orchards	98	Fodder	1
			Sugar cane	3
			Orchard	86
	Yields			
	Wheat (kg/ha)	1288		
	Input use			
		Wheat		
	Seed (kg/ha)	123		
	N (kg/ha)	95		
	P (kg/ha)	17		
	Total fertilizer cost (Rs/ha)	920		
	Value of Agricultural Output			
	Rs/ha of cultivated land	1328		
	Rs/ha of farm area	1315		

Nagnah Watercourses

9-L	Indicators			
	Performance (%)	195		
	Reliability (%)	25.3		
	Wells/hectare	0		
	Cropping intensity (%)	108		
	Cropping Pattern			
	Kharif (%)		Rabi (%)	
	Cotton	8	Wheat	41
	Janter	1	Orchard	59
	Fodder	3		
	Vegetable	18		
	Orchard	70		
	Yields			
	Wheat (kg/ha)	2173		
	Input use			
		Wheat		
	Seed (kg/ha)	156		
	N (kg/ha)	132		
	P (kg/ha)	43		
	Total fertilizer cost (Rs/ha)	2845		
	Value of Agricultural Output			
	Rs/ha of cultivated land	6388		
	Rs/ha of farm area	7613		

Nagnah Watercourses

14-AL	Indicators			
	Performance (%)	112		
	Reliability (%)	63.9		
	Wells/hectare	0		
	Cropping intensity (%)	51		
	Cropping Pattern			
	Kharif (%)		Rabi (%)	
	Cotton	93	Wheat	92
	Janter	4	Vegetable	8
	Vegetable	3		
	Yields			
	Wheat (kg/ha)	1806		
	Input use			
		Wheat		
	Seed (kg/ha)	149		
	N (kg/ha)	63		
	P (kg/ha)	21		
	Total fertilizer cost (Rs/ha)	671		
	Value of Agricultural Output			
	Rs/ha of cultivated land	4603		
	Rs/ha of farm area	3358		

Puran Watercourses

2-R Indicators

Performance (%)	175
Reliability (%)	31.5
Wells/hectare	0
Cropping intensity (%)	101

Cropping Pattern

Kharif (%)		Rabi (%)	
Cotton	69	Wheat	92
Janter	3	Fodder	3
Fodder	1	Sugar cane	4
Vegetable	18	Vegetable	1
Sugar cane	9		

Yields

Wheat (kg/ha)	1910
Cotton (kg/ha)	856

Input use

	Wheat	Cotton
Seed (kg/ha)	124	24
N (kg/ha)	135	135
P (kg/ha)	53	57
Total fertilizer cost (Rs/ha)	1494	1270

Value of Agricultural Output

Rs/ha of cultivated land	6278
Rs/ha of farm area	7558

Puran Watercourses

1-R Indicators

Performance (%)	145
Reliability (%)	35.6
Wells/hectare	0
Cropping intensity (%)	62

Cropping Pattern

Kharif (%)		Rabi (%)	
Cotton	48	Wheat	86
Janter	6	Fodder	5
Vegetable	40	Sugar cane	1
Sugar cane	2	Orchard	2
Orchard	4	Vegetable	5

Yields

Wheat (kg/ha)	1454
Cotton (kg/ha)	694

Input use

	Wheat	Cotton
Seed (kg/ha)	113	21
N (kg/ha)	122	99
P (kg/ha)	31	17
Total fertilizer cost (Rs/ha)	1233	776

Value of Agricultural Output

Rs/ha of cultivated land	8576
Rs/ha of farm area	6615

Puran Watercourses

2-AL Indicators

Performance (%)	168
Reliability (%)	22.1
Wells/hectare	0
Cropping intensity (%)	96

Cropping Pattern

Kharif (%)		Rabi (%)	
Cotton	56	Wheat	49
Janter	7	Fodder	21
Sugar cane	13	Sugar cane	10
Orchard	24	Orchard	18
		Vegetable	2

Yields

Wheat (kg/ha)	1365
Cotton (kg/ha)	487

Input use

	Wheat	Cotton
Seed (kg/ha)	148	25
N (kg/ha)	152	162
P (kg/ha)	25	36
Total fertilizer cost (Rs/ha)	1354	1300

Value of Agricultural Output

Rs/ha of cultivated land	11503
Rs/ha of farm area	11063

Puran Watercourses

2-T Indicators

Performance (%)	161
Reliability (%)	35.6
Wells/hectare	0
Cropping intensity (%)	51

Cropping Pattern

Kharif (%)		Rabi (%)	
B rice	5	Wheat	64
Cotton	55	Fodder	16
Janter	14	Orchard	15
Vegetable	5	Vegetable	5
Orchard	21		

Yields

Wheat (kg/ha)	1986
Cotton (kg/ha)	642

Input use

	Wheat	Cotton
Seed (kg/ha)	140	37
N (kg/ha)	92	102
P (kg/ha)	51	57
Total fertilizer cost (Rs/ha)	1130	1054

Value of Agricultural Output

Rs/ha of cultivated land	5825
Rs/ha of farm area	3525

Pakpattan watercourses

11000-L Indicators

Performance (%)	184
Reliability (%)	45
Wells/hectare	0.058139
Cropping intensity (%)	153

Cropping Pattern

Kharif (%)		Rabi (%)	
Cotton	83	Wheat	76
Cane	2	Fodder	14
Fodder	17	Orchard	1
		Melon	8
		Other	1

Yields

Cotton (kg/ha)	1821
Wheat (kg/ha)	1985

Input use

	Cotton	Wheat
Seed (kg/ha)	21.3	128
N (kg/ha)	138	121
P (kg/ha)	27	65
Total fertilizer cost (Rs/ha)	1323	1507

Value of Agricultural Output

Rs/ha of cultivated land	10035
Rs/ha of farm area	17005

Pakpattan watercourses

38774-L Indicators

Performance (%)	169
Reliability (%)	30.5
Wells/hectare	0.099009
Cropping intensity (%)	187

Cropping Pattern

Kharif (%)		Rabi (%)	
Cotton	77	Wheat	81
Cane	3	Fodder	19
Fodder	19		

Yields

Wheat (kg/ha)	2051
Cotton (kg/ha)	2027

Input use

	Cotton	Wheat
Seed (kg/ha)	20	127
N (kg/ha)	133	128
P (kg/ha)	45	43
Total fertilizer cost (Rs/ha)	1564	1409

Value of Agricultural Output

Rs/ha of cultivated land	10465
Rs/ha of farm area	19410

Pakpattan watercourses

4000-L Indicators

Performance (%)	149
Reliability (%)	14.2
Wells/hectare	0.067114
Cropping intensity (%)	191

Cropping Pattern

Kharif (%)		Rabi (%)	
Cotton	89	Wheat	88
Fodder	11	Fodder	12

Yields

Wheat (kg/ha)	1867
Cotton (kg/ha)	1967

Input use

	Wheat	Cotton
Seed (kg/ha)	22	127
N (kg/ha)	192	168
P (kg/ha)	46	75
Total fertilizer cost (Rs/ha)	2024	1972

Value of Agricultural Output

Rs/ha of cultivated land	9593
Rs/ha of farm area	18125

Pakpattan watercourses

14966-L Indicators

Performance (%)	159		
Reliability (%)	33.9		
Wells/hectare	0.015822		
Cropping intensity (%)	111		
Cropping Pattern			
Kharif (%)		Rabi (%)	
Cotton	89	Wheat	92
Fodder	11	Fodder	8
Yields			
Wheat (kg/ha)	1698		
Cotton (kg/ha)	1460		
Input use			
	Cotton	Wheat	
Seed (kg/ha)	22	125	
N (kg/ha)	145	125	
P (kg/ha)	25	33	
Total fertilizer cost (Rs/ha)	1341	1051	
Value of Agricultural Output			
Rs/ha of cultivated land	8190		
Rs/ha of farm area	11300		

Pakpattan watercourses

127055-L Indicators

Performance (%)	166
Reliability (%)	38.7
Wells/hectare	0.012738
Cropping intensity (%)	138

Cropping Pattern

Kharif (%)		Rabi (%)	
Cotton	84	Wheat	90
Cane	1	Fodder	10
Fodder	14		

Yields

Wheat (kg/ha)	1884
Cotton (kg/ha)	1208

Input use

	Cotton	Wheat
Seed (kg/ha)	215	114
N (kg/ha)	117	121
P (kg/ha)	43	43
Total fertilizer cost (Rs/ha)	1272	1280

Value of Agricultural Output

Rs/ha of cultivated land	7335
Rs/ha of farm area	8858

Venoi Watercourses

3108-L Indicators

Performance (%)	123
Reliability (%)	15
Wells/hectare	0.036900
Cropping intensity (%)	154

Cropping Pattern

Kharif (%)		Rabi (%)	
Cotton	68	Wheat	86
Rice	16	Fodder	14
Fodder	14		
Sugar cane	3		

Yields

Wheat (kg/ha)	2061
Cotton (kg/ha)	1922

Input use

	Wheat	Cotton
Seed (kg/ha)	103	18
N (kg/ha)	108	115
P (kg/ha)	63	45
Total fertilizer cost (Rs/ha)	1113	1045

Value of Agricultural Output

Rs/ha of cultivated land	9883
Rs/ha of farm area	16440

Venoi Watercourses

10783 Indicators

Performance (%)	110
Reliability (%)	23.2
Wells/hectare	0.059880
Cropping intensity (%)	148

Cropping Pattern

Kharif (%)		Rabi (%)	
Sugar cane	6	Wheat	71
Fodder	22	Fodder	24
Cotton	67	Melon	5
Rice	4		

Yields

Wheat (kg/ha)	1820
Cotton (kg/ha)	1434

Input use

	Wheat	Cotton
Seed (kg/ha)	107	20
N (kg/ha)	84	118
P (kg/ha)	65	67
Total fertilizer cost (Rs/ha)	1057	1101

Value of Agricultural Output

Rs/ha of cultivated land	7745
Rs/ha of farm area	12400

Venoi Watercourses

79660 Indicators

Performance (%)	174
Reliability (%)	0.074626
Wells/hectare	0.074626
Cropping intensity (%)	160

Cropping Pattern

Kharif (%)		Rabi (%)	
Cotton	87	Wheat	82
Vegetables	1	Fodder	26
Fodder	12	Orchard	3

Yields

Wheat (kg/ha)	1801
Cotton (kg/ha)	1953

Input use

	Wheat	Cotton
Seed (kg/ha)	105	20
N (kg/ha)	100	131
P (kg/ha)	60	65
Total fertilizer cost (Rs/ha)	1365	1488

Value of Agricultural Output

Rs/ha of cultivated land	11085
Rs/ha of farm area	18268

Venoi Watercourses

75302 Indicators

Performance (%)	200
Reliability (%)	17.3
Wells/hectare	0
Cropping intensity (%)	185

Cropping Pattern

Kharif (%)		Rabi (%)	
Cotton	68	Wheat	69
Fodder	30	Fodder	31
Sugar cane	1		
Vegetable	1		

Yields

Wheat (kg/ha)	2351
Cotton (Rs/ha)	2055

Input use

	Wheat	Cotton
Seed (kg/ha)	102	20
N (kg/ha)	95	91
P (kg/ha)	60	64
Total fertilizer cost (Rs/ha)	1188	959

Value of Agricultural Output

Rs/ha of cultivated land	9913
Rs/ha of farm area	18685

Venoi Watercourses

6068-L Indicators

Performance (%)	140
Reliability (%)	34.7
Wells/hectare	0.021881
Cropping intensity (%)	175

Cropping Pattern

Kharif (%)		Rabi (%)	
Cotton	77	Wheat	77
Fodder	23	Vegetable	23

Yields

Wheat (kg/ha)	2021
Cotton (kg/ha)	2078

Input use

	Wheat	Cotton
Seed (kg/ha)	112	24
N (kg/ha)	96	99
P (kg/ha)	61	56
Total fertilizer cost (Rs/ha)	1155	1192

Value of Agricultural Output

Rs/ha of cultivated land	11840
Rs/ha of farm area	19345

Venoi Watercourses

32558-R Indicators

Performance (%)	131
Reliability (%)	16.4
Wells/hectare	0.079365
Cropping intensity (%)	179

Cropping Pattern

Kharif (%)		Rabi (%)	
Cotton	77	Wheat	86
Rice	4	Fodder	12
Maize	16	Pulses	1
Sugar cane	3		

Yields

Wheat (kg/ha)	1988
Cotton (kg/ha)	1739

Input use

	Wheat	Cotton
Seed (kg/ha)	104	20
N (kg/ha)	94	86
P (kg/ha)	52	43
Total fertilizer cost (Rs/ha)	1137	893

Value of Agricultural Output

Rs/ha of cultivated land	8853
Rs/ha of farm area	15490

Killianwala Watercourses

7136-L Indicators

Performance (%)	155
Reliability (%)	21.1
Wells/hectare	0.078740
Cropping intensity (%)	136

Cropping Pattern

Kharif (%)		Rabi (%)	
Rice	4	Wheat	78
Cotton	24	Fodder	17
Maize	11	Vegetable	1
Fodder	24	Orchard	4
Vegetables	2		
Sugar cane	35		

Yields

Wheat (kg/ha)	2473

Input use

	Wheat
Seed (kg/ha)	100
N (kg/ha)	98
P (kg/ha)	66
Total fertilizer cost (Rs/ha)	1158

Value of Agricultural Output

Rs/ha of cultivated land	7643
Rs/ha of farm area	10783

Killianwala Watercourses

12500-L Indicators

Performance (%)	191
Reliability (%)	52.9
Wells/hectare	0
Cropping intensity (%)	132

Cropping Pattern

Kharif (%)		Rabi (%)	
Cotton	20	Wheat	80
Rice	4	Fodder	18
Sugar cane	29	Orchard	1
Maize	20	Vegetables	1
Fodder	25		
Vegetables	1		

Yields

Wheat (kg/ha)	2014

Input use

	Wheat
Seed (kg/ha)	101
N (kg/ha)	95
P (kg/ha)	64
Total fertilizer cost (Rs/ha)	1228

Value of Agricultural Output

Rs/ha of cultivated land	8075
Rs/ha of farm area	11540

Killianwala Watercourses

15063-L Indicators

Performance (%)	123
Reliability (%)	13.2
Wells/hectare	0.090090
Cropping intensity (%)	156

Cropping Pattern

Kharif (%)		Rabi (%)	
Cotton	44	Wheat	79
Rice	1	Fodder	19
Sugar cane	22	Orchard	2
Maize	7		
Fodder	26		

Yields

Wheat (kg/ha)	2210

Input use

	Wheat
Seed (kg/ha)	100
N (kg/ha)	117
P (kg/ha)	82
Total fertilizer cost (Rs/ha)	1571

Value of Agricultural Output

Rs/ha of cultivated land	9293
Rs/ha of farm area	13798

Killianwala Watercourses

11361-L Indicators

Performance (%)	142
Reliability (%)	13
Wells/hectare	0.035842
Cropping intensity (%)	143

Cropping Pattern

Kharif (%)		Rabi (%)	
Cotton	23	Wheat	79
Rice	2	Orchard	20
Fodder	24	Fodder	1
Sugar cane	16		
Maize	35		

Yields

Wheat (kg/ha)	2387

Input use

	Wheat
Seed (kg/ha)	105
N (kg/ha)	104
P (kg/ha)	76
Total fertilizer cost (Rs/ha)	1215

Value of Agricultural Output

Rs/ha of cultivated land	6768
Rs/ha of farm area	9920

Killianwala Watercourses

17600	Indicators			
	Performance (%)	169		
	Reliability (%)	12.3		
	Wells/hectare	0.045871		
	Cropping intensity (%)	145		
	Cropping Pattern			
	Kharif (%)		Rabi (%)	
	Cotton	28	Wheat	80
	Maize	36	Fodder	16
	Sugar cane	15	Orchard	4
	Fodder	20		
	Yields			
	Wheat (kg/ha)	2353		
	Input use			
		Wheat		
	Seed (kg/ha)	105		
	N (kg/ha)	95		
	P (kg/ha)	53		
	Total fertilizer cost (Rs/ha)	1067		
	Value of Agricultural Output			
	Rs/ha of cultivated land	6743		
	Rs/ha of farm area	12250		

Killianwala Watercourses

136506-L Indicators

Performance (%)	84		
Reliability (%)	19.4		
Wells/hectare	0.3125		
Cropping intensity (%)	174		
Cropping Pattern			
Kharif (%)		Rabi (%)	
Cotton	69	Wheat	79
Fodder	26	Fodder	21
Sugar cane	5		
Maize	1		
Yields			
Wheat (kg/ha)	2001		
Input use			
	Wheat		
Seed (kg/ha)	113		
N (kg/ha)	125		
P (kg/ha)	67		
Total fertilizer cost (Rs/ha)	1624		
Value of Agricultural Output			
Rs/ha of cultivated land	17180		
Rs/ha of farm area	9693		

Killianwala Watercourses

136780-L Indicators

Performance (%)	74		
Reliability (%)	25.3		
Wells/hectare	0.125		
Cropping intensity (%)	142		
Cropping Pattern			
Kharif (%)		Rabi (%)	
Cotton	68	Wheat	82
Fodder	16	Fodder	18
Sugar cane	13		
Oilseeds	2		
Yields			
Wheat (kg/ha)	2482		
Input use			
	Wheat		
Seed (kg/ha)	111		
N (kg/ha)	144		
P (kg/ha)	89		
Total fertilizer cost (Rs/ha)	1854		
Value of Agricultural Output			
Rs/ha of cultivated land	12430		
Rs/ha of farm area	17708		

Chapter Three

THE RELATIONSHIP BETWEEN HYDRAULIC INDICATORS AND AGRICULTRUAL ECONOMICS INDICATORS

The canal rehabilitation program is designed to accomplish three objectives: improve safety, provide a more equitable distribution of water, and increase the reliability of water delivery. Hydraulic indicators are the direct measures of the effectiveness of canal rehabilitation. Agricultural economics indicators are related to canal rehabilitation in so far as these parameters are related to certain water measures. The purpose of this chapter is to establish the relationship between water variables and agricultural economics variables, and to illustrate the possible affect that canal rehabilitation has on crop production. Four agricultural economics indicators will be discussed in this chapter, cropping intensity, crop yields, level of input use, and value of agricultural output.

The Relationship between Water Availability, Reliability and Cropping Intensity

Cropping intensity is deemed the most important indicator to measure the potential impact of canal rehabilition on the agricultural economy. Its importance lies in the presumed close relationship between the amount of water available to farmers and their ability to cultivate large percentages of their farms. This indicator is less dependent on market considerations and prices of inputs and outputs than other indicators, because it is assumed that farmers will, in general, cultivate their land, even if only fodder, if water is not a binding constraint.

This relationship was tested using WMED and PERI data on cropping intensity for the 6 canal sub-systems and ACOP data on outlet performance and reliability of water delivery. These data are shown in Table 1. The incidence of wells in each watercourse was also included in the analysis. Wells are an important source of water, especially for watercourses with poor outlet performance and unreliable surface irrigation supplies.

Specifically, a regression analysis was done which assumed that cropping intensity (CI) was functionally related to the following variables:

1) Outlet performance of each watercourse- defined as the amount of water delivered (Q_o) as a percentage of water sanctioned (Q_s) or Q_o/Q_s*100. This variable was in log form.

2) Reliability - defined as the coefficient of variation (CV) of outlet performance of each watercourse. This variable was also in log form.

3) Well water availability - defined as the number of wells per hectare of land found in each watercourse. This admittedly is a rather crude measure of water available from wells, but no better measure was available. This variable should be positively related to cropping intensity, that is, as the number of wells per hectare increases, or the number of hectares per well decreases, cropping intensity increases. This variable was in linear form.

In addition to these three variables, 5 dummy variables were included to account for qualitative and quantitative variation found in the various watercourses which could have an impact on cropping intensity, but for which no data are available. This would include variables such as soils, market access, groundwater quality and others. The dummy variable has nothing to do with the relationship between independent and dependent variables as characterized by the slope of a regression line. It accounts for changes in the intercept of the line.

The regression equation was:

$$CI = f(\log Q_o/Q_s, \log CV, Wells, dum1, dum2, dum3, dum4, dum5)$$

$\log Q_o/Q_s$ = outlet performance
logCV = reliability index
Wells = wells/hectare
dum1 = dummy variable for Nagnah
dum2 = dummy variable for Puran
dum3 = dummy variable for Pakpattan
dum4 = dummy variable for Venoi
dum5 = dummy variable for Killianwala

Table 1: Watercourse, Outlet performance, reliability index, number of wells per hectare and cropping intensity. 6 canal subsystems, 1992.

Chowky subsystem

Watercourse	Q_o/Q_s %	CV %	Wells (wells/ha)	CI %
6750-R	151	19.7	0.0000	207
17912-R	52	33.5	0.0409	135
25000-TL	45	31.4	0.1123	98
3500-L	72	34.0	0.0564	193
8000-TF	105	55.7	0.2857	186

Nagnah subsystem

Watercourse	Q_o/Q_s %	CV %	Wells (wells/ha)	CI %
3-R	176	27.7	0.0068	102
1-AL	218	38.9	0.0689	123
7-R	118	17.5	0.0000	125
9-L	195	25.3	0.0000	108
14-AL	112	63.9	0.0000	51

Puran subsystem

Watercourse	Q_o/Q_s %	CV %	Wells (wells/ha)	CI %
2-R	175	31.5	0.0	101
1-R	145	35.6	0.0	62
2-AL	168	22.1	0.0	96
2-T	161	35.6	0.0	51

Pakpattan subsystem

Watercourse	Q_o/Q_s %	CV %	Wells (wells/ha)	CI %
11000-L	184	45.0	0.0581	153
38774-L	169	30.5	0.0990	187
4000-L	149	14.2	0.0671	191
14966-L	159	33.9	0.0158	111
127055-L	166	38.7	0.0127	138

Venoi subsystem

Watercourse	Q_o/Q_s %	CV %	Wells (wells/ha)	CI %
3108-L	123	15.0	0.0369	154
10783	110	23.2	0.0598	148
79660	174	13.5	0.0746	160
15302	200	17.3	0.0000	185
6068-L	140	34.7	0.0219	175
32558-R	131	16.4	0.0793	179

Killianwala subsystem

Watercourse	Q_o/Q_s %	CV %	Wells (wells/ha)	CI %
7136-L	155	21.1	0.0787	136
12500-L	191	52.9	0.0000	132
15063-L	123	13.2	0.0901	156
11361-L	142	13.0	0.0358	143
17600	169	12.3	0.0458	145
136506-L	84	19.4	0.0312	174
136780-L	74	25.3	0.1250	142

The regression results using the data in Table 1 are given in Table 2. The second column of Table 2, regression coefficients, is the amount of change one can expect in the dependent variable should a one unit change in the independent variable occur. For example, the regression coefficient for the independent variable Wells is 159.67. This means that the if the ratio wells to hectares increases by 1, cropping intensity would increases 159.67 percent. Likewise, if the ration changes by 0.50, cropping intensity would change by approximately 80 percent.

The third column of Table 2 are the standard errors for each regression coefficient. The ratio of the regression coefficient to the standard error is the T-statistic, shown in column 4 of Table 2. The T-statistic is the most important figure in the table as it indicates if an individual independent variable is statistically significant in explaining the variation of the dependent variable. The levels of the T-statistic are related to the probablility that levels of significance of the independent variables. Normally, the threshold level for statistical significance is 0.05. Note that all variables in the equation are highly significant in explaining the variation of cropping intensity over the 32 watercourses.

Table 2. Results of regression analysis on cropping intensity

Variable	Regression Coefficient	Standard Error	T(DF=23)	Prob
LogCV	-62.49	24.26	-2.576	.01690
$LogQ_o/Q_s$	110.68	34.78	3.182	.00415
Wells	159.67	66.34	2.407	.02453
Dum1	-84.69	17.95	-4.719	.00009
Dum2	-108.34	18.99	-5.706	.00001
Dum3	-39.14	18.12	-2.159	.04152
Dum4	-51.52	17.84	-1.954	.06297
Dum5	34.21	15.96	-3.227	.00373
Constant	34.22			

Adjusted R-squared = .6972

Analysis of Variance Table

Source	Sum of squares	D.F.	Mean Square	F-ratio	Prob
Regression	40564.36	8	5070.54	9.921	.000001
Residual	11754.60	23	511.07		
Total	52318.96	31			

The Adjusted R-squared, or the coefficient of variability, indicates the amount of variation in the dependent variable that is accounted for by the independent variables. In this case, 70 percent of the variation of cropping intensity across watercourses is accounted for by the eight independent variables. This is a satisfactory level.

The bottom half of Table 2, entitle Analysis of Variance Table, show the statistical significance of the regression equation as a whole, not as separate independent variables. The F-ratio is calculated as the mean square of the regression divided by the mean square of the residual. A value on 9.921, as shown in fifth column is very high, and indicates that the equation containing the eight independent variables is highly significant at explaining the variation of dependent variable.

It is clear that the amount of water delivered to watercourses, either from surface irrigation or wells, and the reliability of surface irrigation are significant factors affecting cropping intensity in the respective watercourses.

With regard to canal rehabilitation, it is possible to make this interpretation: If canal rehabilitation improves outlet performance and the reliability of water delivery, an improvement in cropping intensity can be expected. Cropping intensity is

dependent on these two factors, and will thus vary directly with improvements in outlet performance and will increase as variability of water delivery decreases.

The Relationship between Water Availability and Reliability and Crop Yields

A regression analysis similar to that used for indicator one was used to show the relationship between water availability, reliability and wheat yields. Wheat yield was used in this analysis because it is common to all canal subsystems. The data on wheat yields are found in Table 12 in Chapter Two, while those for outlet performance and reliability are found in Table 1 above.

The regression equation assumed that crop yields are functionally related to two variables: the log of outlet performance; and 2) the log of reliability. The results, shown in Table 3, indicate a close relationship, as both variables are highly significant. Both outlet performance and the coefficient of variation of outlet performance are statistically significant factors in explaining the variation in crop yield across watercourses.

The R^2 of the regression is, however, very low. Low goodness of fit results from the exclusion of other variables such as fertilizer input, labor input, soils, and rainfall, all of which will have a significant effect on average yields, in the regression equation. Inclusion of the wells variable in this equation does not improve the results, nor does the inclusion of the canal subsystem dummy variables.

Table 3. Results of the regression analysis on crop yields

Variable	Regression Coefficient	Standard Error	T(DF=23)	Prob
LogCV	-727.07	365.70	2.357	.0253
$\text{Log}Q_o/Q_s$	861.99	304.98	-2.384	.0239

Adjusted R-squared = .2459

Analysis of Variance Table

Source	Sum of squares	D.F.	Mean Square	F-ratio	Prob
Regression	1370191.36	2	685095.68	6.055	.0063
Residual	3281058.60	29	113139.95		
Total	4651249.97	31			

The relationship between water variables and yield is strong, and one can interpret this result as follows: If canal rehabilitation has a direct and positive impact on outlet performance and reliability, yields in outlets that were improved can be expected to increase.

However, caution is advised against placing too much weight on this interpretation, because as mentioned above, a large number of variables which were not in the regression equation are functionally related to wheat yields. In addition, the strength of this analysis is somewhat compromised by the fact that a similar regression using cotton yields showed no relationship between outlet performance and reliability. The lack of a statistical relationship could be affected by a small sample size. In addition, cotton may indeed not be as closely related to outlet performance or reliability because it is grown in Kharif during which time rainfall is more abundant.

The Relationship between Input Use and Water Availability and Reliability

To establish the relationship between input use and hydraulic parameters, a regression equation was estimated using outlet performance, the reliability index (CV), and the incidence of wells as the independent variables, as in previously discussed regressions. The dependent variable was the average value of fertilizer applied to wheat for each watercourse sample. The data on fertilizer use are found in Annex E-1 through Annex E-6 in Chapter two, and those for outlet performance and reliability are in Table 1 above.

The results of this regression are shown in Table 4. All three independent variables are statistically significant factors in accounting for the variation in the value of fertilizer applied to wheat. The R^2 is however low, as in other regressions, indicating that there are other factors not included in the equation that account for fertilizer application. Of course the major factor absent from the equation is soil fertility, and a secondary factor may be farmers' ability to purchase fertilizer or the availability of credit. It should be noted that the dummy variables only marginally improved the goodness of fit of the regression equation.

Table 4. Results of the regression analysis on input use

Variable	Regression Coefficient	Standard Error	T(DF=23)	Prob
Q_o/Q_s	2.53	1.2564	2.014	.05373
CV	-7.53	3.7075	-2.032	.05173
Wells	1563.90	733.325	2.133	.04186

Adjusted R-squared = .1855

Analysis of Variance Table

Source	Sum of squares	D.F.	Mean Square	F-ratio	Prob
Regression	741446.24	3	247148.75	3.353	.0329
Residual	2064010.97	28	73714.67		
Total	2805457.22	31			

Interpretation of these results with respect to canal rehabilitation is as follows: If canal rehabilitation improves outlet performance and reliability of water delivery, it is expected that the value of fertilizer applied to wheat (at least) in those areas where the improvement occurs will increase.

The Relationship between Water Availability and Reliability and Value of Agricultural Output

The relationship between water variables and the value of agricultural output was done with two regression equations. The first equation shows the relationship between the value of agricultural output per farm hectare and outlet performance, water reliability and the incidence of wells in the watercourse, or

$$\text{Valfarm} = f(Q_o/Q_s, \text{ CV, and wells})^{15}$$

The second equation establishes the relationship between the value of agricultural output per cultivated hectare and the same three variables, or

$$\text{Valcul} = f(Q_o/Q_s, \text{ CV, and wells})$$

As with cropping intensity and crop yields, there is a strong relationship between the water variables and the value of

[15] To review, the wells variable is defined as the number of wells per hectare in each watercourse. It is assumed that the number of wells is positively correlated with value.

agricultural output, both on a farm hectare basis and a cultivated hectare basis. The results are given in Tables 5 and 6.

Table 5. Results of the regression analysis on value of agricultural output

Dependent variable is value of output per farm hectare

Variable	Regression Coefficient	Standard Error	T(DF=23)	Prob
CV	-113.275	63.39	-1.787	.0847
Q_o/Q_s	48.668	21.48	2.266	.0314
Wells	26276.489	12538.44	2.096	.0452

Adjusted R-squared = .1796

Analysis of Variance Table

Source	Sum of squares	D.F.	Mean Square	F-ratio	Prob
Regression	210910868.7	3	70303622.9	3.262	.0361
Residual	603400530.0	28	21550018.9		
Total	814311398.7	31			

Table 6. Results of the second regression analysis on value of agricultural output

Dependent variable is value of output per cultivated hectare

Variable	Regression Coefficient	Standard Error	T(DF=23)	Prob
CV	-47.786	40.55	-1.178	.2486
Q_o/Q_s	38.648	13.74	2.812	.0089
Wells	26583.566	8021.76	3.314	.0025

Adjusted R-squared = .1796

Analysis of Variance Table

Source	Sum of squares	D.F.	Mean Square	F-ratio	Prob
Regression	128479728.8	3	42826576.2	4.855	.0076
Residual	246977932.8	28	8820640.5		
Total	375457661.6	31			

The results show that value of agricultural output is highly related to the incidence of wells and output performance. Both variables, outlet performance and wells, are statistically significant factors in both equations. The reliability indicator is only marginally significant in accounting for the variation of value of agricultural output per farm hectare, and it is not statistically significant in the second equation.

Note that the R^2 for both equations is very low. As with the crop yields and the input use regression analyses, the reason for a low goodness of fit is that many variables that account for value of output are not included in the equation.

If rehabilitation improves outlet performance, one may expect a positive impact on the value of agricultural output. If reliability of water supply is improved through rehabilitation, the impact on value of output is expected to be marginal.

Summary of Findings

The four regression analyses show that there are strong statistical relationships between the dependent variables, cropping intensity, crop yields, level of input use, and the value of agricultural output, and the independent hydraulic parameters, outlet performance and reliability of water delivery.

The conclusion to be drawn from these analyses as it relates to canal rehabilitation is that rehabilitation works that improve outlet performance and reliability will have a positive impact on the agricultural economy. Cropping intensity should increase, yields should improve, the level of fertilizer use should increase, and, most important, the value of agricultural output, and hence farm income, should increase.

Chapter Four

ISRP REHABILITATION EXPENDITURES IN MONITORED CANAL SUBSYSTEMS

Chapter three discussed the relationship between hydraulic and agricultural economics indicators. With regard to canal rehabilitation, the conclusion of the analyses used is simple. Canal rehabilitation that is designed to improve outlet performance and the reliability of water delivery can be expected to have a positive impact on the agricultural economy. This chapter looks at expenditures on various aspects of rehabilitation as they relate to project objectives, to determine to what extent one can expect improvements in the agriculture served by the monitored canal subsystems.

Expenditures on Rehabilitation

The largest cost item funded under the Irrigation Systems Rehabilitation Project (ISRP) was canal lining. A review of costs incurred for rehabilitation of seven monitored sub-systems showed that:

1) 55 percent of costs were spent on canal lining;
2) 22 percent of costs were spent on earthwork (silt removal, bank strengthening);
3) 11 percent of costs were spent on canal side protection;
4) 6 percent of costs were spent on mogha repair;
5) 7 percent of costs were spent on other items such as minor structural repairs, bridges, and siphons.

Rehabilitation works on monitored canals are not representative of USAID funded canal systems for which lining was limited to only a few systems. However, though a complete inventory of rehabilitation expenditures has not been compiled, there is evidence to suggest that the Irrigation Departments have used ISRP funding to carry out a lining program. Of the seven monitored systems, five allocated fifty percent or more of the total rehabilitation budget to lining.

The objectives of the ISM project, accepted by all co-donors, were to improve safety, equity, and reliability of canals through rehabilitation. The following identifies which rehabilitation works have the greatest and most direct impact on these objectives:

Safety: Earthwork has the most direct impact

Canal side protection has the next most direct impact

Equity: Mogha repair has the most direct impact

No rehabilitation works have a secondary impact

Reliability: None of the rehabilitation works have a direct impact.

Three conclusions can be drawn:

1) The largest expenditures, on canal lining, had a negligible impact on project objectives.

2) Improved reliability cannot be met by rehabilitation works downstream of the distributary head. Thus, there is no correspondence between project expenditures and reliability. Either this project objective should have been eliminated, or funds should have been allocated for rehabilitation upstream of the distributary head, for improvement of flow reliability.

3) Only 39 percent of total rehabilitation expenditures are directly related to one or two project objectives.

Approaches to Improving Equity

There are two approaches to improving equity: the structural approach, and the management approach. Canal lining, the main type of structural approach, is costly, and the impact on equity is very small. Provincial Irrigation Departments (PIDs) contend that problem channels, defined as those channels in which water delivery to tails is chronically difficult because of very flat slopes, should be lined. In theory, lining increases velocity and improves transport of sediments through the system. Tail outlet performance can be enhanced and equity improved, if sediment is not deposited in the canal. Empirical evidence is not well documented to support the validity of this approach. Moreover, the costs involved in this approach would greatly exceed the value of the additional water.

Mogha repair and monitoring is a management approach to equity improvement. Costs are relatively low and the impact on equity can be large. The basic feature of the management approach is to limit flow to tampered moghas in head reaches, because these outlets take excessive water and deprive tail outlets of their fair share. Installation of more tamper-proof

templates, a cheap form of structural improvement, will enhance the effectiveness of the management approach. Periodic monitoring of outlet dimensions and flow is also a relatively inexpensive way of achieving equity.

Details of ISRP Rehabilitation Works in Seven Monitored Canal Sub-Systems

Chowky

Rehabilitation works included:

1) Lining of more than 12,600 feet of the minors. Approximately 50 percent of the total costs was spent on lining.

2) De-siltation, cleaning the canal prism, bank reinforcement, and repairs to 14,200 feet of stone pitching along the distributary. Repairs to stone pitching and earthwork made up 50 percent of the total costs.

3) Repairs were made to 17 outlets which drew excessive flow. Only minor expenditures went for outlet repair.

The cost of rehabilitation works was Rs. 2.6 million, or $105,000.

Venoi

Rehabilitation works included:

1) Lining of 43,772 feet of the main distributary and minors. Approximately 53 percent of the total costs was spent in lining.

2) De-siltation, cleaning canal prism, bank strengthening, road widening, and compaction. Approximately 2.9 million cubic feet. Approximately 8 percent of the total costs was in earthwork.

3) Side protection, especially near villages, canal side banks were eroded or cut away. Protection (killabushing, canal side lining) was provided to 28,290 feet of canal. Approximately 32 percent of the total costs.

4) Repairs were made to 49 outlets, many of which drew excessive flow. Approximately 0.1 percent of the costs.

5) Cattle ghats: 18 installed.

6) Bridges: 4 repaired. Approximately 6 percent of the costs.

The cost of rehabilitation works was Rs. 13.86 million, or $569,000.

Pakpattan 11-L

Rehabilitation works included:

1) Lining of 33,486 feet of the distributary and minors. Approximately 56 percent of the total costs went for lining.

2) Side protection: killabushing, bank repair. Approximately 22 percent of the total costs.

3) Bank strengthening, road repair, compaction, freeboard restoration. Approximately 14 percent of the costs was expended in earthwork.

4) Steel templates were placed in 15 outlets. Approximately 2 percent of the total costs went for outlet repair.

The cost of rehabilitation works was Rs. 11.3 million, or $463,000.

Killianwala

Rehabilitation works included:

1) Lining of 73,401 feet of the distributary and minors. Approximately 73 percent of the total costs went for lining.

2) Bank strengthening, road repair, compaction, freeboard restoration. Approximately 19 percent of the costs went for earthwork.

3) Structural repairs amounted to 3 percent of the costs.

4) Repairs were made to nearly all the outlets (140). Repairs to outlets amounted to less than 0.5 percent of the total costs.

The cost of rehabilitation works was Rs. 19.05 million, or $780,000.

Nari

Rehabilitation works will include:

1) Lining of 71,600 feet of the distributary and minors. Approximately 69 percent of the total costs are budgeted for lining.

2) Silt removal, canal bank strengthening and other forms of earthwork amount to 19 percent of the rehabilitation budget.

3) Aqueduct: Approximately 7 percent of the budget is in aqueduct construction.

4) Bridges: Approximately 2 percent of the total costs are budgeted for bridge repair.

5) Siphons: Approximately 1 percent of the total costs are budgeted for siphons.

The cost of rehabilitation works are budgeted at Rs. 16.2 million, or $663,000.

Puran

Rehabilitation works included:

1) Bank strengthening, road repair, clearance of vegetation, compaction, freeboard restoration. Approximately 46 percent of the costs was expended in earthwork.

2) Construction of groynes for bank protection and control of erosion. Approximately 11 percent of the rehabilitation budget.

3) Repair to 112 outlets. Approximately 29 percent of the total costs went for outlet repair.

4) Repairs were made to minor structures. Approximately 11 percent of the total costs.

The cost of rehabilitation works was Rs. 4.887 million, or $200,000.

G. Nagnah

Rehabilitation works included:

1) Bank strengthening, road repair, clearance of vegetation, compaction, freeboard restoration. Approximately 3.165 million cubic feet and 50 percent of the budget is in earthwork.

2) Construction of groynes for bank protection and control of erosion. Approximately 6 percent of the rehabilitation budget.

3) Repair to 45 outlets. Approximately 27 percent of the total costs went for outlet repair.

4) Repairs were made to minor structures. Approximately 13 percent of the total costs.

The cost of rehabilitation works was Rs. 5.145 million, or $211,000.

Chapter Five

THE HYDRAULIC AND AGRICULTURAL ECONOMICS IMPACT OF CANAL REHABILITATION IN CHOWKY DISTRIBUTARY

The Chowky Distributary in NWFP is the only subsystem that has sufficient data collected to allow for a comparison of pre- and post rehabilitation status. ACOP has completed all data collection and analysis, and has completed a draft report on post-rehabilitation hydraulic data. WMED has finished the data collection and data management of post-rehabilitation Kharif data. Comparisons of pre- and post-rehabilitation data are presented below. Note that the conclusions are tentative and incomplete. Rabi data have not yet been collected and indicator five, value of agricultural production has not yet been calculated. Further, the conclusions are not necessarily representative of other canal subsystems.

Summary of Findings: Hydraulic Indicators

Rehabilitation works carried out on Chowky Distributary under the ISRP II project have not had the desired impact on hydraulic indicators. Average monthly flow to tail moghas did not increase. Although some tampered outlets were restored to design conditions, others have flow areas well in excess of design. As a consequence, the performance of outlets in middle and tail reaches has deteriorated slightly and equity has worsened. Reliability has also worsened because inflow to the distributary head is insufficient and erratic. Conveyance losses have been slightly reduced as a result of rehabilitation. Freeboard conditions have improved.

Location, Command Area, Design Flow

Located in North West Frontier Province, Chowky Distributary draws flow from Maira Branch at the very tail of the Upper Swat Canal System. Figure 1 show the location of Chowky Distributary.

Figure 2 is the flow diagram of Chowky Distributary showing the locations of minors and outlets, and their design flows. Chowky Distributary is 25,000 feet long and feeds 26 outlets. The canal command area is 6212 acres. Chowky's design flow is 51.70 cfs. However, because of its tail location, the distributary is chronically water deficient, on average receiving about 50 percent of design.

Rehabilitation Works

Prior to rehabilitation, portions of Chowky Distributary were badly eroded. Many of the outlets, particularly those in head reaches, had been tampered and illegal outlets were common. Flow to tail reaches of the distributary and minors was inadequate. To correct these deficiencies, rehabilitation works included:

1) Lining of more than 12,600 feet of the minors[1]. Approximately 50 percent of the total costs was spent for lining.

2) De-siltation, cleaning the canal prism, bank reinforcement, and repairs to 14,200 feet of stone pitching in the distributary. Repairs to stone pitching and earthwork made up 50 percent of the total costs.

3) Repairs were made to 17 outlets which drew excessive flow. Only minor expenditures went for outlet repair.

The cost of rehabilitation works was Rs. 2.6 million, or $106,000.

Rehabilitation was carried out between January and June 1991. Pre-rehabilitation measurements for hydraulic impact were taken between October 1989 and November 1990; post-rehabilitation measurements were made between November 1991 and December 1992.

Inflow to Head of Distributary

ACOP staff monitored inflow to Chowky prior to and following rehabilitation. Separate rating curves were developed to relate discharge and corresponding stage for each of the two time periods. Rating curves were used in combination with gauge observations to determine daily discharge.

With the exception of October, average monthly inflow to the head of Chowky in the post-rehabilitation period is similar to inflow in the pre-rehabilitation period. Figure 3 is a comparison of average monthly discharge during pre- and post-rehabilitation periods. Because inflow conditions are similar, comparisons of hydraulic impact parameters between the two time

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[1] Lining was inspected in November 1992, 21 months following the rehabilitation. The lining of Minor 1 is defective. Many sections of the lining have collapsed and backfilling was inadequate. The quality of the cement mixture was very poor.

periods are valid.

Before making that comparison, it is important to document that Chowky is severely water deficient. Average monthly inflows as a percentage of full supply discharge are shown in Figure 4. Being located at the very tail end of the system, distributary inflows are substantially less than design. Following rehabilitation, monthly inflow averaged 49 percent of design while the monthly maximum and minimum values were 59 and 13 percent respectively. Average monthly inflow during Kharif was 50 percent of full supply; during Rabi it was 46 percent.

Another description of flow availability is seen in Figure 5 which depicts the percentage of days that the flow was within a given range of full supply discharge for pre- and post-rehabilitation periods. The pre-rehabilitation period covered 105 days; the post-rehabilitation period covered 306 days. Scheduled canal closure periods are excluded from the percentages shown. It is generally accepted that a flow of 70-80 percent of design is required if the system is to function as intended, that is, if proportional flows are to be maintained to head and tail outlets. However, for both pre- and post-rehabilitation periods, flow was insufficient to permit proportional flow to outlets. Flow was in excess of 75 percent of design only one day in twenty. Deficient and erratic inflow makes reliable water delivery impossible on Chowky. Since rehabilitation works were not designed to alter inflow, rehabilitation will only have minimal impact upon reliability of flow.

Flow At The Tail

ACOP staff evaluated the availability of flow at the tail of Chowky[2]. Flow at the tail for the corresponding months for the pre- and post-rehabilitation monitoring periods is shown in Figure 6. Flow to the tail averaged 57 percent of full supply for the four-month pre-rehabilitation period; in the post-rehabilitation period, flow averaged 52 percent. Thus, there has been a slight deterioration in tail-flow conditions in the post-rehabilitation period.

Following rehabilitation, mean monthly flow at the tail ranged from 36 to 60 percent of full supply; the average was 47 percent. As a percent of design flow, flow at the tail was less than flow to the head. Average monthly inflow to the tail was 47 percent in Kharif and 45 percent in Rabi.

Availability of flow at the tail is shown in Figure 7. When compared with the pre-rehabilitation period, the post-

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[2] Methods used are furnished in the detailed ACOP reports.

rehabilitation period had fewer days during which flow was less than 25 percent of full supply, and more days of flows in the 25-50 percent range.

Outlet Dimensions

Tampering with outlets is the major reason why flow is inequitable on Chowky. ACOP staff measured the dimensions (and hence the flow area) of all outlets during periods of annual canal closure. Flow area was expressed as a percent of design.

Prior to rehabilitation, 8 of 26 outlets had flow areas in excess of 125 percent of design. In February 1993, two years after rehabilitation, outlet dimensions were again measured. Three (3) of 26 outlets, all in head positions, were 125 percent or more in excess of design. While rehabilitation has resulted in fewer outlets which deviate markedly from design, the impact of tampered outlets continues to be very serious.

It remains to be seen whether the Irrigation Department has the commitment to restore tampered outlets to design and to arrest future tampering. The February 1993 survey revealed that a number of outlets were still in bad condition, having broken roof blocks, damaged side walls, and side leaks. Outlet dimensions should continue to be monitored with time, deviations reported to the authorities, and corrective action taken by the Department. If the Department spent a small fraction of the rehabilitation costs in monitoring flows through outlets, equity conditions would be much improved.

Deviation in outlet flow area is summarized in Table 1 and is shown in Figure 8.

Table 1. Deviation in Outlet Flow Area

Flow Area (% of design)	Head Pre	Head Post	Middle Pre	Middle Post	Tail Pre	Tail Post	Total Pre	Total Post
< 90	-	2	-	1	-	-	-	3
91 - 110	2	1	5	7	7	7	14	15
111 - 125	1	2	1	1	2	2	4	5
126 - 150	1	1	3	-	-	-	4	1
151 - 175	2	1	-	-	-	-	2	1
176 - 200	-	-	-	-	-	-	-	-
> 200	2	1	-	-	-	-	2	1
Total	8	8	9	9	9	9	26	

Outlet Performance

Outlet performance (%) is defined as the observed discharge (Q_o) as a percentage of sanctioned discharge (Q_s), or $(Q_o)/(Q_s)*100$. Outlet performance did not improve with rehabilitation and instead deteriorated. Following rehabilitation, head moghas took more water, and middle and tail moghas received less. Certain outlets, all located in the head reach (1+090R, 6+750R, and 9+200L), drew flows in excess of 150 percent of that sanctioned. These are the tampered outlets which have the greatest deviation in flow area. Outlet performance ranged from a high of 456 percent for outlet 1+090R, to as low as 18 percent for one of the tail outlets.

Performance coefficients for pre-rehabilitation and post-rehabilitation periods in the corresponding months is given in Table 2.

Table 2. Outlet Performance for Pre- and Post-Rehabilitation Periods[3].

Outlet Reach	Average Performance Coefficient (percent)	
	Pre-rehabilitation	Post-rehabilitation
Head Outlets	130	139
Middle Outlets	76	67
Tail Outlets	66	61

Equity

Equity measures variation in access to water between locations at a particular time. If all moghas located along a distributary share equally in excess or deficient supplies, water distribution is said to be equitable; if there is differential access to irrigation water, canal operations are not equitable.

To determine the degree of equity in canal sub-systems, outlets were stratified into "head", "middle", or "tail" based on their distances from the head of the distributary. An equity coefficient was defined as the ratio of measured or observed flow to sanctioned flow in head versus tail outlets:

$$\frac{(\text{Observed Flow/Sanctioned Flow})_{\text{head outlets}}}{(\text{Observed Flow/Sanctioned Flow})_{\text{tail outlets}}}$$

An equity coefficient in excess of unity indicates that head-end moghas obtain a larger relative share of water than tail-end moghas. For example, an equity coefficient of 2.00 indicates that farmers drawing flow from head outlets have twice the differential access to water when compared with farmers in tail reaches of the distributary.

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[3] Outlet performance was calculated for each outlet and averaged across seven corresponding months for both for pre- and post-rehabilitation periods. The average performance coefficient given in this table is the average of all outlets in each of the three reaches.

Rehabilitation works which:

- restore outlet flow areas to meet design specifications;
- improve conveyance efficiency;
- restore modularity in tail moghas; and
- reduce breaches;

are changes which can improve water delivery to tail sections leading to better equity and to improved agricultural productivity. Among the works listed above, restoration of outlet flow area to design specifications, and continued monitoring of outlets to help ensure that they are not tampered, will have the biggest impact on equity.

Equity did not improve following rehabilitation. A comparison of equity coefficients for pre- and post-rehabilitation periods is shown in Table 3. The comparison is for seven months of data for each period. The analysis is very sensitive to certain outlets drawing more than their fair share. If flows through the three tampered outlets in the head reach could be restricted to sanctioned flow, the equity coefficient would be reduced to 1.66, an improvement over pre-rehabilitation conditions. Achievement of such an improvement in equity depends more on Irrigation Department management and political will to control outlet tampering rather than on rehabilitation per se.

Table 3. Comparison of Equity Coefficients for Pre- and Post-rehabilitation period for corresponding months

Season/period	Equity Coefficient	
	Pre-rehabilitation	Post-rehabilitation
Total period	2.06	2.23
Rabi months	2.13	2.38
Kharif months	1.92	1.95

Chowky is supplied with only half of its design discharge. Thus, there is much temptation for head-end farmers to take extra water. This is true for nearly the entire year but more so during the critical months of the growing season. There is some evidence in the data to suggest that equity coefficients become a little better when inflow to the head increases. It can be expected that equity conditions would improve if Chowky is supplied with its appropriate share of water.

Because inflow to the head of Chowky was generally less than 50 percent of full supply, flows to the moghas will not be proportional. Equity is affected. One solution is to install flow control gates at various locations so that rotational irrigation could be practiced and better equity achieved.

Flow Reliability

Reliability is a measure of the regularity or dependability of water supply over time at a particular location. If flow is variable and the reliability is poor, farmer response will be to reduce cropping intensity and to cultivate low value crops. Conversely, if reliability can be improved, farmers will be encouraged to increase plantings and shift to higher value crops.

The coefficient of variation (CV)[4] of outlet performance (flow) was used as one index of reliability. If the CV is low in the head reach, say 10 percent, head watercourses will receive the average flow plus or minus 10 percent of average flow, 68 percent of the time. This would be a reliable water supply. On the other hand, if the CV is high in the tail reach, say 50 percent, tail watercourses receive the average flow plus or minus 50 percent, 68 percent of the time. Even if the mean is high, this must be considered an unreliable water supply.

Based on seven months of data, the CV for middle and tail reaches on Chowky has decreased following rehabilitation. If we use CV as the index to reliability, we may conclude that reliability has improved. See Table 4.

Table 4. Coefficient of Variation (%) in Outlet Performance, Comparison of Pre- and Post-Rehabilitation Conditions.

	Pre-Rehab	Post-Rehab
Head	18.4	18.4
Middle	32.0	21.7
Tail	34.3	20.6

[4] Coefficient of variation of water supply is computed as the standard deviation of outlet performance (Q_o/Q_s x 100) divided by its mean times one hundred.

However, flow reliability may also be measured by the number of days that water was flowing in the distributary. Figure 9 depicts the number of days that there was water flowing in the distributary and the number of days that there was no-flow. The analysis is for an entire year. In the 12 months prior to rehabilitation, the distributary was closed for 31 days of scheduled maintenance and 41 days of unscheduled closure. In other words, 20 percent of the time, there was no flow. In the 12 months following rehabilitation, there were 60 days of scheduled canal closure and 38 days of unscheduled closure, or, there was no flow 27 percent of the time. Seen from the perspective of a farmer on Chowky, flow was less reliable in the post-rehabilitation period.

The analysis of flow and no-flow days as an index to reliability is only concerned with flow <u>to</u> Chowky head. Rehabilitation improvements on Chowky were only designed to improve the reliability of flow once water enters the distributary. Hence, the impact of rehabilitation on reliability cannot be assessed when flows to the head of the distributary are so variable.

Conveyance Losses

Conveyance losses were calculated by determining the sum of the outflows through all outlets and by subtracting that amount from inflow to the head. The difference is attributed to conveyance losses. After rehabilitation, average conveyance losses on Chowky decreased from 9.7 percent to 8.0 percent.

Modularity

Flow through outlets can be characterized as "modular", when a hydraulic jump occurs between the distributary and the watercourse, or "non-modular", when flow is submerged and outlet discharge reduced as a consequence. The Indus irrigation system was designed to operate under modular conditions.

Following rehabilitation, the number of outlets operating in a non-modular mode increased from 2 to 8. Removal of silt from the prism probably resulted in a lower operating level in the distributary and this may have contributed to the increased number of non-modular outlets. The majority of non-modular outlets were in the middle reach. See Table 5.

Table 5. Modularity Characteristics of Outlets

Reach	Number of Outlets Operating in Non-Modular Mode	
	Pre	Post
Head	-	-
Middle	2	7
Tail	-	1
Total	2	8

Freeboard

Freeboard is the vertical distance from the water surface level to the lowest point of the bank level, dowel level/ or spoil bank. For design discharges between 0 and 100 cfs, the recommended freeboard is one foot.

Before undergoing rehabilitation, Chowky had deficient freeboard in the vicinity of RD 8+180, RD 24+000 and RD 24+980. Those problem locations were corrected during the rehabilitation. As a result of the rehabilitation, ample freeboard was restored throughout the distributary.

Summary of Findings: Agricultural Economics Indicators

The agricultural indicators from pre- and post-rehabilitation seasons, in general, shows improvement in the agricultural economy in the five sample watercourses. Cropping intensities increased in all but one watercourse, average maize yields increased, though fertilizer applications on maize were reduced. Cropping patterns were altered also. A greater percentage of total cultivated area was allocated to tobacco and sugar cane, or tobacco or sugar cane. Higher value crops were more prevalent in Kharif 1992 than Kharfi 1990.

Changes in outlet performance and reliability for the five watercourses were not uniform. Apart from watercourse 6750-L, which had little changes between the two seasons, the other four watercourses had improvement in outlet performance or reliability, but not both. Thus, 17912-R and 25000-TL had improved outlet performance, but reliability was reduced, while 3500-L and 8000-TF had improved reliability but decreased water supply. The non-uniform changes in hydraulic parameters leads to

ambiguous conclusions regarding the impact of canal rehabilitation on the agricultural economy. There is little doubt that water supply and reliability are important for crop production, but it is difficult at this time to conclude that the changes in agricultural economics indicators are an impact of changes in hydraulic variables.

Outlet performance and reliability index

Changes in outlet performance from pre- to post-rehabilitation status for the individual sample watercourses are shown in Figure 10. Watercourse 6750-L, the outlet of which remains tampered, had a slight increase in water supply, and averaged over 150 percent of sanctioned discharge. Watercourses 17912-R and 25000-TL, those which had the lowest outlet performance during the pre-rehabilitation period, improved, though not greatly. The outlet performances of the final two watercourses, 3500-L and 8000-TF, deteriorated from pre-to post-rehabilitation.

The reliability of water supply was virtually unchanged for watercourse 6750-L. This watercourse had the lowest reliability index, indicating that of all watercourses in the sample, it had the most reliable supply. 6750-L has not only abundant, but reliable water supply.

The changes in the reliability index for the four other watercourses were mixed. 17912-R and 25000-TL, those which had improved outlet performance, had worsened reliability conditions. Conversely, watercourses 3500-L and 8000-TF experienced improved reliability conditions, though they had less water.

To conclude, the water supply to the five watercourses in the agricultural economics sample did not appreciably change from pre-rehabilitation to the post-rehabilitation period. Watercourse 6750-L continued to receive an abundant and reliable water supply. The other Chowky watercourses either improved outlet performance, but had reduced reliability, or had improved reliability and reduced flow.

Cropping intensity

The cropping intensity in the five watercourses in general increased during the period. All watercourses, except 8000-TF, had higher cropping intensities in Kharif 1992 relative to Kharif 1990. Watercourse 6750-L increased from about 100 percent to 150 percent, and 17912-R and 3500-L showed much higher cropping intensities. The watercourse that showed a decrease in cropping intensity was 8000-TF, which reduced its cropping intensity from about 90 to 80 percent of the cultivable area (Figure 12).

Cropping intensity is closely tied to water availability. Note the similarity of Figures 10 and 12. Outlet performance and cropping intensity clearly correspond. However, there is not enough evidence to show that canal rehabilitation had an influence on the changes in cropping intensity that occurred from one season previous to rehabilitation to the one season following rehabilitation. For example, was the 50 percent increase in cropping intensity in watercourse 6750-L due to improved outlet performance, or was the 25 percent increase in cropping intensity in watercourse 17912-R the result of improved supply. The improvements in water supply and reliability may be a factor accounting for increases in intensity, but the evidence currently available is ambiguous for firm conclusions.

Cropping patterns

Comparisons of cropping patterns from Kharif 1990 to Kharif 1992 are summarized below and are graphically shown in Figures 13 to 17.

6750-L: The percentages of land allocated to maize and orchards remained unchanged, but there was a large increase in the percentage area devoted to tobacco. Tobacco replaced sugar cane, which decreased substantially from pre- to post-rehabilitation seasons. The change is probably due to the high value given for Virginia tobacco, and assurance of marketing that accompanies the tobacco contract growing schemes. (Figure 13)

17912-R: Farmers in this watercourse, like those of 6750-L, significantly increased cultivation of tobacco. Sugar cane and oilseeds also increased from negligible amounts to about 7 or 8 percent of the total cultivated area. Fodder decreased from 20 percent of total cultivated area to about 6 percent. The changes in cropping pattern are indicative of improved water supply, as farmers have shifted a significant amount of land out of fodder and into high value crops, tobacco and sugar cane. (Figure 14)

25000-TL: During the pre-rehabilitation Kharif, farmers in this watercourse cultivated maize and sugar cane. In the post-rehabilitation Kharif, less land is devoted to maize and sugar cane, and small amounts of land are allocated to oilseeds, tobacco, fodder, janter, and pulses. (Figure 15)

3500-L: This watercourse saw a jump in tobacco cultivation, from a small percentage of total cultivated area in Kharif 1990 to over 25 percent in Kharif 1992. Figure 16 shows that this increase was done primarily at the expense of sugar cane. The area allocated to sugar cane fell from almost 30 percent of the total cultivated area to about 10 percent. In general, the other crops remained at their 1990 levels, though maize decreased from about 65 percent to about 60 percent of the total cultivated

area.

8000-TF: In Kharif 1990, almost 50 percent of the total cultivated area was devoted to vegetables and almost 40 percent was allocated to maize, with the balance distributed between tobacco, fodder, and rice. In Kharif 1992, no vegetables were grown and sugar cane accounted for about 40 percent of the total cultivated area. In addition, melons and janter were included in the Kharif 1992 cropping pattern. It may be possible that the increase in sugar cane cultivation is an impact of the significant improvement in water reliability. (Figure 17)

Crop yields

Maize yields for the five watercourses for both Kharif 1990 and Kharif 1992 are shown in Figure 18. Average maize yields improved in all watercourses except 6750-L, though the decrease in this watercourse is not great, only 70 kg/ha. The increases in average yields were sometimes substantial; watercourse 17912-L had an average increase of 14 percent; 25000-TL increased 22 percent, 3500-L increased 11 percent and 8000-TF increased 21 percent.

Average input use

Average value of fertilizer applied to maize from pre- to post-rehabilitation periods in general declined. In some cases, the declines were substantial. For example watercourse 8000-TF witnessed a decline in fertilizer use of over 50 percent of the Kharif 1990 level. Only one watercourse, 17912-R, increased applications of fertilizer on maize, from about Rs 600/ha to over Rs 1000/ha.

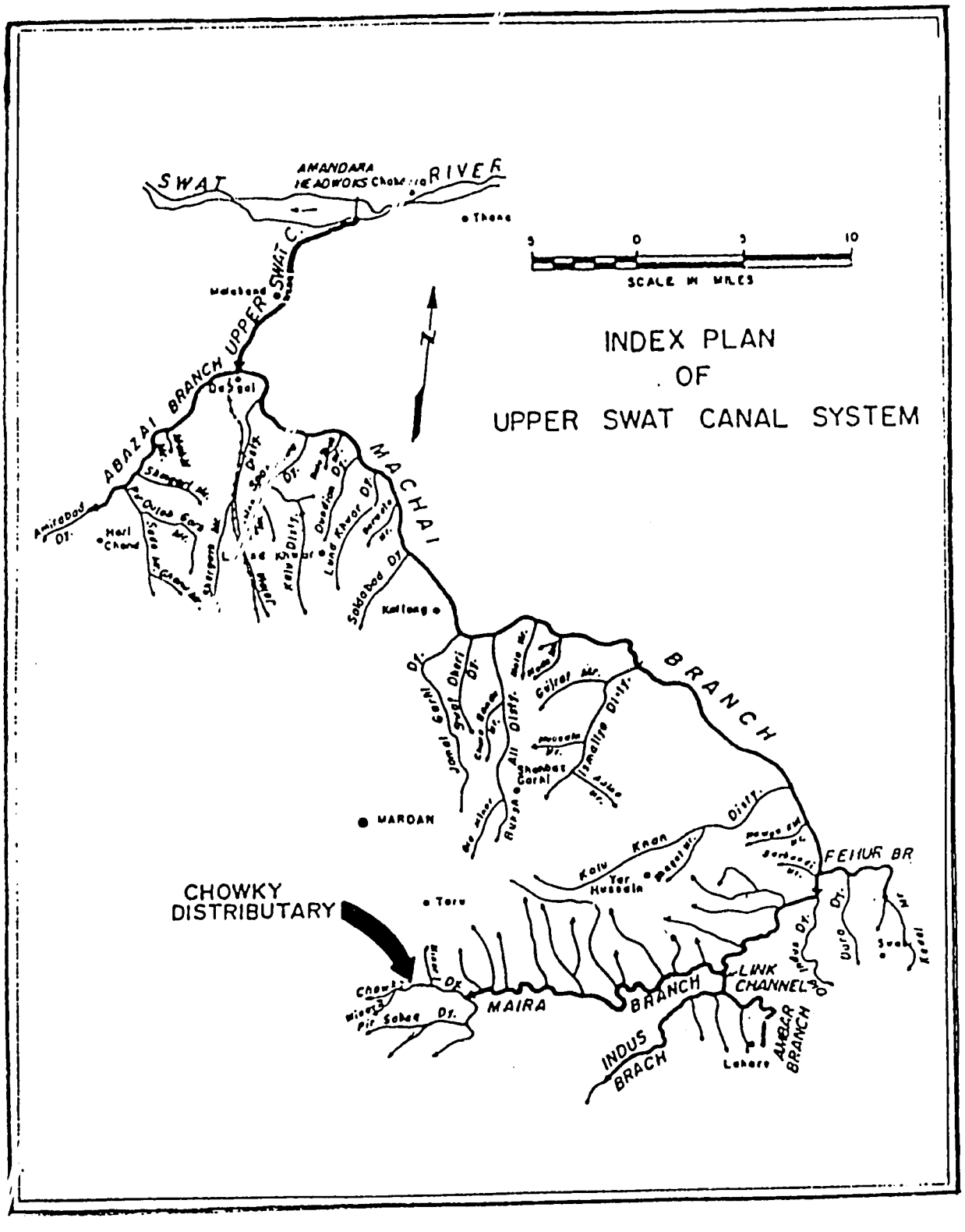


Figure-1. Location Map.

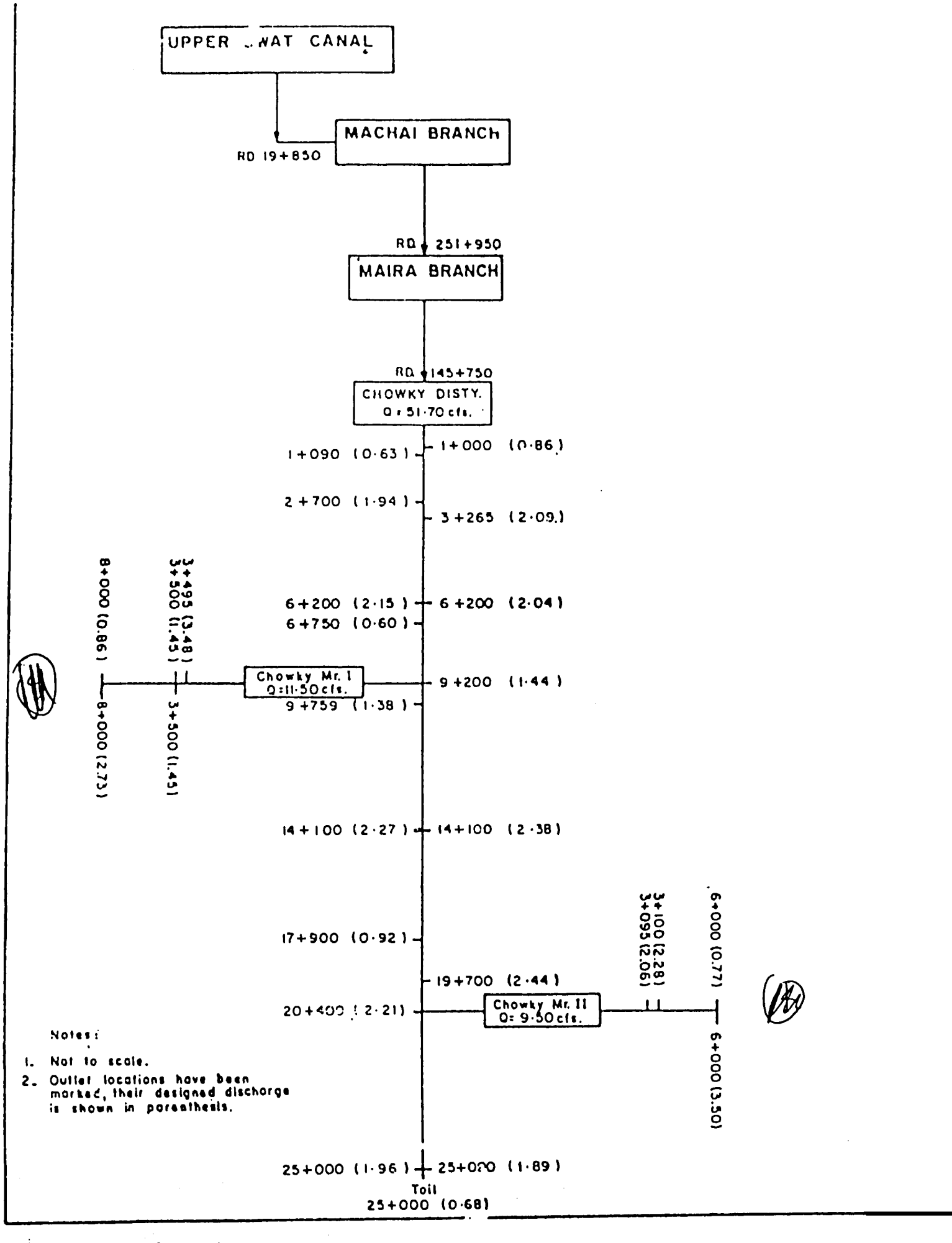


Figure-2. Flow Diagram.

Figure 3 CHOWKY DISTRIBUTARY
Average Monthly Flow at Head

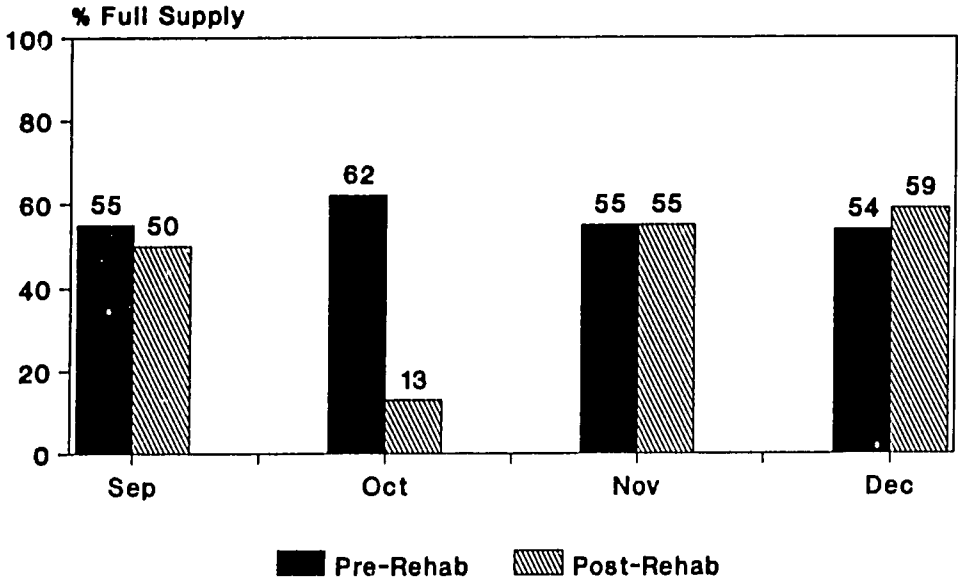
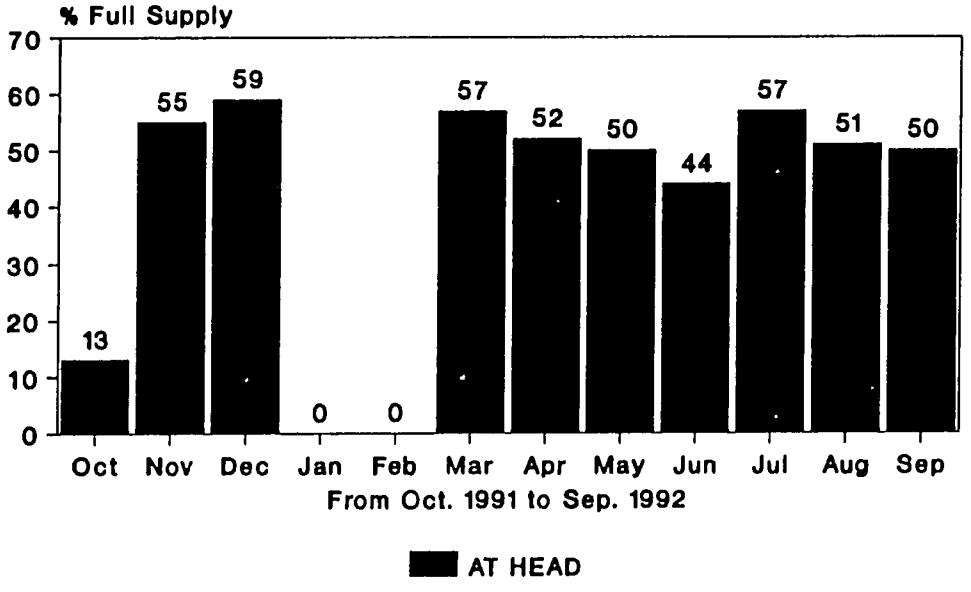


Figure 4 CHOWKY DISTRIBUTARY
Average Monthly Flow at Head



Post-Rehabilitation

Figure 5

CHOWKY DISTRIBUTARY
Availability of Flows at Head

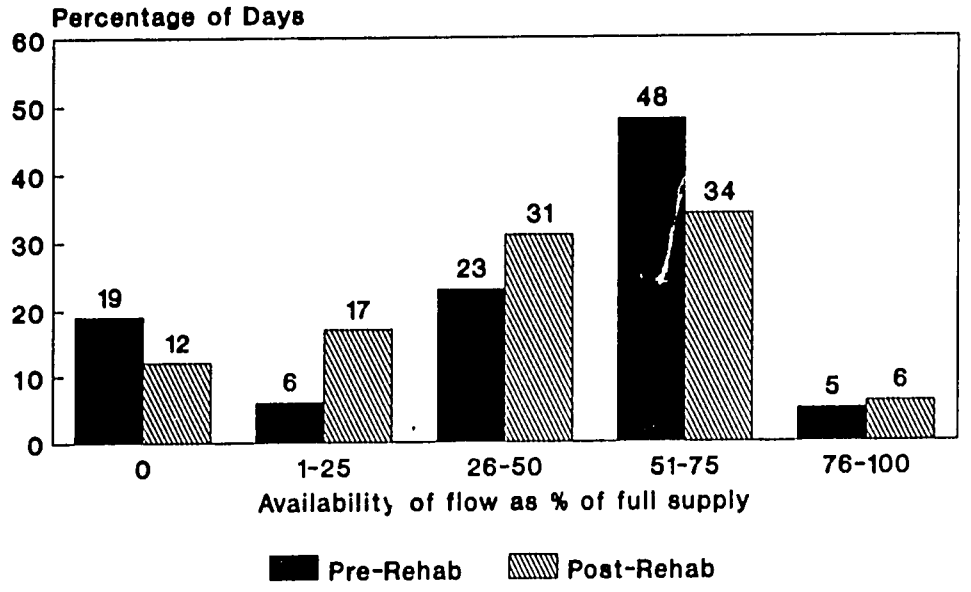


Figure 6

CHOWKY DISTRIBUTARY
Average Monthly Flow at Tail

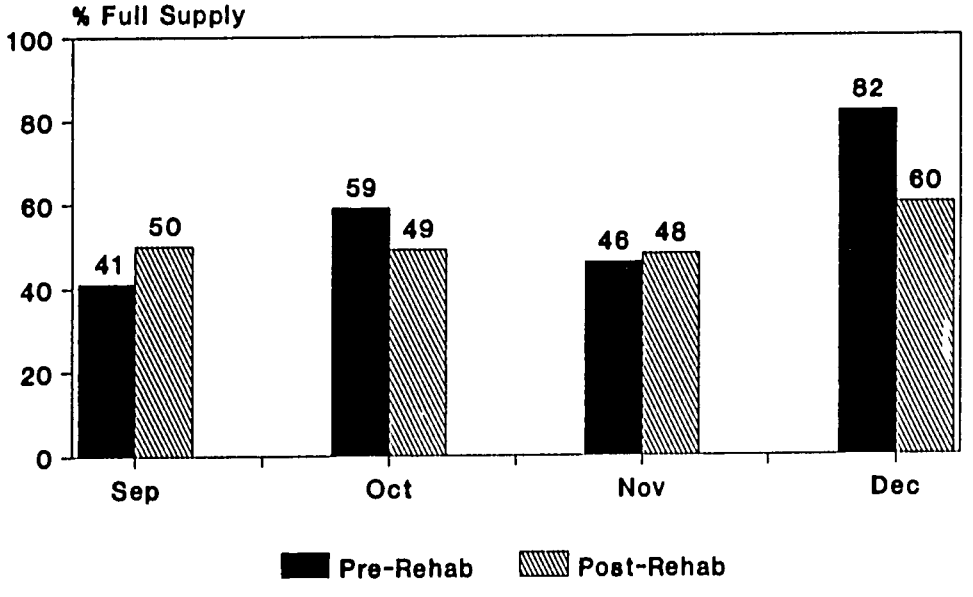


Figure 7 CHOWKY DISTRIBUTARY
Availability of Flows at Tail

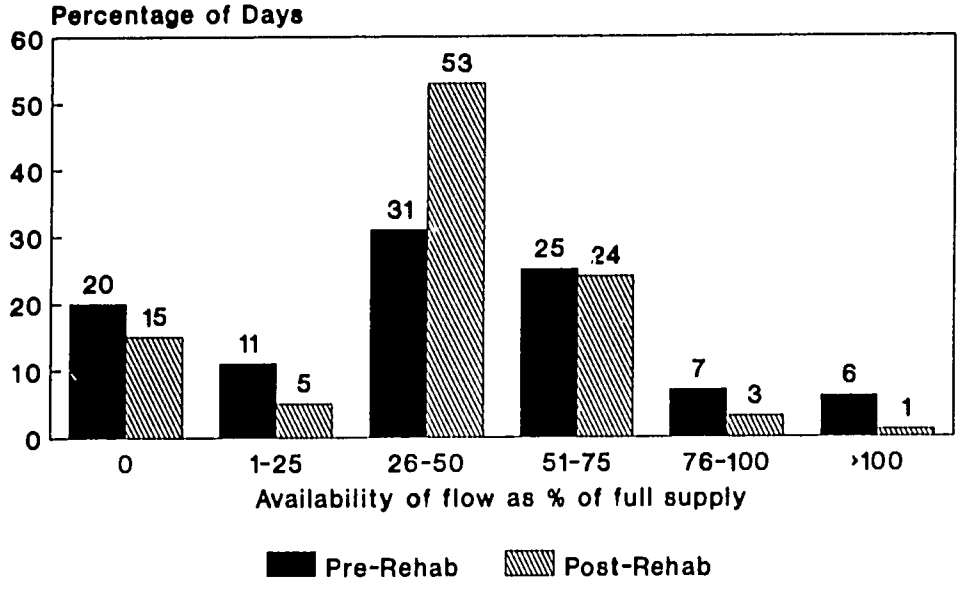


Figure 8 CHOWKY DISTRIBUTARY
Deviation in Flow Area of Outlets

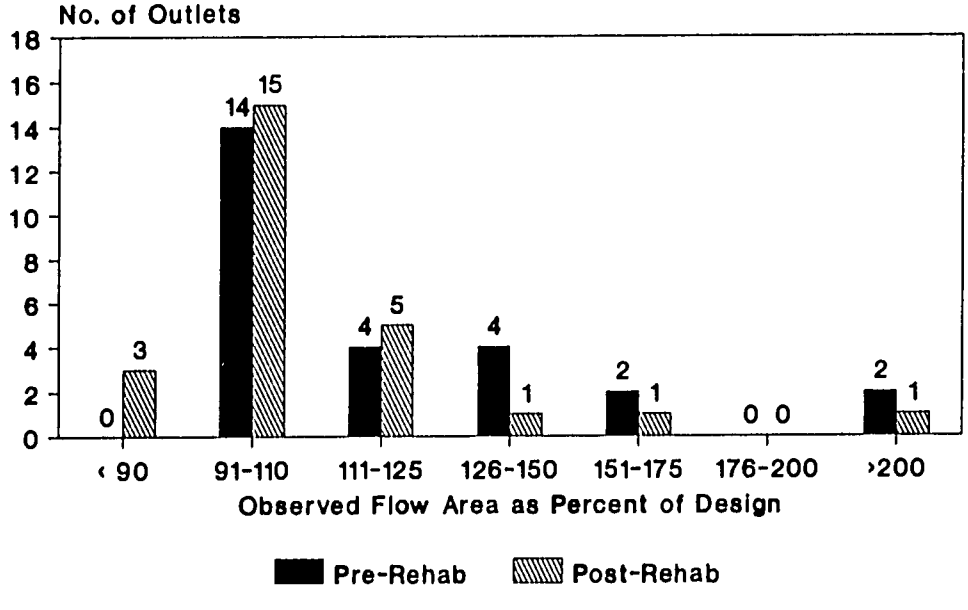
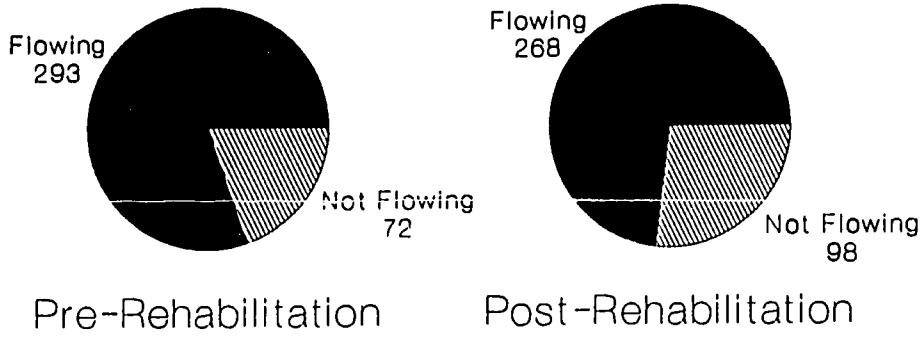


Figure 9

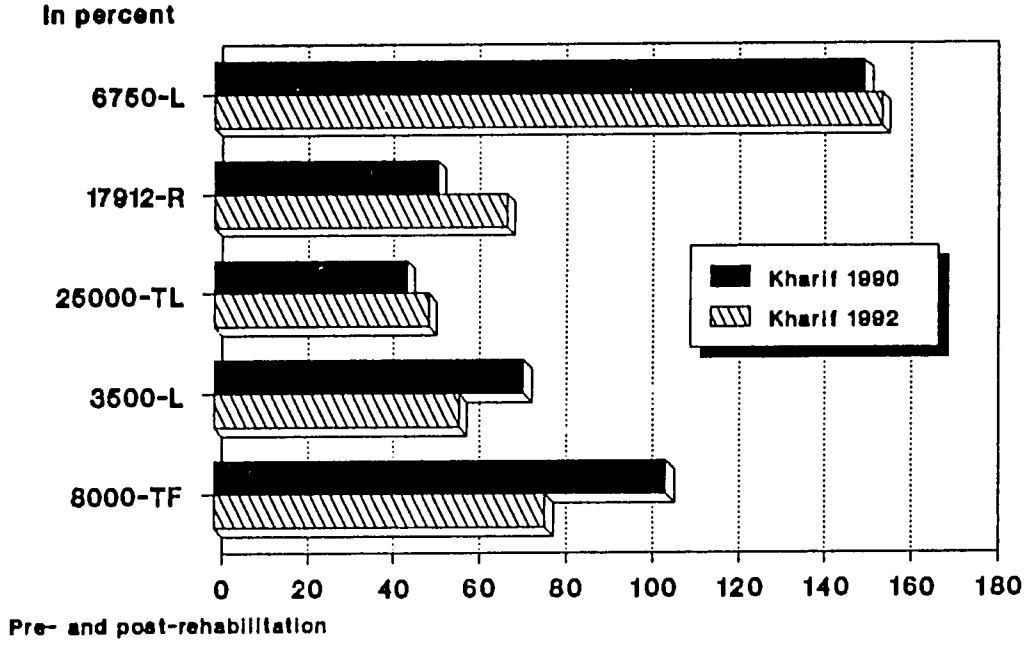
FLOW RELIABILITY
To Head of Chowky Distributary



(Number of Days)

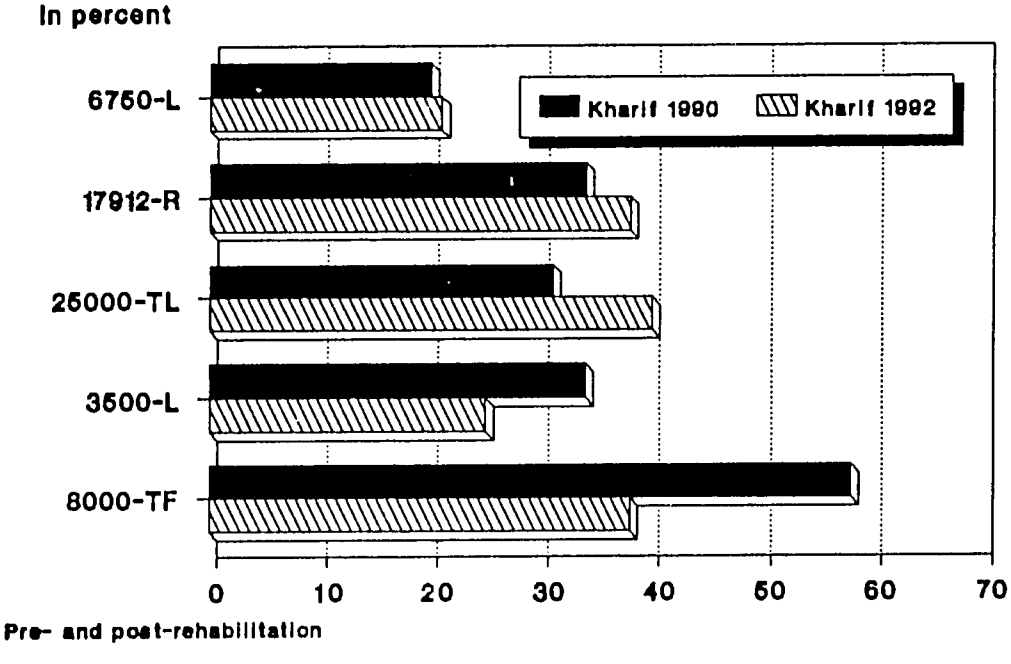
Outlet Performance Coefficients, Chowky Watercourses, Kharif 90 and Kharif 92

Figure 10



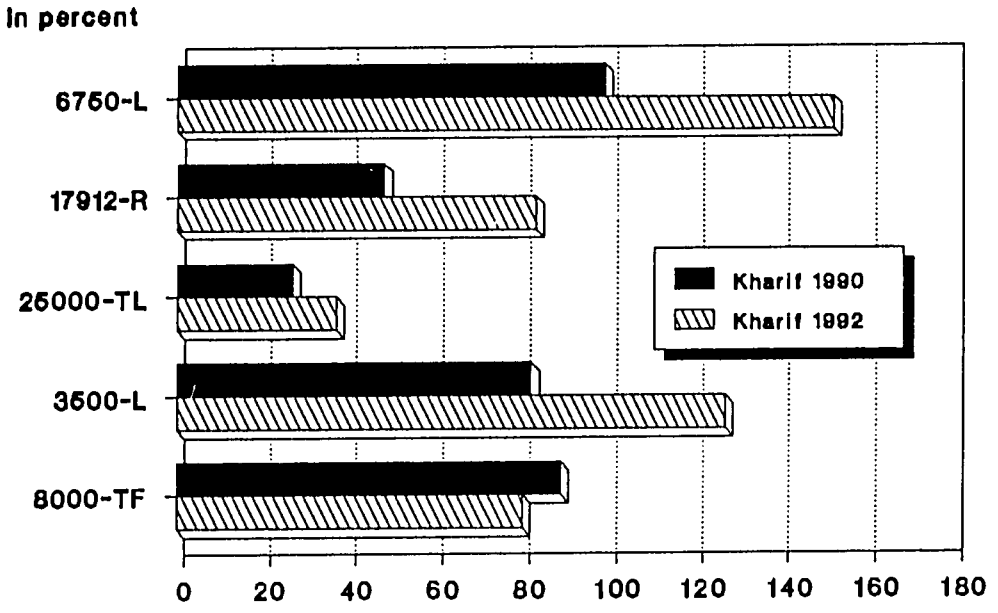
Reliability Index, Chowky Watercourses Kharif 90 and Kharif 92

Figure 11



Cropping Intensity; Chowky Watercourses Kharif 90 and Kharif 92

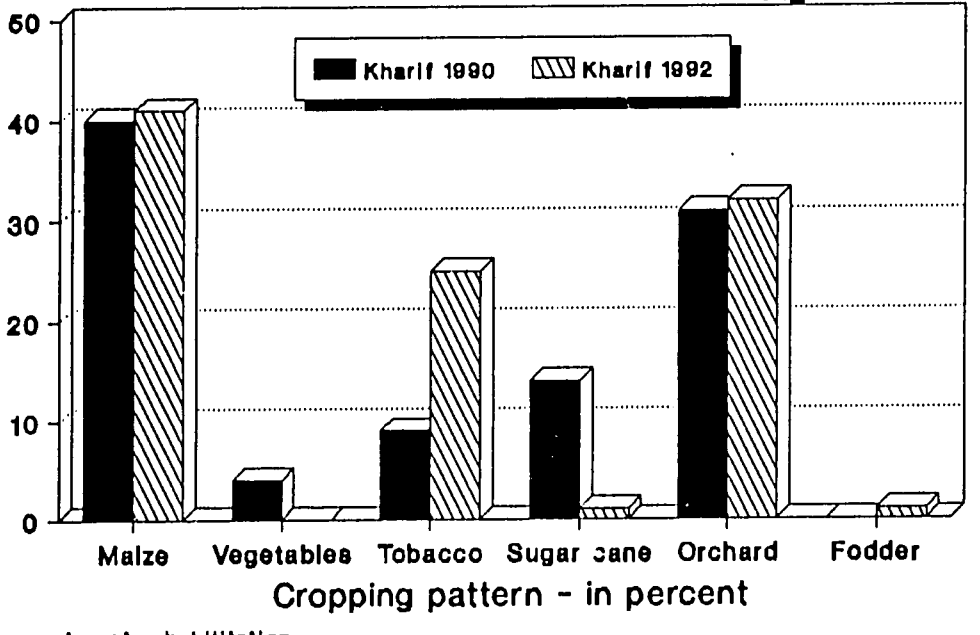
Figure 12



Pre- and post-rehabilitation

Cropping Pattern, Watercourse 6750-L Chowky, Kharif 1990 and Kharif 1992

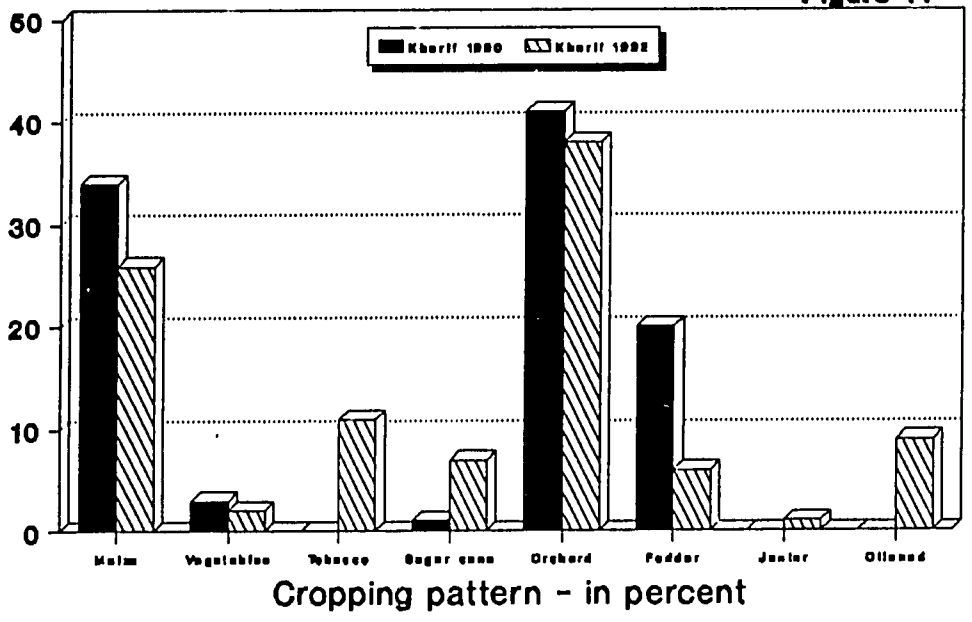
Figure 13



Pre- and post-rehabilitation

Cropping Pattern, Watercourse 17912-R Chowky, Kharif 1990 and Kharif 1992

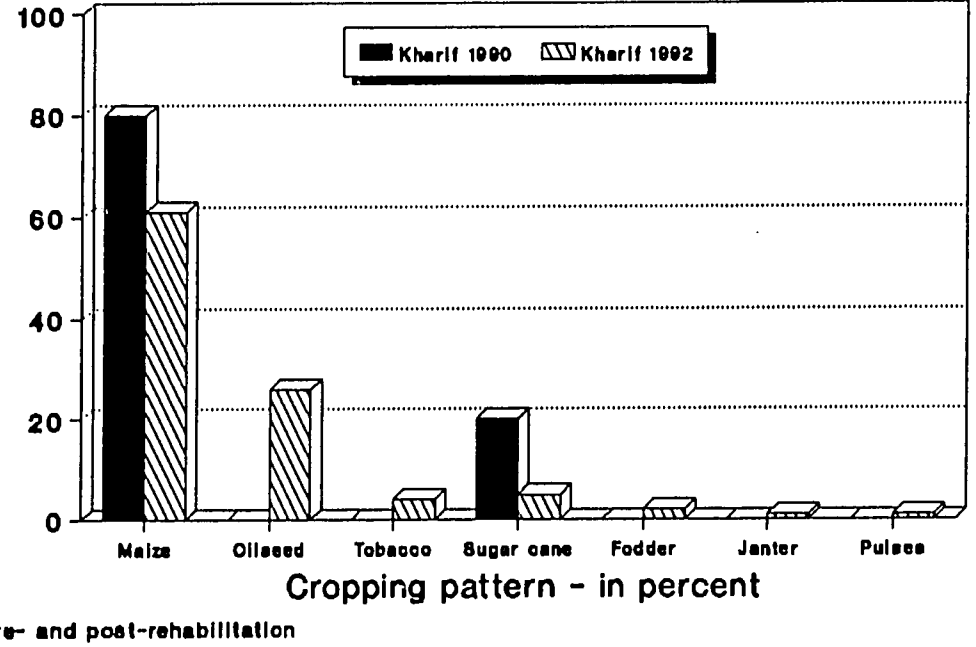
Figure 14



Pre- and post-rehabilitation

Cropping Pattern, Watercourse 25000-TL Chowky, Kharif 1990 and Kharif 1992

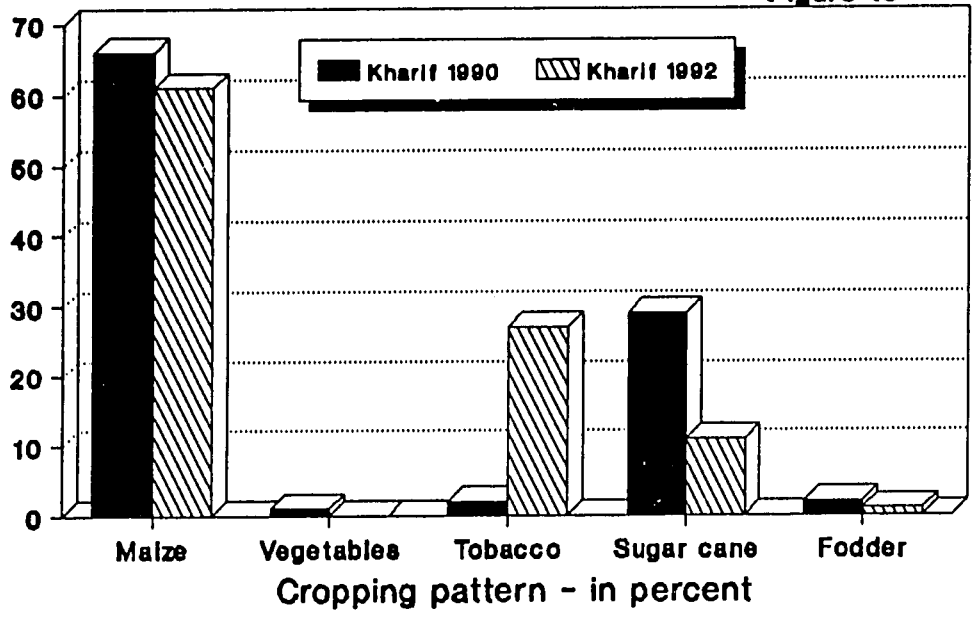
Figure 15



Pre- and post-rehabilitation

Cropping Pattern, Watercourse 3500-L Chowky, Kharif 1990 and Kharif 1992

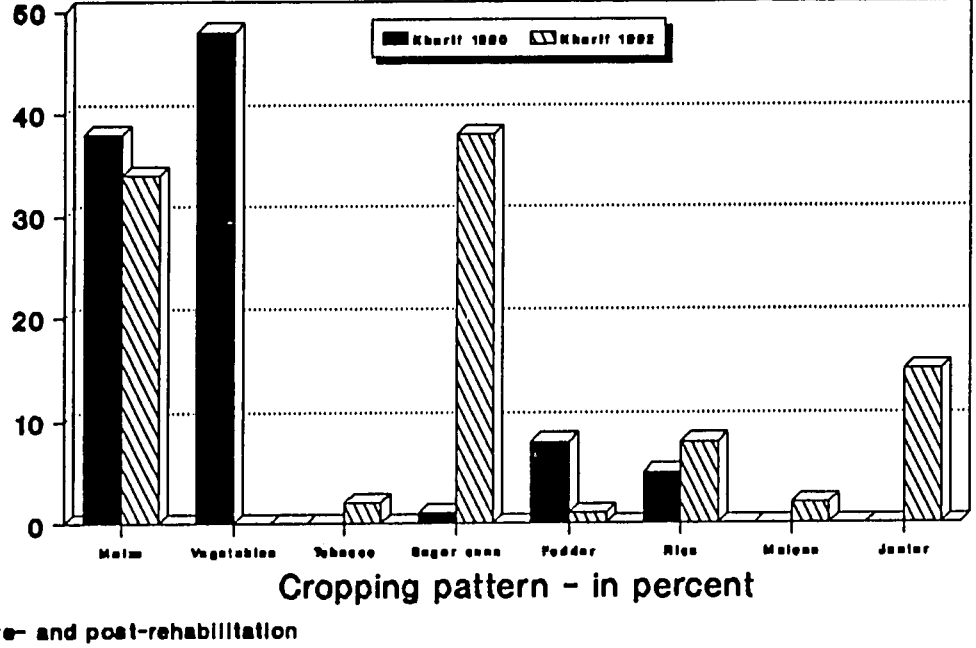
Figure 16



Pre- and post-rehabilitation

Cropping Pattern, Watercourse 8000-TF Chowky, Kharif 1990 and Kharif 1992

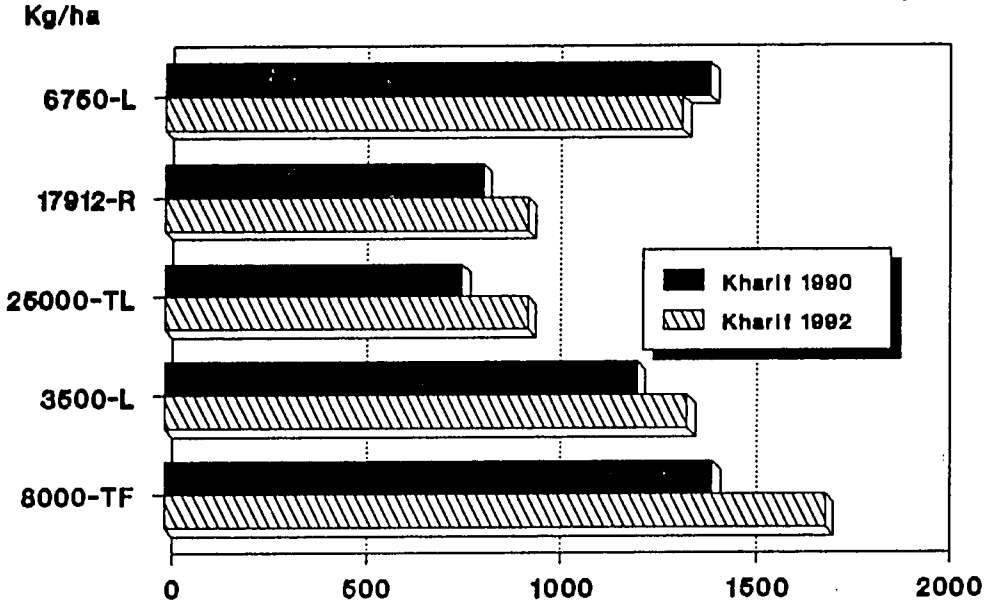
Figure 17



Pre- and post-rehabilitation

Yields of Maize, Chowky Watercourses Kharif 1990 and Kharif 1992

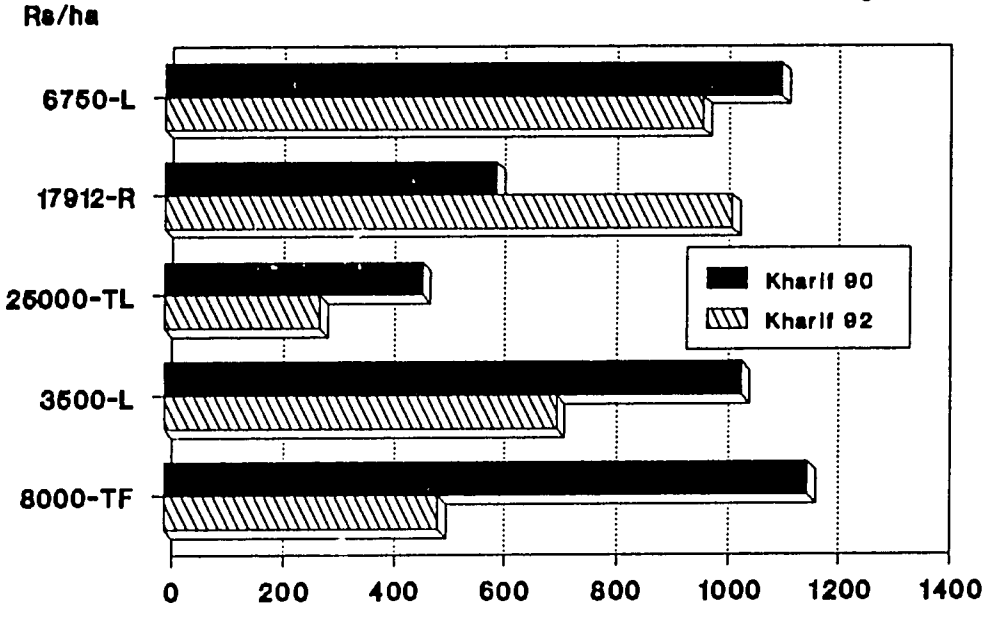
Figure 18



Pre- and post-rehabilitation

Value of Fertilizer on Maize; Chowky Watercourses;

Figure 19



Pre- and post-rehabilitation

Chapter Six

RECOMMENDATIONS FOR POST-REHABILITATION DATA COLLECTION AND REPORTING

Hydraulic data

Recommendation 1

ACOP should collect post-rehabilitation data during the 12 months immediately following completion of rehabilitation works. It is recommended that ACOP publish reports comparing pre- and post-rehabilitation status, and draw conclusions regarding the impact of rehabilitation works on project goals.

As mentioned in earlier chapters, the hydraulic data are designed to give direct measurements of the effect of canal rehabilitation on water equity, reliability and safety of water delivery. While there is some concern that the bulk of the rehabilitation expenditures in some canal subsystems, those spent on canal lining, in particular, are not designed to improve equity, reliability and safety, there is value in continuing to monitor the changes in canal performance after completion of rehabilitation.

Post-rehabilitation data collection and analysis are important for two reasons. First, post-rehabilitation data will aid in verifying the extent to which canal lining has an impact on conveyance losses and the equity of water delivery. Evidence from this study may support the Provincial Irrigation Department's claim that lining has a positive impact on water delivery in problem channels. Conversely, this study may show that lining has little impact on project goals. Either result will help in the planning and implementation of future rehabilitation projects, in that greater stress may be placed on a management approach to improving canal performance if lining proves to have little impact.

Second, the post-rehabilitation data will indicate the extent of project success at rectifying some of the serious problems caused by deferred maintenance. This includes repair of outlets, establishment of adequate freeboard, and desilting.

Recommendation 2

Two years after the post-rehabilitation data are collected and analyzed, ACOP should carry out another similar study to track the rate of deterioration of the rehabilitation works.

Inadequate or deferred maintenance is one of the main causes

of poor performance of Pakistan's irrigation system. Concerned with poor upkeep of thee irrigation and drainage system, agencies such as the World Bank have attempted to reach agreement with the Government of Pakistan to increase funding for canal maintenance. However, the frequency with which maintenance must be performed has not been established via field observations. As a consequence, costs associated with fully adequate maintenance are developed only indirectly.

The World Bank has sought to inject stepped-up maintenance funding targets into the conditions precedent for loan approval. Establishment of funding targets have been based on one of two approaches: 1) PIDs establish "yardsticks" to estimate maintenance costs, an approach which does not encounter the problem of accumulated deferred maintenance; and 2) past spending levels are used to estimate future levels.

ACOP, by conducting a study on the status of the rehabilitation works two or three years after completion, can contribute a third approach to estimating maintenance funding requirements. Comparison of post-rehabilitation data and data collected two years later can determine the rate at which the irrigation and drainage system deteriorates, and will provide a firm foundation for estimation of the magnitude of maintenance costs needed to arrest deterioration.

Agricultural Economics Data

Recommendation 1

WMED should complete the post-rehabilitation of Chowky Distributary and finish a report comparing pre- and post-rehabilitation agricultural economics indicators.

WMED has already completed data collection on the Chowky Distributary for the Kharif 1992 season and is currently collecting the data for Rabi 1992/93. Chowky is the one subsystem that offers some promise of producing interesting and worthwhile results from the agricultural economics data. The watercourses chosen in Chowky exhibit considerable variation. As was seen in Chapter 5, there is some evidence of change between the pre-and post-rehabilitation indicators for Chowky's Kharif season. Comparing Rabi data also will help to clarify to what extent canal rehabilitation may have an impact on the agricultural economy.

Recommendation 2

Post-rehabilitation data collection for other canal subsystems should not be initiated.

Data collection for other canal subsystems should not be initiated for reasons already alluded to earlier in this report. First, the watercourses chosen for the study in general do not reflect the full range of conditions in the command areas of the subsystems. For example, the outlet performance levels for 32 watercourses were very high, with only five, about 15 percent, receiving surface irrigation water below sanctioned discharge. This is not indicative of the actual performance of the universe of outlets. It is my view that there is little value in collecting data on watercourses which are not representative of the range of actual conditions. Conclusions or interpretations resulting from these data would not be valid.

In future, agencies involved in this type of data collection should reevaluate the use of random sampling procedures. It may be more appropriate to sample purposively, to guarantee that data are collected on watercourses which exhibit certain qualities.

Second, USAID funding for this activity is not available. Given that there is little value in collecting further data on this set of watercourses, it is not recommended that effort be applied to generating funding for the activity.