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FARM IRRIGATION CONSTRAINTS AND FARMERS' RESPONSES: COMPREHENSIVE FIELD SURVEY IN PAKISTAN

By Alan C. Early,
Max K. Lowdermilk,
David M. Freeman

Water Management Research Project
Colorado State University
Fort Collins, Colorado
September 1978

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Volume III

FARM IRRIGATION CONSTRAINTS AND FARMERS' RESPONSES: COMPREHENSIVE FIELD SURVEY IN PAKISTAN

VOLUME III

CONSEQUENCES OF THE PRESENT FARM WATER MANAGEMENT SYSTEM

Prepared under support of
United States Agency for International Development
Contracts AID/ta-c-1100 and AID/ta-C-1411
in cooperation with
Master Planning and Review Division
Water and Power Development Authority
Lahore, Pakistan

Prepared by

Alan C. Early
Max K. Lowdermilk
David M. Freeman

Water Management Research Project
Engineering Research Center
Colorado State University

September 1978

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ABSTRACT

The goal of an irrigation system is to distribute a sufficient volume of water such that it can be applied by farmers to the crop root zone soil moisture reservoir in required amounts and at the proper time for optimum production. Volume Two, after presenting an overview of the irrigation system and study design for approaching it, proceeded to detail the local legal system and constraints within which farmers labor. This volume, then, builds upon Volume Two by presenting findings having to do with outcomes or consequences of the existing system as it is presently structured. This volume is organized as follows:

1. Chapter One begins by comparing actual mogha discharges on sample watercourses to those which are authorized. One of the consequences of the existing system is that there are significant differences between prescribed and actual discharges. The discussion then turns to problems of watercourses, field ditches, and farm layouts; it concludes with a discussion of the generally poor level of watercourse maintenance.
2. Chapter Two treats delivery efficiency as a major consequence of the existing system and examines variation in sample farmer conveyance efficiencies by looking at associations with differences in water supply, farm watercourse position, soil type, and farmer behavior. Efficiency is examined in two major ways: 1) the losses between mogha outlet and sample farmer field nakka; and 2) the losses per thousand feet of watercourse distance.
3. Chapter Three focuses on a third set of consequences--the efficiency of water application to crop root zones. Explanatory

variables for this dependent variable include season and time of application, agro-climatic region, water supply situations, soil types, farm size, location on the watercourse, and farmer behavior.

4. Conveyance efficiency values, when combined with efficiency of water application, yield overall irrigation efficiencies. Irrigation efficiencies are the subject of Chapter Four and they are analyzed by many of the same independent variables employed in the two preceding chapters.

Chapters Five and Six examine consequences of the existing irrigation system as they are reflected in cropping patterns, cropping intensities, and yields of wheat, rice and cotton.

Water Management Research Project
Engineering Research Center
303/491-8216

Colorado State University
Fort Collins, Colorado
80523

September 11, 1978

Mr. Mian Mohammad Ashraf
Chief Engineer
Master Planning and Review Division
Water and Power Development Authority
Lahore, Pakistan

Dear Mr. Ashraf:

We are transmitting herewith our final reports in six volumes on the watercourse survey entitled "Farm Irrigation Constraints and Farmers' Responses: Comprehensive Field Survey in Pakistan." These volumes represent a tremendous amount of work by your organization, the U.S. Agency for International Development and Colorado State University. We have enjoyed the long standing working relationship and diligent efforts of your staff in completing this task.

As you are well aware, numerous members of your staff participated in the field data collection program report in these six volumes. At the same time, our field staff in Pakistan has spent numerous man-months in cooperatively accomplishing the field work and some of the initial data analysis. Most of the analysis has been done on the campus of Colorado State University in Fort Collins. Besides the authors of these reports, numerous university staff members have participated in the data reduction and analysis, as well as drafting the preparation of tables.

This study has consumed tremendous resources of this project, but we have felt the effort was worthwhile. Hopefully, your staff will also feel proud of this particular effort.

We sincerely appreciate your leadership in facilitating the completion of this effort and we look forward to continued cooperation in seeking to improve on-farm water management in Pakistan.

Sincerely,

Gaylord V. Skogerboe
Project Codirector

John O. Reuss
Chief of Party

W Doral Kemper
W. Doral Kemper
Project Codirector

UF-86

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251-A NEW MUSLIM TOWN, LAHORE.

No. MP/CE/S&R/Works/1W-WCS/6702

Date September 24, 1978

Mr. Mohiuddin Khan,
General Manager,
MP&RD., WAPDA,
WAPDA House, LAHORE

Subject: Report on "Farm Irrigation Constraints and Farmers' Responses".

I have the honour to transmit herewith the final report of comprehensive field survey carried out on 40 sample water-courses in Pakistan, jointly by Survey and Research Organization, WAPDA and Colorado State University. The survey work was under-taken under the provision of the Agreement No. 204-76-1 dated Nov. 7, 1975 signed between the Government of Pakistan & USAID.

The report presented under the title, "Farm Irrigation Constraints and Farmers' Responses: Comprehensive Field Survey in Pakistan" spreads over six volumes and is in fact a continuation of research work at Mona Reclamation Experimental Project on a wider area covering the entire irrigated area of Indus plains. The findings of this report further elaborate the new strategy that along with the development of present water resources, the prevailing wasteful irrigation practices beyond the outlet must be improved. This report contributes towards highlighting the social constraints in the field of water management thus providing sound guidelines for future planners.

It would not be out of place to mention that this survey made useful contribution in providing guidelines for the main Watercourse Chak Farming Survey Project to organize its activities in addition to providing trained staff and necessary equipment.

Nevertheless I wish to place on record my appreciation and thanks for CSU Field Party as well as Campus Staff, U.S. Agency for International Development who provided funds for this study and the staff of Watercourse Chak Farming Survey Project who made this monumental task a reality. I avail this opportunity to express my thanks for the interest and valuable guidelines provided by you from time to time without which it would have not been possible to accomplish this arduous task.

24-9-78

Mohammad Ashraf)
Chief Engineer,
Survey & Research Organization

ACKNOWLEDGEMENTS

Initiating, conducting, analyzing and reporting results of a field study of this size requires the skill and active cooperation of a large number of individuals. It is estimated that more than 30 man-years of planning, training, field work, data reduction, analysis, drafting and reporting have been contributed by Pakistani cooperators with the Water and Power Development Authority, Pakistani staff of Colorado State University in Lahore, part time staff of Colorado State University in Fort Collins, and Colorado State University principal investigators.

The authors wish to acknowledge the financial support of the United States Agency for International Development,[1] the cooperation of the WAPDA Master Planning and Review Division, Chief Engineer Mian Moh'd Ashraf, and Director of Watercourse Studies Chaudhry Rehmat Ali, the patience and endurance of the CSU Water Management Field Research Team in Pakistan and in Fort Collins, and Wayne Clyma, who helped initiate the original study of a single village near Lahore which ultimately led to this survey.

Special thanks is due to Waryam Ali Mohsin who helped throughout the survey from selection of personnel through data reduction and who inspired everyone associated with the survey to higher pursuits and greater efforts. The initial field team members who became supervisors in the later phase Allah Bakhsh Sufi, Abdul Rehman, Barkat Ali Khan and Nazir Ahmad, plus Zahid Sayeed Khan, Peter Joseph and A. R. Bhatti are due a special thanks for all their long hours of work put forth in

---

[1] The study was conducted with resources provided under Colorado State University contract with the United States Agency for International Development, Contract No. AID/ta-C-1411, supplemented by a USAID rupee grant--Watercourse Survey 204-87-1.

the cause. David A. Lauer deserves special mention for his substantial assistance in coding of the data and with establishment of a system for data management. Gail Woods and James Layton have contributed substantially to this report by virtue of their willingness to render additional assistance. In addition, we extend our deepest appreciation to all of those unnamed Pakistani farmers who so willingly gave of their time and energy to make this research effort possible.

We gratefully acknowledge the helpful review comments submitted by WAPDA personnel, Dr. John Reuss of the CSU Field Party, Dr. Michael Cernea of the Rural Development Division of the World Bank, and Mr. Ken Lyvers of USAID/Pakistan. The authors, of course, accept full responsibility for any errors of fact or interpretation.

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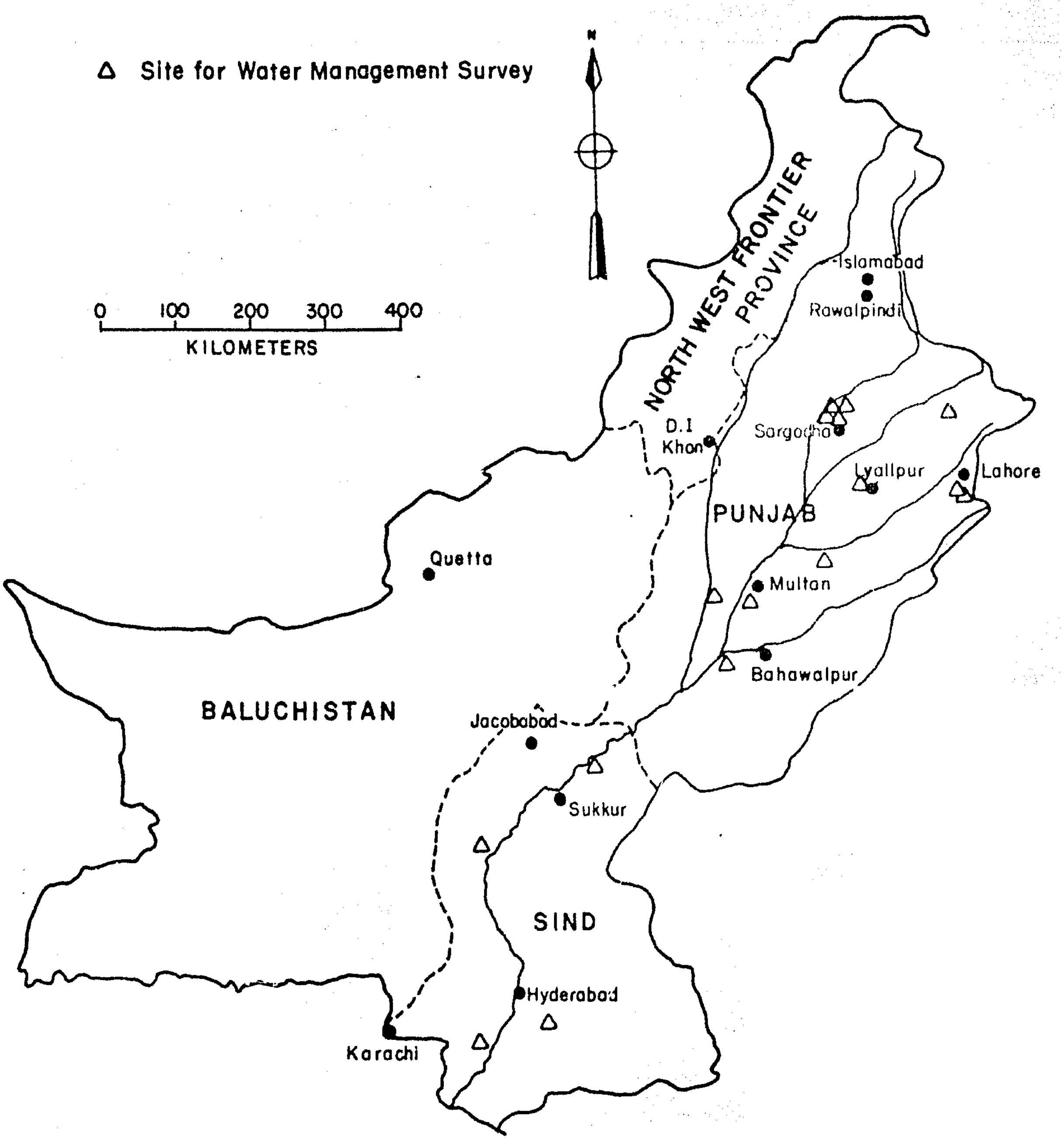

Figure 1. Distribution of 16 field survey sites.

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CHAPTER ONE

PHYSICAL AND SOCIAL CHARACTERISTICS OF THE IRRIGATION SYSTEM

I. ACTUAL MOGHA DISCHARGE AND PERCENT OF PRESCRIBED DISCHARGE

Moghas are the outlet openings that determine the volume of flow from the canal to the watercourse channel. The outlet size is fixed by the Irrigation Department, an Irrigation Department official--the Overseer--is charged with the responsibility for maintaining each mogha in accordance with prescribed specifications, and it is illegal for anyone to alter moghas without the express approval of the Irrigation Department. This section of Chapter One presents data comparing actual measured mogha discharges to the discharge prescribed by the Irrigation Department. It is important to note, however, that:

1. Whereas prescribed flows might well be above the measured flows due to the fact that a given canal is running less than full capacity, actual flows through the mogha should not normally exceed prescribed flows unless an unauthorized alteration has taken place;
2. The data presented reflect only one complete rotation of irrigation turns (warabundi) for a 168 hour period and do not represent measurements over a full cropping season or seasons. The measurements reported here are based on data gathered over 24 hour periods each day for seven consecutive days by flumes with time recorders.

Table 1 presents data comparing actual to authorized mogha discharges. The reader may examine Table 1 by comparing differences between type of canal on which the mogha is located (perennial/nonperennial) or by type

Table 1. Actual versus authorized mogha discharge (cubic feet per second).

Watercourse	Actual mean mogha discharge	Authorized mean mogha discharge	Difference
Perennial			
101-1	2.27	0.96	1.31
101-2+	2.18	1.43	0.75
102-1++	1.21	1.76	-0.55
103-1+	0.30	0.49	-0.19
104-1	1.97	0.74	1.23
104-2	0.88	0.50	0.38
104-3	0.28	0.26	0.02
106-1*	2.17	1.87	0.30
107-1++	1.85	2.15	-0.30
107-2++	2.13	1.76	0.37
107-3++	1.04	1.17	-0.13
109-1*	1.14	1.11	0.03
109-2*	1.74	1.13	0.61
110-1++	0.70	2.14	-1.44
110-2++	1.54	1.35	0.19
112-1	2.66	missing	missing
112-2	0.41	0.38	0.03
112-3	1.70	0.77	0.93
113-1	0.57	0.76	-0.19
113-2	1.76	1.43	0.33
113-3	1.41	1.36	0.05
116-1	0.84	2.50	-1.66
116-2	0.98	2.08	-1.60
116-3	0.54	1.09	-0.55
116-4	0.46	0.50	-0.04
$\overline{X}$ =	1.39	1.30	
SD =	.70	.64	

Watercourse	Actual mean mogha discharge	Authorized mean mogha discharge	Difference
Nonperennial			
105-1*	1.99	2.19	-0.20
108-1*	2.86	3.00	-0.14
111-1*	missing	2.36	missing
111-2*	missing	1.90	missing
114-1	0.66	1.06	-0.40
114-2	1.11	1.73	-0.62
114-3	0.98	1.06	-0.08
114-4	0.91	1.19	-0.28
115-1	0.83	0.74	0.09
115-2	0.48	0.35	0.13
115-3+	0.74	0.97	-0.23
115-4	1.27	0.77	0.50
115-5+	0.76	0.71	0.05
115-6	0.79	1.02	-0.23
$\overline{X}$ =	1.15	1.47	
SD =	0.67	.75	
110-3++	No mogha - noncommanded		

Correlation between actual and authorized mogha discharges, Pearson's r

Overall	.52(339)
Perennial	.34(244)
Nonperennial	.93(95)
Public TW*	.92(43)
Private TW+	.79(152)
Heavy Density++	.36(79)
Private TW's (6+)	

*Public tubewells on watercourse

+Private tubewells on watercourse

++Six or more private tubewells on watercourse of supplementation of canal supplies (public and private tubewells). Given the lack of time series data, it is not possible to reach conclusions about why there is a higher coefficient of correlation between actual and authorized discharges on nonperennial watercourses as compared to perennial ones or why the correlation between actual and authorized discharges is lower for those watercourses with a heavy private tubewell density than for other commands.

One factor which affects mogha discharge is mogha submergence due to a high watercourse elevation relative to the mogha. Moghas which have problems of submergence are those at 102-1, 107-2, 107-3, 110-1, and 110-2 (see Figures 3, 11, 12, 16 and 17, Appendix II, Part A, Section 3, Volume VI for watercourse slope profiles).

Given the relatively high standard deviation values on Table 1, and the operation of a complex set of variables uncontrolled in this study, further research employing time series data will be necessary to sort out the factors explaining variability of differences between actual and authorized mogha discharges.

Table 2 presents data showing the difference in mogha discharge factors in cubic feet per second per one thousand acres of land. The actual discharge factor represents the actual mogha discharge per thousand acres calculated as a quotient:

$$1000 \times \frac{\text{Actual mean mogha discharge (weighted by time)}}{\text{Actual measured cultivated command area}}$$

The authorized discharge factor represents the Department of Irrigation prescribed mogha discharge per thousand acres also calculated as a quotient:

$$1000 \times \frac{\text{Mogha discharge authorized by Irrigation Department}}{\begin{array}{l}\text{Authorized culturable command area as determined from}\\ \text{Irrigation Department records}\end{array}}$$

Table 2. Distribution of discharge factor values (cusecs per thousand acres).

Watercourse	Authorized discharge factor	Actual discharge factor	Actual potential discharge factor	Gross potential discharge factor
Perennial				
101-1	2.89	5.22	5.22	5.22
101-2+	3.24	5.91	9.15	9.15
102-1++	3.27	2.29	9.11	9.11
103-1+	4.41	2.34	7.03	7.03
104-1+	4.68	12.16	12.16	12.16
104-2+	3.03	5.15	8.65	20.35
104-3	4.48	6.22	6.22	6.22
106-1*	3.39	4.41	7.05	7.05
107-1++	3.34	2.26	13.88	13.88
107-2++	3.33	3.35	10.90	10.90
107-3++	3.32	3.54	13.74	13.74
109-1*	2.84	3.29	6.47	6.47
109-2*	2.88	5.37	8.46	8.46
110-1++	4.55	1.96	30.53	30.53
110-2++	4.55	3.68	16.56	16.56
112-1	missing	3.31	3.31	3.31
112-2	2.73	5.94	5.94	5.94
112-3	2.80	6.69	6.69	6.69
113-1	3.30	3.70	3.70	3.70
113-2	3.83	7.01	7.01	7.01
113-3	3.33	4.59	4.59	4.59
116-1	14.62	11.35	11.35	11.35
116-2	9.59	4.49	4.49	4.49
116-3	4.41	1.99	1.99	33.05
116-4	4.72	8.85	8.85	8.85
$\overline{X}$	3.82	4.82	10.73	11.81
SD	1.42	2.67	8.17	8.71

*Public tubewells
+Private tubewells
++Heavy density of private tubewells

Watercourse	Authorized discharge factor	Actual discharge factor	Actual potential discharge factor	Gross potential discharge factor
Nonperennial				
105-1*	4.29	3.92	7.48	7.48
108-1*	5.85	5.64	11.56	11.56
111-1*	7.74	missing	7.66	7.66
111-2*	5.19	missing	7.66	7.66
114-1	5.52	3.93	11.07	11.07
114-2	5.51	3.59	3.59	3.59
114-3	5.52	3.94	3.94	3.94
114-4	5.51	4.84	4.84	4.84
115-1	6.02	7.16	7.16	7.16
115-2	6.14	9.06	9.06	9.06
115-3+	6.10	10.57	19.14	19.14
115-4	6.75	14.60	14.60	14.60
115-5+	5.77	7.84	20.21	30.52
115-6	6.00	4.27	7.51	12.92
$\overline{X}$	5.86	6.27	9.15	9.99
SD	.89	3.13	4.91	6.61
Noncommanded				
110-3++	no mogha	no mogha	40.34	40.34

Single correlation between authorized and actual discharge factors (Pearson's r)

	N
Overall	.29(330)
Perennial	.08(235)
Nonperennial	.70(95)
Public TW	.54(93)
Private TW	.54(152)
Heavy Density	-.06(79)

Simple correlation between authorized and actual discharge factors (Pearson's r)

	N
Overall	.039 (389)
Perennial	.032 (270)
Nonperennial	.120 (119)
Public TW	.356 (67)
Private TW	.462 (152)
Heavy Density	.790 (79)

The actual potential discharge factor represents the following quotient:

$$\frac{\text{Actual mogha discharge} + \text{discharge of all public and private tubewells*}}{\text{Authorized culturable command area as determined from Irrigation Department records}} \times 1000$$

The gross potential discharge factor equals:

$$\frac{\text{Actual mogha discharge} + \text{discharge of public \& private tubewells} + \text{discharge of illegal moghas**}}{\text{Authorized culturable command area as determined from Irrigation Department records}} \times 1000$$

The analysis of Table 2 data is severely constrained by the lack of time series data. There is a low overall correlation between actual and authorized discharge factors. The relationship drops on perennial watercourses, but is strong on nonperennial watercourses. When one examines the correlation between authorized and gross potential discharge factors (see Table 2), one finds no association overall on perennial and non-perennial watercourses. Yet for watercourses with public, private, and a high density (six or more) of private tubewells the relationship becomes positive and strong.

Table 3 provides information regarding the actual average time in minutes for each irrigation turn (warabundi) and the authorized time on a per acre basis. It is interesting to note that for 377 farms evaluated, the simple correlation between actual and authorized minutes per acre is a .86. Yet there is much variation among farms on a given watercourse command area. Many variables influence the actual time consumed in a given irrigation--e.g., the power and influence of the irrigator, season

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*The rate of discharge of private tubewells is assumed to be 0.6 cusecs. The rate of discharge of public tubewells was measured at the well during field irrigation evaluations.

**The rate of discharge of each illegal mogha is assumed to equal one cubic foot per second.

Table 3. Actual versus authorized warabundi time.

Watercourse	Actual average warabundi time/acre	Authorized average warabundi time/acre
Perennial		
101-1	23.0 x	30
101-2+	27.3	23
102-1++	19.1	19
103-1+	78.8	91
104-1+	62.2	64
104-2+	58.9	61
104-3✓	224.0	174
106-1*	20.5	18
107-1++	14.5	16
107-2++	15.8	19
107-3++	34.3	29
109-1*	29.1	26
109-2*	31.1	26
110-1++	28.2	21
110-2++	24,1	34
112-1	12.5 x	22
112-2✓	146.1	73
112-3	39.7	37
113-1✓	65.5	44
113-2✓	40.2	27
113-3✓	32.8	25
116-1✓	136.2	59
116-2✓	94.2	46
116-3	37.1	41
116-4✓	193.8	95
$\bar{X}$	51.85	40.84
SD	44.60	29.18

Watercourse	Actual average warabundi time/acre	Authorized average warabundi time/acre
Nonperennial		
105-1*	19.9	20
108-1*	19.9	20
111-1*	45.4	33
111-2*	45.4	28
114-1	60.0	53
114-2	32.0	32
114-3	40.5 x	53
114-4	53.6	47
115-1	86.9	82
115-2	190.2	177
115-3+	144.0	53
115-4	115.9	79
115-5+	103.9	82
115-6	54.5	59
$\bar{X}$	67.0	54.54
SD	47.67	38.19
Noncommanded (no canal water)		
110-3++		no mogha

*Public tubewells

+Private tubewells

++Heavy density of private tubewells (six or more)

✓(Act > auth) = (Act CCA < Auth CCA)

104-3 Has much smaller area served than authorized because all of the water must be lifted by jhallar.

112-2 Has much smaller area served than authorized because of a significant high area near head of watercourse command area due to unlevel land.

113-1
113-2 .....due to large uncultivated waterlogged area near mogha
113-3

116-1 .....due to large uncultivated waterlogged areas in command
116-2 (116-3 is not affected as much, has the Brohi Baluch farmers
116-4 and 6+ illegal moghas).

115-3
115-4 .....due to large uncultivated areas
115-5

x(Act < Auth) = (Act CCA > Auth CCA)

101-1 Farmers have expanded command area

112-1 Hugh areas expanded beyond original planned CCA

114-3 " " " " " " "

of the year, quantity of water in the canal system, and trading arrangements.

II. WATERCOURSE AND FIELD CHANNEL LENGTH AND FARM LAYOUT CHARACTERISTICS

This section focuses on several characteristics of watercourse and field channels, layouts of farms and fields of both sample and nonsample farms on the 40 sample watercourse command areas.

Farmers in Pakistan face a number of constraints in applying water to their fields---unreliable canal supplies, lack of technology for adequately leveling fields and for improving the inefficient main watercourses. There is also a problem, in some areas, of land fragmentation which results in many widely scattered noncontiguous land units, each with its separate irrigation time. Farmers respond to these constraints in several ways, some of which are ingenious. For example, they construct small basins for increased water control. Small bunded units are more amenable to leveling with available techniques. Because the fields are small, farmers also must create an intricate maze of small field channels. Many nakka cuts are required to divert water onto fields that often have excessive elevation differences within them. Given short supplies of water, farmers often are forced to engage in extra-legal activities such as creating illegal moghas and cutting nakkas into the main watercourse channel to irrigate problem fields. Also, where fields with topographical problems are best served by private tubewells, it is both a common and a rational practice for farmers to violate legal regulations and trade canal water for tubewell water. When tubewell water is traded it is usually not on a par basis in terms of minutes due to differences in discharge rates between tubewells and the canal mogha and due to perceived differences in water quality. Farmers also develop other approaches to obtain more water.

These are discussed in some detail in Volume V. Any long term observer of Pakistani farmer responses to their physical and legal constraints imposed by the present irrigation system must marvel at their sagacity. This study has confirmed an earlier observation that at the farm level in Pakistan the farmer is presently the "expert" in irrigation.

A. Watercourses, Watercourse Command Areas and Field Channel Length

Measured lengths of the total main and branch watercourses plus field channel length in miles are shown in Table 4. The total miles of watercourse and field channel length for the 11,864 acres of cultivated land for the 40 sample commands is 371.5 miles or an average of about 9.29 miles per command area. The cultivated acreage for the individual command areas vary radically as well as the miles of watercourse and field channels. Note, for example, the small cultivated acreages of watercourse commands 103-1, 104-1, 104-2, 104-3 and especially the noncommanded area of site 110-3. The site at 103 has only 130 acres primarily because it is a jhallar lift command where all canal supplies have to be lifted from the main watercourse to irrigate this small acreage. Jhallar lifts usually average only about .2-.3 cusecs of discharge depending on the variability of both animals and men. Site 104 watercourse commands are small because they are located at the tail of a distributary where water supplies are usually very low. Watercourse 104-3 is like 103-1 in that all water is lifted by jhallar to serve the land. At this site farmers often cut directly into the rajbah or distributary to receive scarce supplies. Picture Glossary Figure 11M shows where this was done. These data suggest that there is hardly a typical watercourse command in Pakistan. Even at village sites as 107, 110 and others we note great variations in size of commanded area and miles of conveyance channels.

Table 4. Actual gross cultivated area and total watercourse length (main and branch watercourse plus field channel length) for 40 sample watercourse sites.

WC command site	Actual gross cultivated area (acres)	Total watercourse length (miles)	WC command site	Actual gross cultivated area (acres)	Total watercourse length (miles)
PERENNIAL			NONPERENNIAL		
101-1	448	14.05	105-1	571	14.75
101-2	455	13.47	108-1	519	12.15
102-1	538	13.34	111-1	333	7.27
103-1	130	4.55	111-2	241	9.09
104-1	165	3.73	114-1	170	3.74
104-2	216	4.25	114-2	365	9.44
104-3	83	1.58	114-3	295	4.31
106-1	515	17.04	114-4	198	5.55
107-1	742	42.30	115-1	121	4.07
107-2	684	30.24	115-2	62	1.76
107-3	303	18.63	115-3	75	2.02
109-1	349	11.46	115-4	101	2.93
109-2	324	12.28	115-5	104	2.68
110-1	361	8.79	115-6	233	7.17
110-2	419	8.06			
112-1	1377	15.12	NONCOMMANDED AREA		
112-2	145	2.37			
112-3	952	8.45	110-3	119	5.42
113-1	274	15.63			
113-2	407	5.23			
113-3	468	11.40			
116-1	213	3.32			
116-2	219	5.42			
116-3	282	7.03			
116-4	115	2.73			

A striking fact from Table 4 is not only the variation but the actual miles of channels. The mean and median miles of the conveyance system from the mogha to the last farm on the command areas respectively are 9.3 and 7.2 miles. The range, however, is 1.6 miles at 104-3 site to 42.3 miles at site 107-1. Likewise, when one thinks in terms of the average cultivated acreage for command areas one must realize that the ranges are as extreme as 45 acres at site 104-3 site to 695 acres at 107-1 site. There are too many special cases to assume that the typical command area in Pakistan is 400 acres as we did in the introduction of this report. When one speaks of an average or typical command area he must use the same caution as speaking about average weather or average water supply situations.

Table 5 provides summary data about watercourse and farm characteristics to be examined in this section of the report. This table shows total cultivated acreage for commands at 16 village sites and information about watercourse length, nakka cuts, bunded units and number of parcels per site. Figure 2 shows the authorized cultivatable command area (CCA) as compared with the actual CCA. Note that at all sample sites, except 102, 104, 105, 106, 108, 109, 111, 112, 113, 115 and 116, farmers are cultivating more than the authorized CCA. Where possible, given private supplemental tubewell water in addition to canal supplies, farmers attempt to extend their cultivated acreages as much as possible. Two of these sites, 107 and 110, have a combined total of 40 private tubewells and have the largest CCA extension. At sites 102, 105 and 109, there are fields which are too high for irrigation by gravity from public tubewell and canal water supplies. Site 106 has a considerable area at the tail influenced by salinity and waterlogging and 111 has nonperennial supplies.

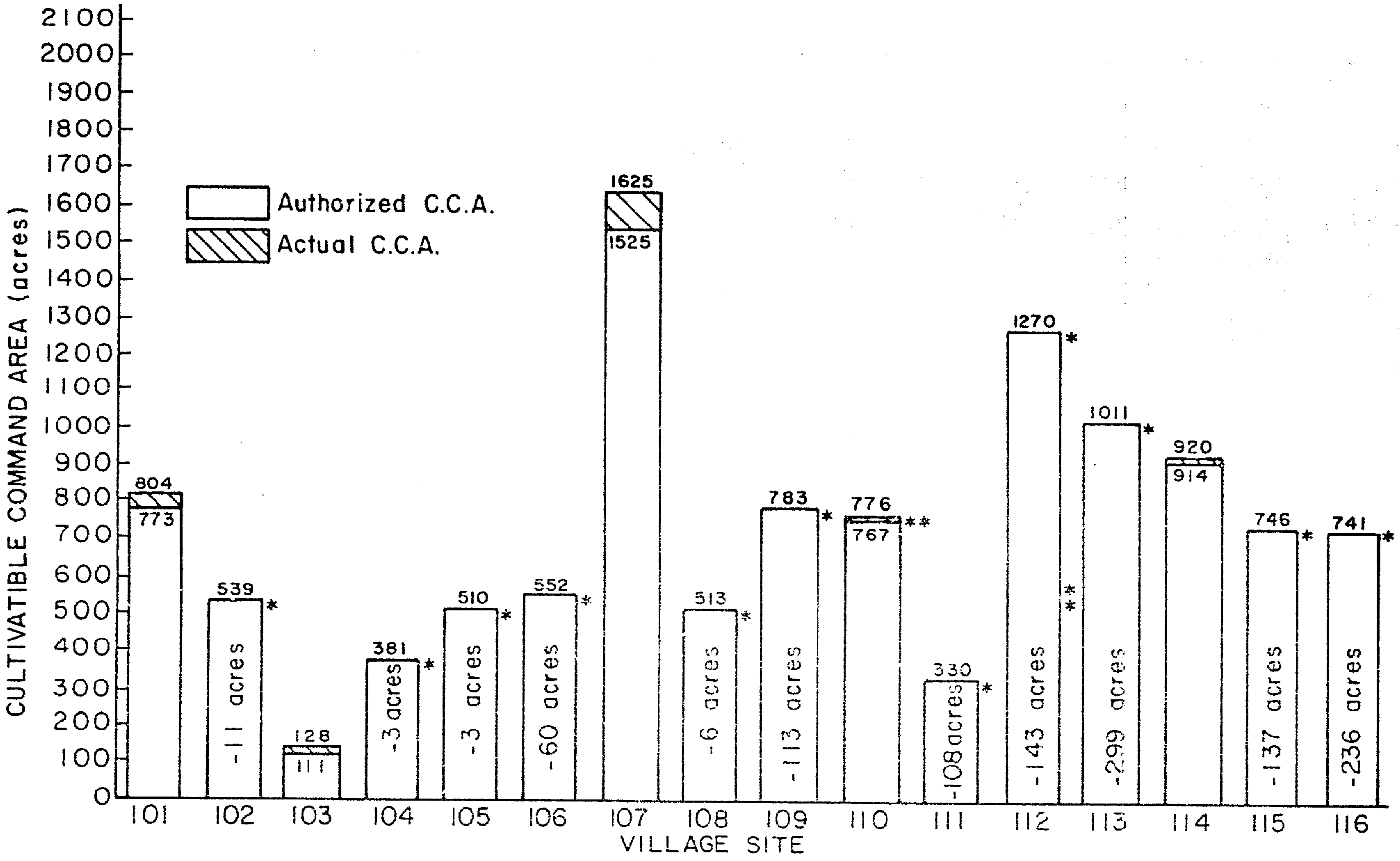
TABLE 5. Village level summary data--watercourse characteristics

Village	Number of water-courses (WC)	Number of farms	Number of separate parcels	Actual gross command area (acres)	Total water-course length (miles)	AGCA acres per WC length	Number of nakka cuts	Number of bunded units	Total barren	Total acres
101	2 wc	15	205	903	27.52	33	2576	3921	99	1002
102	1 wc	9	34	538	13.53	40	1719	983	10	548
103	1 wc	16	27	130	4.48	29	438	616	2	132
104	3 wc	36	48	464	9.56	49	783	636	86	550
105	1 wc	8	54	571	15.50	37	1007	968	64	635
106	1 wc	12	110	515	16.25	32	1403	1044	23	538
107	3 wc	55	588	1729	91.17	19	5714	4982	104	1833
108	1 wc	9	35	519	12.15	43	1162	923	12	531
109	2 wc	14	71	673	23.74	28	2553	1266	3	676
110	3 wc	27	157	899	21.84	41	2393	1939	4	903
111	2 wc	24	25	574	16.36	35	1420	1024	130	704
112	3 wc	34	64	1974	25.94	76	1931	1466	847	2821
113	3 wc	26	52	1149	32.26	36	1717	1444	437	1586
114	4 wc	39	71	1028	23.04	45	2319	2317	108	1136
115	6 wc	39	67	696	20.63	34	1780	1751	88	784
116	4 wc	26	22	829	18.50	45	1919	1718	330	1159
Totals	40 wc			13,191	372.47	35.4**	30,834	26,998		
Totals* for 40 wc				329.8	9.31		771	675		

**Obtained by dividing the total area cultivated (13,191 acres) by the total watercourse length (372.47 miles).

*Not Weighted

FIGURE 2. AUTHORIZED C.C.A. VERSUS ACTUAL C.C.A. IN ACRES FOR COMMANDS AT VILLAGE SITES



*At 102, 104, 105, 106, 108, 109, 111, 112, 113, 115, and 116 Sites Farmers Cultivating Less than the Authorized C.C.A. Due to a Number of Factors such as Sand Dunes, Salinity, Water Logging or Lack of Water.

**WC 110-3 Deleted; WC 112-1 Deleted

The mean cultivated acreage per mile of watercourse and field channel length as shown in Table 5 is about 35.4 miles. The median is a little over 30 acres per mile of conveyance channels. This suggests a major problem in routing water to fields and a high potential for watercourse losses. Several factors make it necessary for farmers to develop the intricate patterns of lengthy conveyance channels. Land fragmentation, topographical problems of high fields, and small discharges of water, especially at tails of command areas, are major factors involved. These are described in the remainder of this section.

B. Land Fragmentation on Watercourse Commands

Fragmentation of holdings refers to the noncontinguous parcels of land which comprise farm units. While the data in Table 5 summarizes the information on separate parcels it must be remembered that these data refer only to sample command areas. Farmers also have other parcels on nearby command areas. At site 107 some farmers had parcels two to three miles or more apart. Fragmentation is a problem for farmers because: it makes for wastage of time and labor; extra expense is incurred in moving people, animals, seed, fertilizer, equipment and produce from one field to another; the problem of securing crops from thieves and predators is exacebrated; land is wasted in excess bunds, banks, boundaries and field ditches; mechanization is constrained by small size of fields and problems of field access; irrigation water is lost through dead storage and leakage in long irregular conveyance channels.

Table 6 shows the degree of land fragmentation on 307 reporting sample farms. Earlier data about separate parcels is reference to all farms on the 40 commands. The mean number of parcels is about 2 for

Table 6. Mean, median and range of parcel size for sample farms by sample farm size and tenure classes.

Farm size classes (acres)	No.of farms reporting	Mean	Median	Range*
Under 2.5	53	1.7	1.4	1-7
2.5 - 7.49	82	1.9	1.5	1-5
7.5 - 12.49	74	2.5	2.0	1-21
12.5 - 24.99	74	2.1	1.5	1-11
25.0 - 49.99	17	2.4	2.0	1-6
50.0 and over	7	3.7	2.8	1-10
Totals	307	2.1		1-21
<u>Tenure classes</u>				
Owner-operators	215	2.1	1.6	1-21
Owner-cum-tenants	46	2.2	2.0	1-6
Tenants	46	2.0	1.4	1-7

*Range of separate parcels for the farms in each farm size category.

farms under 25 acres and 3 for the 24 farms with 25 acres or more of cultivated holding. However, for some individual farms there are as many as 7 or more separate parcels. For example, of the sample farms of the 7.5-12.49 acre class size, one has as many as 21 separate parcels. When tenure classes are examined in relationship to land fragmentation, little difference is noted. All classes have both a mean and median of approximately two separate or noncontiguous parcels. One owner operator, for example, has 21 separate parcels which presents major problems.

According to an earlier study where farmers have separate parcels on a watercourse command area with a pucca warabundi system, "There is no flexibility possible... and if a farmer has fragments in squares which are watered on separate days, he must have a crop in a part or whole of each fragment in order to use the water available to him during that squares' irrigation (Gibb, 1966, Vol. 10:5). This statement does not usually hold in practice because farmers have evolved a system of trading irrigation turns as a means to partially overcome this constraint. During the survey, investigators observed several types of water trading systems in operation. The pucca, "inflexible distribution system," is actually quite flexible in practice. On some commands, the rozewari method is used where water is allotted to a square or large block of land on the pacca warabundi system within which farmers allocate water on an informal basis. We also observed that where farmers have not worked out informal trading agreements much water is lost in conveyance due to seepage, leaks, spills, and dead storage. Water often does not follow a systematic route from mogha down the command area from square to square. Other studies have shown that farmers lose much water by moving water back and forth between sections of the command area using their warabundi turn on the parcel of land whose crop is most in need of the water (Kemper et al., 1975). Observations show that this is often practical where farmers have a number of separate parcels to irrigate. Engineers, making irrigation evaluations on the survey, were often perplexed when they reported to farms to conduct evaluations where irrigations were scheduled according to the pucca warabundi only to find that the schedule was not being followed. The theory that farmers seldom trade irrigation turns on the pucca warabundi system is not correct. Trading of turns during the survey became such a problem that the sampling procedures had to be changed. At sites 101 to 110, irrigation evaluations were made after the sample was randomly selected and interviews conducted. Several return trips had to be made to sample farms to complete evaluations. About one sixth of the farms were not evaluated because engineers could not find the farmer irrigating during his turn. This problem was solved later in the survey as engineers learned to follow the water up and down stream as it was diverted to meet farmers' demands and overcome problems of land fragmentation.

Overall, for the 40 command areas, fragmentation of holdings does not appear to be a major problem for improvement of farm design and precision land leveling. Table 7 provides a summary of the separate parcels for each village site by perennial and nonperennial commands. The average number of separate parcels for all farms on the 40 commands is only two per farm, the median is also two and the range is from 1 to 21. Note that the average parcel size is 5.6 acres. Parcel size represents a key variable affecting the adoption of precision land leveling. Parcel size determines the ease of use of tractor drawn soil scrapers

Table 7. Summary data on farm size and land fragmentation for total area in commands at village sites (includes sample and nonsample farms unless otherwise designated).

Command type and village site	Actual Gross Cultivated Area (acre)	Number of farms	Average farm size (acres)	Number of separate parcels	Average No. of parcels per farm	Average acres per separate parcels
Perennial						
101-2 wc	981	88	11.1	205	2.3	4.8
102-1 wc	522	34	15.4	34	1.0	15.4
103-1 wc	149	17	8.8	27	1.6	5.5
104-3 wc	411	22	18.7	48	2.2	8.6
106-1 wc	540	51	10.7	110	2.2	4.9
107-3 wc	2054	427	4.8	588	1.4	3.5
109-2 wc	730	46	15.9	71	1.5	10.3
110-3 wc	1032	107	9.6	157	1.5	6.6
112-3 wc	1974	26*	75.9*	64*	2.5	30.8*
113-3 wc	1149	24*	47.9*	52*	2.2	22.1*
116-4 wc	829	18*	46.1*	22*	1.2	37.7*
Nonperennial						
105-1 wc	458	36	12.7	54	1.5	8.5
108-1 wc	561	28	20.0	35	1.3	16.0
111-2 wc	574	15*	38.3*	25*	1.7	23.0*
114-4 wc	1028	36*	28.6*	71*	2.0	14.5*
115-6 wc	696	36*	19.3*	67*	1.9	10.4*

*Denotes only sample farms (not total farms).

and planers. Existing farm units of five or six acres in size can be developed into more efficient units for irrigation by reducing the number of small basins and simultaneously returning to production valuable land area required presently for bunds and farm conveyance channels. The parcels in villages 102, 108, and 109 are larger because these villages were settled about 1948--much later than most other villages. Village sites 108 and 109 also have a larger percentage of larger landlords than other sites.

The largest and smallest noncontiguous parcels of sample farms were measured. Table 8 provides these data by village site. Modal frequencies are underlined for both largest and smallest separate parcels for each sample village site. This information is relevant for land leveling, especially for the design of more efficient farms for improved irrigation practices. Our interest is in the percentage frequencies for each separate parcel size interval and these values can be inspected in Table 8. Sites 102 and 109 have the highest percentage of sample farms, the largest parcels of which are in 10-15 acre range. The 102 site was primarily settled at partition (after 1947), and the Cooperative Farming Society provided refugees holdings of 12.5 acres each with one condition that that parcel not be divided when inherited by heirs. Site 109 is one where 50 percent of the farms are owned by farmers with holdings of 25 acres or more. Village sites with farms having a majority of largest parcels in the 5 to 10 acre category are sites 104, 105, 107, 108, 110, 112 and 113. A precision land leveling program with the purpose of leveling fields and designing larger farm irrigation units is very feasible. Of the 40 command areas, 23 have a majority of farms with separate parcels over 5 acres in size

Table 8. Percentage distribution of farmers by parcel size for each village site on the basis of largest and smallest parcels**

Village site	# Parcels N	LARGEST PARCEL PARCEL SIZE (ACRES) ≤2.5	2.6-5.0	5.1-10.0	10.1-15.0	15.1-25.0	25+	SMALLEST PARCEL (PARCEL SIZE (ACRES) ≤1	1.1-2.0	2.1-3.0	3.1-4.0	4.1-5.0	5.1-10.0	10.1-15.0	15.1+
101-2 wc	15	13.3%	20.0%	20.0%	20.0%	26.7%	-%	53.3%	-%	-%	6.7%	6.7%	6.7%	20.0%	6.7%
102-1 wc	9	-	-	11.1	44.4	22.2	22.2	-	-	-	-	-	11.1	44.4	44.4
103-1 wc	16	37.5	25.0	12.5	12.5	12.5	-	12.5	25.0	18.8	12.5	-	12.5	12.5	6.3
104-3 wc	12	8.3	25.0	25.0	25.0	16.7	-	6.7	40.0	-	6.7	13.3	6.7	6.7	20.0
105-1*wc	2	-	-	50.0	-	-	50.0	-	-	-	-	-	50.0	-	50.0
106-1*wc	12	-	58.3	25.0	-	16.7	-	25.0	25.0	33.3	8.3	8.3	-	-	-
107-3 wc	55	30.9	30.9	34.5	1.8	1.8	-	40.0	9.1	5.5	9.1	10.9	21.8	1.8	1.8
108-1*wc	9	-	-	33.3	22.2	33.3	11.1	11.1	-	-	-	-	44.4	11.1	33.3
109-2*wc	13	15.4	7.7	15.4	38.5	-	23.1	7.7	7.7	7.7	7.7	15.4	7.7	30.8	15.4
110-3 wc	25	12.0	16.0	48.0	8.0	8.0	8.0	36.0	4.0	8.0	8.0	8.0	24.0	4.0	8.0
111-2*wc	17	52.9	11.8	11.8	11.8	-	11.8	44.4	16.7	5.6	-	-	11.1	11.1	11.1
112-3 wc	25	4.0	28.0	36.0	12.0	20.0	-	44.4	12.0	-	8.0	-	28.0	4.0	4.0
113-3 wc	21	4.8	4.8	47.6	19.0	19.0	4.8	4.8	9.5	14.3	19.0	-	28.6	14.3	9.5
114-3 wc	34	26.5	32.4	11.8	17.6	11.8	-	55.9	5.9	5.9	8.8	5.9	5.9	5.9	5.9
115-6 wc	38	47.4	21.1	13.2	5.3	5.3	7.9	60.5	10.6	7.8	5.3	2.6	-	2.7	10.5
116-4 wc	17	41.2	23.5	29.4	-	-	5.9	11.8	17.6	17.6	23.5	5.9	17.6	-	5.9
Totals	320	23.8	22.5	26.3	12.2	10.3	5.0	34.5	11.1	7.8	8.7	5.5	15.2	8.0	9.1

*Denotes commands supplied with public tubewells.

**Modal categories are underlined for both largest and smallest parcels for each sample village site.

which could be redesigned into more efficient irrigation units. Small parcels, however, will remain unless there is a stronger emphasis given to land consolidation programs. Farmers, however, can benefit even with such small units, if small and appropriate technologies are made available for improved land leveling. In Pakistan, to date there has been insufficient attention given small scale technologies for either land leveling or other farm operations. Observation and experience in operating these small units show, due to the lack of long equipment runs and many field corners to negotiate, that both plowing and other operations leave small areas either untilled or poorly tilled for good seedbed preparation. The information presented in Table 8 shows that there is a substantial potential for improving the scale of farm units by improving the present layout or design of farm units. Longer runs with fewer irrigation channels and bunds not only result in a saving of land but also in more control of irrigation water for more efficient irrigation practices.

C. Irrigation Basin Size

The size of the irrigation basins, or bunded units, used for flood irrigation in Pakistan are influenced by a number of factors: water supply, the position of the farm in the command area, soil types, watercourse slope, field topography, farm size and type of crop. Many of these factors are interrelated and combine to make the type of water supply situation and the volume of water discharged critical variables. The basins are usually only about .2 to .4 of an acre in size because farmers have learned that such small basins are necessary to distribute small volumes of water over land leveled by guess work. Larger basins are not feasible under present conditions because with typical small supplies of water it is difficult to cover unlevel areas. Table 9 provides information on the size of bunded units by site categorized into perennial and nonperennial commands. The percentages of bunded units are cummulative for each interval size expressed in tenths of an acre. The percentage is underlined where 50 percent or more of the cases fall in the median category. Of the almost 27,000 bunded units for 40 commands or 11,865 cultivated acres there is an average of about 2.3 bunded units per acre. Note that those sites which have a majority of basins in the .5 < .6 size, category and larger, tend to be supported by public and private tubewells. At site 103, for example where the majority of farms fall in the .1 < .2 acre basin interval, there is only one small private tubewell. At this site all canal water is lifted by jhallars to irrigate these small basins. A jhallar lift probably will average a volume of .2 to .3 cusecs over time, depending on the power of animals. Sites 116, 115 and 114[1/] have no public tubewell supplements to the canal supply and the last two mentioned sites have 10 nonperennial commands on which a high frequency of Persian wells exists. The bunded units must be small to be served by the 0.04 to 0.10 cusec discharge. It is interesting that of those village sites where about 15 percent or more of the farms have basins in the range of one or more acres--106, 109, 104, 110, 112, 105, 108 and 111--all except 104 and 112 have public tubewell supplies or a high density of private tubewells (110).[2/]

[1/] At site 116 there are no tubewells and for the 10 command areas at sites 114 and 115 there are only 6 small private tubewells.

[2/] See Appendix II, A-11 for a summary of bunded unit sizes for each of the 40 command areas of the 6 commands with 20 percent or more basins one acre or greater in size, 4 of these are on public tubewell commands. In contrast, of the 9 commands with 10 percent or more of the farms with basin sizes under .1 of an acre all of these are on nontubewell watercourse commands or where there is only one private tubewell.

Table 9. Size of irrigation basins in acres by watercourse command water supply situation and village sites (cumulative percentages and median intervals).

Type of watercourse command and public vs. nonpublic tubewell supplements	No. of bunded units	Cumulative percentages of bunded unit sizes (acres)										
		<.1	.1<.2	.2<.3	.3<.4	.4<.5	.5<.6	.6<.7	.7<.8	.8<.9	.9<1.0	1.0+
PERENNIAL												
Public tubewell												
106-1 wc	1044	3.2%	13.2%	25.4%	37.6%	49.9%	81.0%	84.5%	84.9%	85.7%	86.2%	100.0%
109-2 wc	1266	1.4	4.2	13.3	22.1	37.7	80.4	83.9	84.5	85.0	85.5	100.0
Nonpublic tubewell												
101-2 wc	3921	2.3	15.5	47.2	62.1	70.0	86.6	87.7	88.6	89.1	89.5	100.0
102-1 wc	983	1.5	4.5	13.7	18.5	30.6	84.7	85.8	86.1	86.4	87.1	100.0
103-1 wc	616	13.0	54.7	74.7	89.1	93.6	97.7	98.7	98.9	99.5	99.7	100.0
104-3 wc	636	1.4	7.4	20.0	32.3	45.7	58.6	66.5	72.5	79.1	83.7	100.0
107-3 wc	4982	1.2	13.3	49.3	70.1	82.9	94.8	95.5	95.8	96.0	96.2	100.1
110-3 wc	1939	4.8	12.8	26.4	35.5	47.9	65.3	68.3	70.7	73.2	75.6	100.0
112-3 wc	1466	.2	3.7	21.0	25.5	32.2	78.7	81.5	82.5	83.7	84.0	100.0
113-3 wc	1444	3.3	7.6	13.4	21.4	39.3	78.3	92.9	95.9	97.1	98.3	100.0
116-4 wc	1718	6.1	29.4	59.0	76.3	86.9	92.4	95.8	97.3	98.2	98.4	100.0
NONPERENNIAL												
Public tubewell												
105-1 wc	968	3.3	14.0	23.4	33.6	51.2	73.4	77.4	79.1	80.0	83.3	100.0
108-1 wc	923	3.3	14.6	29.9	43.4	49.6	65.1	69.3	72.4	75.1	76.5	100.0
111-2 wc	1024	3.8	14.6	27.8	40.9	54.8	67.2	74.4	78.2	81.4	84.6	100.0
Nonpublic tubewell												
114-4 wc	2317	14.3	39.2	54.3	61.7	68.1	83.1	86.4	88.2	90.0	91.1	100.0
115-6 wc	1751	11.7	30.2	50.3	66.8	76.6	83.8	88.5	91.7	93.6	95.8	100.0
Totals	26,998	4.4	17.3	38.6	51.7	62.7	82.7	86.0	87.6	88.8	89.9	100.0

Note: Median intervals underlined.

For the 40 commands, about 22 percent of the basins are less than .2 acres in size; 39 percent are under .3 acres and over 50 percent are less than .4 acres. Note that fully 83 percent are under .6 of an acre. In order to gain a clearer understanding of the influence of the water supply situation on size of irrigation basins, basin size data are presented in Table 10. Differences between head and tail farms is masked by the influence of private tubewells and Persian wells located along the watercourse command reaches. Forty-four percent of the 78 private tubewells are located at the tail as are 33 percent of the 45 Persian wells. Major differences in median size of bunded units are found only for the case of 1 to 2 private tubewells located on commands where the head farm median basin size is .4 acres versus .2 acres for tail farms. This indicates that farmers with greater losses of canal water in conveyance tend to adjust their basin sizes downward in order to control the lower volume of water. Over the total sample, little difference is found between basin sizes for head and tail farms in relationship to type of supplements to canal supplies.

Table 11 provides a summary of both median and mean bunded unit sizes of sample farms in relationship to several different water supply situation factors. The modal percentage is underlined to indicate size categories where the highest percentage of sample farms fall. There are no differences in the modal percentage of farms in basin size categories by different farmer reports of tubewell use or perceived tubewell water availability (see Table 11). Nearly 60 percent of the farmers who report tubewell water as not available have median basin sizes under .4 acres as compared with more than 53 percent of farmers who report tubewell water as "easily available."

Table 10. Mean, median and range of farm locations on watercourse command reach and weighted area of basin (individual bunded units) irrigated x type of watercourse supply situation.

Type of watercourse supply situation	Mean, median, and range for head and tail farms							
	Head farms				Tail farms			
	# cases	Mean	Median	Range	# cases	Mean	Median	Range
A. <u>Perennial</u>								
1. No tubewells	35	.6	.4	.1-4.0	31	.5	.5	.1-1.1
2. Public tubewells only	10	.5	.4	.3-1.0	4	.7	.6	.5-1.0
3. Private tubewells (1-2)	22	.4	.4	.1-1.4	47	.3	.2	.1-3.4
4. Private tubewells (3+)	77	.6	.3	.1-1.7	21	.5	.4	.1-1.1
B. <u>Nonperennial</u>								
1. No tubewells	-	-	-	-	-	-	-	-
2. Public tubewells only	9	.7	.7	.3-1.1	14	.6	.5	.3-1.6
3. Public and private tubewells	2	.4	.4	.3-.4	2	.4	.4	.3-.4
4. Private tubewells (1-2) plus Persian wells	74	.4	.3	.01*-2.0	6	.6	.4	.2-1.0
5. Weighted Mean and Total Range	229	.51		.01*-4.0	125	.45		.1-3.4

*.01 acres or less.

Table 11. Percentage of median bunded unit categories and mean bunded unit size by water supply situation.

Water supply situation	Bunded units N	Median bunded unit size (acres)						Mean bunded unit size (acres)					
		<.2	.2-.39	.4-.59	.6-.79	.8-.99	1+	<.2	.2-.39	.4-.59	.6-.79	.8-.99	1+
1. Type of tubewell supplement	-												
None	146	11.7%	43.2%	37.7%	4.1%	2.1%	1.4%	9.1%	43.8%	34.9%	6.8%	4.1%	1.4%
Private	156	16.7	51.9	27.6	2.6	0.6	0.6	10.3	55.8	21.8	10.3	0.6	0.6
Public	32	-	12.5	75.0	-	6.3	6.3	3.1	9.4	59.4	21.9	-	6.3
Public & private	19	-	15.8	52.6	5.3	5.3	21.1	-	10.5	42.1	26.3	10.5	10.5
2. Farm position on command*													
Head	130	9.2	45.4	36.2	3.8	2.3	3.1	5.6	45.4	29.2	15.4	2.3	2.3
Middle	86	14.0	34.9	44.2	2.3	3.5	1.2	10.5	43.0	31.4	10.5	3.5	1.2
Tail	113	15.1	45.1	35.4	1.8	-	2.7	12.6	43.0	36.3	6.2	0.9	0.9
More than one	22	9.1	45.5	27.3	9.1	4.5	4.5	4.5	45.5	22.7	9.1	9.1	9.1
3. Reported use of tubewells													
None	181	16.0	39.2	39.2	2.2	1.7	1.7	10.8	45.9	32.0	6.6	3.3	1.7
Hires	117	7.7	41.0	39.3	4.3	3.4	4.3	7.8	36.8	31.6	19.7	1.7	2.6
Owns	42	7.2	66.7	21.4	2.4	-	2.4	2.4	61.9	31.6	2.4	-	2.4
4. Reported tubewell water availability													
Not available	133	16.5	42.1	34.6	3.8	2.3	0.8	10.8	45.1	33.1	6.0	4.5	0.8
With difficulty	62	8.1	41.9	45.2	-	1.6	3.2	11.2	40.3	32.3	12.9	1.6	1.6
Easily	124	8.1	45.2	36.3	4.0	1.6	4.8	4.0	44.4	33.9	12.9	0.8	4.0
5. Command type													
Perennial	237	11.8	39.7	42.6	2.1	2.1	1.7	10.6	51.9	21.2	10.6	3.8	3.8
Nonperennial	104	13.5	51.9	25.0	2.9	1.9	4.8	6.9	41.4	36.3	9.3	2.1	0.8

*Interviewer's estimate of farm location, based on "farmer's idea."

Factors which may influence the size of bunded units are farm size and physical soil types. Smaller farmers in general have less access to supplemental tubewell water as well as to land leveling services. The data, however, in Table 12 do not show much difference in either median or mean bunded unit size among farm size categories.[3/] Size intervals in which the majority of the sample farmers fall are shown by underlining the modal frequency.

Table 12 also displays mean and median irrigation basin sizes by five general physical soil types; no clear differences are revealed. One would expect that where soils are predominately of the light to medium (sandy loam to loam) category, farmers would have smaller basins to more easily move water across basins where infiltration rates are higher. Maintaining bunds on fields with light sandy soils also presents greater problems than with more heavy clay soils. Slight differences are observed between farms with more sandy soils and those with fine clay soils (see Table 12). More than 65 percent of the mean basin sizes of farms with the more sandy soils are under .4 of an acre as compared with 46 percent of the farms with predominately fine (clay loam) soils. With this exception there is little difference in basin sizes by soil types. The general soil type categories used are either not sufficiently specific or other factors such as water supply are more important in explaining differences in basin sizes.

D. Kacha nakkas: Perennial source of watercourse losses

The junction nakka is the opening made by the irrigator to convey water from the main watercourse to the branch watercourse and eventually to the farm field ditches. The field nakka is the opening made from

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[3/] Farm size classes are those for cultivated land in the sample watercourse command areas, as opposed to land owned.

Table 12. Percentage of median bunded unit categories and mean bunded unit size by farm size class and physical soil types.

Farm size class and physical soil types	Bunded Units N	Median bunded unit size (acres)						Mean bunded unit size (acres)					
		.2	.2-.39	.4-.59	.6-.79	.8-.99	1+	.2	.2-.39	.4-.59	.6-.79	.8-.99	1+
1. Farm size (in acres)													
< 2.49	98%	23.4%	44.9%	23.5%	2.0%	1.0%	5.1%	19.2%	52.0%	16.3%	7.1%	3.1%	2.0%
2.5-7.49	91	7.7	51.6	33.0	3.3	2.2	2.2	7.7	48.4	30.8	8.8	3.3	1.0
7.5-12.49	62	6.5	33.9	54.8	4.8	-	-	3.2	33.9	41.9	19.4	-	1.6
12.5-24.99	52	9.6	38.5	44.2	3.8	-	1.9	1.9	46.2	36.5	3.8	5.8	5.8
25.0-49.99	16	-	56.3	31.3	6.3	-	6.3	-	37.5	43.8	18.8	-	-
50 -74.99	22	13.6	18.2	54.5	-	13.6	-	9.0	18.2	50.0	22.7	-	-
75+	12	-	50.0	41.7	-	8.3	-	-	50.0	41.7	8.3	-	-
2. Soil types													
Light to medium (sandy loam to loam)	26	11.5	53.8	26.9	3.8	-	3.8	7.6	57.7	19.2	7.7	-	7.7
Medium loam	28	3.6	28.6	57.1	-	3.6	7.1	7.2	28.6	46.4	10.9	-	7.1
Medium to fine (loam to clay loam)	56	21.4	37.5	32.1	1.8	3.6	3.6	14.4	44.6	23.2	14.3	3.0	-
Fine (clay loam)	75	18.9	27.0	40.5	8.1	2.7	2.7	13.8	24.3	39.2	17.6	5.4	-
Multistoried	169	7.7	52.1	36.1	1.8	1.2	1.2	5.4	53.3	30.8	7.1	1.8	1.8

the field channel at the basin to be irrigated. Along the main watercourse there is a stipulated number of junction nakkas per unit of land to be irrigated--usually one nakka per 25 acres of land. Farmers, however, rarely adhere to this stipulation; the tendency is for individual farmers to want their own nakka junctions on the main or branch watercourse. These openings or nakkas are made by making a cut into the ditch bank with the kassi (spade). After an irrigation is completed, nakka cuts are sealed off by soil material from either the watercourse channel or from edges of fields. As shown in the Photo Glossary Figures 7-C, N, X, and AA, there are typically leaky junction and field nakkas all along watercourses and field channels. Each nakka cut is a potential source of substantial losses in water conveyance. An intensive investigation of one watercourse command (Kemper, 1977a: 202-209) concluded that as much as 50 to 75 percent of all losses occur at junctions and kacha nakkas. As seen from the nakka cut maps in Volume VI, Appendix IV, Section B, all nakka cuts were counted and plotted as arrows. Field observations indicate that during irrigations the sealed nakkas often break and farmers must spend considerable time checking and repairing upstream channels to seal nakka leaks. The nakka maps represent a clear picture of the magnitude of potential nakka leaks on watercourses. Numerous nakkas are necessary, however, for farmers to conduct water. Both topographical problems and the small volume of water influence the number of nakka cuts per bunded unit.

Table 13 provides data on nakka cuts per acre, bunded unit, and farm. The point here has to do with the incidence of nakkas. In individual command areas, nakka cuts range up to 1719 outlets per command area. For the 40 commands, representing great variation in

Table 13. Summary of bunded units and nakka cuts by water supply situation and village sites.

Type watercourse command area and supplemental canal supplies	Average number of bunded units and nakka cuts				
	Bunded units		Nakka cuts on farmer conveyance ditches		
	Per acre	Per farm	Per acre	Per bunded unit	Per farm
Perennial					
Public tubewell					
106-1 wc	1.9	20.5	2.6	1.3	27.5
109-2 wc	1.7	27.5	3.5	2.0	55.5
Nonpublic tubewell					
101-2 wc	4.0	44.5	2.6	1.0	29.3
102-1 wc	1.9	28.9	3.3	1.7	50.6
103-1 wc	4.1	36.2	2.9	1.0	16.2
104-3 wc	1.5	28.9	1.9	1.2	35.6
107-3 wc	2.4	11.7	2.8	1.1	13.4
110-3 wc	1.9	18.1	2.3	1.2	22.4
112-3 wc	1.6	*	2.2	1.3	*
113-3 wc	1.9	*	2.3	1.2	*
116-4 wc	3.0	*	3.4	1.1	*
Nonperennial					
Public tubewell					
105-1 wc	2.1	26.9	2.2	1.0	18.6
108-1 wc	1.6	33.0	2.1	1.3	41.5
111-2 wc	1.7	*	2.4	1.4	*
Nonpublic tubewell					
114-4 wc	2.6	*	2.6	1.0	*
115-6 wc	2.4	*	2.5	1.0	*
Average for 40 wc	2.3	27.6	2.6	1.2	31.1

*Total number of farms in village not known, per farm calculation not made.

cultivated acres, the average is 771 nakka cuts per command area. Table 13 also shows the nakka cuts per acre of cultivated land, per bunded unit, and per farm. Overall, there are approximately 2.6 nakka cuts per acre of cultivated land in the 40 commands. The most nakka cuts, 3.5 per acre, are found at site 109. Table 14 shows that there is little or no variation in nakka cuts per bunded unit by type of water supply situation. The major reason is that basin sizes are small throughout the sample sites.

One would expect fewer nakkas per bunded unit and per acre for farms with good water supplies--augmented by private and public tubewells. This is not the case, however, as the data in Table 14 show, because extra nakkas are also necessary where farmers have unlevel fields. Sometimes it takes more nakka openings to route water around more than one side of basins. The farmer usually tries to completely cover the basin and to accomplish this he requires extra nakkas along basin sides. Nakka cuts per acre vary in relationship to number of basins per acre, which, in turn, varies with adequacy of water supply. Note that none of the farms with public tubewells have more than 4 nakkas per acre while 24 percent of the farmers on commands with private tubewells and 15 percent of farmers on commands with no tubewells have over 4 nakkas per acre. When farm watercourse location is examined there are no major differences observed in nakkas per acre. When farmers' reports of tubewell use and tubewell water availability are examined, it is interesting to note that a lower percengate of farmers who own tubewells have up to two nakkas per acre than other farmers and a greater percentage of tubewell owners fall into three to four nakkas per acre category. The same trend appears with regard to ease of tubewell

Table 14. Cumulative percentages of field outlets (nakkas) per bunded unit and acre by water supply situation.

Water supply situation	Nakkas per bunded unit				Nakkas per acre				
	N (BU)**	1	2-3	4*	≤2	3-4	5-6	7-8	9+
1. Type of tubewell supplement									
None	146%	97.3%	100.0%	-%	45.9%	84.9%	94.5%	97.2%	100.0%
Private	156	95.5	99.3	100.0	23.1	76.3	94.9	98.7	100.0
Public	32	90.6	96.9	100.0	56.3	100.0	-	-	-
Public + private	19	78.9	100.0	-	57.9	100.0	-	-	-
2. Farm position on command*									
Head	130	93.8	98.4	100.0	35.4	86.9	96.1	97.6	100.0
Middle	86	94.2	100.0	-	40.7	80.2	95.3	98.8	100.0
Tail	113	96.5	100.0	-	31.9	80.6	93.9	98.3	100.0
More than one	22	95.5	100.0	-	63.6	86.3	100.0	-	-
3 Reported use of tubewells									
None	181	97.2	100.0	-	42.0	81.2	93.9	97.2	100.0
Hires	117	92.3	98.3	100.0	35.0	88.8	96.5	99.1	100.0
Owns	42	92.9	100.0	-	21.4	80.9	100.0	-	-
4. Reported tubewell water availability									
Not available	133	97.0	100.0	-	40.6	82.0	95.5	97.8	100.0
With difficulty	62	95.2	100.0	-	33.9	82.3	96.8	100.0	-
Easily	124	93.5	98.3	100.0	31.5	88.8	96.9	99.3	100.0
5. Command type									
Perennial	237	95.8	99.6	100.0	33.8	80.2	95.4	98.4	100.0
Nonperennial	104	93.3	100.0	-	44.2	89.4	95.2	98.1	100.0

*As estimated by the interviewer.
**Bunded units

water availability (see Table 14). This tends to contradict the view that easier availability of tubewell water results in fewer nakkas per acre.

Table 15 displays data on nakkas per bunded unit and per acre in relationship to farm size classes and five physical soil types. Again, because there is little variation in nakkas per bunded unit, no important differences are observed. No consistent pattern is detected between farm size classes and nakkas per acre except for the smallest farm size class of under 2.5 acres. About 30 percent of these farms have 5 or more nakkas per acre as compared to from 6 to 19 percent of the other farm size groups. This may reflect the problem of smaller farmers in tubewell water availability and their added efforts to shepherd small amounts of water around basins to gain good coverage with limited water supplies. The pattern, however, is not clear as about 18 percent of the farms with 50 or more acres also have 5 or more nakkas per acre.

One would expect that fields where soils are predominately of a sandy loam texture (light to medium category) farmers would have fewer nakkas to increase the working head of the irrigation supplies in order to gain better coverage of the fields. Evidently this is not the case because a greater percentage of the 26 farms with the more sandy textured soils have 5 or more nakkas per acre than other farms with less sandy soils.

E. Field Levelness

The most widely used method of applying irrigation water to fields in Pakistan is to continue an irrigation until the basin is completely covered with water. This is practiced at Agricultural Research Stations, government farms, and by private farmers. Farmers attempt to cover all high spots on fields. Of 376 farmers reporting how they decide to stop

Table 15. Cumulative percentage of field outlets (nakkas) per bunded unit and acre by farm size class and soil types.

Farm size classes and physical soil types	Nakkas per bunded unit				Nakkas per acre				
	N	1	2-3	4-5	≤2	3-4	5-6	7-8	9+
Farm size class									
2.4	98	93.9	99.0	100.0	28.6	71.5	86.8	95.0	100.0
2.5-7.49	91	96.7	98.9	100.0	37.4	81.4	99.0	100.0	-
7.5-12.4	62	100.0	-	-	58.1	98.4	-	-	100.0
12.5-24	52	92.3	100.0	-	40.4	88.5	100.0	-	-
25 -49	16	87.5	100.0	-	25.0	93.8	100.0	-	-
50 -74	22	90.9	100.0	-	31.8	81.8	95.4	100.0	-
75+	12	91.7	100.0	-	16.7	83.4	100.0	-	-
Soil types									
Light (sandy loam) to medium	26	96.2	100.0	-	34.6	73.1	92.3	96.1	100.0
Medium (loam)	28	89.3	96.4	100.0	50.0	96.4	-	-	100.0
Medium to fine (loam to clay loam)	56	89.3	100.0	-	26.8	73.2	91.1	94.7	100.0
Fine (clay loam)	75	94.6	98.7	100.0	40.5	78.3	94.5	98.6	100.0
Multistoried	169	97.6	100.0	-	37.9	88.2	97.7	100.0	-

an irrigation, 47 percent report they stop when water completely covers the basin and 37 percent report stopping when all high spots are covered. When fields are unlevel, low spots often receive too much water and the high points too little water. When a high spot is midway down the field or near the edge of the far basin borders, often the farmer has to apply as much as 5 to 7 acre inches of water to gain coverage. Even then high areas are not covered for a sufficient time to provide adequate moisture to the soil. It is common to find saline patches where there are either no plants or stunted ones due to lack of moisture and high salinity.

Given the method of level basin irrigation almost universally practiced in Pakistan, it is important that fields be almost dead level to assure good seed germination, crop emergence, and adequate moisture throughout the growing season for good crop yields. Precision land leveling not only provides conditions for improved crop yields but is a means to achieve improved field design and consequent reduction of land devoted to field channels and bunds. Land leveling is, therefore, a means of increasing the area cultivated as well as to provide more uniform water distribution. A study of measured (by survey instruments) field levelness (Wahla and Reuss, 1976: 281-287), cotton stands and yields found that cotton yields were reduced by 50 percent or more by unlevel fields. The mean number of cotton stalks per 400 square feet was 124 at high elevations, 130 at middle elevations and 80 at low elevations. Likewise yields, in maunds per acre, were 7.5 at high elevations, 8.1 at middle elevations and 3.8 at low elevations. The mean elevation between the high and low spots for this study was 4.65 inches with a range of 3.0 to 10.6 inches.

Though field levelness was estimated by visual inspection in the Lower Indus Basin Watercourse Study (1963-64); investigators found a relationship between crop yields for several crops and the leveling standard of fields. Their estimates are presented below (Table 16):

Table 16. Relationship between levelness and crop yields (maunds/acre).

Crop	Estimated leveling standard Poor	Fair	Good
Rice	7	13	32
Cotton	6	7	11
Wheat	6	14	14
Sugarcane	300	530	460

Source: MacDonald, 1966, Vol 1.

Though one cannot be certain what "poor," "fair" and "good" leveling represents in actual inches of elevation difference, it is widely accepted that precision land leveling is positively related to improved crop yields.

In this study, topographical surveys were made of all sample watercourse command areas. Four instrument shots were taken per bunded unit for sample farms and four readings were taken per acre on nonsample farms. The reader is referred to Volume VI, Appendix IV, for topographical maps showing elevation differences. In order to obtain a factor for sample farm field levelness elevation differences for the two most extreme contours are used to obtain maximum differences for each sample farmer's largest field or parcel. In using such a measure much data is lost such as minimum and maximum differences for a given field and we also are not able to report data on individual bunded units. These differences, however, can be observed from the maps in Volume VI, ppendix IV F.

The data obtained from the 353 sample farmers' largest parcels range in mean sizes from 3.5 to 15.4 acres and have a weighted mean of 5.6 acres. The frequency distribution of range in elevation differences for these 353 fields are given below:

Range of elevation differences (maximum and minimum) in feet	Number and percent of fields (3.5 to 15.4 acres in size)	
	No.	%
≤.5	37	10.5
.06 - 1.00	192	54.5
1.01 - 1.50	47	13.3
1.51 - 2.00	32	9.1
2.01 - 3.00	24	6.8
3.01 and over	21	5.9

These data are comparable to a similar study (Ali, Clyma and Early, 1975: 391) of other command areas where 51 percent of the fields ranging in size from 6 to 10 acres had a difference between maximum and minimum elevations of up to 1.00 foot. Our data show that nearly 46 percent of the parcels had an elevation difference of over 1.0 foot as compared to the study cited above in which 49 percent of the parcels had a difference of over one foot. The range in elevation differences for sample farmer blocks of land was 0 to 4.5 feet; the mean and median differences were 1.05 and .80 respectively for the 353 parcels. Using the criterion that 0.10 foot is the maximum elevation difference for a level field, about 70 percent of the sample parcels failed to meet minimum requirements for levelness.

Cox and Dempster,[4] based on a limited survey, estimated that to level an average acre would require moving about 200 cubic meters of soil at a cost of about Rs. 3.00 per cubic meter. This amounts to about

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[4] Cox and Dempster, 1975, private communication.

Rs. 600 per acre. Given a uniform slope and equal volumes of cut and fill, the volume and cost of leveling as estimated by Cox and Dempster are as follows:

Range of elevation (maximum-mimimum)	Estimated volume of soil in cubic meters	Estimated cost of leveling 1 acre in Rupees
0.2	40	92
0.4	80	184
0.6	120	276
0.8	160	368
1.0	200	460
1.2	240	552
1.4	280	644
1.6	320	736

Using these estimates and mean and median elevation differences for fields in the present survey, about 46 percent of the sample farmers would have to spend from 460 to 720 rupees an acre for land leveling.

With this in mind we observe in Table 17 vast differences in the need for land leveling on farms at different village sites. For example, note that at five sites (103, 109, 113, 105 and 111) from 33 to 44 percent of the farms have field elevation differences of over 1.5 feet. Only at sites 102, 104, 106, 107, 108 and 112 do we observe from 74 to 93 percent of the farmers' fields have elevation differences of 1.0 foot or less. Of the sites with the most extreme elevation differences in fields (over 2.0 feet) sites 103, 105 and 111 stand out. The last two mentioned are both nonperennial commands with public tubewells where one can suppose that less leveling is required when large working heads are available to cover unlevel fields. Furthermore, site 103 is totally dependent upon jhallars for lifting all irrigation water before application. No clear relationship emerges between field levelness and water

Table 17. Field levelness in terms of maximum elevation differences in fields by village site.

Village site and type command	Cumulative percentage of evaluated fields and levelness (Tenths of a foot in maximum elevation difference)						
	No. cases	≤.5	.6-1.00	1.01-1.50	1.51-2.00	2.01-3.00	3.01 and over
Perennial							
101-2 wc	15	40.0	46.7	73.3	86.7	93.3	100.0
102-1 wc	9	44.4	77.8	77.8	100.0	-	-
103-1 wc	16	18.8	43.8	56.3	62.5	81.3	100.0
104-3 wc	12	41.7	75.0	83.3	100.0	-	-
106-1 wc	12	50.0	83.3	83.3	83.3	100.0	-
107-3 wc	55	69.1	92.7	98.2	100.0	-	-
109-2 wc	13	46.2	61.5	61.5	76.9	100.0	-
110-3 wc	25	48.0	68.0	84.0	92.0	92.0	100.0
112-3 wc	31	54.8	74.2	83.9	90.3	93.5	100.0
113-3 wc	24	29.2	58.3	66.7	95.8	95.8	100.0
116-4 wc	23	13.0	34.8	73.9	78.3	95.7	100.0
Weighted mean cumulative perennial	235	45.5	68.5	80.4	89.8	93.8	100.0
Nonperennial							
105-1 wc	8	12.5	25.0	62.5	62.5	62.5	100.0
108-1 wc	9	33.3	88.9	100.0	-	-	-
111-2 wc	24	45.8	54.2	66.7	75.0	87.5	100.0
114-4 wc	38	36.8	52.6	76.3	92.1	92.1	100.0
115-6 wc	39	43.6	64.1	71.8	76.9	94.9	100.0
Weighted mean cumulative nonperennial	118	39.0	57.7	73.8	80.8	90.0	100.0
Total*- 40 wc	353	43.3	54.4	13.3	9.1	6.8	5.9

*Weighted mean by category, noncumulative.

supply situation (see Table 17). Mean, median and range field elevation differences are presented in Table 18. The watercourse command at site 114 was severely affected by a flood, such that considerable volumes of silt and sand were deposited across the command area making the topographic situation more difficult. The need for land leveling is widespread on all types of command areas. Low mean and median values of field elevation differences at sites 106 and 107 can be partially explained by the fact that the average farm parcel sizes here are respectively only 3.5 and 4.9 acres. In contrast average parcel sizes at sites 105 and 109 are 8.5 and 10.3 acres respectively. Parcel size, however, does not explain the large elevation differences at sites 101 and 103 where average sizes of the parcels surveyed are 4.8 and 5.5 acres respectively.

Table 19 presents data on field elevation differences in relationship to various water supply situations and farm location in the command area. Farmers with good water supplies might attempt to compensate for unlevel fields by applying more water. Where water supplies are adequate, farmers may have less incentive to level their fields. The data do show a trend for farmers with public tubewell supplies to have less level fields than farmers with private tubewell supplies (see Table 19). Note that about 30 percent of the farms with public tubewell supplies have fields with elevation differences over 1.5 feet as compared to about 18 to 23 percent for other farms. Examining item 2 in Table 19, a larger percentage (13 to 19) of the farmers who own private tubewells and buy tubewell water have parcels less than or equal to 0.05 foot elevation difference. To further confirm that the water supply situation has little influence over field levelness simple first

Table 18. Mean, median, and ranges of field elevation differences by village sites.

Village sites and type command	Levelness of largest field of sample farmers (in feet elevation differences)			
	Number of farms	Mean	Median	Range
Perennial				
101-2 wc	15	1.18	1.25	0 -3.50
102-1 wc	9	.81	.69	0 -2.0
103-1 wc	16	1.75	1.38	.25-4.0
104-3 wc	12	.85	.75	.25-2.0
106-1 wc	12	.71	.13	0 -3.0
107-3 wc	55	.47	.33	0 -2.0
109-2 wc	13	1.20	.94	.25-3.0
110-3 wc	25	.91	.75	0 -3.18
112-3 wc	31	.90	.53	0 -3.75
113-3 wc	24	1.20	.98	.15-4.0
116-4 wc	23	1.43	1.25	.17-4.51
Weighted mean and Total Range	235	.96		0 -4.51
Nonperennial				
105-1 wc	8	2.22	1.54	.5 -4.0
108-1 wc	9	.75	.72	.5 -1.25
111-2 wc	24	1.37	.75	0 -4.25
114-4 wc	38	1.11	1.04	0 -3.5
115-6 wc	39	1.17	.75	0 -4.5
Weighted mean and Total Range	118	1.23		0 -4.5

Table 19. Cumulative field elevation differences of sample farms by water supply situations.

Water supply situation	No. of farms	Cumulative percentage of levelness of farmers' fields (in feet of field elevation differences)					
		≤.05	.06≤1.00	1.01≤1.50	1.51≤2.00	2.01≤3.00	3.01≤9.98
1. Type of tubewell supplement							
None	145	5.5	57.9	77.2	90.3	95.8	100
Private	156	14.7	74.3	82.0	87.8	94.2	100
Public	32	18.8	59.4	68.8	75.1	90.7	100
Private & public	20	0.0	50.0	70.0	80.0	85.0	100
2. Farmers' reports of tubewell use							
No use	181	7.2	59.7	75.2	88.5	95.1	100
Hire	123	13.2	70.1	83.3	87.1	96.0	100
Own	42	19.0	73.8	76.2	83.3	85.7	100
3. Farmers' reports of availability of tubewell water							
Not available	132	3.8	56.1	74.3	88.7	94.0	100
Available w/difficulty	62	14.5	71.0	79.1	87.2	95.3	100
Easily available	123	13.6	70.4	80.8	86.4	92.8	100
4. Farm location on watercourse command (adjusted position)							
Head	115	9.6	66.1	74.8	86.1	93.9	100
Middle	82	8.5	69.5	82.9	90.2	93.9	100
Tail	60	10.0	66.7	75.0	85.0	95.0	100
More than one position	23	4.3	30.4	56.5	60.8	78.2	100

order correlations were made between field elevation differences and both mogha discharge and the amount of water reaching field outlets. The correlation with mogha Q was -.03 and the correlation of nakka Q or water arriving at the farmer's field was -.12. These low correlations support the view that water supply has little relationship with field levelness. In terms of farm location on the watercourse command reaches, important differences are not observed between head and tail farms in field elevation (see Table 19, item 4). The major difference is seen in farms with parcels at more than one area of the command area. These farmers appear to have more severe land leveling problems. The simple correlation between distance of the farm from the mogha outlet in feet and field elevation differences is only -.09 which reveals little relationship.

Data in Table 19 indicate that the water supply situation and farm location on the command area has little association with field elevation differences. Land leveling is required on all watercourse commands by the majority of farmers.

It was thought that farm size[5/] and the predominant physical soil types of farms would explain some of the differences in field elevations. Though data are not presented in tabular form in relationship to these factors no important differences were observed. For example, of the farms with under 2.5 acres in size, about 29 percent of the field elevation differences were over 1.0 feet, and for the 6 farms with 100 acres or more 33 percent had field elevation differences of over 1.0 feet. Little difference was found between other farm size classes. Soil type also does not appear to be a factor. About 20 percent of the

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[5/] Farm size here refers to the total acreage on the sample command.

farms with light to medium (sandy loam to loam) soils had elevation differences 1.5 feet as compared to 27 percent of the farms with fine clay loam soils. Farms with the intermediate soil types fell within this small range. On the basis of these data it cannot be concluded that soil type makes much difference in elevation differences.

As would be expected, the larger the farm parcel the greater the elevation differences as seen in Table 20. Mean, median, and ranges of field elevation differences are compared with the area of sample farmers' fields. The simple correlation coefficient for size of parcel and elevation difference is .45 and is significant at the .001 level. Observe in Table 20 that parcels up to one acre in size had mean and median elevation differences of only .49 and .26 feet while parcels between 4 and 6 acres had mean and median elevation differences of .83 and .50 feet. As farm parcel sizes increase to 10 to 15 acres the average elevation difference increases to 1.3 feet and for fields 15 acres or more to 1.83 feet. This confirms our earlier finding that farmers, in order to more adequately control irrigation water, design small basins to attempt to overcome problems of field levelness. Given present technology, this is about the only means they possess to control irrigation water.

In order to provide a rough estimate of the need for land leveling, a measure is used to ascertain the acre feet of soil to be moved to achieve level fields (within plus or minus .05 of a foot). Table 21 provides information on the mean, median and ranges of acre feet of soil that must be moved on farms at the 16 village sites to achieve dead level parcels. This measure does not show the substantial variation

Table 20. Field elevation differences by size of farm parcel.*

Farm parcel size classes (acres)	No. of Cases	Field elevation differences (feet)		
		Mean	Median	Range
up to 1.0	29	.49	.26	0-2.0
1.1 - 2.0	35	.48	.26	0-3.0
2.1 - 4.0	65	.69	.50	0-3.5
4.1 - 6.0	43	.83	.50	0-3.25
6.1 - 8.0	33	1.00	.75	0-4.51
8.1 - 10.0	26	1.00	.75	0-3.18
10.1 - 15.0	39	1.29	1.04	0-3.75
15.1 and over	50	1.83	1.72	0-4.50

*The portion of land owned by a farmer that is contiguous at one location.

Table 21. Estimated acre feet of soil to excavate for the average farm parcel to obtain level fields by village sites.

Type of watercourse command and village site	No. of Cases	Volume of excavation (acre feet of soil)*			Using median values of volume of cubic meters of soil to be excavated for a typical farm
		Mean	Median	Range	
Perennial					
101-2 wc	15	2.15	.62	0 -10.9	765
102-1 wc	9	3.81	.90	0 -20.0	1111
103-1 wc	16	2.21	.55	.10- 9.3	679
104-3 wc	12	1.45	1.05	.10- 7.4	1296
106-1 wc	12	.90	.05	0 - 5.4	62
107-3 wc	55	.44	.14	0 - 6.3	173
109-2 wc	13	3.13	1.10	.10-12.5	1357
110-3 wc	25	1.41	.40	0 - 9.6	494
112-3 wc	31	2.31	.34	0 -18.9	420
113-3 wc	24	2.20	1.65	.10-11.0	2036
116-4 wc	23	1.45	.70	.10-13.4	864
Totals (Weighted)	235	1.65		0-20.0	723
Nonperennial					
105-1 wc	8	23.99	8.20	.60-57.0	10119
108-1 wc	9	1.51	1.20	.50-4.20	1481
111-2 wc	24	13.74	.70	0 -99.8	834
114-4 wc	38	3.74	.45	0 -99.8	555
115-6 wc	39	2.39	.22	0 -25.4	272
Totals (weighted)	118	6.53		0 -99.8	1237

*Cubic yards are obtained from acre feet by dividing by 27. Cubic meters are obtained by dividing by 35.3.

1 acre foot = 43,560 ft.^{3}; 1 yd.^{3} = 27 ft.^{3};

1 meter^3 = 35.3 ft.^{3}

$$43{,}560 \text{ ft.} \times \frac{1 \text{ yd}^3}{27 \text{ ft.}^3} = 1613.3 \text{ yd.}^3$$

$$43{,}560 \text{ ft.} \times \frac{1\text{M}^3}{35.3 \text{ ft.}^3} = 1234.0 \text{ M}^3$$

among farms but provides an estimate of land leveling needs. Given the wide variation in the ranges we will use the median values for acre feet of soil to excavate level fields. For example, using the median acre feet at site 107 of .14 the cubic meters of soil that will have to be excavated on the typical farm acre is about 173 cubic meters. Recalling from p. 37 that the estimated cost per acre, given a volume of 173 cubic meters, is roughly Rs. 370-400, and noting that about 320 cubic meters would have to be moved per acre on a typical sample farm at a cost of approximately Rs. 700 per acre, one concludes that land leveling problems are serious for the typical farm at all sites except 106, 107 and 115. We note from Table 21 that of the 40 watercourse command areas only 10 have less than 320 cubic meters of soil to excavate per acre.

The data above is based on the assumption that a farmer will bring his complete parcel to level. This is often not a valid assumption because many farmers have orchards or sugarcane which they will not allow to be leveled. Therefore, it is important to examine the levelness of the existing irrigation basins employed for other crops which are typically .2 to .3 acres in size. Within these small basins there are often elevation problems. However, they are much less than when separate parcels containing several basins are considered as shown above.

Table 22 shows the minimum, maximum, mean and median range of differences in 198 basin elevations. Four instrument survey shots were made for each of the irrigation basins. The table shows the following. First, the minimum range of difference in elevations shows that 77 percent of the basins had a tolerance of up to .1 of a foot. Second, the maximum differences in elevations show that only

Table 22. Minimum, maximum, mean, and median range of irrigation basin elevations.

Range of elevation differences in feet	Minimum range		Maximum range		Mean range		Median range	
	No. of basins	Cum. % of basins	No. of basins	Cum. % of basins	No. of basins	Cum. % of basins	No. of basins	Cum. % of basins
0	6	3.0	0	0.0	0	0	1	.5
.01 - .05	98	52.5	6	3.0	7	3.5	7	4.0
.05 - .10	48	77.0	21	13.6	28	17.7	46	27.3
.10 - .15	11	82.5	17	22.2	36	35.9	46	50.5
.15 - .20	7	86.0	17	30.8	40	56.1	44	72.7
.20 - .25	6	89.0	9	35.4	37	74.7	26	85.9
.25 - .30	3	90.5	10	40.4	22	85.9	14	92.9
.30 - .35	1	91.0	18	49.5	11	91.4	5	95.5
.35 - .40	1	91.5	10	54.5	6	94.4	5	98.0
.40 - .45	2	92.5	10	59.6	3	96.0	2	99.0
.45 - .50	1	93.0	5	62.1	3	97.5	0	99.0
.50 <	14	100.0	75	100.0	5	100.0	2	100.0
Total basins	198		198		198		198	

about 14 percent of the basins had a tolerance of up to .1 of a foot and 31 percent had maximum elevations of up to 2! About 70 percent of the basins had high spots of .2 or greater--there is a need for precision land leveling. If we examine the mean and median range of elevation differences in Table 22, we note that respectively 44 and 27 percent of the fields have elevations over .2 foot.

Table 23 provides information about the actual acre inches of water applied to irrigation basins with maximum ranges of elevation differences. The data do not show that elevation differences influence the acre inches of water applied by an irrigator; other factors are important such as type of irrigation, water supply situation, season, crop maturity and time and amount of prior irrigations. A simple Pearsonian correlation between maximum elevation differences and depth of water application is not found to be significant. When the last two categories (.16-.20 and .20 and over) are collapsed the weighted mean acre inches of water applied equals only 2.8 inches. In order to understand the influence of field elevation on the amount of water applied these variables need to be controlled and irrigation measurements need to be evaluated over a full crop season. This is not possible with the type of data available.

A simple correlation between field application efficiencies and the minimum, maximum, mean, and median elevation differences of four instrument shots per basin reveal the following:

Elevation difference x field application efficiencies	
Minimum	- .22 (significant at .002 level)
Maximum	- .07 (NS)
Mean	- .14 (significant at .03 level)
Median	- .12 (significant at .06 level)

Table 23. Maximum elevation differences and acre inches of water applied.

Maximum range of field elevations in feet	No. of basins	Acre inches of water applied	
		Mean	S.D.*
0.0	7	2.3	.92
.01-.05	20	1.9	1.25
.06-.10	10	2.0	1.57
.11-.15	14	2.8	1.59
.16-.20	24	3.4	2.59
.20 and over	100	2.6	1.71
Weighted totals	175	2.6	1.73

*Standard Deviation.

These differences again are not to be interpreted as important. Many other factors are involved. Also, time series data are not available. The minus sign means the greater the elevation difference the lower the field application efficiency--that is the more water applied at a given irrigation. Further research is needed to determine the actual influence of basin elevation differences and the amount of water applied.

F. Land Savings by Improved Farm Layouts

Advocates of land leveling report many benefits from precision land forming such as increased uniformity of crop stands, improved germination of seed, reductions in nitrate leaching, improved field application efficiencies, savings of water and reduction in salinity and waterlogging. Little of the research on land leveling in Pakistan to date has documented the benefits of land savings through larger farm units. It is hoped that the UNDP sponsored watercourse surveys being conducted presently (1976-1978) by the WAPDA Master Planning organization will document the land area presently in miles of field channels and bunds that could be used for crops given improved farm design and precision leveled fields. In a land-scarce agricultural economy, any land saved has high economic value. Corners of fields are often not tilled properly because even with bullock equipment each turn results in areas missed unless the operator practices great care in both plowing and seeding. The great maze of field channels leading to small irrigation units also result in much borrowing of earth from edges of fields to control water at junctions and nakkas. With improved field design achieved by precision land leveling these problems could be reduced to a minimum. Such changes should also take place with the rehabilitation of the existing watercourse system.

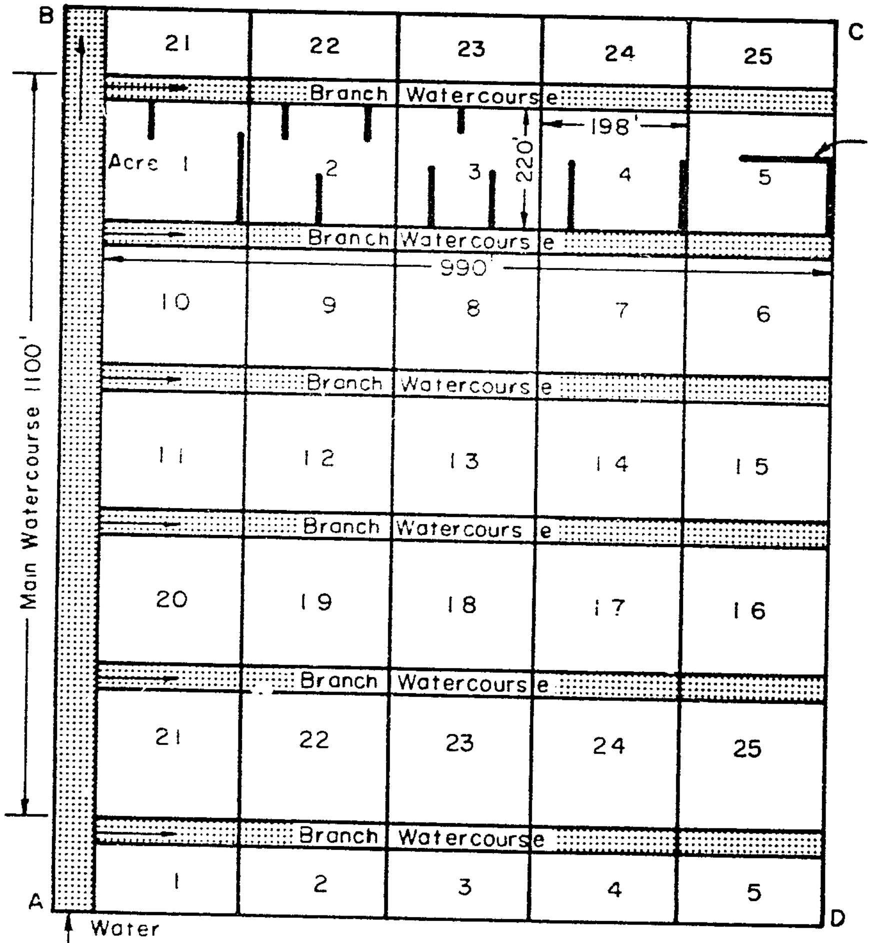
For example, if we make the conservative assumption that the average basin size is 220 x 66 ft. or about .33 acre and that a bund has an average width of 1.0 foot, the area of 14,526 sq. ft. has bunds measuring 572 linear feet or (572 x 1.0) 572 sq. ft. For an area given about 3 bunded units per acre assuming shared internal bunds of length of 220 feet this amounts to about 1276 sq. ft. or 2.9 percent of the cultivated acre of land. Of this total, 836 feet of the total periphery is shared with adjacent acres so the rate over an entire watercourse is approximately 2.0 percent. On a 302 acre watercourse this equals 5.9 acres. This does not include the miles of field ditches on watercourse commands which result from land fragmentation, difficult to command fields, and human factors such as denial of channel rights of way. For the 40 command areas we have found one mile of main and branch watercourse and field channel lengths for about 31.9 acres, although the variability between commands is large. Approximately 8 percent of total watercourse length is the main sarkari khal and the rest is in branch watercourses or laterals and field channels. While there is an official 16½ foot right-of-way for the sarkari khal, there is no official right-of-way for laterals and field channels. However, not counting the right-of-way area using the data in Table 5 we estimate (372.46 (.92) ÷ 40 command areas) that there is about an average of 8.6 miles of laterals and field ditches and (372.46 x .08 ÷ 40) about 0.75 miles of main watercourse, on the average, per command area. We further assume that the average overall width outside of the banks of a lateral or field channel is 3 feet (8.6 miles x 5280 ft/mile x 3 ft. = 135.695). This equals 135,695 square feet per command area or 3 acres of land in laterals and field channels for an "average" command area. The average sarkari khal occupies (.75 x 5280 x 16.5) 64,897 square feet or 1.5

acres per command area. Thus the average sample command area of 302 acres has 5.9 acres in bunds, 3.1 acres in lateral and field watercourses and 1.5 acres in main watercourses. This provides a gross estimate of the area presently utilized for bunds and field channels on command areas under present practices. Of course much of this area must continue to be utilized even given economies of scale in improved field design and leveled fields.

For more than 50 years the Agriculture Departments and the Irrigation Department have recommended to farmers to develop up to 8 small basins (kiaris) per acre for efficient irrigation. This recommendation was based on traditional technology for farmers at a time when improved technologies for, and the awareness of, benefits from precision land leveling were not widespread.

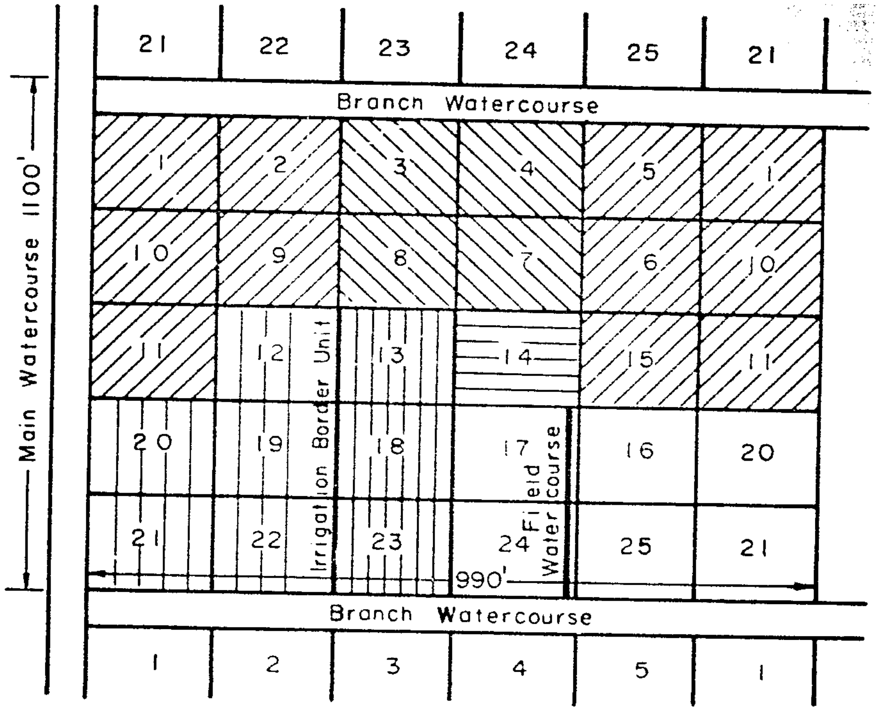
A "modern" farm layout design (Roberts and Singh, 1951: 167-9) was recommended about 25 years ago for the Punjab. This model required one mile of main and branch watercourse per 22 acres of land. A representation of this model is presented in Figure 3. Actual layouts used by farmers today are more efficient in land utilization than Roberts' model. Sample command areas have one mile per 32 acres of land, including field branches. The model layout in Figure 4 shows water coming to AB where acre 21 to acre 25 is irrigated followed by acres 20 to 16 etc. Acre 5 would be irrigated last. As shown on the layout, this would still require about 1.14 miles of main and branch watercourse per 25 acres. As we have shown, farmers today, instead of having acre basin units, in fact have from 4 or more basins per acre.

Given the need for more productive land, it is not realistic to place a branch watercourse on each acre boundary as per Robert's



Total Length of All Main and Branch Watercourses 6050' or 1.14 miles per 25 acres, or 1 mile per 22 acres. (Acres 1-5 Indicate a Sample of Field Watercourse Channels as Often Occurs When Very Small Bunded Units are Used.)

Figure 3. Roberts' 1950 Modern Layout of watercourse for 25 acre plot. (Roberts op cit p. 168.)



Main Watercourse Averages 44 feet per acre and Branch Watercourse Averages 44 feet per acre or 60 acres per mile of Watercourse. (Acres 12, 19, 20, 21, 22 Indicate the Layout of Long Narrow Borders About 40 feet Wide and 440 to 660 feet Long.)

Figure 4. Recommended design for field layout.

recommendation. A better design would be that shown in Figure 4, which provides a main watercourse serving one branch watercourse, which in turn serves the entire 25 acres, a square of land, or 12.5 acres on each side of the branch watercourse. The figure indicates an ownership pattern with various degrees of shading among the seven owners. In this pattern all but one of the farms have land adjacent to a branch watercourse. If the land were precisely leveled and if crops were irrigated in long narrow borders as shown, there would be no need for field ditches. Field channels would be needed only for landlocked farm parcels, those not adjacent to square boundaries as the parcel at acre number 14. To serve this parcel a 440 foot watercourse would be required as shown. This would be an uncommon occurrence since most farm parcels do border or intersect square boundaries.

Recent research (Ali, Clyma, Early, 1975) has demonstrated that narrow borders as long as 1100 feet can be irrigated efficiently. A long, relatively narrow border, precisely leveled, allows water to be applied uniformly with the required time to irrigate an acre cut to one-third to one-half the time necessary for traditional fields. Less land is taken up in permanent bunds. Farming operations are more efficient, especially with tractors or machines, as fewer turns are required. Fewer field corners exist. The number of acres per mile of watercourse has not been increased to 60 or more if the main watercourse length is distributed over more squares, representing a reduction in proportionate watercourse length of over 63 percent over Roberts' model and 47 percent over current watercourse densities. In a number of instances where the layout in Figure 4 has been installed, farmers on their own initiative have investigated or attempted land consolidation in order to place all their land in one contiguous block for more efficient field layout. Studies in Taiwan and Japan have shown that significant land consolidation has resulted from farmer initiative when farmers perceived advantages of contiguous fields (Tai, 1974).

The land area added for cultivation by converting to an improved layout with larger border irrigation units, fewer bunds, fewer branch watercourses, and a minimum of field watercourses would add, on the average, 3.12 acres per 302 acre watercourse command area or a 1 percent increase in cultivated area. This would imply that the irrigated area in Pakistan could be increased by more than one-third of a million acres by redesign of watercourses and field layout. If a serious land consolidation program were undertaken, ultimately only alternate square boundaries need to have branch watercourses. The intake rates of Pakistan's soils are such that if the land were leveled and the fields arranged into 1100 foot borders and a sufficient flow were available, efficient irrigation of these long narrow border units would be possible, and one mile of watercourse (main and branch) could serve over 200 acres.

III. ECONOMIC DUALISM AND THE FARM IRRIGATION SYSTEM

Socio-economic dualism is usually discussed in terms of the agrarian structure with special attention given to differential agricultural growth rates and distribution of benefits between farm size classes, tenure classes, and landless labor. A consistent pattern emerges to show that the availability and use of inputs and improved technologies are significantly related to farm size and in most cases to tenure status.

Another type of dualism exists which is primarily related to the nature of the present irrigation system in Pakistan. Though the irrigation system was designed to promote an equity objective in water distribution, there are many inequities which result from differential loss rates and types of supplies. For example, farms located near heads of canal distributaries are in a better water supply situation than farmers at the tails. Likewise, on a given farm irrigation system the farmers at the heads of the command area receive more total supplies of canal water than farmers at the tail. The difference in delivery efficiencies between head and tail farms range between 10 to 50 percent for the 40 command areas with a mean difference of 13 percent.

Dualism also results among the perennial and nonperennial systems. Where possible, the government has attempted to provide more large capacity public tubewells for nonperennial commands to lessen the inequities in water supplies. The so-called "private tubewell explosion" in Pakistan also added to the existing patterns of dualism between classes of farmers. About 44 percent of our sample of 389 farmers make use of tubewells but only 12 percent are owners of private tubewells and they tend to be larger landholders. The private tubewell owner has greater control over irrigation water. Essentially, the private tubewell makes it possible to irrigate in accordance with crop demands. The tubewell innovation reduces the risk factor in decision making about crops.

Summary data are presented in Table 24 to highlight some of the differences found between several types of farms. Note the differences between these farms with respect to crop yields, percentage of cultivated area in certain crops, number of irrigations, nutrient lbs. of nitrogen for wheat and farmers' estimates of crop increases. The last column of the Table 24 shows the differences in irrigation efficiencies. Public

Table 24. Summary information related to economic dualism among and within command areas (CA).

Selected types of farms	No. of cases	Crop yields (maunds/acre)			Percentage of CA in			No. of irrigations applied to wheat crop	Nutrient lbs. of nitrogen applied to wheat	Percentage of farmers who estimate 50% or more increases in crops given a doubling of irri. supplies				Irrigation efficiency %
		Wheat	Rice	Cotton	Wheat	Rice	% of CA in crop			Wheat	Cotton	Rice	Sugar-cane	
Tubewell supplements										P = perennial (NP) = nonperennial				
Public TW[1]	33	20	19	8	37	10	160	5-6	55	P 0 (NP20)	P 0 (NP55)	P 0 (NP45)	P 0 (NP52)	23
Owns private TW[2]	42	24	23	13	48	8	151	8-9	57	P 0 (NP50)	P 0 (NP20)	P 0 (NP35)	P 0 (NP35)	44
No tubewell	139	18	15	7	43	6	140	4-5	45	P45 (NP68)	P35 (P55)	P35 (NP45)	P30 (P50)	42
Farm location on command area														
Head	49	20*	17	7				NA	61	P10 (NP57)	P 9 (NP47)	P11 (NP45)	P 4 (NP47)	47
Tail	64	18	15	6				NA	59	P28 (NP36)	P22 (NP36)	P24 (NP36)	P23 (NP36)	32
Type Command														
Perennial	242	21	18	10	44	16	150	5-6	54[3]	21	14	16	19	39
Nonperennial	80	16	13	7	43	3	130	4-5	35	48	38	53	38	45

*In order to control on private tubewells for yields only head and tail farms were selected where there were no tubewells.

1/Only public tubewell commands are taken where there are no private tubewells.

2/Only owners of tubewells are used here. Farmers who purchase private tubewell water are excluded.

3/Nitrogen for cotton was 37 lbs/acre for perennial command farms and 27 lbs/acre for nonperennial command farms.

tubewell farms are those on commands with no private tubewell supplements to canal supplies. Private tubewell farms are those on which no public tubewell water is available. "No tubewell" refers to farms on commands with no supplements to canal supplies. Head and tail farms are only those for which there are no tubewell supplements. Since private tubewells are located on many commands it was thought best to show differences between head and tail farms without the confounding factor of tubewells. The last two types of farms shown in the Table 24 are those located on perennial versus nonperennial commands. In using average figures for the various types of farms, many of the differences observed on individual command areas are masked.

Data in Table 24 provides the basis for a number of generalizations. First, note the differences between farmers served by public tubewells, private tubewells and those without tubewell supplies. Both crop yields, and cropping intensities are higher for tubewell farmers. Tubewell farmers also apply more irrigations and use more fertilizer for wheat. Farmers were asked how much they would increase their present cropping intensities of crops given a doubling of irrigation supplies. Note that of the public and private tubewell farms, none reported increases in intensities of 50 percent or more among perennial farms. Secondly, note the higher yields due to increased control of tubewell water by tubewell owners. This control makes it possible to time irrigations more adequately which, in turn, leads to increased yields. Farmers on public tubewell supplemented commands receive their tubewell water along with canal supplies on a regular warabundi system, hence, they have adequate water in most cases but less control over timing as compared to tubewell owners.

Thirdly, the location of a farm on a command area makes a considerable water supply difference. Head and tail farms chosen for crop yield analysis are those located on commands with no tubewells in order to not confound the data by varying distributions of private tubewells. Yields of head farmers are, on the average, about two maunds more per acre for wheat and rice and one maund for cotton. Also, note the difference in the percentage of farmers who would increase present acreages by 50 percent or more. Fewer head perennial farmers report increases as compared to tail farms. Farm irrigation efficiencies are only 32 percent for tail farms and 47 percent for head farms. Differences between head and tail farmers for certain individual watercourses are much greater than these aggregated data reveal. Several options are available to improve the situation of tail farms. One of these is to establish a reverse warabundi--the turn system would begin at the tail rather than the head. Another is for the placement of small discharge tubewells near the tail or middle reaches of command areas.

A fourth type of dualism exists within regions of the same canal systems. Perennial command areas receive canal water for both rabi and kharif season. Unlike perennial commands, nonperennial commands receive seasonal supplies for kharif and sometimes extra supplies when they are available. Note differences (see Table 24) in yields when all the command areas of both types are compared. All nonperennial sites, except 114 and 115, have public tubewell supplies and still, due to the lack of canal water supplies, these yield differences result. Note also the difference in percentage of the CA in rice and the total cropping intensities. It is interesting to note the differences in nitrogen applied for wheat by the two types of command area. Perennial farmers apply almost 20 lbs. per acre more because, during rabi, they have canal supplies. During rabi season, nonperennial farmers have no canal supplies, tubewell or Persian well water. As expected, a much larger percentage of nonperennial command farmers would increase their acerage of wheat, cotton, rice and sugarcane than perennial farmers.

As a means of high-lighting differences between farms with various water supply situations, estimated production costs and average per acre returns are presented to show the degree of economic dualism that exists between types of farms. Certain data for inputs are taken from a recent study (Johnson, 1976) of farms on a watercourse command in the Sargodha District which is supplemented by a public tubewell. Therefore, we utilize those data for seed, fertilizer, labor, bullock power, land taxes, harvest costs, farm yard manure and a miscellaneous category. While these cost figures represent our sample of public tubewell farms, they are not representative of other areas of Pakistan. Given this limitation the data appear sufficient for our purpose of showing the differences in net returns per acre for five types of farms for three crops.

A. Average Per Acre Returns for Wheat

Table 25 provides information on production costs, gross income, and net income. The differences in wheat yields are not great because almost all farmers are growing HYV of wheat and apply about one bag of nitrogen per acre. Also, timely winter rains in rabi 1975-76 gave a boost to the wheat crop. Still the difference between farmers who own tubewells and those who don't is striking. There are at least two very critical irrigations for wheat, which if missed, can cause much reduction in yields--an initial irrigation within 15-18 days after planting, and

Table 25. Average per acre returns to land, risks, and management for selected types of wheat farms (1975-76).

Item	Type farm				
			No tubewells		
	Public tubewell	Private tubewell	No tubewell[1]	Head farm	Tail farm
			(Rs.)		
Seed	40.0	40.0	40.0	40.0	40.0
Fertilizer	82.5	82.5	67.5	90.0	87.0
Labor	77.5	77.5	77.5	77.5	77.5
Bullock power	185.0	185.0	185.0	185.0	185.0
Taxes (land/water)	35.0[2]	45.0[3]	24.6	24.6	24.6
Harvest costs[4]	75.2	90.3	67.7	75.2	67.7
Payments artisans and tools	31.4	31.4	31.4	31.4	31.4
Farm manure	20.0	20.0	20.0	20.0	20.0
Miscellaneous	32.95	32.95	32.95	32.95	32.95
Total cost/acre	579.55	604.65	546.65	576.65	566.15
Yields/acre in maunds	20	24	18	20	18
Maunds at Rs. 40 ea	800.00	960	720	800	720
Straw at Rs.4/md[5]	160	192	144	160	144
Gross income	960.0	1152	864	960	864
Net income (Gross income-total cost)	Rs.380.45	Rs.547.35	Rs.317.35	Rs.383.35	Rs.297.85

1/"No tubewells" represents all commands both perennial and nonperennial, head, middle and tail farms plus those farms with portions of land at more than one location.

2/Land and canal water revenue combined. In case of public tubewell water the assessment is included in the abania or canal rate.

3/The cost of tubewell water included with irrigation water is estimated as 3 extra irrigations from private tubewell at a cost of Rs. 5.00 per hour for 6 hours assuming 50% delivery efficiency.

4/Harvest costs are related to the yield of the crop.

5/Bhoosa or straw sells at various rates depending on the nearness to a market center. Roughly 2 md. of straw per 1 md. of grain.

the irrigation before heading begins. Tubewell owners operate more on a demand system and apply more irrigations than do other farmers. One report (Chaudhry and Eckert, 1975:434) states that "assuming an unstressed yield potential of 40 mds/acre delay in the first irrigation can result in a loss of about a md per day for each day beyond 21 days after planting." The net income/acre for farms with no tubewells is only a little more than half as much as that of tubewell owners (Table 25). Also, note the difference between head and tail farms on commands with no tubewells. The difference in net income per acre is about 20 to 25 percent which becomes substantial given several acres of wheat.

B. Average Per Acre Returns For Rice

Rice yields vary a great deal between regions and between different varieties of rice. The majority of sample farmers grow either Basmati varieties or other local varieties and yields are roughly the same. In Table 26 it is obvious that the factor creating the greatest difference in average net income is yield because production costs, as in the case of wheat, are fairly stable. Again, note that tubewell owners had an average net income about 35 percent greater than farms which receive public tubewell supplies, while public tubewell farmers have net income of more than 100 percent greater than farmers with no tubewells. When head and tail farms are compared the head farms receive an average net return about 22 percent greater than the tail farms (see Table 26).

C. Average Per Acre Returns For Cotton

A major limitation of cotton production figures for public tubewell farms is that the relatively low yields represent commands in the SCARP areas of Sargodha District. In this non-cotton belt area, yields range from 5 to 11 mds with a mean of about 8 mds per acre. Therefore,

Table 26. Average per acre returns to land, risks and management for selected types of rice farms (1975-76).

	Type farm				
			No tubewell		
Item	Public tubewell	Private tubewell	No tubewell*	Head farm	Tail farm
	- - - - -	- - - - - -	- (Rs.) -	- - - - - - -	- - -
Seed	10.0	10.0	10.0	10.0	10.0
Fertilizer	70.5	58.5	48.8	54.7	56.3
Labor	45.0	45.0	45.0	45.0	45.0
Bullock power	160.0	160.0	160.0	160.0	160.0
Taxes (land/water)	64.0	78.0	48.0	48.0	48.0
Harvest costs	92.4	111.8	72.9	77.74	72.9
Artisans & tools	22.2	22.2	22.2	22.2	22.2
Farm manure	25.0	25.0	25.0	25.0	25.0
Miscellaneous	23.3	23.3	23.3	23.3	23.3
Total cost/acre	512.4	533.8	455.2	465.94	462.7
Yields/acre, mds.	19	23	15	16	15
Rs.38 x mds.	722	874	570	608	570
Rice staw Rs. 2/md.	38	40	38	32	30
Gross income	760	914	600	640	600
Net income	Rs.247.6	Rs.380.2	Rs.144.8	Rs.174.1	Rs.137.3

*"No tubewells" represents all commands both perennial and nonperennial, head, middle and tail farms plus those farms with portions of land at more than one location.

for the analysis shown in Table 27 SCARP public tubewell commands are excluded. Note that costs remain about the same for the remaining four farm types. Cotton, as a kharif crop, requires about 30-35 acre inches of water due to the high evapotranspiration rates of the summer season. Without tubewell supplements or good kharif canal supplies cotton yields fall drastically. A strong bias in these data is the fact that on all major cotton commands such as 102 and 107, and 1 of 4 commands at site 114 in the Punjab there are private tubewells. On the commands in Sind at Site 115 there are tubewells on only 2 of the 6 commands and yields at this site average only about 7 maunds per acre. Therefore, the low net income for cotton reflects these low yields. Cotton is hardly a profitable crop given limited water supplies.

IV. SUMMARY OF ECONOMIC DUALISM AND THE FARMING IRRIGATION SYSTEM

Though the data have limitations they present a rather clear picture of several factors associated with economic dualism. Ratios of the highest net income farm type in relationship to each of the other type farms are given in Table 28. With the exception of the unusually low net income for cotton by tail farmers, the ratios provide a more clear picture of the importance of control over irrigation water. Tail farms are at a disadvantage on all types of systems unless the farmer owns a tubewell. Even with watercourse rehabilitation, total losses will continue to be greater for tail farmers. Large, medium, and small farms are about evenly distributed over the command areas. This problem affects farms of various sizes, but small farmers at the tail probably suffer most due to a lack of capital for tubewell installation. Several policy suggestions have been offered. One is to reverse the warabundi distribution of water by starting at the tail of the watercourse and

Table 27. Average per acre returns to land, risks and management for selected types of cotton farms (1975-76).

Item	Type farm Private tubewell	No tubewell	Head farms	Tail farms
Seed	15.0	15.0	15.0	15.0
Fertilizer	61.5	53.3	64.5	44.3
Labor	63.0	63.0	63.0	63.0
Bullock power	164.0	164.0	164.0	164.0
Taxes (land/water)	69.2	48.4	48.4	48.4
Harvest costs	141.7	76.3	76.3	65.4
Artesans & tools	22.4	22.4	22.4	22.4
Farm manure	25.0	25.0	25.0	25.0
Miscellaneous	23.5	23.5	23.5	23.5
Total costs/acre	585.3	490.9	502.1	471.0
Yields/acre (seed cotton)	13	7	7	6
Rs.77 x mds.	1001	539	539	462
Cotton sticks/acre	13	7	7	6
Gross income	1014	546	546	468
Net income	Rs.428.7	Rs. 55.1	Rs. 43.9	Rs. -3

Table 28. Ratio of difference in net income by type of farm (in relationship to highest net income).

Type farm	Net income Wheat (Rs/A)	Ratio of net income*	Rice (Rs/A)	Ratio of net income	Cotton (Rs/A)	Ratio of net income*
Private tubewell farms	547.35	-	380.20	-	428.70	-
Public tubewell farms	380.45	1.44	247.6	1.54	NA	-
No tubewell farms	317.35	1.72	144.8	2.63	55.10	7.78
Head farms (no tubewells)	383.35	1.43	174.06	2.18	43.9	6.21
Tail farms (no tubewells)	297.85	1,84	137.3	2.77	-3	35.7

$$\text{*Ratio of net income} = \frac{\text{net income of private tubewell farm}}{\text{net income of respective other farm types}}$$

proceed to the head. This would reduce inequity imposed on tail farmers, and would tend to make head farmers more interested in watercourse cleaning and maintenance. Another recommendation is the private tubewell solution where there is good quality groundwater. Private tubewells have been shown to be more efficient than the large SCARP tubewells, but special incentives could be given to small farmers at the middle and tails of watercourse commands for the installation of tubewells. At village site 107 the majority of the 26 tubewells are jointly owned by small holders--but in all cases but one the owners are relatives. Another advantage of small discharge tubewells as CSU research has shown is that the small wells can often be used as skimming wells where groundwater is at decreasing marginal quality with increasing depth. Large discharge wells produce a coning effect which causes more saline water to be pumped (McWhorter et al., 1975).

Though not shown in the production cost tables, the difference in net income between perennial command farms versus non-perennial command farms is also a problem. When all perennial farms are examined in comparison to nonperennial farms the former groups of farmers produce yields about 5 mds greater on the average for wheat and rice per acre and 3 mds greater for cotton. By looking at the ratio of difference in yields we find the following ratios in favor of perennial farms: wheat 1.3/1; rice 1.4/1 and cotton 1.4/1. The government has realized this problem and where possible has installed public tubewells on nonperennial commands.

V. LOW LEVEL OF WATERCOURSE MAINTENANCE

The low level of watercourse maintenance has been alluded to often in this report. Low conveyance efficiencies point to this major problem. A World Bank Report (World Bank, 1976, Vol. 3:vi) calls for programs to provide both incentives and discipline for improved watercourse cleaning and regular maintenance to reduce the high level of losses. The report estimates that five million acre feet of scarce water resources could be saved between 1976 and 1978 without capital costs simply by the government enforcing the Canal and Drainage Act of 1873 which states that:

> The Divisional Canal Officer may stop the supply of water to any watercourse whenever and so long as any watercourse is not maintained in such proper customary repair as to prevent the wasteful escape of water therefrom. (Canal and Drainage Act, 1974:21.)

The patwari is also to report the wastage of water due to poor maintenance. The ziliadars are also under orders to use their influence with cultivators to keep watercourses in customary repair as stated:

> When on tour the zilladar should take steps by using his influence with the zamindars (farmers) to pursuade them to put in order any watercourse which he finds in a bad state of repair. Should they refuse to do so, he should report the matter to the sub-divisional officer, who will warn the owners jointly in writing that unless

> within a given time they do so, after personal inspection by himself or the deputy collector, the watercourse will be closed by the Divisional Officer under Rule Section 32, Act VIII of 1873. (Canal and Drainage Act, 1974:115-116.)

In the same section of the act the zilladar is admonished to try to get the farmers to settle such problems amicably among themselves. The philosophy of the act in regard to the watercourse command area is to not interfere with farmers in most matters except the regular collection of water rates and major violations which seldom include maintenance of the watercourse system.

A. Watercourse Alignment

The reader is referred to Figure 7 in the photo glossary to examine pictures A, B and D. These indicate major watercourse alignment problems. Usually, the main delivery channels with a 16 ft right-of-way constitute about 7.5 percent of the total delivery channels. Where topography, unusual watercourse geometry or ownership patterns require multiple main channels, the percentage of ditch length for the sarkari khal (government ditch) may exceed 10 percent of the total length of the conveyance system: when the irrigation system was established, farmers were responsible for developing the farm ditches, and where there were topographical problems, the main watercourse was routed to avoid obstacles. Two maps of village command areas are presented to indicate the alignment of these ditches (Figures 5 and 6). The reader may inspect the remaining maps of command areas in Volume VI, Appendix IV which show all main watercourse and field channels. Watercourse alignment problems are complex because they relate to land ownership rights. When a farmer or group of farmers want a watercourse changed and a new channel constructed the approval process is lengthy and complex. For example, the Divisional

Figure 5.

WATER MANAGEMENT RESEARCH PROJECT

WATERCOURSE SURVEY SAMPLE VILLAGE 106 SCARP TWO DISTRICT SARGODHA

WATERCOURSE COMMAND I

BUNDED UNITS

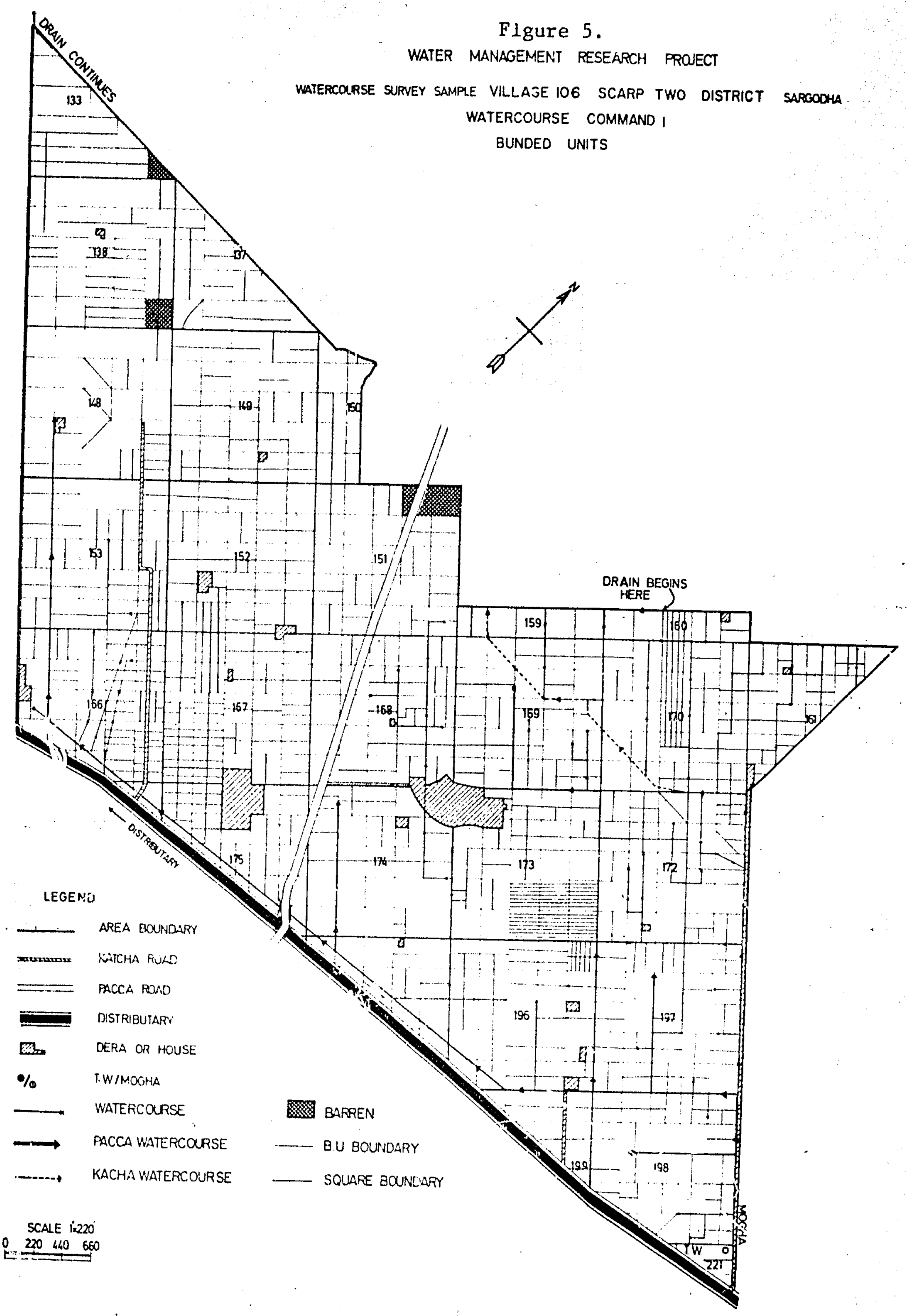


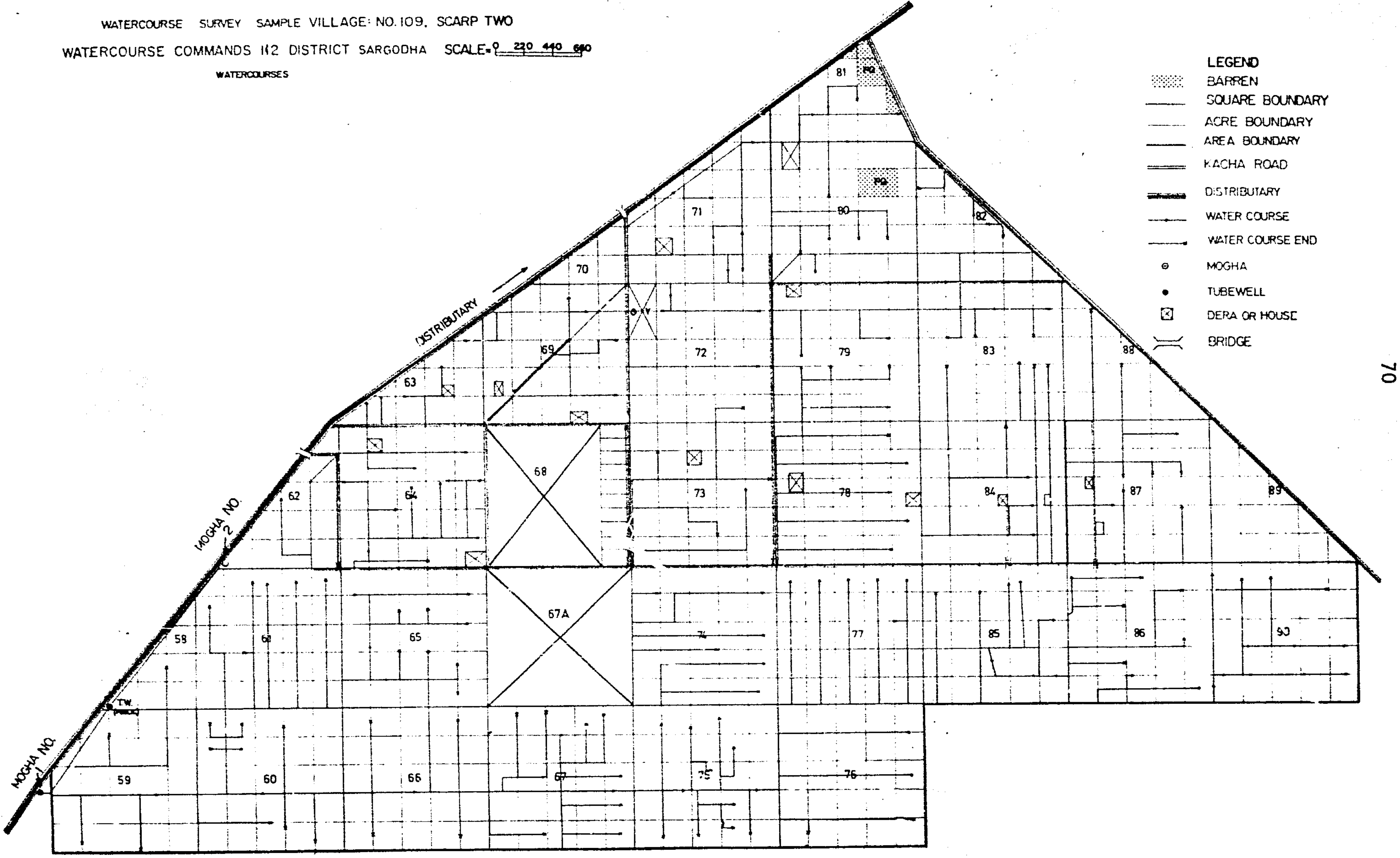
Figure 6.

WATER MANAGEMENT RESEARCH PROJECT

WATERCOURSE SURVEY SAMPLE VILLAGE: NO. 109, SCARP TWO

WATERCOURSE COMMANDS 112 DISTRICT SARGODHA SCALE = 0 220 440 660

WATERCOURSES



Canal Officer is not competent to make the decision which must be referred to the Commissioner. At site 103, one group of farmers reported in 1975 that they had filed for a new watercourse after Partition in 1948 and had not yet gained approval. Many of the conflicts in villages result from right of way questions for watercourses and laterals. As farms become more fragmented these problems tend to become more acute especially where field ditches are concerned. Land consolidation progress in Pakistan to date has been slow. If a major land leveling program is implemented for improved farm layouts, ways and means must be developed to solve these problems of land and water rights.

B. Watercourse Profiles

The slope of the watercourse from the mogha is influenced by general topography and the quality of cleaning and maintenance. Silt is a problem especially during the rabi season when canal supplies are lower and especially for those watercourses near the tail of distributaries where discharge rates are low. When farmers clean the main channels they have no means of maintaining proper slope except by guess work.

Several watercourse profiles are presented to indicate some of the problems involved. Figure 7 shows the slope of an 8000 foot watercourse. The difference in elevation over this distance is about three feet. At the time the watercourse was surveyed, cleaning had taken place about two months before. Farmers reported that this watercourse is cleaned about every three months. In general, this watercourse, in terms of slope, was better than most of the 40 surveyed. Figure 8 shows the profile of watercourse two at site 104. Farmers reported that this channel had been cleaned about six months before and cleaning takes place only twice a year according to farmers' reports. Note that silt has been

Figure 7. Watercourse Profile - Sargodha W. C. No. 1 - Village No. 106.

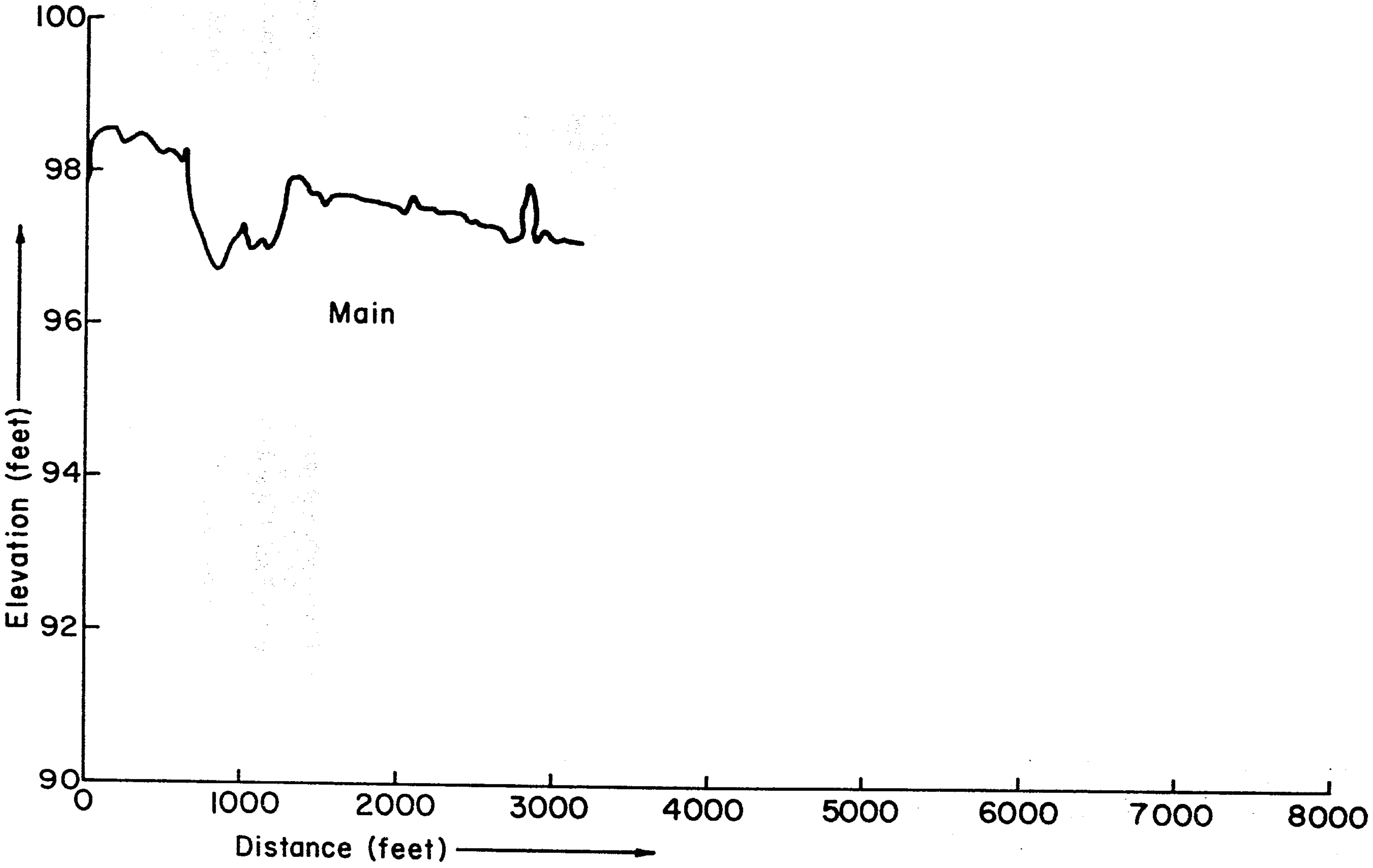


Figure 8. Watercourse Profile - Lahore W.C. No. 2 - Village No. 104.

deposited at the mogha causing some submergence of the outlet and water loss. At about 500 feet to 1500 feet down the watercourse silt had been cleaned but this area becomes one for dead storage because the remainder of the channel was not cleaned. Also note another problem at about 3000 ft. from the mogha. Due to the high spot, water must build up in the ditch sometimes causing upstream overtopping before fields below the point can receive water. This is not an uncommon problem for watercourses where cleaning is done haphazardly.

Figure 9 presents another problem. Water from the canal is routed to a collection pool where it is lifted about 2 ft. by a jhallar to irrigate higher fields. The cost of lifting irrigation water by bullock power is costly and inefficient. On these problem watercourses small diesel or electrical powered lift pumps would be more efficient and reduce the long hours required by man and animals. Farmers report that the main watercourse from the mogha to the jhallar is cleaned about 3 times a year. Figure 10 shows a watercourse profile located in village 101 which farmers report is cleaned about twice a year. There is no special informal committee for cleanings here, and the work is haphazard. Note that at about the 2000 ft. distance mark there is a sharp drop of more than a foot followed by an irregular slope from that point to the high elevation at 5000 feet. This high point is such that water in the system must rist about a foot before fields downstream can be irrigated. Along the watercourse from about 2000 feet to 5000 feet from the mogha many spills and leaks were observed due to the build-up of water in the ditch. Also considerable amounts of water were lost to dead storage due to the high place in the bed of the ditch. This indicates the need for improved cleaning methods, incentives and sanctions to gain farmer compliance for cleaning.

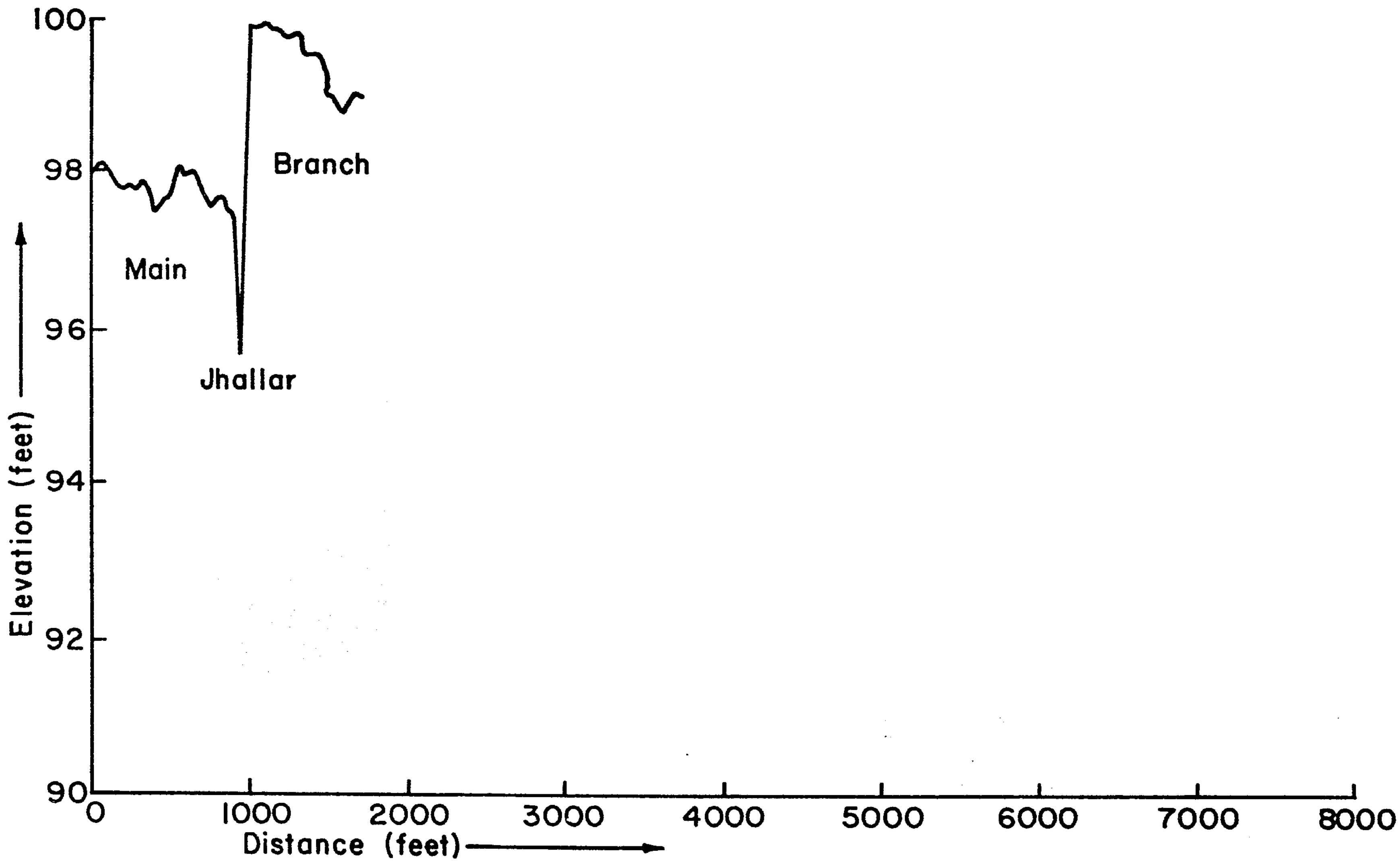


Figure 9. Watercourse Profile - Lahore W.C. No. 3 - Village No. 104.

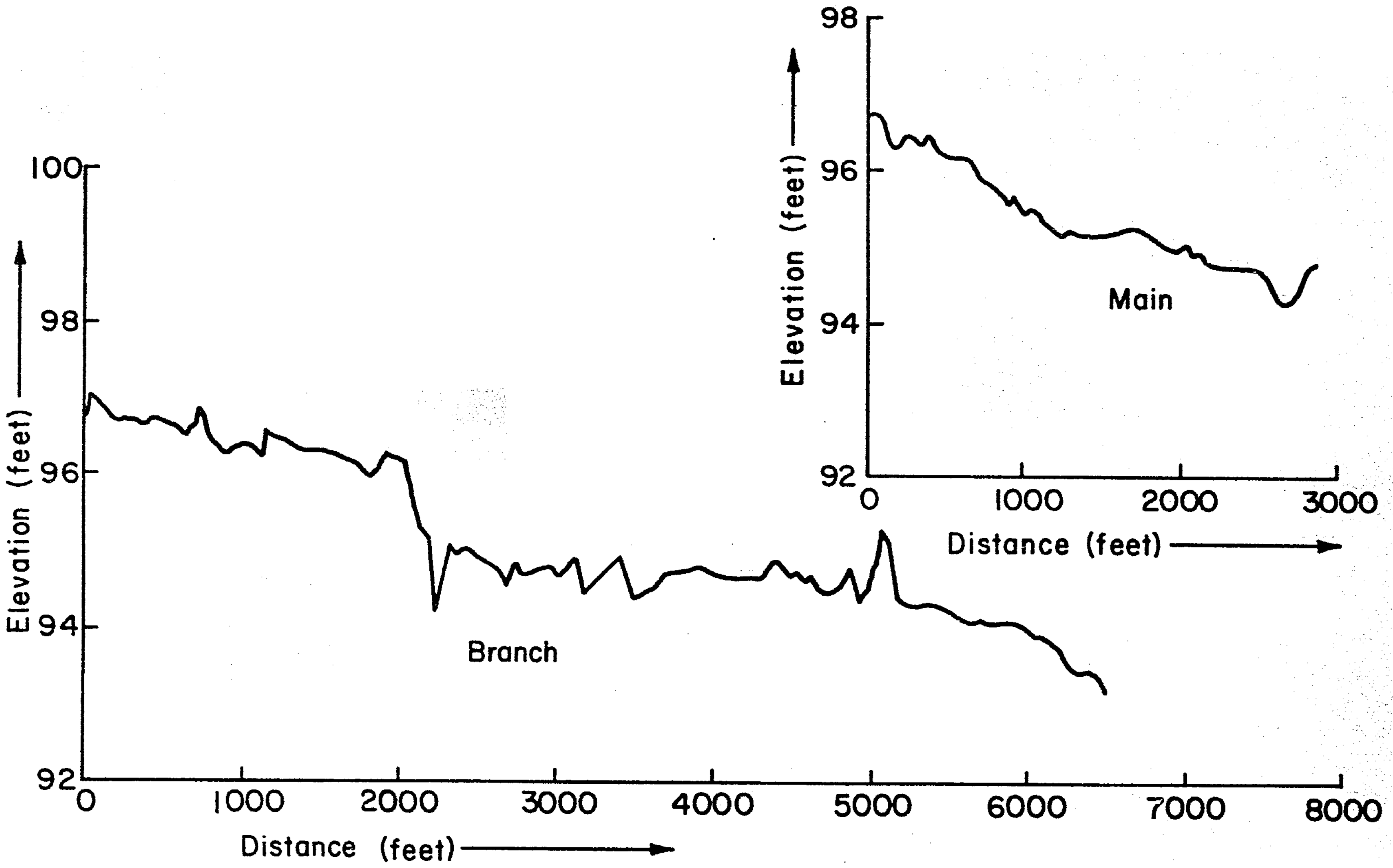


Figure 10. Watercourse Profile - Lyallpur W. C. No. 1 - Village No. 101.

Figure 11 shows a watercourse profile at site 102 which indicates graphically a critical problem of submergence. Farmers reported that they have applied to have the mogha raised. Farmers claim they clean this watercourse 18 or more times a year due to the silt deposits. Mogha submergence is a problem for many watercourses; however, this is the most severe case noted in the sample. Before fields can be irrigated, the water level in the main channel near the mogha must be raised about a foot; such ponding submerges the mogha, and farmers are unable to obtain all of their allotted supply. This is a watercourse where farmers eventually may have to install a lift pump.

In Volume VI, Appendix II, Part A, Section 3, the watercourse profiles for the 40 sample watercourses are available to the reader.

C. Organization for Watercourse Maintenance

Farmers in Pakistan are responsible for regular cleaning and maintenance of the main (sarkari) watercourse channel beginning at the mogha. The main watercourse channel constituted about 8 to 10 percent, on the average, of the total length of all watercourse and field channels on the command area. The Irrigation Department officials under the 1873 Canal and Drainage Act have powers to close mogha supplies or levy other penalties when farmers do not meet their responsibilities in cleaning and maintenance of the main watercourse channels. These sanctions are seldom enforced according to farmer reports and no instance of such sanctioning was reported by informants on any of the 40 sample watercourses. Farmers reported that, at times, threats had been made by irrigation officials, but no enforcement of the code was reported.

This section describes several informal organizational approaches used by farmers for the collective cleaning of the main watercourse

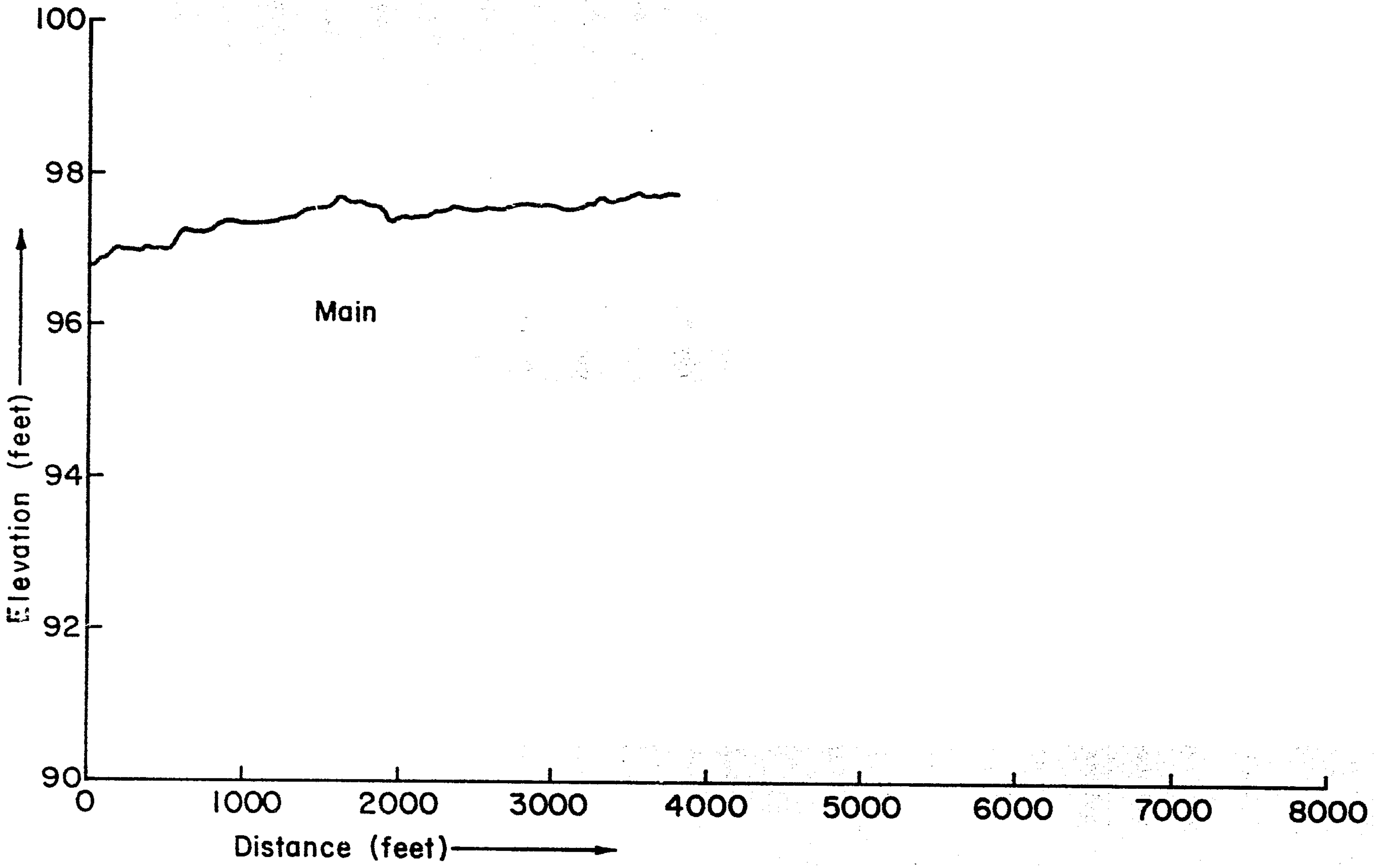


Figure 11. Watercourse Profile - Multan W. C. No. 1 - Village No. 102.

channels. Photo glossary Figures 5 F, K and Figures 7 A thru C show the typically poor level of maintenance found at most sites. Man/days of cleaning and times cleaned per year vary greatly because silt accumulation problems vary greatly between watercourses. Some watercourses, due to location on the canal system and topography, have much more silting problems than others. For example watercourses at the tail or near the tails of a distributary usually face more problems with silt.

The purpose of the data presented below is to describe selected social mechanisms involved in cleaning and maintaining the main watercourse system. Table 29 provides information related to the two types of warabundi systems, regulated and nonregulated. Note that on 81 percent of the 21 regulated warabundi watercourse commands, sanctions are applied when farmers do not participate in cleaning activities as compared to only 37 percent for nonregulated commands. Watercourse members who have a regulated turn system for distribution of water are typically more organized for cleaning and maintenance.[6/] Sanctions are usually applied by informal, or ad hoc, committees for cleaning or by all watercourse members. It is interesting that for nonregulated warabundi commands there are no informal committees while about 40 percent of the regulated warabundi commands have committees. There is also much variation in the types of sanctions applied. These range from a fine levied to pay for substitute labor, to cutting off an offender's water for a stipulated period, social pressure, purchasing sweets for the other

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[6/] The mean and median conveyance efficiencies for nonregulated warabundi watercourses are 48 and 47 percent respectively. For regulated systems the mean and medians respectively are 56 and 59 percent. Since these are not time series data we can't definitely conclude that regulated systems have higher conveyance efficiencies, but we have a strong indication that it is so.

Table 29. Sanctioning for nonparticipation in watercourse cleaning by type of warabundi system.

Sanctions for Non-Participation in Watercourse Cleaning	Regulated Warabundi System (n=21)		Non-Regulated Warabundi System (n=19)	
	No.	%	No.	%
1. Sanctions applied				
a) yes	17	81	7	37
b) no	3	41	12	3
c) no response	1	5	0	-
2. Who applies sanctions				
a) no one	3	14	12	63
b) individual	0	-	1	5
c) informal committee	8	38	0	-
d) all wc members	7	33	5	26
e) no response	3	14	1	5
3. Nature of sanction				
a) none	3	14	12	63
b) money to pay labor	2	9	1	5
c) cut off water	4	19	1	5
d) cut off water & money fine	1	5	1	5
e) social pressure members	1	5		
f) sweets for wc members	1	5	3	16
g) fine used for mosque	1	5	0	-
h*) Nakka Fund	4	19	0	-
g) data not available	4	19	1	5
4. Who can escape sanctions?				
a) Numberdor and/or landlord	4	19	0	-
b) everyone	1	5	0	-
c) no one	7	33	3	16
d) no data	9	42	16	84

*Nakka Fund - fine money used for constructing diversion structures at junctions on watercourses.

watercourse members, or fines used to install permanent structures at watercourse junctions. Though the data are incomplete as shown under item 4 in Table 29, the sanctions appear to work. For example, the ability to exact fines or to cut off an offender's water is a good test of the power of the informal organizations. For the 12 regulated warabundi commands for which data are available, key informants are unanimous on seven commands that no one can escape the social sanctions applied. Those who sometimes escape from the fines or other sanctions applied are the powerful landlords and the influential numbardars.

Table 30 presents information on the regularity of cleaning the main portion of watercourses and the satisfaction of farmers with cleaning activities. Observe the wide range in watercourse cleaning frequencies per year. At the one regulated command area (site 105) farmers had not cleaned the brick and cement lined watercourse in one year. This site provides a special case of an experimental watercourse project where farmers provided little participation in decision making or in the actual construction activities. Therefore, watercourse members reported that the Government built the watercourse and should maintain it. As a result of lack of cleaning some parts of the main watercourse contained much silt and aquatic plant life. Unless farmers participate in projects for their benefit they most likely will not maintain them.

Several patterns are involved in cleaning of the main watercourse system. On 19 of the 40 commands studied, farmers work together at certain periods to clean the total length of the main channels. On 21 of the commands, certain sections of the main watercourses were allotted to certain brotherhood and family groups for cleaning. These designated sections are usually allotted on the basis of so many kadams (2 paces or

Table 30. Watercourse cleaning (regularity and farmer perceptions) by type of warabundi system

	Regulated Waribundi System (n=21)		Non-Regulated Waribundi System (n=19)	
	No. of Cases	%	No. of Cases	%
1. Times cleaned/yr				
0-1	1	5	2	11
2-4	14	67	11	58
5-7	4	19	1	5
8-10	0	-	2	11
11-13	0	-	2	11
14 and over	2	9	1	5
	$\bar{x}$ = 6, median = 3, range 0-28		$\bar{x}$=5, median = 2, range 1-12	
2. Man days/year				
None	1	5	0	-
> 40	6	29	5	24
41-80	9	43	5	24
81-120	3	14	3	16
121-160	0	-	2	11
161-200	0	-	0	-
201 and over	2	9	4	21
	$\bar{x}$ = 113, median = 80, range 0-420		$\bar{x}$ = 116, median = 60, range 10 to 135	
3. Farmer perceptions Regularity of Cleaning				
None	1	.5	3	16
Low	3	14	3	16
Medium	9	43	4	21
High	8	38	9	47
4. Farmer satisfaction with cleaning				
None	0	-	4	21
Low	4	19	5	26
Medium	7	33	5	26
High	9	43	5	26
No Response	1	5	0	
Simple correlation coefficient between regularity & satisfaction with cleaning		.68		.57

about 5½ feet) per acre of land owned or cultivated. Another method is to allocate a specified number of kadams per phar (3 hour unit) of irrigation water received. When such areas are allotted to individual families or brotherhood groups due consideration is given for the area of the watercourse to be cleared. If sections near the mogha are allotted 1 kadam/phar of the irrigation turn may be stipulated but if the area is further from the mogha 2 kadam/phar may be designated. The rationale relates to the incidence of silt deposits which usually are greater near the mogha.

The man days per year for watercourse cleaning is a function of several factors which vary a great deal for the 40 sample command areas. These are the number of farmers on a given watercourse command, the length of the main watercourse and the degree of silting which takes place. For example, at site 103 the main watercourse is several feet below the level of the field and water must be lifted by the jhalar system. The problem of silt accumulation is such that farmers report regular cleaning twice a month during rabi and once per month during the kharif season. Total man days per year for the 18 cleanings is over 400. This, however, is a most extreme case. The median man days required for cleaning main watercourse channels are 80 and 60 days, respectively, for regulated and nonregulated commands.

Key informants were asked if they perceived the present levels of cleaning to be regular and whether they were satisfied with the quality of the cleaning. The reports show that the majority of key informants report medium to high regularity of cleaning for both types of warabundi commands (see Table 30). For commands where key informants reported "no" regularity in cleaning (sites 105-1, 109-2, 115-3, 116-3 and 4) watercourses were cleared on the average of twice per year.

Item 4 in Table 30 presents key informants reports about satisfaction with cleaning quality. The majority of farmers report satisfaction with present efforts.

Table 31, below, shows the difference in reported regularity of cleaning between commands with no watercourse cleaning committee and those with an informal committee.

Table 31. Presence of informal committee and regularity of watercourse cleaning.

Regularity of Cleaning	No Informal Committee (n=6)		Informal Committee (n=34)	
	No. of Cases	%	No. of Cases	%
None	1	16.7	4	11.8
Low	-	-	5	14.7
Medium	4	66.7	10	29.4
High	1	16.7	15	44.1

Watercourses with no informal committee were cleaned on an average of twice per year while watercourses with informal committees the average number of cleanings per year equaled seven. This difference suggests the importance of committees for cleaning. Forty-four percent of the key informants on commands with committees report high regularity in cleaning as compared to only 17 percent for commands with no committees. A similar relationship is found from key informants' satisfaction with cleaning.

Table 32 presents information on cleaning regularity for perennial and nonperennial command areas. As one would expect, mean frequencies of watercourse cleaning are much higher (7) for perennial commands than for

Table 32. Watercourse cleaning (regularing, key informants, perceptions, sanctioning and committee existence) by type of command system.

	Perennial Commands (n=25)		Non-Perennial Commands (n=14)	
	No.	%	No.	%
1. Times cleaned/yr				
0-1	2	8	1	7
2-4	13	52	11	79
5-7	3	12	2	14
8-10	2	8	-	-
11-13	2	8	-	-
14 and over	3	12	-	-
2. Man days/year				
None	0	-		
> 40	9	36		
41-80	7	28	7	50
81-120	3	12	2	14
121-160	1	4	-	-
161-200	0	-	-	-
201 and over	5	20	1	7
3. Farmer Perceptions regularity of cleaning				
None (0)	3	12	2	14
Low (1)	3	12	3	21
Medium (2)	9	36	3	21
High (3)	10	40	6	43
4. Farmer satisfaction with cleaning				
None (0)	4	16	1	7
Low (1)	4	16	4	29
Medium (2)	8	32	3	21
High (3)	9	36	6	43
5. Sanctions applied for non-participation in cleaning	15	60	10	71
6. Informal wc committee exists for cleaning	20	80	13	93

nonperennial commands (3). A similar relationship exists for man days/ year of cleaning. On nonperennial commands canal supplies are available only for kharif season; fewer cleanings are required. Little difference is found between key informants' perceptions of regularity of cleaning and satisfaction of cleaning for perennial versus nonperennial commands. Likewise, little difference is found between the two types of commands in regard to sanctions applied for nonparticipation in cleaning and the existence of informal watercourse committees.

In conclusion, important findings about farmer organization for watercourse maintenance are summarized below:

1. Farmers on most watercourses have informal arrangements for cleaning and use a variety of sanctions to insure farmer participation.
2. Farmers on regulated warabundi systems tend to be better organized for cleaning than farmers on nonregulated warabundi systems.
3. Informal committees are used on some watercourses for settling disputes over water and for cleaning purposes.
4. Where sanctions are used to enforce participation for cleaning these are applied by informal committees elected by watercourse members or by all the members as a group.
5. Large landlords and village leaders sometime escape sanctions.
6. There is great variation in the times the watercourses are cleaned each year resulting primarily from the incidence of silt deposition in channels.
7. Man days/year of cleaning are related to the incidence of silt deposits, the number of farms on the command, and the length of main watercourse to be cleaned.

8. On about half of the watercourses, farmers clean the main channels together and on other commands designated sections of the main channel are given to individual farmers to clean.
9. The majority of key informants perceive that the present regularity of cleaning is from fairly high to high and are generally satisfied with current quality of cleaning.
10. Watercourse cleanings are about double for perennial commands as opposed to nonperennial commands.

The measured conveyance losses, the photographs in the photo glossary, and information about cleaning reported in this section suggests that watercourse cleaning is neither regular or well done on most command areas. Conversation with farmers about this problem provide the following generalizations: First, farmers are not aware of many types of conveyance losses such as vertical and horizontal seepage, and those due to dead storage. Secondly, farmers are not aware of the magnitude of the losses until convinced by measurements. Thirdly, the Irrigation Department officials seldom enforce the regulations dealing with watercourse cleaning. Fourthly, there are currently no farm-level extension advisors or other personnel to help farmers improve watercourse cleaning and maintenance activities. And finally, until recently there were few proven procedures for watercourse rehabilitation and low cost technologies for junction structures and farm turnouts.

CHAPTER TWO

CONSEQUENCES OF THE PRESENT FARM WATER MANAGEMENT

I. CONVEYANCE EFFICIENCIES AND LOSS RATES ON THE WATERCOURSE

Actual losses in on-farm delivery systems are affected by many physical and behavioral factors. This chapter will examine several factors and their influence on the delivery efficiency and loss rates per 1000 feet of watercourse length. Delivery losses, especially those due to seepage, are expected to be higher where soils are sandy loam to sandy and are not easily compacted. Where channels are lower than field elevations, losses result from "dead storage"--water left in the ditch bottom after an irrigation has been completed. If the main watercourse channel is too high in relation to the canal outlet, the effect of increased water surface elevation on the outside of the mogha results in reduced discharge. In earthen channels, the losses are expected to increase in proportion to distance from the mogha outlets to field outlets. When rates of discharge are large relative to channel size, losses increase due to spills. Where public and/or private tubewells discharge concurrently with canal water into ditches constructed only for traditional canal allotments, substantial losses via spills can be expected.

Behavioral factors which relate to farm delivery losses are the general maintenance and repair of both main delivery channels and farm ditches. Where maintenance is poor there are silt deposits, excessive vegetation along the channels, and holes created by rodents and other animals. Farmers' collective and individual actions are important factors in reducing these losses.

As a result of these and other factors, farm delivery efficiencies for earthen channels around the world are quite low. A recent preliminary investigation (Bos and Nugteren, 1974, 25) in 50 irrigated areas of 16 developing countries shows that farm delivery efficiencies of earthen channels constructed in sandy, sandy loam, silt and silty clay soils range from less than 50 to about 65 percent.

Data collected for the present study do not include information about all the factors affecting conveyance losses. Under pressure to complete evaluations in a single week on a given watercourse, researchers had to limit data collection to mogha discharge and field outlet discharge by flow measurements and other topographic and profile variables.

A total of 559 usable evaluations were obtained on 40 sample watercourses at 16 village sites located in 11 different agro-climatological zones. Prior to reading the analysis of the data, the reader may wish to examine the pictures in the photo glossary, Volume 1 (Figures 1 to 8), to acquaint oneself with general watercourse conditions and the field work in collecting data. This will provide an overview of the types of problem situations encountered related to various types of conveyance losses.

A. Summary of Delivery Efficiencies

Figure 12 provides a distribution of the weighted farm delivery efficiencies by interval categories. Overall, the data obtained presents a rough fit to a normal distribution. The mean and the median delivery efficiencies for the sample farms respectively are 53.2 and 53.4 for the 306 sample farms.

Since month of the evaluation may affect the delivery efficiencies obtained due to the differences in distributary discharges into the farm system, Table 33 shows the dates and number of farms evaluated by type of

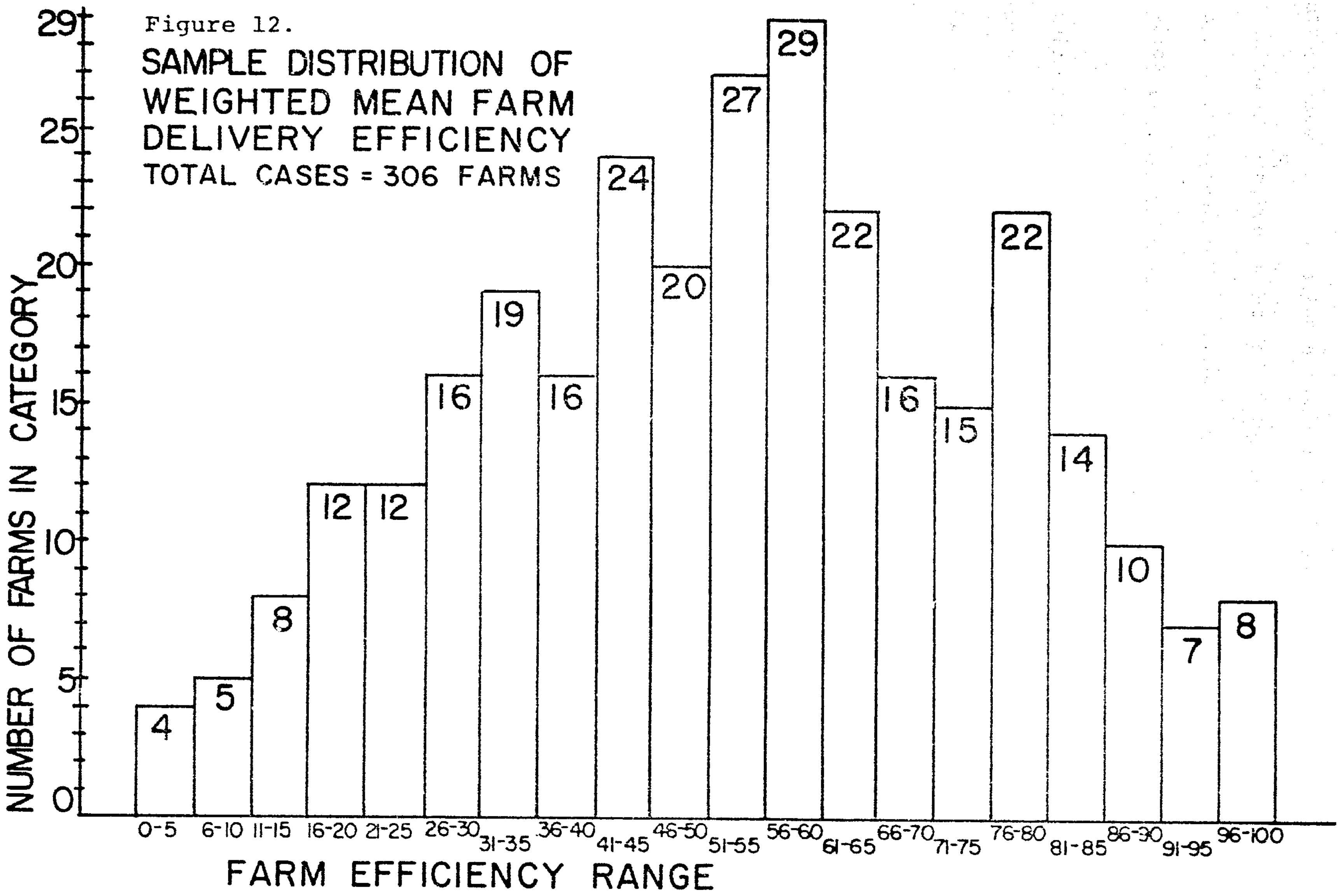

Figure 12.

SAMPLE DISTRIBUTION OF WEIGHTED MEAN FARM DELIVERY EFFICIENCY

TOTAL CASES = 306 FARMS

Table 33. Number and percentage of physical irrigation evaluations completed at village sites by month.

Type of command and sites	No. of cases	Months when evaluations of sample farms were completed (Number of farms)											
		Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Perennial													
101-2	14					7	3	2	1			1	
102-1	5						2					3	
103-1	5						5						
104-3	27				10	12		5					
106-1	7							1	5				1
107-3	33						30					3	
109-2	11				7				3				1
110-3	27				12				2	3	10		
112-3	33		22	6				5					
113-3	25		24					1					
116-4	22		6	16									
Nonperennial													
105-1	7											7	
108-1	4								2			2	
111-2	22	19					3						
114-4	33	11	13				9						
115-6	37		14				17	6					
Number of farms	312	30	79	22	29	19	69	20	13	3	10	16	2
Percentage of farms		9.6	25.3	7.1	9.3	6.1	22.1	6.4	4.2	1.0	3.2	5.1	.6
Total number of individual evaluations*	559	66	133	24	36	42	158	34	22	3	12	27	2

*On some farms only one evaluation was made and on others several were made. Individual values are weighted to create the farm value.

command and village site. When ample supplies of canal water are available during the monsoon season, farmers often close the mogha as is seen in the Photo Glossary, Figure 11-L. Also, the greater the supply of water in the main watercourse channels and laterals, the greater are the losses (Kemper, 1975b:243-249). Losses increase through permeable banks and also greater overtopping on channels with inadequate freeboard as shown in the Photo Glossary Figures 7-E and F. Until recently these losses through watercourse banks were not considered important. One experiment, using the ponding method of estimating these losses, however, showed that by lowering the water level in the highly permeable upper levels of a watercourse by 2 inches reduced the loss rate one-third.

Delivery efficiencies are examined by month of evaluation for different water supply situations. Nonperennial commands, which do not receive regular canal supplies in the rabi (approximately November-March) season, would be expected to have less loss than in kharif (approximately) April-October) when canal supplies are available. Of the 14 nonperennial commands, all are supplemented by public or private tubewells or Persian wells. For 10 of these commands with no public tubewells, however, irrigation supplies are greatly reduced for the rabi season. See sites 114 and 115 in Table 33 where 38 farms out of 70 on these two nonperennial commands were evaluated. The mean delivery efficiency evaluations obtained at these sites were for January and February, 60 percent, and for June and July, 51 percent. Though there are 6 private tubewells and 43 Persian wells for these 10 watercourse command areas, irrigation supplies are very limited during rabi season. The conveyance losses, therefore, on the farm system are expected to be considerably less in volumetric measure but more in percentage measure than during kharif, when canal supplies are available, due to the smaller discharge carried by these channels in rabi season (Kemper, 1975c:137-153). If this assumption is correct our estimates for delivery efficiencies for these two sites, 114 and 115, are conservative.

Figure 13 provides summary data on delivery efficiencies by month of the year. In terms of months when the evaluations were completed there is little variation.

It may be thought that delivery efficiencies would be higher for daytime irrigations as compared to nighttime irrigations. At night it is more difficult to spot leaks and spills quickly and some farmers discuss their fears of snakes and animals such as wild pigs. The mean and median delivery efficiencies obtained for 241 daytime evaluations, however, were 53 percent as compared to 56 and 58 percent for nighttime evaluations. Several evaluations were done which include both day and night and these are excluded. The major difference seems to be cold winter nights versus spring and summer nights. When winter (November-February) nighttime delivery efficiencies are examined, the mean value for 36 farms is 53 percent as compared to a mean summer nighttime value for 16 farms of 63 percent. It is interesting to note that the winter day conveyance efficiencies (52%) as compared to summer day efficiencies (53%) are almost identical. On the basis of these data it appears that summer night delivery efficiencies were higher than winter night efficiencies. Where we have comparative data, however, as at sites 114 and 115, we note the differences between seasons are partially due to nonperennial commands carrying less water in rabi season. Therefore, we conclude that an important factor causing differences in delivery efficiencies is the supply of water available at the mogha, tubewell or both.

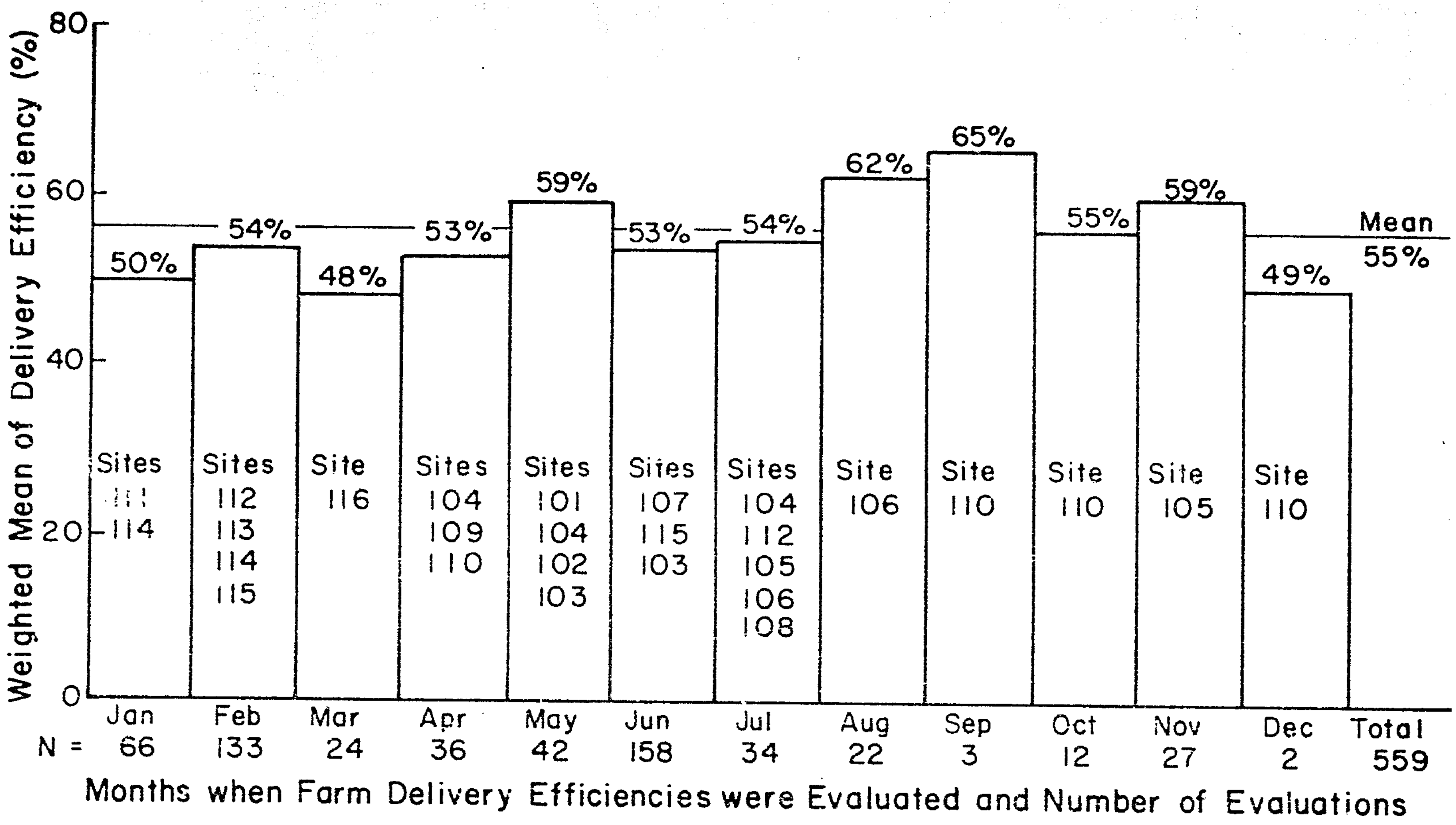

Figure 13. Summary data on delivery efficiencies by month of year.

Wide ranges appear in the data obtained for delivery efficiencies on all watercourses.[7] On a given watercourse there are several interdependent factors which result in different rates of losses, such as the volume of water discharged into the farm system, the distance from the source of supply, the care of the irrigator in making repairs along the main watercourse channels and branches to his farm, general watercourse maintenance, soil types, and slope of the watercourse. A critical factor is the care or shepherding of the water by farmers.

B. Delivery Efficiencies for Respective Sites

Table 34 displays conveyance efficiencies for 40 sample watercourse commands at the 16 village sites. For the 305 sample farmers on which usable information is available, both the weighted mean and the median efficiencies equal 53 percent. Note that sites with public tubewells (106, 108, 109 and 111) have lower efficiencies than other commands with the exception of site 116 which had a mean efficiency of 35 percent and a median of only 25 percent. Site 105 is also a public tubewell supplemented command but the main watercourse and most branches have been lined. The efficiency, therefore, is higher than other public tubewell supplemented commands with unimproved earthen channels. The four commands at site 116 are special cases because the canal supplies at this site, in lower Sind, has excess canal water throughout the year. Farmers at this site block the mogha to reduce the excess water supply. Little or no checking of leaks by irrigators was observed. Farmers at site 116 report that there is no real turn system (warabundi). Each farmer irrigates when he feels his crop needs it. Along the four watercourses at this site, seven

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[7] See Volume VI, Appendix II, Part A-1, which provides detailed information in mean, median and range values for major variables related to delivery losses.

Table 34. Summary of farm delivery efficiencies by village site (each farm weighted).

No.of Village site-wc's	No. of cases	Delivery Efficiencies (%)		
		Mean	Median	Range
101 - 2 wc	14	68.6	71.0	49-91
102 - 1 wc	6	65.0	62.0	45-87
103 - 1 wc	2	61.0	61.0	49-73
104 - 3 wc	25	47.6	50.0	0-100
105*- 1 wc	5	60.8	60.0	32-84
106*- 1 wc	6	45.2	41.5	27-66
107 - 3 wc	28	55.1	52.5	33-92
108*- 1 wc	4	51.0	53.5	12-85
109*- 2 wc	12	43.7	34.5	11-72
110 - 3 wc	27	66.0	70.0	28-95
111*- 2 wc	24	43.4	41.5	2-100
112 - 3 wc	33	54.5	52.0	27-82
113 - 3 wc	25	55.6	55.0	16-85
114 - 4 wc	35	53.1	57.0	10-90
115 - 6 wc	38	55.5	50.5	11-100
116**-4 wc	21	35.1	25.0	7-100
Total 40 wc	305	53.2		0-100

*Denotes SCARP public tubewell supplemented commands; command area site 105 has main watercourse and some laterals lined.

**Denotes 4 command areas where there is excess canal supplies and where farmers, as shown in Photo Glossary Figure 11-L & O, block the mogha due to excess supplies.

illegal moghas were identified which suggests that farmers at this site operate an open system!

With the exception of site 105, efficiencies of public tubewell commands are from 10 to 20 percent less than on other commands which leads to the conclusion that losses on the public tubewell commands are greater than that of other commands. Data has also been reported (Clyma, Ali, Ashraf, 1975b:170-191) showing higher average watercourse losses for tubewell supplemented watercourses versus nonsupplemented watercourses for several areas in Pakistan. The large extremes in the range values result from two main factors. First, farms located at the head and tail reaches of command areas are expected to have large differences in efficiencies. Second, due to some large breaks in dams at watercourse junctions and nakkas, several farmers at sites 104 and 111 lost almost all the water delivered from the mogha because they had left the fields and did not bother to check and repair the breaks. The highest weighted efficiency obtained was for site 101 where all farmers are of one social group (Arians) and not only exhibit much cohesion but also organize to do a fair to good job of maintenance of the main watercourse.

C. Delivery Efficiencies and Water Supply Situation

Table 35 shows several different watercourse command supply situations and watercourse conveyance efficiencies. Under item (A) we find no difference between losses on perennial commands versus nonperennial commands. Both types of commands have both mean and median efficiency percentages of just over 50 percent. The major difference is seen in item (B) where the public versus private tubewell commands are compared. The public tubewell command farms have lower efficiencies than those with only private tubewells. The value for farms on commands with no tubewells

Table 35. Mean, median and range of delivery efficiencies by water supply situation.

Water supply situations	No. of farms	Delivery efficiencies (%)		
		Mean	Median	Range
A. Type command				
Perennial	198	52	53	0-100
Nonperennial	95	53	53	10-100
B. Tubewell supplemented				
None	157	51	51	0-100
Private	111	58	57	2-100
Public	22	47	50	11-84
Private + public	15	50	51	12-85
C. Mogha Q (cusecs)				
up to 1.00	124	56	57	0-100
1.01-1.59	53	57	61	10-87
1.60-2.00	46	47	47	11-92
2.01-2.59	44	53	54	2-91
2.60-3.00	11	54	49	11-100
3.00 and over	6	46	44	7-43

is somewhat misleading due to the 21 farms at site 116 with a mean delivery efficiency of 35 percent and a median efficiency percentage of 25. The actual mean and median respectively for commands with no tubewells, when these 21 farms are removed, are 53 and 55 percent. The major difference is observed under item (B), Table 35, where public tubewells with large discharges on watercourses create more losses due to the fact that the main watercourses and branches were not sufficiently enlarged or improved after the public tubewells were installed. Reported losses on watercourses supplemented by public tubewells (Kemper, Clyma, Ashraf, 1975d:208-212) indicate that public tubewell augmented watercourses have greater losses because:

(1) "The farmers have not enlarged their watercourse to properly handle the water;"

(2) "Having more water has allowed the farmers to be more careless with their supply;" and/or

(3) "Tubewell water pure or mixed with canal water has more tendency to erode and deteriorate and leak from watercourses."

When the mogha discharge which may also include tubewell water is examined in relationship to delivery efficiencies, the median percentages show a weak relationship. The simple correlation between mogha Q and delivery efficiency is only -.13. The conclusion can be that whatever the water supply situation and the amounts of water available, loss rates in the farm irrigation system are unusually high for all sample watercourses. Essentially only half the water available reaches the fields of the typical farmer for irrigation of crops.

D. Delivery Efficiencies and Farm Position on Command Reaches

Another factor that influences delivery efficiencies is location of the farm on the command system since total losses are primarily a function of distance.[8/] Measures for determining head, middle and tail locations are described in Volume VI, Appendix I, Part B. Three measures were used. First, each command area was demarcated into three equal length sections--head, middle and tail--and each sample farm was located on one or more of these sections based on distance from the mogha. Second, to adjust these positions for two or more commands within a village site where large differences often occurred in the length of watercourse channels, it was necessary to allocate farm positions, in thirds. relative to the longest watercourse plus branches. A third measure was that of the interviewer's estimate of each farm location on the basis of farmers' responses. The three measures are presented in Table 36 to show that when compared to using the delivery efficiencies values obtained, these three measures have some validity and reliability. Note that under item (1)(Table 36) where location was measured by the engineers for each irrigation evaluation, head farms have a delivery efficiency of about 58 percent as compared with about 44 percent for tail farms. Likewise under item (2) when we adjust for all watercourses at a given village site the mean efficiencies for head and tail respectively are 61 and 42 percent. Even the more crude estimate of the interviewers shows that head farmers have a weighted mean conveyance efficiency from the mogha to their fields of 61 percent and tail farms have an efficiency of 46 percent. The simple correlation coefficient for distance of farm from the mogha and delivery

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[8/] Farms which had fields at more than one location on the command are noted in the tables that follow.

Table 36. Mean, median and range of delivery efficiencies from mogha to the farmers' fields by three measures of farm location.

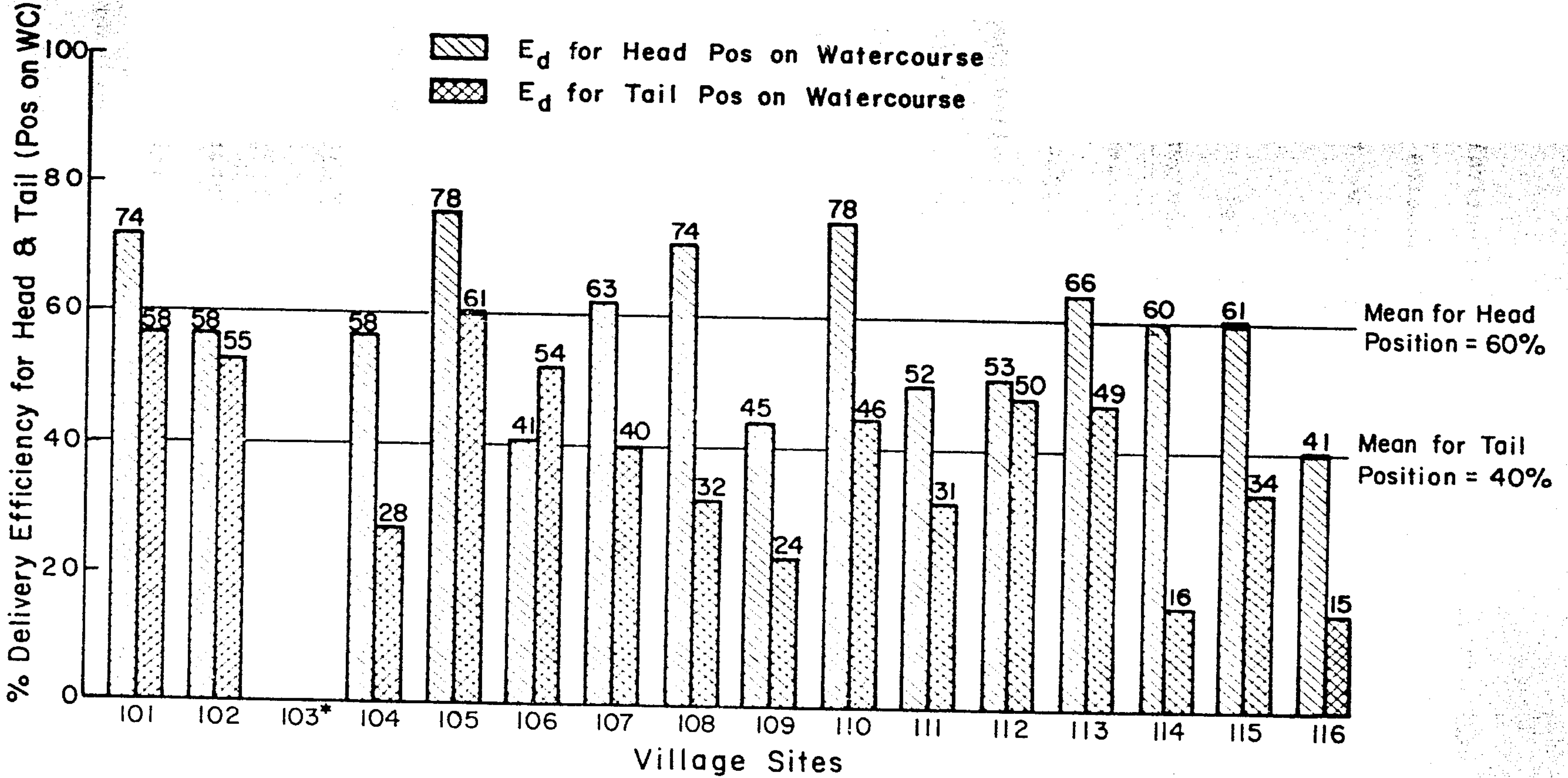
Watercourse command reaches	No. of farms	Delivery efficiencies (percentage)		
		Mean	Median	Range
1. Measured watercourse position				
Head	94	57.8	58.0	11-100
Middle	41	52.8	52.8	16-91
Tail	58	44.5	42.5	7-83
	193			
2. Adjusted measured watercourse position*				
Head	112	60.8	60.8	12-100
Middle	82	50.5	49.3	2-95
Tail	55	42.3	43.0	0-82
More than one**	20	58.4	60.5	18-87
	269			
3. Interviewer's estimate				
Head	119	60.7	60.9	2-100
Middle	60	50.7	50.0	16-95
Tail	95	46.4	49.0	7-83
More than one**	29	49.3	50.3	0-80
	303			

*Positions (head, middle, tail) adjusted by longest watercourse at each sample village site.

**More than one refers to farms with parcels of land at more than one of the three locations, head, middle, or tail.

efficiency is .27 which is significant at the .001 level. Volume VI, Appendix II, A-2 provides data for each watercourse command showing these differences between head and tail farms. The differences between head and tail farms are much greater than the summary data presented in Table 36 implies. To obtain a more graphic view of the differences between head and tail farms for each sample site, Figure 14 is presented to reveal the wide variations between command areas and village sites. Note that for site 103 no evaluations are presented--all water entering the mogha from the distributary flows to collection ponds or small tanks and is lifted by jhallar (Persian well) due to extreme topographical differences between the distributary and the land to be irrigated. The extremes for some of the sites in delivery efficiencies (Figure 14) are as much as 100 percent in some cases. At site 104, 109, 114 and 116 less than 30 percent of the water available reached tail farms. This leads to a type of mini-dualism on watercourses. Somewhat to our surprise, we find that in terms of distribution of farm sizes there is no indication that farm size is associated with farm location on the command area. Thus the problem affects small and large farmers but the greater impact is on small farmers at the tail who do not have the same access to private tubewells as larger farmers.

While not presented in tabular form, no important differences were found in delivery efficiencies for different farm size or tenure classes. For the following farm size classes (area cultivated only on sample command) the following mean delivery efficiencies are: farms under 7.5 acres, 52%; 7.5-12.49, 55%; 12.5-24.99, 50%; and farms 25.0 and more acres in



* Not Available Because Deliveries from the Mogha Flow to a Pond and all Irrigation is Lifted by a Jhallar.

Figure 14. Mean delivery efficiencies for head and tail farms on watercourse.

size 55%. The mean and median values are almost identical. Likewise owner operators had mean and median delivery efficiencies of 53%; owner-cum-tenants had mean and median values of 55 and 53% and tenants had mean and median values of 53 and 54 percent.

E. Delivery Efficiencies and Physical Soil Types

The physical soil type categories are perhaps too general to be useful in explaining further impacts on delivery efficiencies. None of the sample commands had soils that were of the sandy to light sandy types. No physical analysis was made except the field method of feeling the soil for texture to determine its general textural class. The data obtained are in Table 37 for the five predominant physical types of soils and delivery efficiencies on the 40 commands. The two soil types where delivery efficiencies were higher were fine clay and multistoried soils which have mean values about 5 to 7 percent higher than the light medium sandy loam soils and the median fine loam soils. The median values, however, show smaller differences. We cannot, therefore, conclude from these textural analyses of soil types that this is not an important factor. Casual observations on commands with sandy soils lead one to believe this should be examined more carefully.

F. Irrigation Behavior of Farmer and Social Factors With Delivery Efficiencies

About midway of the watercourse survey, field experience had indicated wide differences in the behavior of farmers in the care they took in irrigating their fields. A check list was developed for engineers' field books and the engineers assigned to make irrigation evaluations were asked to check various behaviors or activities of farmers during their irrigation turns. Whether a farmer upon arrival at the field inspects

Table 37. Mean, median and range of delivery efficiencies by physical soil types.

Soil Textural Class	No. of farms	Delivery Efficiencies (%)		
		Mean	Median	Range
Light medium sandy loam	26	47.0	50.5	2-100
Medium loam	25	53.1	53.3	11-85
Medium fine	49	49.7	50.0	7-100
Fine clay loam	64	54.8	56.5	0-100
Multistoried soils	141	54.9	53.4	10-100

and repairs leaks and potential leaks and spills, remains throughout the irrigation period, and whether the irrigator is a landlord's servant or a small boy (under 12 years of age) is expected to make a difference in delivery efficiency.

Irrigation as practiced in Pakistan is anything but simple. It requires great care and skill by irrigators. It involves checking and repairing leaks and spills, surveillance activities to assure water is not stolen during a given turn, and continual building and rebuilding, checking bunds, all in addition to trying to apply water efficiently to fields that are often not sufficiently level. The good irrigator under present conditions is always on the move in his attempt to control scarce water resources in a system where conveyance losses are often 50 percent or more. Where farmers have the labor,as shown under item (5) in Table 38, more than one individual is active in a single irrigation. In the second phase of the survey in southern Punjab and Sind of the 189 farms observed during irrigation activities, 31 percent of the farms were being irrigated by two or more individuals. Where there are jhallar lifts and Persian wells often three individuals are busy for a given irrigation because one must drive the animals to lift the water. Farmers on these systems often related to interviewers that the extra work of lifting canal water by jhallar was a "killing operation." Until one has remained awake with farmers on cold nights watching him prod animals around the endless circle to pump water, he cannot appreciate how labor intensive these operations are. It is surprising that Pakistan has not promoted the use of small portable lift pumps as has been done in East Punjab of India.

Both delivery efficiencies and field application efficiencies depend to a substantial degree on the care with which the irrigator handles water.

Table 38. Mean, median and range of delivery efficiencies from mogha to farm by irrigation behavior.

Farmers' irrigation behavior	No. of observations	Delivery efficiencies from mogha to farm (percentages)		
		Mean	Median	Range
1. Inspects for leaks & spills				
Yes	148	55	54	10-100
No	59	50	50	7-100
2. Repairs leaks and spills				
Yes	148	55	54	10-100
No	59	49	50	7-100
3. Farmer remains at field throughout irrigation				
Yes	120	55	54	10-100
No	75	49	49	7-100
4. Status of irrigator				
Owner operator	150	55	55	10-100
Tenant operator	39	52	48	11-100
Servant of landlord	12	38	34	7-71
Small boy (12 years or less)	10	53	50	30-82
No one appeared	1	28	28	30-82
5. More than one irrigator				
Yes	58	53	51	12-100
No	131	53	53	7-100

For example, under items (1) and (2) of Table 38, farmers who are active in checking and repairing leaks and spills have mean delivery efficiencies from 5 to 7 percent higher than those who do not. Under item (3) farmers who remain at or near the site (he often goes back to the mogha to check), also have delivery efficiencies about 6 percent higher than those who do not remain at the site. As seen from the table, a surprising number of irrigators would not remain at the field but would open the field nakka and then depart. Under item (4) we found that servants did less checking and repairs and also often went away after beginning irrigation. In fact, of the 12 servants only 5 inspected for leaks and spills; only 6 repaired leaks and spills, and 6 arrived to initiate the irrigation and then went away. Irrigators who were not servants had delivery efficiencies about 16 percent higher than those where servants were involved. Almost no differences were found between the other irrigators (owners, tenants and small boys as irrigators). There were cases where the farmer did not come to his field at the time of irrigation as the warabundi turn had been traded to someone else. Consequently, no field application evaluations could be made. One of these is shown under item (4) and the amount of water to reach his farm was only 28 percent of the discharge measured at the mogha.

G. Summary Regression Analysis of Delivery Efficiencies

A total of 14 variables were used in a step-wise multiple regression model in an attempt to search out those factors most important for explaining low delivery efficiencies. These ranged from distance to the mogha and cusecs of water entering the farm system, to physical soil type and slope of main watercourse channel. Of variables examined, only the following were found to be important in explaining differences in farm delivery efficiencies: Distance to the mogha, soil type, and mogha discharge. These three factors explained 25 percent of the total variation of 30 percent explained by 14 variables. Table 39 provides the statistics on five of the variables which combine to explain 28 percent of the variation in delivery efficiencies.

The multiple regression model is:

$$y = a + b_1x_1 + b_2x_2 + b_3x_3 + b_4x_4 + b_5x_5$$

As noted earlier, distance from the mogha is highly correlated with farm delivery efficiencies. This variable explains 18 percent of the differences observed. Also the second factor, soil type, shows that the light to medium sandy loam soils explain about 5 percent of the variation. By using the dummy variable of light to medium sandy loam soils versus other physical types we find an inverse relationship which means the more sandy the soil the lower the total efficiency obtained. The three other variables are not significant and combined add only about 5 percent to the explanation of differences. Mogha discharge, however, indicates that the greater the total quantity of water in the channel, the greater the losses and thus the lower the efficiency of conveyance. Farmers' reports of intensity of stealing also is in the right direction in that the greater the stealing reported the lower the delivery efficiency.

We conclude from this brief analysis that the present system of poorly maintained watercourses and branches are such that farmers located near the tails are at a definite disadvantage. For example, Figure 15 shows that the delivery efficiencies for tail farmers are about one-third less than that for head farmers. Consequently, programs to improve the delivery system should give special focus on the needs of these farmers. Even on improved delivery systems tail farmers will have greater total

Table 39. Multiple regression analysis (stepwise) with selected factors and delivery efficiencies.

Variable	Beta	S.E. of Beta	t ratio	Multiple R	Multiple R^2	Final F ratio
x_1	- .0030	.0009	3.33*	.426	.182	10.05**
x_2	-8.9855	6.9078	1.30	.484	.235	2.69
x_3	-3.7808	2.3645	1.60	.502	.252	2.56
x_4	-2.9072	1.9519	1.49	.518	.269	2.22
x_5	-3.9571	3.7228	1.06	.525	.276	1.13

*Denotes significance level of .05.
**Denotes significance level of .01.

x_1 = distance to mogha in feet

x_2 = dummy variable for soil type, light to medium sandy loam = 1, and other types = 0

x_3 = discharge at source of supply, mogha discharge plus supplemental supplies in cusecs

x_4 = times of stealing reported in last six months

x_5 = dummy variable, status of irrigator: owner operator = 1, tenant = 2, servant = 3

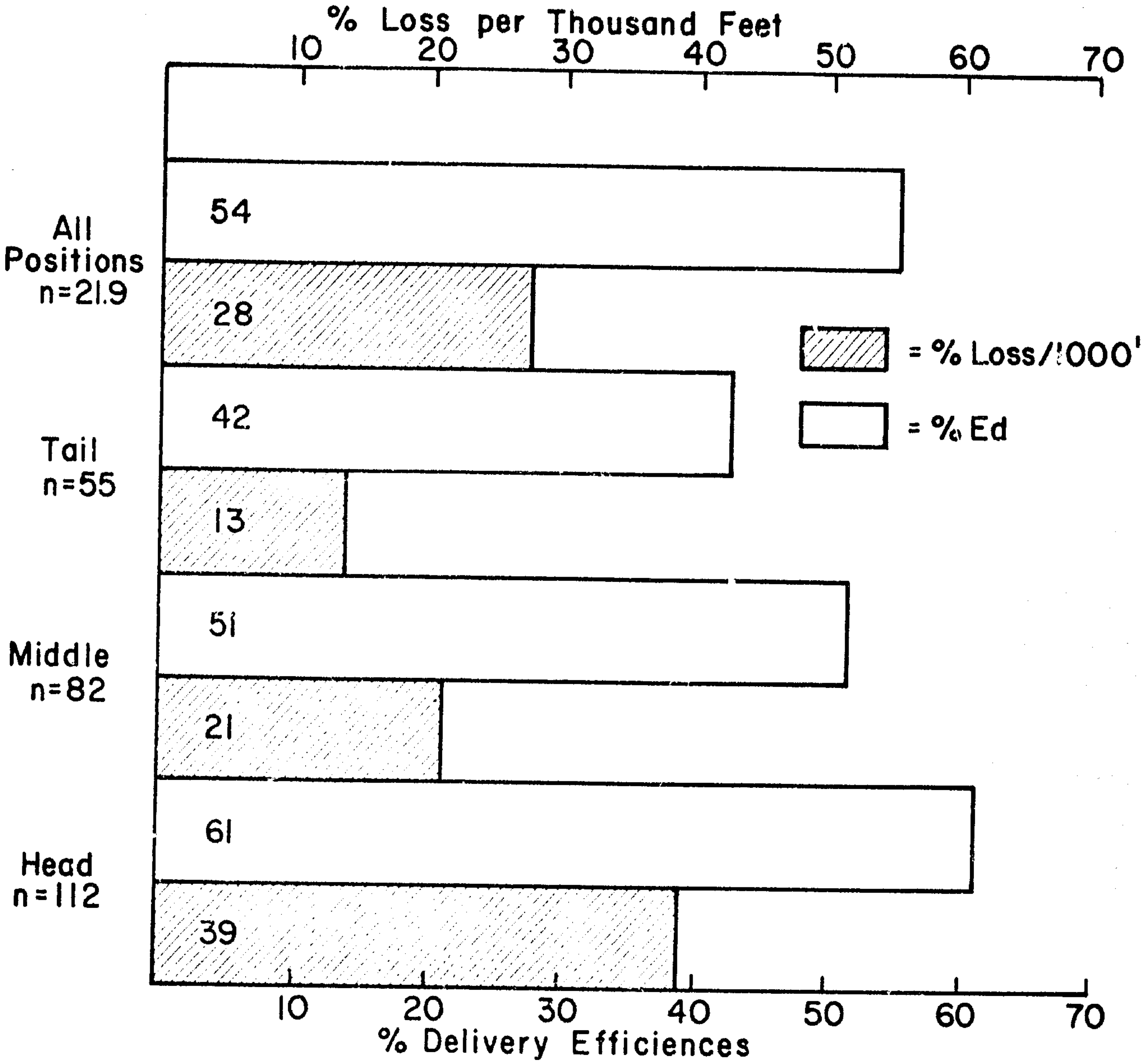


Figure 15. Farm delivery efficiencies (Ed) and loss per 1000 feet shown in percentages by adjusting postion on watercourse.

losses but there are ways to organize the delivery system to provide them with more water. One of these suggestions is to reverse the warabundi turn system from delivery of supplies down the watercourse from the mogha to first filling the main watercourse channel and beginning turns at the tail and rotating progressively up the watercourse. Water would have to be allocated on a volume basis, rather than time period. Losses will still occur, but this change has the merit of making all farmers more concerned about the maintenance of the system. Presently, as has been shown (Mirza, Freeman, Eckert, 1974), tail farmers tend to be more interested in watercourse improvements than head farmers. Another option is to establish tubewells near the middle or tails of command areas to provide tail farmers increased supplies. This has the added advantage of lowering the water table in those parts of the watercourse command where waterlogging usually appears first. Such augmentation of supply may be achieved best by providing incentives to tail farmers to install private tubewells. Another option is to help farmers organize to improve and maintain the present system with a hired ditch rider or khal chowkidar to check leaks, spills, and stealing as well as to make repairs along the improved watercourse.

Another factor needing consideration in watercourse improvements is soil type. Where soils are sandy to light, an improvement program may have to consider lining the main channels to reduce seepage, leaks through porous banks, and the losses shown in the Photo Glossary Figures 5-F, 7-0, and T, which occur due to junction washouts.

This analysis of losses shows that simply an increase in the volume of water available to the farm system, as in the SCARP systems analyzed, does not provide a viable solution. The more water available to the present system the more losses and the less value farmers place on reducing losses. As previously noted, at sites such as 116, excess water leads to delivery efficiencies as low as 35 percent and results in massive waterlogging problems.

II. LOSS RATES PER 1000 FEET OF WATERCOURSE LENGTH

It is important to examine the loss rates per 1000 feet of watercourse length. Loss rates as discussed are a function of distance from the mogha outlet, the water supply situation, the soil type, the slope of the delivery channels and maintenance of the system. The losses per 1000 feet are shown in both percentage loss of the total amount of water discharged to the farm divided by the distance, and also by cubic feet per second. There is some debate about the measure that is most appropriate but this depends primarily on the purpose for which the data are applied. Cubic feet per second as a measure is perhaps more flexible in that it is more easily converted into acre inches or feet per hour and per day, and other common units of irrigation measurements. The loss rate here is defined as:

$$\text{Loss rate} = \frac{\text{initial flow - final flow}}{\text{distance between points in feet}}$$

Simple correlation coefficients for percentage loss per 1000 feet and cubic feet per second losses per 1000 feet for all watercourses with distance to mogha respectively are -.57 and -.22. The percentage loss is a measure of the relative water lost that entered the system, and cubic feet per second is a measure of the actual amount of water lost in transit.

At a later point in the analysis these variables are combined with others in a regression model. These simple correlation coefficients are presented to show that there is an inverse relationship in loss rates per 1000 feet of channel length with distance to the mogha. The greater the distance the lower the losses per 1000 feet. These relationships are significant at the .001 level as would normally be expected for the type of delivery system which exists in Pakistan.

Several precautions are necessary for the reader to keep in mind when referring to the statistics for the two types of measures described above. First, as the extreme ranges signify, there are cases over short sections of the watercourses, usually near the mogha, where some farmers lost most of the water on given turns due to leaving the fields after starting an irrigation. When an earthen bund, or nakka blocked only with soil, breaks and no one is around to repair these breaks, extreme losses inevitably result. Second, flow rate units of cubic feet per second provides a quantitative measure of the total amount of water lost per 1000 feet, while percent loss per 1000 feet only gives a measure of the percentage lost of the total inflow into the conveyance system to the farmer's field. Both of these measures, however, will have a few extreme values. If 20 percent of the water, for example, is lost in 200 feet then a factor of 5 makes this 100 percent loss per 1000 feet. Likewise, if 1.0 cubic foot per second is lost in 200 feet, this becomes 5 cfs for a thousand feet. Table 1, Appendix II, Part A, Section 1, provides data on the mean, median and range of feet from the mogha for head, middle and tail farms. Of the 271 individual evaluations of losses at the head farm locations, 45 were made at mean and median distances of under 1000 feet. In fact 30 evaluations were made at mean distances of only 657 feet. This explains some of the extreme values reflected in the data. Third, the data presented are weighted for farms, i.e. often as many as 6 or 7 evaluations of losses were made for a single farm while for others only one was made.

A. Loss Rates per 1000 feet at Village Sites

Table 40 provides summary data showing the weighted farm values for losses per 1000 feet. For all farms, an average of about 26 percent of the water was lost per 1000 feet. In terms of cubic feet per second lost per 1000 feet the mean is about 0.4 and the median is 0.2. Note however the wide differences reflected in the ranges. If we convert the average discharge loss per 1000 feet value of (.36 cfs) to acre inches, we find that, about every 3 hours, water equivalent to about one acre inch was lost. If the median loss value (.2) is converted, an acre inch of water is lost every 5 hours. Several facts emerge from the summary data. First loss rates are very high for all sample village sites. Second, using median values, major losses of 20 percent or more per 1000 feet occurred at sites 116, 111, 114, and 115. In terms of total amounts of losses, however, those losses which are 0.25 cfs or more per 1000 feet are at sites 104, 106, 109, 105, 111, and 115. All of the sites, except 104 and 115, are public tubewell supplemented command areas. At site 104, near the tail of a distributary, farmers had made some illegal cuts into the distributary and often could not handle the volume of water discharged. At site 115 illegal moghas were being used. Public tubewell commands had high losses as compared to other commands. For example, the mean and median cfs of water lost per 1000 feet at site 106 are 1.0 cubic feet per second or an acre inch per hour. At public tubewell watercourses at site 109 the losses were between 0.3 and 0.4 cfs and only a little less at public tubewell sites 105 and 111. The only exception to this is at public tubewell site 108 where the losses were only .15 cfs.

Table 41 provides data to show losses on commands with various water supply situations as well as a breakdown of losses by several categories

Table 40. Loss rates per 1000 feet of watercourse length by village.

Type command & village sites	No. of farms	Percentage loss/1000 feet			No. of farms	Cubic feet/second loss/1000 ft.		
		Mean	Median	Range		Mean	Median	Range
Perennial								
101-2wc	14	7.4	5.8	4.5-22.0	14	.50	.17	.11-3.0
102-1wc	6	12.5	10.3	8.3-25.8	6	.28	.15	.11-.9
103-1wc	0	-	-	-	2	.09	.09	.03-.1
104-3wc	27	27.2	20.4	0-98.6	26	.29	.25	0-.7
106-1wc*	7	18.2	12.3	7-37.7	6	1.01	1.14	.25-2.1
107-3wc	30	13.7	9.8	4.2-75.3	30	.32	.17	.05-2.8
109-2wc*	11	13.5	11.5	2.0-37.2	11	.41	.32	.07-1.0
110-3wc	26	42.86	15.35	4.2-98.9	8	.17	.10	.01-.7
112-3wc	33	17.2	11.8	1.2-91.6	33	.26	.16	0-2.0
113-3wc	25	18.6	16.0	2.9-59.9	25	.34	.14	.03-1.9
116-4wc	22	41.7	35.7	0-98.9	21	.30	.15	0-1.8
Weighted Totals	201	23.2	15.8	0-98.9	182	.34	.21	0-3.0
Nonperennial								
105-1wc*	6	11.4	12.0	5-16.7	5	.69	.26	.10-2.6
108-1wc*	4	22.1	8.5	6.4-49.1	4	.15	.15	.12-.2
111-2wc*	22	29.6	25.6	0-86.7	24	.50	.30	0-1.6
114-4wc	33	36.5	27.0	2-98.9	35	.23	.15	0-1.0
115-6wc	37	44.0	30.7	0-100	38	.49	.30	0-5.5
Weighted Totals	102	35.7	26.4	0-100	106	.40	.24	0-5.5
Sum Totals Weighted	303	27.4	19.4	0-100	288	.36	.22	0-5.5

*Denotes public tubewell supplemented canal commands.

Table 41. Loss rates per 1000 feet of watercourse length by water supply situation.

Type water-course supply situation	Percentage loss/1000 feet				Cubic feet per second loss/1000 feet			
	No. of farms	Mean	Median	Range	No. of farms	Mean	Median	Range
1. Perennial	200	20	13	0-99	200	.35	.19	0-3.00
2. Nonperennial	95	38	27	0-100	95	.38	.19	0-5.49
3. Type tubewell supplement								
None	159	28	20	0-100	158	.32	.18	0-3.00
Private	106	29	14	0-99	104	.37	.17	0-5.49
Public	23	15	12	4-38	21	.66	.32	.07-13.9
Both private & public	15	26	23	2-87	15	.23	.17	.11-.61
4. Tubewell Density*								
None	158	28	20	0-100	159	.32	.19	0-3.00
Under 3	49	34	26	0-99	49	.50	.19	0-5.49
3-6	21	16	11	6-75	22	.19	.16	.05-.90
7 or more	79	25	13	2-99	68	.40	.23	.01-2.76
5. Mogha Q (cusecs)								
Less 1.0	126	37	26	0-100	122	.24	.11	0-3.00
1.0-1.5	54	26	17	3-100	47	.37	.21	0-5.49
1.6-2.0	50	17	13	4-83	47	.33	.26	.03-1.93
2.1-2.5	46	18	12	1-92	45	.48	.27	.05-2.76
2.6-3.0	11	16	9.	0-49	11	.33	.24	0-1.1
3.1 and over	16	21	17	7-43	16	1.00	.62	.19-2.55

*Public tubewells with discharges of 1.8 cusecs are counted equivalent to 3 private tubewells and public tubewells with a discharge into one watercourse of 1.2 cusecs is counted as 2 private tubewells.

of volume of water supplied at the mogha. In terms of actual amounts of water lost (cubic feet/second) per 1000 feet of watercourse length there is little difference between the perennial versus nonperennial commands. However, there is a higher percentage of losses on nonperennial commands.

In terms of loss rates per 1000 feet, the farms with no tubewell supplements and those with public plus private tubewells had loss rates of 20 percent or more. The high value for unsupplemented commands is influenced by the high values at sites 104, 115 and 116. We have mentioned a reason for the high mean losses at site 104 due to large cuts in the tail of the distributary and the high frequency of water theft at 115. At 116, losses were great because farmers have an excess of canal water and often allow it to run for long periods while being absent from their fields. Of the 22 farms evaluated at site 116, only 6 of the farmers remained at their fields throughout the irrigation. Here they use the "pancho" method and allow the water to fill one bunded unit and then overflow into the next unit.

B. Loss Rates per 1000 Feet and Water Supply Situation

There is little difference in percentage losses per 1000 feet between farms on private versus public tubewell supplemented commands, but the farms on commands with both public and private tubewells have loss rates jump to about 23 percent per 1000 feet. However, in terms of the total amount of water lost per 1000 feet, i.e. cubic feet per second, it is evident that public tubewell supplemented command farms have a mean and median about twice that of other farms. The cases of the public plus private tubewell supplemented farms are misleading in that these watercourses possess only one to two private tubewells, and the public tubewells serve two commands each. However, the weighted mean for all farms with public tubewell supplements versus those with private and no tubewells respectively are .5 versus about .3 cubic feet per second.

When private tubewell equivalents are used to examine the density of tubewells, there is a trend for commands with more tubewells to have slightly higher total losses of water per 1000 feet than those with less. However, the situation is not clear because in Table 40 we noted that the loss rates for site 107 farmers, where there are respectively 5, 8 and 13 private tubewells for the three watercourse commands, the median loss rates per thousand feet are only about .2 cfs. Likewise at site 110, with three commands with 8, 9 and 17 private tubewells, the median loss rates are 0.1 cubic feet per second. This is primarily due to length of the watercourses and channels on these commands. For example, watercourse 107-1 has a total length of watercourse and field channels of over 42 miles; 107-2 watercourse has a length of 30 miles and 107-3 has 19 miles of main watercourse, laterals and field channels, whereas watercourses 110-1 had 9 miles, 110-2 had 8 miles and 110-3 had 5.5 miles of channel.

As discussed earlier, loss rates per 1000 feet are influenced greatly by two factors among many others--the volume of water available and distance from the mogha. First, in an examination of mogha discharge, we have noted a significant correlation between discharge and loss rates. Table 41 provides information about these loss rates by different categories under mogha Q, or mean discharge in cusecs. These mogha discharges include tubewell water additions. Data show that when the discharge in cusecs is low there is a trend for a larger percentage of the total water available to be lost in transit. This reflects the fact that much of the water is lost through dead storage and seepage due to submergence of the mogha and the lack of sufficient gradient. When cubic feet per second loss rates per 1000 feet are examined, the data show that the larger the discharge the larger the total amount of water lost in transit. Where the discharge into the system is only about 1.0 to 1.5 cusecs, the median loss rates are .21 cubic feet per second but rises to .62 cfs when the discharge is over 3 cusecs using the median values. The mean cfs losses per 1000 feet are much higher ranging from .24 cfs to a high of 1.00 cfs, depending on the mogha discharge. Therefore, on public tubewell augmented commands and commands with a high density of private tubewells, total losses, given the present poorly maintained watercourses, can be expected to be as high as .30 cfs or greater over time.

C. Loss Rates per 1000 Feet and Farm Location

As shown earlier the distance from farm to mogha is highly correlated with both percentage loss and total loss of water (cfs). Given the nature of the present farm conveyance system of poorly maintained watercourses and field channels, the further from the source of irrigation supplies the less water is available; therefore, loss rates are less on a per 1000 foot basis. Table 42 provides data to show the differences in these losses in relationship to location of farms on the command reaches.

First, using the criterion of losses per 1000 feet, we note how each farm location measure shows higher average losses per 1000 feet in terms of percent loss and cfs losses per 1000 feet for head as compared to tail farms. When we examine losses in terms of the distance categories, item 4 in Table 42, we note much variation. For example, note that for the 33 farms evaluated, located up to 500 feet from the mogha, and those farms from 500 to 1000 feet the average percentage loss rates per 1000 feet are 64 and 54 percent. Over half the water was lost. In terms of cubic feet per second, the mean was .66 and .44 which means that within 1000 feet of

Table 42. Loss rates per 1000 feet of watercourse length by position of farms on watercourse command reaches.

Farm location on watercourse command	Percentage loss/1000 feet (%)				Cubic feet per second loss/1000 feet			
	No. of farms	Mean	Median	Range	No. of farms	Mean	Median	Range
1. Measured position								
Head	94	33	15	0-100	85	.41	.20	0-5.49
Middle	41	27	20	1-99	41	.27	.16	0-1.60
Tail	58	28	18	2-100	58	.25	.13	0-1.93
2. Adjusted position on village basis								
Head	108	39	28	0-100	103	.44	.22	0-5.49
Middle	78	22	14	4-99	82	.34	.20	0-1.82
Tail	53	13	9	0-99	53	.24	.14	0-1.93
More than one position	21	31	26	2-99	21	.48	.20	.01-3.0
3. Interviewer's estimated position								
Head	117	33	23	0-100	112	.51	.27	0-5.49
Middle	61	26	18	1-99	60	.24	.15	0-1.93
Tail	95	20	11	2-99	96	.25	.15	0-3.00
More than one position	28	32	18	0-100	28	.38	.29	.05-1.6
4. Distance from mogha (feet)								
less 500	33	64	86	0-100	27	.66	.29	0-5.49
501-1000	31	54	58	11-100	29	.44	.40	.01-2.03
1001-2000	56	30	28	2-64	56	.42	.26	0-2.08
2001-3000	54	23	22	4-98	53	.27	.20	0-1.18
3001-4000	43	16	14	5-60	41	.35	.21	.04-2.76
4001-5000	23	15	11	5-97	21	.36	.16	.01-1.93
5001-6000	24	10	10	3-15	23	.28	.17	.01-3.00
6001 and over	37	8	6	1-75	37	.15	.13	0-.36

the mogha amounts equal to about .5 of an acre inch is lost per hour. In terms of acre feet, about 1 acre foot in a 24 hour period was lost. As distance increases, the percentage loss and the actual amount of lost water decreases.

D. Loss Rates per 1000 Feet and Soil Types

Loss rates are also examined in relationship to the physical soil types predominant on command areas. These soil types are highly general and in future studies should be classified more specifically. The type of soil in the channels is important but usually in relationship to the actual level of water in the channels (Kemper, et al., 1975c:137). Fluctuations due to discharges of tubewell and canal water into channels creates large losses through channel sides due to permeable soils, root systems, rodents and microorganisms. When the water level is at its usual height in channels the silt and clay particles have a plastering effect that seals many of the holes. Small increases in water levels above the sealed portions of the banks can lead to large increases in water losses.

Data in Table 43 display water losses by soil type. Using the median cubic feet per second value, there is some relationship to the 5 general soil types encountered. Physical soil type is important, but more investigation is required to make any generalizations about the volume of losses to expect due to different soil types. Of course, at this point we have no control on variables such as distance from the mogha or the volume of water discharged into the system. As a means to account for the interrelationships among these variables a regression model is used to determine the factors which are most influential in explaining the cubic feet per second losses on watercourses and the percentage losses.

Table 43. Loss per 1000 feet of watercourse length by general textural soil types.

General physical soil types	Percentage loss/1000 feet				Cubic feet per second loss/1000 ft.			
	No. of cases	Mean	Median	Range	No. of cases	Mean	Median	Range
Light to medium sandy loam	24	24.3	22.7	0-63.6	26	.68	.44	0-3.00
Medium sandy loam to loam	25	25.5	16.7	2-92.7	24	.41	.25	.07-2.55
Medium to fine loam	49	37.0	25.1	0-99.8	49	.38	.12	0-5.49
Fine clay loam	64	31.6	18.8	0-98.9	56	.40	.21	0-2.08
Multistoried soils	141	23.0	13.5	0-99.8	143	.27	.16	0-2.76

E. Regression Analysis of Selected Factors Related to Loss Rates per 1000 feet

Several step-wise multiple regression models were used to ascertain the most important factors explaining variation in loss rates per 1000 feet. The regression model used is:

$y = a + b_1x_1 + b_2x_2 \ldots b_8x_8$

Y = Loss rate

x_1 = distance to the mogha in feet

x_2 = total acres cultivated on the sample watercourse command area by a sample farm

x_3 = mogha discharge in cusecs plus tubewell supplies

x_4 = reported times of water stealing in last six months

x_5 = dummy variable for physical soil types, light to medium sandy loam soils = 1, and other types = 0

x_6 = dummy variable for season of year, rabi season = 0, karif season = 1

x_7 = dummy variable for tenue status, owner operator = 1, owner-cum-tenant = 2, and tenant = 3

x_8 = dummy variable for supplemental water supplies, no tubewells = 0, private tubewells = 1, public tubewells = 2.

The step-wise multiple regression analysis is presented in Table 44 where the variables are ranked in order of importance. Only about 31 percent of the variation in percent loss per 1000 feet is explained by these 8 variables. Of the 8 factors the first three, distance to mogha, area cultivated on the command, and mogha discharge, explain about 30 percent of the difference in percent loss per 1000 feet. The other variables add almost nothing in explaining the variation.

Loss rates are a function of distance from the source of water supplies. The percentage of losses decreases with distance from the mogha. The second variable x_2, area cultivated on the command area, is

Table 44. Multiple regression analysis (stepwise) of factors related to percent loss per 1000 feet of watercourse length.

Variable	Beta	S.E. of Beta	t ratio	Multiple R	Multiple R^2	Final F ratio
x^1	-.0050	.0006	-8.33*	.523	.274	75.76*
x^2	.0766	.0404	1.90	.535	.286	3.59**
x^3	-2.6357	1.7187	-1.53	.544	.296	2.35***
x^4	1.4376	1.4810	.97	.547	.299	.94
x^5	-3.9097	5.0683	- .77	.549	.302	.60
x^6	2.3518	3.0250	- .78	.551	.303	.60
x^7	1.3364	1.8568	.72	.552	.305	.52
x^8	.7346	2.3607	.31	.553	.305	.97

*Denotes significance at .001 level.
**Denotes significance at .05 level.
***Denotes significance at .06 level.

found to be significant at the .04 level and indicates that the larger the holding on the command in acres, the greater the losses. This results from the fact that the larger the area the more field channels. Smaller farms do not have as long field channels as larger units. The third factor shows that the greater the mogha Q and the volume of water available from tubewells, the greater the percentage of losses per 1000 feet.

In terms of the discharge amounts of water lost (cubic feet per second), a regression analysis was conducted using the same eight independent variables. The analysis showed that both mogha discharge plus tubewell supplies, distance to the mogha, and soil type explain only 20 percent of the total variation in losses. Mogha discharge has a simple correlation coefficient of .34 and distance to mogha -.18. Soil type shows that light to medium sandy soils are weakly correlated with total losses with a coefficient of .17. When these variables are controlled in the regression they contribute respectively only 11, 8, and 1 percent to the explanation of total losses in cubic feet per second per thousand feet.

In summary, the most important factors explaining losses are distance from the source of water supplies, and the volume of water available to the farm system. Given the high conveyance loss rates on all command areas, these data suggest that merely providing more water to farmers without substantially improving the earthen conveyance system will result in few benefits to farmers. The more water made available from canals or pumping groundwater, the more total losses can be expected. Advocates of more public tubewells and private tubewells to pump these losses back for use must include in their analysis the present cost of pumping tubewell water, the degradation of quality of groundwater, the perennial problems of salinity and waterlogging, and the damage to crops created by losses along the farm conveyance system.

CHAPTER THREE

FARMERS' APPLICATION EFFICIENCIES

After water reaches a farmer's field inlet or nakka, the primary goal is to apply it as uniformly as possible over the field in order that the depth of application will match the soil moisture depletion in the crop root zone. The irrigation method used in Pakistan is the basin type and farmers apply water mostly by guesswork. Factors that influence the application of irrigation water for crops include: field levelness, basin length and width, nakka discharge versus infiltration rate, soil moisture depletion, crop rooting depth, and leaching requirements. Also, temperature, wind, humidity, and sunshine determine evaporation which, in turn, affects the crop's consumptive use. All of the important variables could not be considered in this survey when only one week was allotted for an evaluation of each watercourse command area. In the measurement of application efficiency, variables included farm inlet (nakka) discharge, size of field, time required for the irrigation, soil moisture depletion, depth of root system, the type of crop, and the crop stage of growth. The major limitation on the irrigation application efficiency results obtained was the lack of time series data. In order to obtain a good measure of a farmer's efficiency in applying water to crops, it is essential to make evaluations throughout a cropping cycle to include periods of water excesses and deficiencies. Given these limitations, the particular time of irrigations and type irrigations will be examined because the date of irrigation helps to explain the high incidence of underirrigation for certain command areas. The format of the presentation of field application efficiency data for this chapter will be as follows:

1. First, a summary of application efficiencies is made on macro site and positional variables. Field application efficiencies are summarized by village sites, month of evaluation, agro-climatic regions, by various canal and tubewell supply situations, and by position on the watercourse command. Some of these comparisons will utilize the 559 individual evaluations and others will utilize the 309 weighted mean farm field application efficiencies for data analysis.
2. Secondly, farm application efficiencies are also examined in relationship to micro site characteristics. These include the type of crop irrigated, the predominate soil types on sample farms, the irrigation basin size, the stage of crop maturity, field nakka discharge, night versus day irrigations, farm tenure classes and several social and behavioral factors including an index of the irrigator's behavior during the irrigation turn.

   The phenomenon of underirrigation is also examined in relationship to some of the variables listed under 1. and 2. above, as well as a measure of irrigation adequacy in relationship to the determined soil moisture deficiency observed. In most of the tables presented two measures of application efficiency are presented. One of these includes all irrigations which were under and overirrigations. The other excludes all cases that were underirrigations.

The section following this presentation of data on farmers field application efficiencies will present data combining both delivery and application efficiencies into a measure of irrigation efficiency which includes the efficiency of water conveyance from the mogha to the farmer's field and the level of efficiency obtained in application of water.

Since the measured field application efficiency (Ea) is a term which is sometimes not fully understood by those who are not fully oriented to irrigation terminology, the measure is defined here. It is defined as:

$$Ea = \frac{\text{water stored in the root zone}}{\text{water applied to the field basin}} \times 100 \leq 100\%^{9/}$$

In order to determine the water stored in the root zone, soil moisture samples were taken on each field to be evaluated at each foot, to a depth of four feet with soil tube samples. These samplers were evaluated by both the "feel" method and the gravimetric method of weighing and drying of soil moisture samples to determine the resultant moisture percentage. From this the soil moisture depletion (SMD) in inches of water equivalent of the evaluated fields was estimated; the time of the irrigation turn in minutes and the discharge of water onto the field in cusecs were measured to determine each farmer's application efficiency. For example, if the SMD was 2.5 acre inches and the farmer applied 5.0 acre inches, the result would be 2.5 divided by 5.0 x 100 or 50 percent application efficiency. If the farmer had applied 2.5 acre inches when 5.0 acre inches were required the result would be 5.0 divided by 2.5 x 100 or 100 percent. This is to demonstrate that any underirrigation receives a value of 100 because the measure is one designed to determine the degree to which farmers overirrigate. This measure, when used alone, is not sufficient in periods of water

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9/In cases where the soil moisture deficiency was not completely filled by the lesser amount of irrigation water applied, the quotient is maintained at 100%.

shortage. We find in the data, during some periods, that many, if not all farmers on a command area, underirrigate and receive scores of 100 percent application efficiency. For this reason we will present, side by side on most tables and figures, two field application efficiencies. The first will include all irrigations and the second will exclude the underirrigations. We will also introduce a measure that will show the degree to which a farmer underirrigated. This will show his water availability adequacy, or the percent completion of given irrigations, and is defined as:

$$\begin{array}{c}\text{\% water}\\ \text{adequacy}\end{array} = \frac{\text{Water applied to the field basin}}{\text{Soil Moisture Depletion}} \times 100 \leq 100\%$$

In using this measure, if a farmer applied 2.5 inches and the SMD was 5.0 inches the adequacy of this particular irrigation would be 2.5 divided by 5.0 x 100 or 50 percent. This represents the degree to which the required soil moisture was replenished. If the farmer applies 5.0 inches when only 2.5 inches are required the result is 200 percent or double the amount of water required.

I. APPLICATION EFFICIENCIES EXAMINED BY MACRO SITE AND POSITIONAL VARIABLES

Variation of field application efficiencies for the 16 village sites in each village is shown in Figure 16. Observe that at site 103 all evaluations were underirrigations and the Ea for farmers at this site was 100 percent. Likewise at sites 102, 104 and 107 with high Ea's of 96, 91 and 92 percent note that respectively 50, 73, and 84 percent of all evaluations were underirrigations. All of these four sites were evaluated during peak kharif demand and real deficiencies of water existed at these times. The same pattern exists for sites

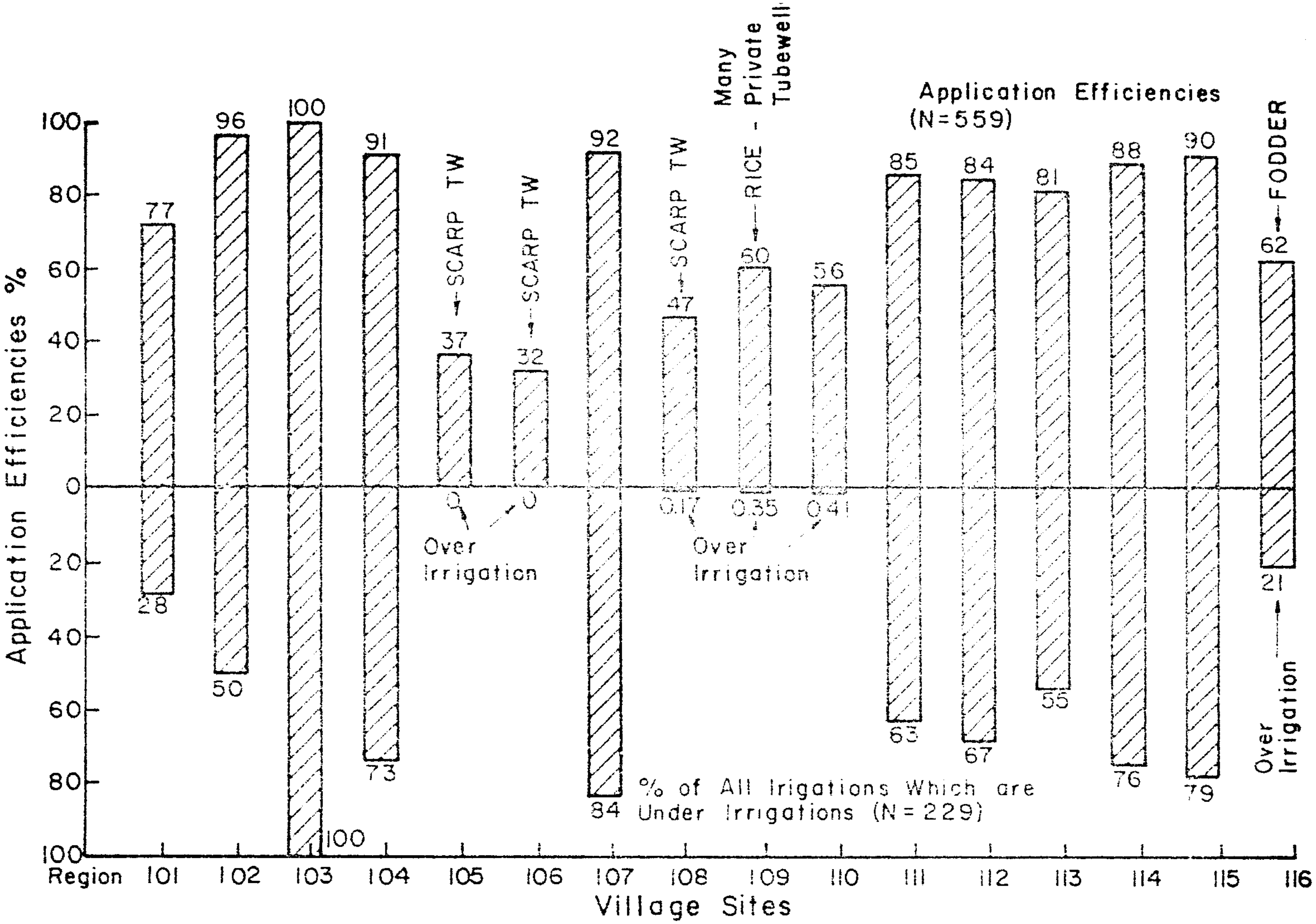


Figure 16. Application efficiencies by village sites and percent of total irrigations which are under irrigation.

111 to 115 where there were from 55 to 79 percent of all irrigations where farmers applied less water than needed to replenish completely the SMD. These five sites were all evaluated during a period of peak rabi season deficiency. Sites 111 and 115 were without perennial water supplies. It is interesting to also observe that at sites 105, 106, 108, 109, 110, and 116 where application efficiencies are very low and range from 32 to 63 percent that the percentage of underirrigations are small. All of these sites are public tubewell supplemented command areas except 110 and 116. Site 110 has 32 private tubewells for 3 command areas and site 116 has excess water supplies throughout the year. This leads to the conclusion that where farmers have good water supplies, they tend to overirrigate. Figure 17 shows the same data for field application efficiencies but also shows the resulting weighted efficiencies when the 229 underirrigations are removed. The general pattern does not change but note that all efficiencies drop considerably. This demonstrates the inflated values of the Ea measure when there are a large number of underirrigations. The darkened portions of the histogram, excluding the underirrigations, provides a measure of the excess water applied at particular times to fields in relationship to the soil moisture deficit. The lowest Ea values (those 50% or less) are found at sites 105, 106, and 108. Sites 109, 110, 112, 114, 115, and 116 have values from 50 to 60%. As observed earlier, sites 105, 106, 108 and 109 are all command areas with SCARP (public) tubewells. Site 110 has three commands and a high density of private tubewells (32). Site 112 has no tubewell supplements but is a perennial command area. Site 116, as explained, is the area where four commands have excess canal water throughout the year. When the underirrigations are removed the data still indicate that where water is more ample the incidence of overirrigation increases.

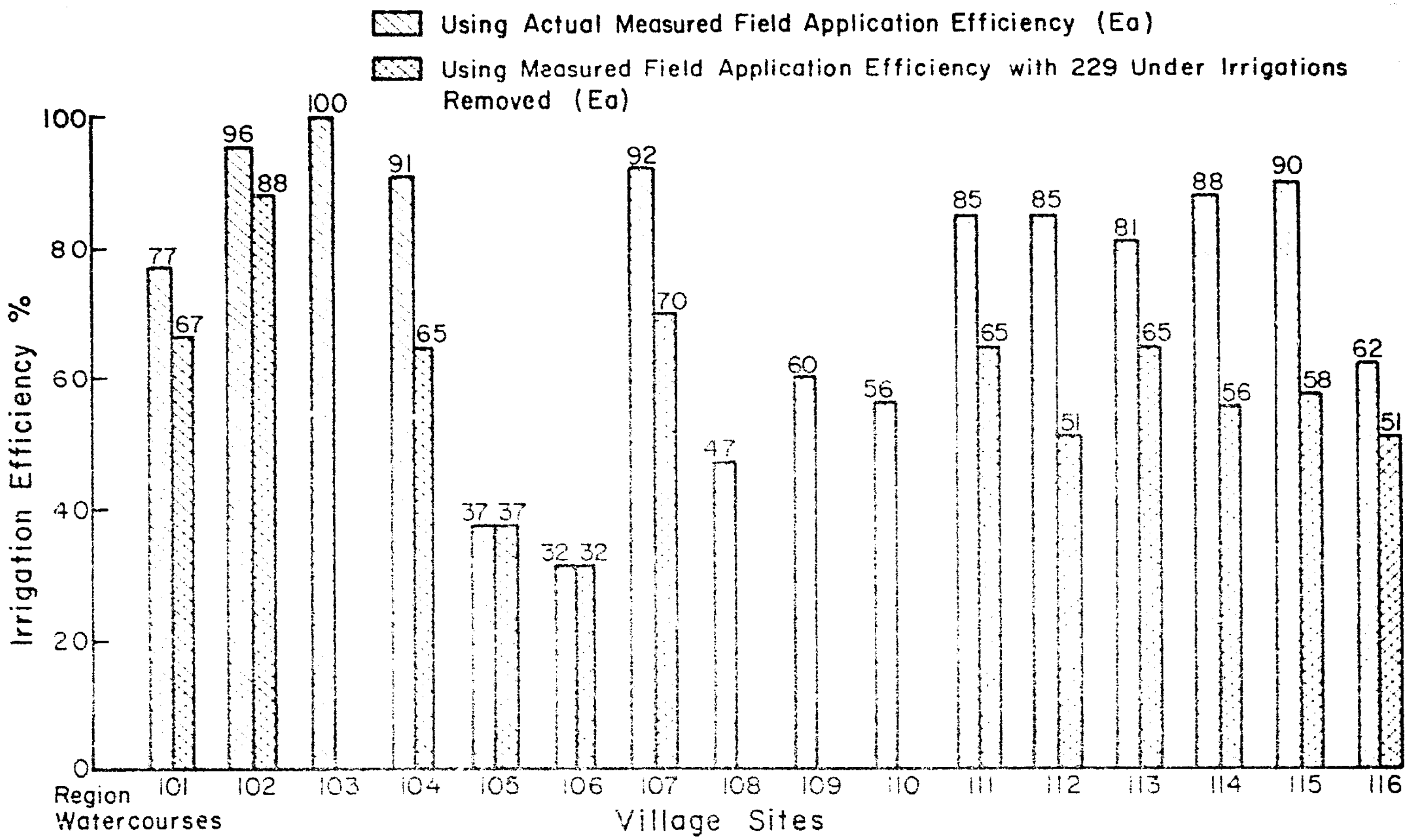


Figure 17. Actual and adjusted mean irrigation efficiencies by village sites.

A. The Time of Evaluations

Given the lack of time series data it is important to present the months in which the evaluations were made in order to judge if the particular season influenced the values obtained. Figure 18 provides information about the percentage of all evaluations made by month and the field application values obtained for each month. From February to July, when the percentages of underirrigations are high, correspondingly, the efficiency values are high. In March, when the weighted mean efficiencies were 68 percent, about all evaluations were conducted at site 116 where water is in surplus for most of the year. In August and September, the two months of the year with monsoon rainfall, 22 of 39 evaluations were conducted at sites 106, 108 and 109, which have public tubewells for supplements to canal supplies. In October, 15 to 16 evaluations were conducted at site 110 (high density of private tubewells) where the weighted Ea value is only 50 percent. Note that in November the Ea value is 75 percent due primarily to the large percentage of underirrigations obtained at sites 102, 104 and 107. In December, only 2 farms were evaluated and these were at sites 106 and 109, sites with SCARP tubewells.

Table 45 provides the same data by month, including mean and median values of the weighted application efficiencies. Also included are values for field application efficiencies excluding the underirrigations. Note also that no difference is found in farmers application efficiencies between night and day irrigations. Fifty percent of the night irrigations were underirrigations as were 50 percent of the day irrigations.

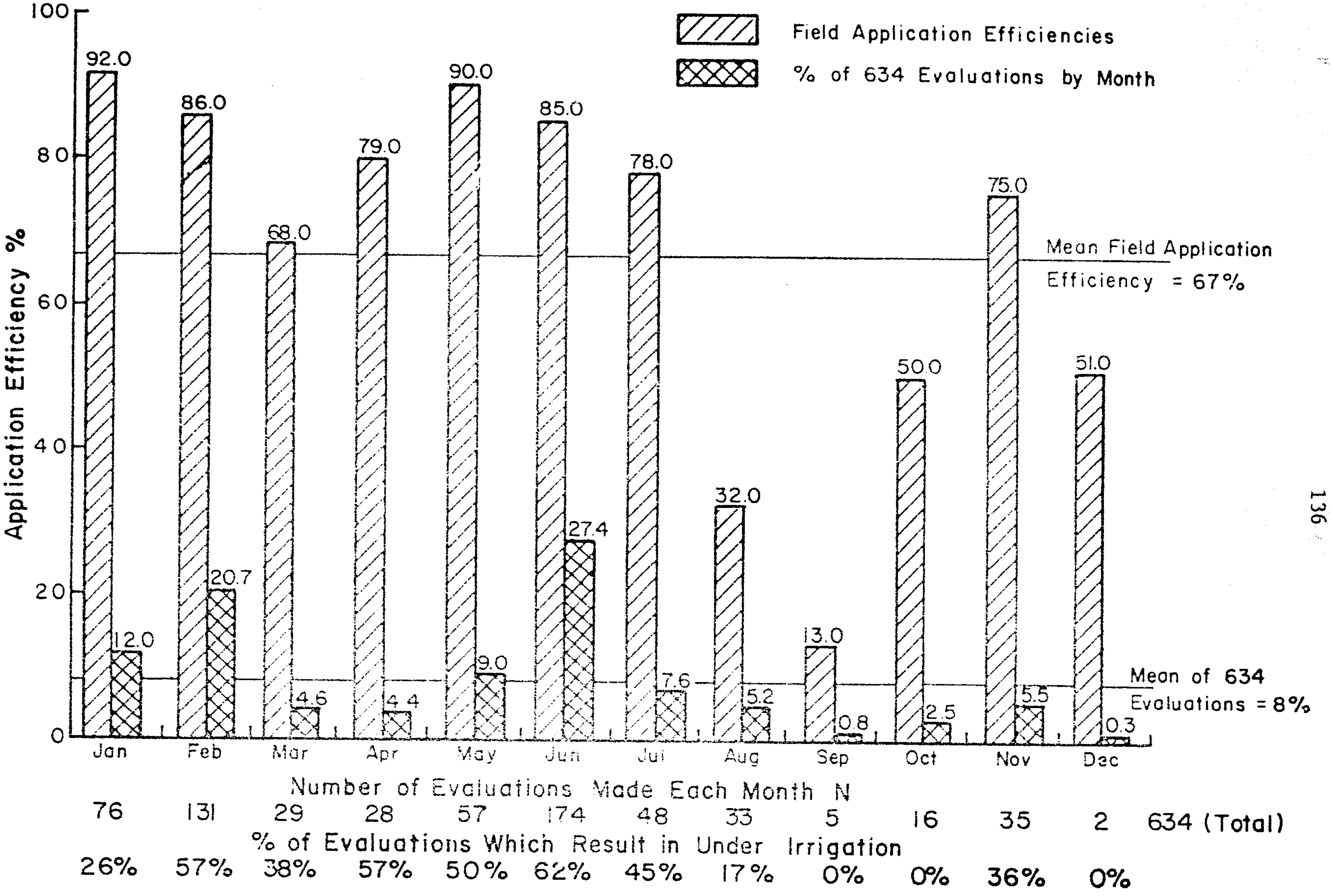


Figure 18. Weighted mean application efficiency distribution by month.

Table 45. Month of year and day/night evaluations by mean and median field application efficiency percentages.

Month of Evaluation	Farm Ea including under-irrigations			Farm Ea excluding under-irrigations		
	No. Farms	Mean	Median	No. Farms	Mean	Median
January	30	92	100	12	72	82
February	79	86	100	34	62	63
March	21	68	83	13	46	48
April	28	79	100	12	52	51
May	18	90	98	9	74	73
June	63	85	100	25	57	60
July	20	78	95	11	55	76
August	12	32	25	10	26	25
September	3	13	19	3	13	19
October	10	50	57	10	48	51
November	14	75	88	9	59	56
December	2	51	51	2	51	51
Day/Night						
Day (1)	242	79	100	122	55	58
Night (2)	54	79	100	26	58	61
Both (3)	5	81	81	3	58	61

Season of the year is an influence on the high values of Ea's obtained due to overirrigations. Both the month of year and the particular water supply situations influence field application efficiencies.

B. Agro-Climatic Regions

Climatic regions and associated type of crop cultivated may influence farmers application efficiencies. Table 46 provides such data. Climatic region is determined by the measure of estimated annual atmospheric evaporative moisture demand in inches. Even when excluding the cases of underirrigations, rice-wheat, rice-fodder, and mixed orchard regions have the lowest EA values. The explanation is not the nature of the crop region but the nature of the water supply situation. The rice-wheat efficiency reflects site 110 where, respectively, in August, September and October, 19, 5 and 15 evaluations were made. These are distributed between rabi (wheat) and kharif (rice) seasons. There are 34 private tubewells supplementing canal water by 20 cusecs on a combined acreage of 1032 acres of cultivatable land. The case of the mixed orchard, in the medium low deficit region where the weighted Ea is 48%, includes farms all of which are supplemented by public tubewell water. Likewise, the case of the rice-fodder farms in the high deficit region reflect site 116 conditions where canal water supplies are in surplus. This confirms our previous finding that the water supply situation provides the strongest influence over farmers' field application practices. Where more water is available, more is applied and more is wasted through overirrigation. Note that of the three cases cited for low Ea efficiencies, of the 75 evaluations, only 15 were underirrigation (see Table 46). The trend, although complicated by season of evaluation and water supply characteristics of the site,

Table 46. Agro-Climatic regions by field application efficiency percentages.*

Agro-Climatic Regions	Farm Ea including underirrigation (%)			Farm Ea excluding underirrigation (%)		
	No. Cases	Mean	Median	No. Cases	Mean	Median
Low Deficit*	57	75	80	28	49	56
Rice/Wheat	27	56	58	21	43	49
Rice/Fodder	25	91	100	7	65	77
Fodder/Wheat	5	100	100	0	-	-
Medium-Low Deficit**	41	58	57	35	49	48
Sugarcane/ Wheat	14	77	72	14	68	66
Mixed Orchard	27	48	49	21	37	36
Medium-High Deficit**	94	89	100	37	66	67
Cotton/Wheat	70	90	100	26	66	62
Mixed/Orchard	24	85	100	11	65	80
High Deficit**	117	81	90	55	56	53
Rice/Fodder	21	62	67	17	51	53
Cottor/Wheat	33	84	100	12	51	38
Rice/Wheat	38	90	100	10	58	51
Sugarcane	25	81	83	16	65	64

*Percentage figures in the table refer to irrigation application efficiencies (Ea)

*denotes code for annual atmospheric evaporative deficit where low deficit < 45" per year; medium-low deficit = 45-55" per year; medium-high deficit = 55-65" per year, and high deficit >65" per year.

No. Cases	No. Sites		wt mean Ea excluding under-irrigation	Remarks
31	2	Rice/Wheat	48	private tubewell supplemented
24	2	Rice/Fodder	55	farmers cut into distributary to get excessive water at will at both sites
30	2	Sugarcane/Wheat	66	minimal to zero tubewell supplements
32	5	Mixed Orchard	47	all SCARP supplemented--excessive water
38	4	Cotton/Wheat	61	low to high private tubewell supplemented
155	15			

is for sites with greater atmospheric moisture demand to have greater farm application efficiencies.

When the cropping pattern data are aggregated over the climatic regions, the mixed orchard pattern has the lowest weighted mean application efficiency, 47%, followed closely by the rice-wheat sites at 48%. The highest is for the sugarcane-wheat cropping areas with a weighted mean of 66%. The column label remarks indicates the water supply modifiers at the sites. The sample of 16 sites is classed into 11 categories, obviously the sample is too small to draw conclusions.

C. Water Supply Situation

Table 47 provides data to show the difference in application efficiencies by farmers who have public tubewell supplements to canal water supplies versus those who do not. Note under item 1 (type of tubewell supplements) that farmers receiving only public tubewell supplemental supplies have a weighted efficiency of 48 percent as compared with 80 percent or more for nonpublic tubewell farmers. The case of 15 farmers with both public and private supplemental supplies is misleading in that at this command the one public tubewell supplies two watercourse command areas which are of the nonperennial type. When underirrigations are removed, the public tubewell farmers still have the lowest efficiencies, 38%, 20 percent lower than the weighted mean of all other categories combined. Little or no important differences are observed between farmers' reports of availability and use of tubewell supplies. When the density of tubewells is examined, there is a relationship between number of tubewells on a command and Ea values. For example, when the equivalent density of tubewells reaches seven or more, application efficiencies begin to drop considerably. The value

Table 47. Supplemental tubewell water supply situation by field application efficiency percentages.*

Supplemental water supply situation	Farm Ea including underirrigations (%)			Farm Ea excluding underirrigations (%)		
	No. farms	Mean	Median	No. farms	Mean	Median
1) Type of tubewell supplement						
None	157	83	100	71	57	61
Private	115	81	100	58	59	61
Public	22	48	50	17	38	36
Public & private	15	75	86	9	56	63
2) Farmers' reports of tubewater availability						
Not available	134	81	95	68	57	60
With difficulty	44	80	100	20	53	57
Easily available	97	75	99	52	53	54
3) Farmers' reports of use of tubewell water						
None used	185	82	100	89	58	63
Purchases water	81	74	88	45	52	51
Owns tubewell	32	80	100	16	55	55
4) Density of tubewell** (Private tubewell equivalent)						
None	158	83	100	72	58	62
1-2	52	85	100	22	62	67
3-6	22	78	100	12	57	59
7+	77	68	77	49	49	51
5) Water supply duration			S.D.			S.D.
Perennial	202	76	30	115	55	27
Nonperennial	95	86	27	34	56	30
6) Type of warabundi						
Pucca	175	79	28	96	59	27
Kucha	117	80	31	48	47	30

*Percentage figures in the table refer to irrigation application efficiencies (Ea).

**Tubewell density is obtained by counting public tubewells with discharge rates of 1.8 cusecs as equivalent to 3 private tubewells and public tubewells with discharges of 1.2 cusecs (usually serving two command areas) as equivalent to 2 private tubewells. These added to the actual number of private tubewells provides the density.

still remains high, where tubewell densities are seven or more, because of the four commands at villages 102 and 107, with a high density of tubewells, the Ea weighted values are 92 percent for 35 evaluations, of which, 21 were underirrigations conducted primarily in June and July. Still when the underirrigations are excluded farmers on commands with seven or more tubewells have application efficiencies about 10 percent less than farmers with no tubewells. Availability of more water results in more overirrigation.

D. Farm Location on Watercourse

Since water delivered to a given farm is a function of discharge and delivery efficiency, the further from the source of the supply the greater the conveyance losses. Tail farmers, having greater total losses as compared to head farmers, are expected to have higher field application efficiencies. Table 48 provides information using two measures of watercourse position. No relationship is evident when the Ea measure with all underirrigations is used. When the underirrigations are removed the Ea scores are not inflated. Note that tail farms do have slightly higher field application efficiencies than head farms, especially when compared on a watercourse basis. This tends to suggest that tail farmers given greater water constraints, are more careful in the application of water or that they just don't have the water to waste.

II. APPLICATION EFFICIENCIES BY MICRO SITE CHARACTERISTICS

A. The Type of Irrigation

The type of irrigation (pre-irrigations versus crop irrigations), and irrigations for different crops at particular stages of growth influence application efficiencies.

Table 48. Farm location on watercourse command by field application efficiency percentages.*

Watercourse Position Measures	Farm Ea including underirrigations (%)			Farm Ea excluding underirrigations (%)		
	No. Farms	Mean	Median	No. Farms	Mean	Median
Adjusted Village Position**						
Head	114	78	100	52	50	49
Middle	82	81	100	41	60	62
Tail	56	77	87	30	56	60
Measured Watercourse Position						
Head	94	70	83	53	47	54
Middle	41	84	95	21	65	67
Tail	58	83	100	29	61	62

*Percentages figures in the table refer to irrigation application efficiencies (Ea).

**Adjusted on a village basis; all farmers are categorized on the basis of the distance from the mogha, into 1/3 and 2/3 fractions of the longest watercourse length in the village. Hence, called the village basis position.

Table 49 does not show conclusively that there are important differences between types of irrigations and field application efficiencies. The five cases for cotton and seven for "other crops" are too few for generalization. No great differences are found in the number of applications which resulted in underirrigations except for sugarcane, where only 33 percent of the farms applied amounts insufficient to meet the SMD values. In general, we would expect that preirrigations and those for crops with high evapotranspiration rates, such as sugarcane and cotton, would yield lower values of efficiency than other types of irrigations. The data point in that direction, especially when all underirrigations are removed, but the few cotton irrigations makes it difficult to generalize. Therefore, it appears that the water supply situation has greater influence on farmers' application efficiencies than does type of irrigation.

B. Physical Soil Type and Field Application Efficiencies

Table 50 presents data which indicate that farmers generally have higher application efficiencies on light-medium (sandy loam) soils, fine (clay loam) soils and multistoried soils than for other types. Perhaps those farmers have learned through trial and error about the particular moisture needs of these two extreme types of soil. The weighted mean application efficiency for these three textural classes is 60% whereas the weighted mean for the medium to medium-fine classes is 47%. The differences are not striking though, and one must be careful in any generalization. It is interesting to note that of the total irrigations for each soil type, the highest percentage of underirrigations occurred on these two extreme types of soil plus the multistoried class. About 50 percent of these irrigations and those for multistoried soils were underirrigations as compared to about 30 percent of the other types.

Table 49. Irrigation type by application efficiency percentages.*

Type of irrigation	Farm Ea including underirrigations (%)			Farm Ea excluding underirrigations (%)		
	No. farms	Mean	Median	No. farms	Mean	Median
Pre-irrigation	52	74	85	32	57	58
Sugarcane	24	68	72	16	44	49
Cotton	5	47	36	3	12	9
Fodder crops	78	80	94	42	60	65
Wheat	67	88	100	23	64	63
Other crops	7	71	98	3	63	89
Polyculture**	12	90	100	4	63	59

*Percentage figures in the table refer to irrigation application efficiencies (Ea). Kharif sugarcane, cotton and polyculture have a weighted Ea including water irrigations of 67 percent and with underirrigations excluded, 44 percent. This is to be compared with preirrigations and rabi wheat which respectively have higher efficiencies.

**Orchard crops which usually include fodder are excluded from the data above.

Table 50. Physical soil type by field application efficiency percentages.*

Physical soil types and sample texture through 4 ft. profile	Farm Ea including underirrigations (%)			Farm Ea excluding underirrigations (%)		
	No. farms	Mean	Median	No. farms	Mean	Median
Light-medium (sandy loam)	26	85	92	13	62	61
Medium (loam)	25	65	63	16	44	45
Medium-fine (loam-clay loam)	49	67	80	32	48	54
Fine (clay loam)	67	83	100	34	63	67
Multistoried** (loam)	142	84	100	60	57	59

*Percentage figures in the table refer to irrigation application efficiencies (Ea).

**Two or more widely different soil textures present in the four foot examined profile.

C. Farm Size and Tenure Classes

In an examination of farmers' field application efficiencies by farm size classes, there is some indication that smaller farms have higher efficiencies than larger farms (see Table 51). Given such a small sample a definite conclusion cannot be reached; the larger the farm the more availability of private tubewell water, and the greater is the tendency to waste water when it is available in excess. Almost no differences in field application efficiencies are found between the tenure classes; therefore, we cannot conclude that either farm size or tenure status makes much difference in how efficiently farmers apply irrigation water.

D. Behavior of Irrigator and Agricultural Caste Groups

The actions of the irrigator as he applies water are related to the application efficiency obtained. As mentioned earlier, about midway through the survey a checklist was developed to record the behavior of the irrigator during the evaluation. It is suspected that the presence of the engineers influenced the behavior of farmers considerably. For example, farmers probably took more care in irrigating than they might if no one was present. Some farmers also remained at their fields to talk with the evaluators and to watch their work. The limited data available of farmers' observed behavior are presented in Table 52. As one might expect, owner-operators who irrigated achieved higher efficiencies than other irrigators (see Table 52). While these data are not complete for the total sample of farms evaluated, they point to the importance of the behavior or care with which the irrigator applies water. Farmers face considerable constraints, and applying water to fields is not an easy job. The skill and the care of the irrigator is important.

Table 51. Farm size and tenure classes by field application efficiency percentages.*

Farm Size and Tenure Classes	Farm Ea including underirrigations(%)			Farm Ea excluding underirrigations(%)		
	No. Farms	Mean	Median	No. Farms	Mean	Median
1. <u>Total Acres Cultivated</u>						
under 25	66	83**	100	29	57	59
2.5- 7.49	73	80**	100	32	51	58
7.5-12.49	77	78**	99	38	56	56
12.5-24.99	75	81**	97	42	60	67
25.0-49.99	14	69	68	11	50	59
50 and over	4	47	26	3	26	17
2. <u>Tenure Classes</u>						
Owner operators	208	80	100	104	55	59
Owner-cum tenants	43	77	99	20	52	55
Tenants	58	79	94	31	58	61

*Percentage figures in the table refer to irrigation application efficiencies (Ea).

**The weighted mean for this group is 80 percent.

Table 52. Irrigation behavior by application efficiency percentages.*

Behavior of Irrigators	Farm Ea including underirrigations(%)			Farm Ea excluding underirrigations(%)		
	No. Cases	Mean	Median	No. Cases	Mean	Median
1. Status of Irrigator						
Owner-Operator	152	83	100	68	59	61
Tenant	39	66	79	27	47	49
Servant	12	73	97	6	45	37
Small Boy	10	63	57	7	46	55
2. Inspects for Leaks-Spills						
Yes	150	80	100	74	56	58
No	59	73	83	34	50	51
3. Repairs Leaks-Spills						
Yes	150	80	100	72	56	58
No	59	72	82	36	51	54
4. Irrigator Leaves Field During Irrigation						
Yes	61	77	93	34	53	56
No	134	82	100	60	59	58

*Percentage figures in the table refer to irrigation application efficiencies (Ea).

While some observers contend that certain agricultural castes and/or tribal groups are better at crop husbandry than others our data do not support such views. Table 53 makes it appear that gundal farmers are less efficient than others in the application of irrigation water with a weighted value of only 35. This is misleading in that these farmers are all located on a public tubewell supplemented command area at site 109. Gujars have an efficiency value of 100 but all of these evaluations resulted in underirrigations on a jalari command with only one private tubewell. One must look further than the particular social origin of the farmer to actual water supply problems. We conclude, therefore, that farmers in Pakistan, whatever their social origins or status, on the whole respond the best they can to the constraints which confront them. Where water is in short supply they often have to underirrigate, and where water is in relatively better supplies, more is applied to crops even to the point of overirrigation.

III. SUMMARY OF FIELD APPLICATION EFFICIENCIES

A major factor creating high application efficiency values for farmers on commands with no public tubewell supplies or a high density of private tubewells is the large number of underirrigations which represents the constraint of scarce water supplies. The major exception to this is site 116 which has surplus canal supplies throughout the year. No clear pattern develops in relationship to season when the evaluations were made, because the water supply situation for particular sites is crucial. Where supplies are from good to very good, the data consistently show low field application efficiencies ranging from 32 to 60 percent even when underirrigations are included.

Table 53. Caste/Tribal groups by field application efficiency percentages*

Agricultural Caste/Tribal Groups	Farm Ea including underirrigations (%)			Farm Ea excluding underirrigations (%)		
	No. Farms	Mean	Median	No. Farms	Mean	Median
Arain	68	71	76	53	59	61
Rajput	5	85	98	2	64	64
Jat	35	93	100	11	72	80
Khumbo	10	95	100	3	78	76
Gujar	5	100	100	0**		
Dogar	27	92	100	8	69	78
Gundol	6	35	20	6	35	20
Other	152	77	100	72	50	51

*Percentage figures in the table refer to irrigation application efficiencies (Ea).

**All irrigations were underirrigations.

In relationship to agro-climatic regions, variations in Ea's are explained by the water supply situation primarily. Command areas dominated by rice and sugarcane and mixed crop and orchard commands are those with relatively good water supplies year round. Public tubewell supplemented commands have lower field application efficiencies that other commands followed by those with a very high density of private tubewells, such as at site 110. When private tubewells reach about seven or more, field application efficiencies of farmers begin to fall dramatically. Farms located at the tail reaches have higher efficiencies than head farms when the high incidence of underirrigation is removed.

No substantial differences are found in efficiencies between the various types of irrigations except for five cotton farms and 24 sugarcane farms, where weighted mean values respectively are 47 and 68 percent. When the underirrigations are removed the values fall to 12 and 44 percent. Also, no major differences are detected in field efficiency values between farmers with different physical soil types, although sandy loam, clay loam and multistoried soils have higher efficiencies than the other texture classes. Farm sizes above 25 acres tend to have gradually decreasing application efficiencies. Tenure classes do not explain differences in application efficiences with one exception. Farmers with 25 acres or more tend to have lower efficiencies perhaps due to their greater access to private tubewell supplies.

No difference is found in the efficiency of application of irrigation water and the various agricultural castes or tribal groups that cannot be explained by the water supply situation. The data do show a trend for owner operators to apply water more efficiently than either servants, small boys (under 12 years) and tenants, but these data are limited only to about half the total sample and must not be generalized to the total number of sample farmers. The data do suggest that it is important to record information on the behavior of the irrigator at the time of making field efficiency evaluations because the human factor is important in management of irrigation water.

No summary regression analysis is made for irrigation application efficiencies because the values are inflated by the high incidence (41 percent) of 100 percent Ea's due to underirrigation. A summary regression analysis is made for farm irrigation efficiencies in the next section which shows that underirrigations explain 24 percent of the difference in irrigation efficiencies for the variables used.

CHAPTER FOUR

IRRIGATION EFFICIENCY OF SAMPLE FARMS

Irrigation efficiency is a measure which combines delivery efficiency with the farmers' field application efficiency by multiplication. This is a measure of the total irrigation efficiency--the proportion of water discharged at the mogha and/or tubewell applied to the plant root zone. It must be recalled that a large number of underirrigations inflated the values for farmers' field application efficiencies. Since those same inflated values are combined (Ed x Ea) this also inflates the values obtained for the overall efficiency. The reader is reminded of this.

I. IRRIGATION EFFICIENCIES BY TYPE OF COMMAND AND SUPPLEMENTAL WATER SUPPLY SITUATION

Summary data for irrigation efficiencies are provided in Table 54. Even with values inflated by a large number of underirrigations we note that the mean efficiencies for perennial commands is only 39 percent and for nonperennial commands 45 percent. For these commands this means that on the average over 50 percent of the water available does not benefit the farmer. Watercourse command farmers who achieved the highest efficiencies are located at sites 101, 102, 103, 107 and 115. The two farms evaluated at 103 were from the jhallar lift to the farm because all supplies flow from the mogha to a tank at the jhallar site. None of these sites have public tubewells. In contrast, sites 106 (Ei = 15 percent), site 109 (Ei = 23 percent, 105 (Ei = 22 percent) and 108 (Ei = 15 percent) are all SCARP public tubewell supplemented commands. The weighted mean irrigation efficiency for SCARP commands is 29 percent. Site 116 with 4 commands is an exception because these watercourses have excess irrigation water most

Table 54. Command type and tubewell water supply situation by farm irrigation efficiency percentages.

Type of Command and Supplemental Water Supply Situation	No. Cases	Weighted Farm Irrigation Efficiency (%)	
		Mean	Median
Perennial			
101-2WC	14	52	52
102-1WC	6	62	51
103-1WC	2	61	61
104-3WC	25	44	45
106-1WC*	6	15	10
107-3WC	27	52	47
109-2WC*	12	23	24
110-3WC	27	37	40
112-3WC	33	45	46
113-3WC	25	45	45
116-4WC	21	18	14
Perennial Totals	198	41	40
Nonperennial			
105-1WC*	5	22	25
108-1WC*	4	16	6
111-2WC*	24	37	35
114-4WC	35	47	51
115-6WC	38	50	48
Nonperennial Totals	106	44	44
Type of Tubewell Supplements			
None	157	42	45
Private	110	47	47
Public	22	20	20
Public and Private	15	34	34
Density of Tubewells (Private Tubewell Equivalents)			
None	158	42	45
1-2	49	47	48
3-6	22	45	45
7 and above	75	37	36

*Denotes public tubewell supplemented canal commands.

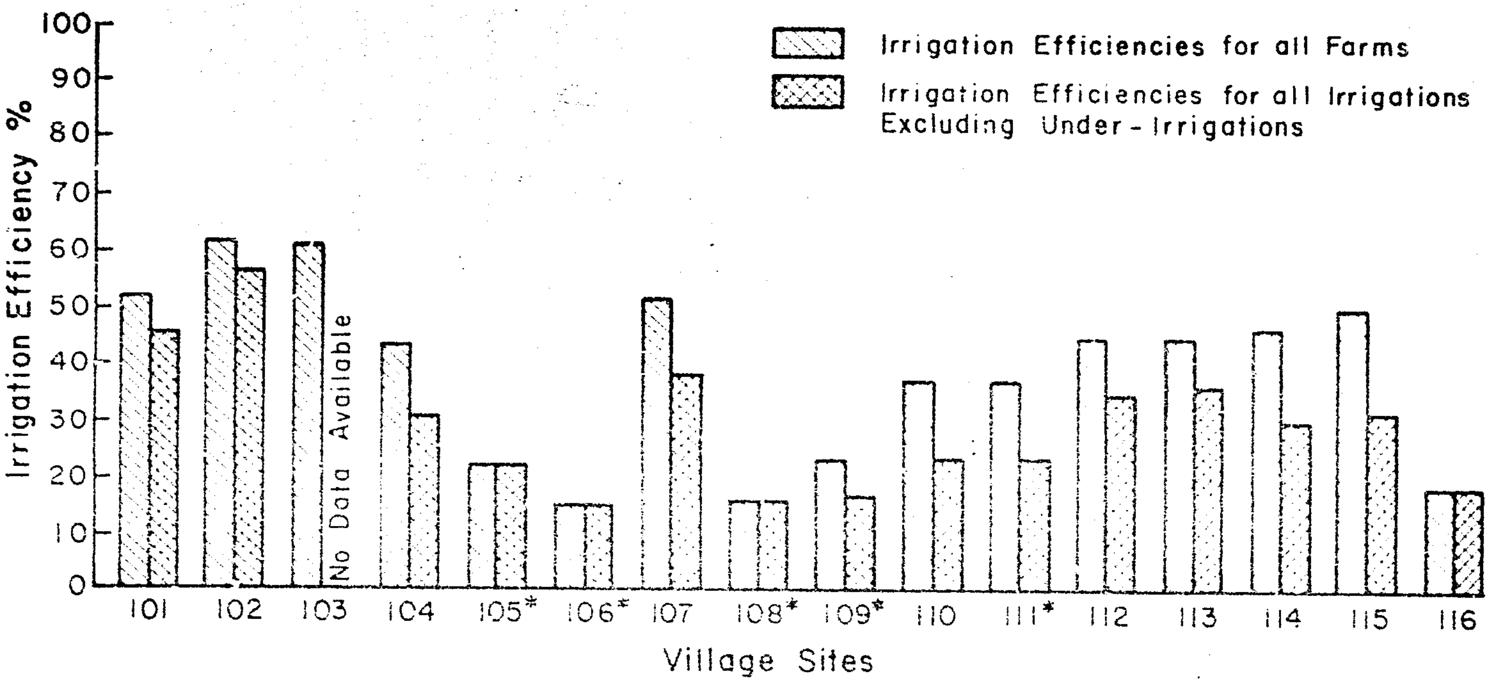
of the year. The weighted irrigation efficiency for the 4 commands is only 18 percent. It is at this site that we have an interesting combination of factors that result in much wastage of water: excess supplies, no formal warabundi turn system, paddy to paddy or "pancho" irrigation method, topographical problems, and seven illegal moghas where farmers take water at will.

Farmers with no tubewell water or only private tubewell supplies have overall irrigation efficiencies from 22 to 27 percent higher than public tubewell command farmers. Again, when we examine the density of tubewells in terms of private tubewell equivalents, it is evident that when commands have 7 or more tubewells (estimated at 4.0 to 4.2 cusecs) for supplemental supplies, efficiencies begin to drop off.

While the values are all low enough, they are still inflated due to the fact that 41 percent of all farm level field applications were under-irrigations. The efficiencies presented in Table 54 can be considered to be conservative. Figure 19 shows the changes in the weighted irrigation efficiency values for farmers at each site. The lowest values hardly change but most of the high values are reduced considerably.

The location of the farm on the command area is related to the amount of water available for irrigation. Delivery efficiencies are largely a function of discharge of water into the system and lengths of conveyance channels. In using the measured distance for each farm adjusted by the longest watercourse at each site, the head, middle and tail farms had the following mean and median efficiencies:

Adjusted Farm Position	Irrigation Efficiency	
	Mean	Median
Head	47	50
Middle	41	43
Tail	32	35



*Denotes Commands Supplied by Supplemental Public Tubewell Supplies

Figure 19. Farms at village sites and irrigation efficiencies.

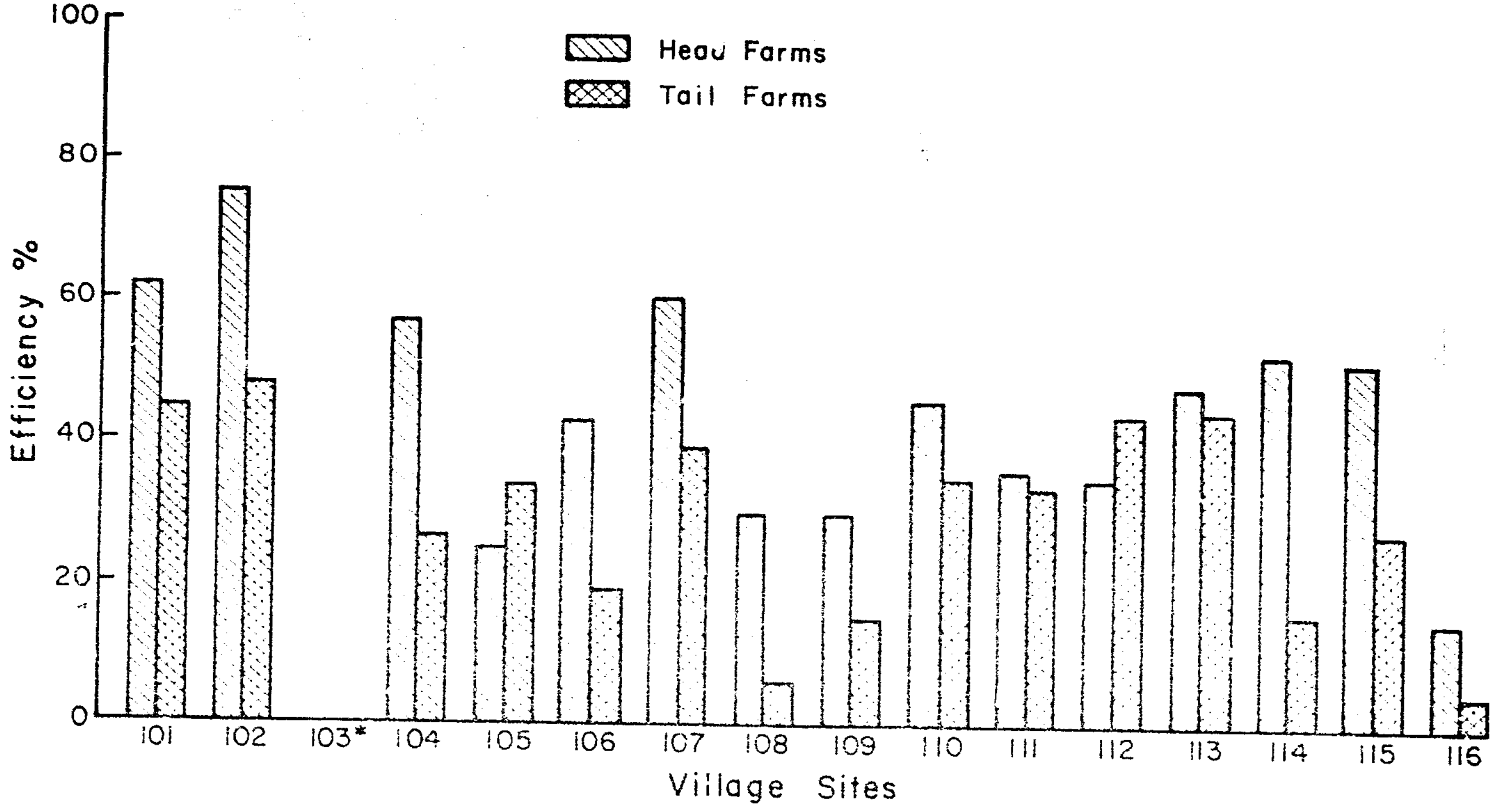
This suggests that in actual use of the available water supplies that head farmers utilized efficiently about half of the water and tail farmers about one-third of the water. To show this more graphically see Figure 20 which shows the differences in head and tail farms for all sample sites. There is on the average about 15 to 20 percent difference in head and tail farm efficiencies. At some sites, such as 114 and 115, head and tail efficiency differences are as much as 35 percent or more.

II. PREDOMINANT SOIL TYPE

As seen earlier, there is some relationship to the predominant soil type of watercourse command areas and delivery and field application efficiencies. The farms with the following physical soil types are shown with the corresponding mean and median irrigation efficiencies:

		Irrigation Efficiency		
Soil Type	# Farms	Mean		Median
Light-medium sandy loam	26	37	wt. mean 34	41
Medium loam	25	35		29
Medium fine loam	49	31		29
Fine clay loam	64	45	wt. mean 46	47
Multi-storied	140	46		44

Though not clear, there appears to be some relationship between farms with soils which are predominately fine clay or multi-storied. These two types taken as a category have a 46 percent irrigation efficiency while the other three sandier soil types have a weighted mean efficiency of 34. In general, one would expect lower efficiencies on the more sandy soils due to percolation, seepage losses and high infiltration rates. One cannot make a firm generalization from the data.



*Not Available Because Deliveries from the Mogha Flow to a Pond and all Irrigation is Lifted by a Jhallar.

Figure 20. Irrigation efficiencies for head and tail farms by village sites.

III. HUMAN AND SOCIAL FACTORS

We have stressed the importance of the irrigator in reducing losses. He, however, is confronted with a complex job of irrigating at a given time and many factors are not within his control. For example, leaks and washouts can occur a mile or more from his farm and by the time the source of the loss has been repaired considerable water is lost. Table 55 provides information on the observed behavior of irrigators and the corresponding efficiency values. Note that the owner operators had higher values than tenants, servants, or small boys. Also farmers who inspected for leaks and spills and made repairs had higher efficiencies than farmers who did not. Farmers who remained at the fields throughout the irrigation had slightly higher efficiencies than those who did not. These differences are not large because there are many factors which the farmer alone cannot control easily, such as the supply at the mogha, stealing and transit losses.

When farm size and tenure classes are examined in relationship to irrigation efficiencies, the differences are insignificant. There are no differences among the three tenure classes and only minor differences between most farm size classes. The weighted irrigation efficiency value for the large farms is 30 percent and for other farms about 43 percent. Larger farmers have greater access to supplemental tubewell water and with more available water tend to have lower efficiencies. With this exception, it appears that low irrigation efficiencies are a problem for all farmers regardless of size of holding or tenure status. Farm efficiencies were examined for various agricultural caste and tribal groups and no differences were found. The problems of water losses and efficiency of use on the sample command farms is one affecting all types of farmers.

Table 55. Irrigation behavior of farmers by irrigation efficiency percentages.

Observed Behavior of Irrigator	No. Cases	Irrigation Efficiency (%)	
		Mean	Median
1. Status of Irrigator			
Owner-Operator	150	45	44
Tenant	39	32	31
Servant	12	29	26
Small Boy	10	32	26
No one seen irrigating*	1	14	14
2. Irrigator Inspects for Leaks/Spills			
Yes	148	42	43
No	59	36	34
3. Irrigator Repairs Leaks/Spills			
Yes	148	43	43
No	59	34	31
4. Irrigator Leaves Field			
Yes	61	39	39
No	132	43	43

*Another farmer stopped the irrigation and turned the water into his field.

IV. SUMMARY OF SELECTED FACTORS AND IRRIGATION EFFICIENCY

In an attempt to discover those factors which exert the strongest influence on the irrigation efficiencies of farmers on the 40 command areas a step-wise multiple regression model was constructed.

The regression model used was:

$y = a + b_1x_1 + b_2x_2 - - - b_6x_6$

x_1 - dummy variable farms with underirrigations = 1

farms without underirrigations = 0

X_2 - dummy variable public tubewell commands and site 116 (excess water command) = 1, nonpublic tubewell commands = 0

x_3 - distance to mogha from farm in feet

x_4 - discharge at field nakka (acre inches)

x_5 - dummy variable season of year (April-September = 1, other months = 0)

x_6 - private tubewell equivalents (number)

Table 56. Summary regression analysis of selected factors and irrigation efficiencies.

Variable	Beta	S.E. of Beta	t Ratio	Multiple R	Multiple R^2	Final F ratio
x_1	20.965	2.2566	9.29**	.488	.238	86.32*
x_2	-20.948	2.7780	7.54**	.564	.318	56.86
x_3	- .002	.0004	5.00**	.594	.353	23.91
x_4	6.687	1.8474	3.62*	.613	.376	13.10
x_5	- 8.448	2.2511	3.75*	.629	.395	14.08
x_6	- 2.785	.8731	3.19*	.645	.416	10.17

*Significance at .05 level, **Significance at .01 level

This analysis shows that the most important factor in relationship to data in Table 56 is the influence of inflated field application efficiency values traceable to underirrigation. When farms with underirrigations are removed the field application efficiencies are reduced. Underirrigation explained 24 percent of the variation in irrigation efficiencies.

Secondly, the water supply situation explains about 8 percent of the variation. This confirms the earlier finding that where supplies are good (public tubewell supplemented commands) or excessive efficiencies are reduced. Farmers with good supplies of public tubewell water not only apply larger amounts per irrigation, which leads to overirrigation, but also are confronted with a problem of efficient conveyance of water. When the supplementary tubewell supplies were made available, no attempt was made to enlarge and improve the farm delivery system.

Thirdly, distance in feet from the farm to source of water supplies is an important factor due to greater total losses in conveyance of irrigation water. Farms at the tails of command areas are at a disadvantage because losses are both a function of water available and distance of the transport of water. Distance alone explains about 4 percent of the variation in irrigation efficiencies.

Season of the year is hardly important in explaining differences in irrigation efficiencies. The relationship is in the right direction showing that for kharif (summer), when canal supplies are more abundant, the losses are greater.

The number of tubewells per command also are inversely related to irrigation efficiencies but explain only about 2 percent of the observed differences in efficiencies. We do find that whether tubewells are private or public, the greater the supplemental water supplies available the less the irrigation efficiency. The greater the amount of water available for command areas (cusecs) the greater the losses and therefore the lower delivery efficiencies (Clyma, Ali, Ashraf, 1975b:17).

V. AREA IRRIGATED AND AMOUNTS OF WATER APPLIED

The area irrigated may influence the amounts of water actually applied. Farmers usually attempt to irrigate as much area as possible and often spread the limited supplies for a given irrigation thinly. This is a typical practice in situations of short and unpredictable water supplies. Table 57 presents the areas irrigated by the amounts of water actually applied (inches).

Table 57. Size of irrigated area by acre inches of water applied.

Size of irrigated area (acres)	No. farms	Acre inches of water applied		
		Mean	Median	Range
up to .1	11	3.04	1.83	1.3-9.8
.2- .3	45	2.79	2.38	.6-9.8
.4- .5	72	2.44	2.15	.2-5.9
.6- .7	42	2.62	1.86	.7-9.8
.8- .9	28	2.40	1.95	.1-5.4
1.0-1.2	43	2.33	2.00	.9-5.4
1.3-1.5	17	2.28	1.90	.1-6.2
1.6 and over	42	2.51	2.22	.1-9.8

Mean acre inch values cover up much variation. The median values, however, do not show that size of the area irrigated makes much difference in the amounts of water applied by irrigators. Other variables are important--levelness of the basin, the amount of water available, and particular soil characteristics. When predominant physical soil types of farms are examined, the median water application by various predominant soil types of farms are: light-medium (sandy loam) soils - 2.3 acre inches, medium (loam) soil - 2.4 acre inches, medium-fine (loam to clay loam) - 1.9 acre inches, fine (clay loam) - 2.1 acre inches, and multi-storied soils - 1.3 acre inches. Farmers with soils which are lighter and have higher infiltration rates received slightly higher irrigation applications than fields with heavier soils.

VI. ADEQUACY OF PARTICULAR IRRIGATIONS

Without time series data over a full crop season, we do not attempt to estimate the total amounts of water applied in relationship to seasonal crop evapotranspiration demands. Given the limitations of point data, we are interested in an estimate of how much a particular irrigation was deficient or in excess of the soil moisture requirements of the crop at a definite point in time. In order to examine this phenomenon, the irrigations that were underirrigations are treated separately from the analysis to ascertain how much overirrigation occurred. The measure water adequacy is defined as:

$$WA = \text{water adequacy} = \frac{\text{acre inches of water applied}}{\text{soil moisture requirements}} \times 100$$

In other words, if the moisture required was 2 acre inches and 4 were applied the value is (4 divided by 2 x 100) 200 percent. This value does not include a leaching factor which could require 10 percent or more water than the soil moisture requirement would indicate. The leaching factor varies with the particular type of soil, the time of year, the type of crop, and, in Pakistan, with the intensity of the monsoon rains. It can be argued that for some seasons in nonwaterlogged areas the monsoon rains are sufficient for adequate leaching requirements. Our interest is in the magnitudes of over- and underirrigation on sample farms. For example, we are interested in those values of 100 percent or greater where more than twice the required water was applied and those less than 100 which were inadequate applications. The reader should remember the constraints of farmers in applying irrigation water. When water is available at a given time the farmer, unsure of supplies for the next turn, may intentionally overirrigate.

A. Physical Factors That Influence Water Adequacy

Table 58 provides the sample sites and the general water supply situations and the estimates of water adequacy. Our major interest is in the extremes where farmers' values are over 150 percent. For example, at sites 101 and 110 farmers applied more than 50 percent more water than was required for those particular irrigations. There are two private tubewells at 101 and, near the tail of the command area, evidence of waterlogging which is not yet a critical problem. At public tubewell supplemented sites 109 and 105 farmers applied from two to three times the amounts required, and several individual farmers applied as much as six times the amounts required to replenish the soil reservoir. Site 116, already badly waterlogged, is an area where farmers on the average applied close to three times the water necessary. Some farmers at this site applied as many as 8 to 10 times the amount of water required for berseem fodder during the survey. The ranges in water adequacy were 61 to 998 for the 21 farms at site 116. At the opposite extreme, farmers at sites 103, 108 and 114 applied only about 40 percent of the required water.

To examine the importance of the type of tubewell supplements as an influence, see the section on tubewell supplements of Table 58. The weighted value for farmers with public tubewell supplies is 212 percent as compared with about 116 percent for other farmers. Another measure of the water supply situation is the location of the farm on the command area. Using measured distance to the mogha, farms have mean values of 152% at the head, 115% at the middle and 117% at the tail. Farmers at head positions on watercourse commands are in a more wasteful water supply situation.

Table 58. Water supply situation by adequacy of irrigation water applied.

Water Supply Situation	No. Farms	Adequacy of the Irrigation Water Applied	
		Mean %	Median %
Perennial Commands			
101-2WC	14	153	148
102-1WC	6	79	62
103-1WC	5	47	50
104-3WC	25	67	62
106-1WC*	6	78	60
107-3WC	29	95	70
109-2WC*	12	234	186
110-3WC	27	167	141
112-3WC	33	90	72
113-3WC	25	124	120
116-4WC	21	276	149
Perennial Totals	203	133	104
Non-Perennial Commands			
105-1WC*	5	321	303
108-1WC*	4	46	24
111-2WC*	24	89	84
114-4WC	35	47	51
115-6WC	38	93	71
Nonperennial Totals	106	86	77
Tubewell Supplements			
None	157	114	85
Private	115	118	90
Public	22	212	179
Private and Public	15	88	83
Density of Tubewells Private TW Equivalents			
None	158	114	86
1-2	52	111	81
3-6	22	74	54
7 or more	77	157	116

* Denotes public tubewell supplemented commands.

B. Adequacy of the Irrigation, Type of Crop and Agro-Climatic Region

The type of irrigation usually influences the amount of water farmers apply along with the water available and the stage of growth of the crop. Table 59 shows the adequacy of given irrigations and the type of crop irrigated. Rice irrigations are not included because application efficiency, in the sense of the soil moisture depletion model, does not apply to a flooded crop grown under standing water. High water demand crops, sugarcane and berseem fodder, are over-irrigated on the average of 83 and 68 percent respectively. Also, note that farmers applying pre-irrigations tend to apply amounts one-third greater than that required to meet the soil moisture requirements. This reflects the usual practice of farmers to apply very heavy irrigations prior to seedbed preparation. There is a term in the local Punjabi language to express light and heavy irrigations for seedbed preparation. Without controlling any other factors, such as water supply situation, the data indicate that farmers apply heavier irrigations for high water demand crops and for seedbed preparation than for other crops.

Table 59. Irrigation Type by Irrigation Adequacy Percentages

Irrigation type	No. farms	Irrigation adequacy (%) Mean	Irrigation adequacy (%) Median
Sugarcane	24	183	137
Preirrigations	52	167	123
Fodder	78	134	86
Wheat	67	93	78
Cotton	5	79	29
Polyculture	12	90	74

Table 60 displays mean and median values for adequacy of irrigations by agro-climatic region which includes the dominant crops and the estimated annual atmospheric evaporative deficit. The differences under each region can be explained primarily by the supplemental water

Table 60. Agro-climatic and cropping regions by adequacy of irrigation percentages.

Agro-Climatic Regions*	No. Farms	Irrigation Water Adequacy	
		Mean	Median
1. Low Deficit (<45")**	57	113	
Rice-Wheat	27	167	141
Rice-Fodder	25	67	62
Fodder-Wheat	5	47	50
2. Medium Low Deficit** (45-55)"	41	176	
Sugarcane-Wheat	14	154	148
Mixed Crops-Orchard	27	188	155
3. Medium High Deficits** (55-65")	94	90	
Cotton-Wheat	70	91	69
Mixed Crops-Orchard	24	89	84
4. High Deficit (>65")**	117	132	
Rice-Fodder	21	276	149
Cotton-Wheat	33	90	72
Rice-Wheat	38	93	71
Sugarcane-Wheat	25	124	120

*Low to high deficit areas refer to the estimated annual atmospheric evaporation in excess of rainfall for the four areas above in inches. Inches in estimated evaporation are shown as (<45"), (45-55"), (55-65") and (>65").
**Weighted totals.

5.	Summary of Cropping region	No. Farms	Irrigation Water Adequacy	
			Mean	Median
2	Rice-wheat	65	124	100
2	Rice-fodder	46	162	101
2	Sugarcane-wheat	39	135	104
5	Mixed crops-orchard	51	141	122
4	Cotton-wheat	103	91	73

supply situation. For example, the rice-wheat area, under low deficit conditions, is at site 110 where there are 34 private tubewells for 3 watercourse commands. The other sites in the low deficit region have no tubewell supplements or one private tubewell on some commands. The next region, labeled medium-low deficit, includes sites 101, 105, 106, 108 and 109. The first site is a sugarcane-wheat dominated command with farm canal supplies, and two private tubewells, and, for about one-third to one-quarter of the command, a water table that provides some moisture for berseem and sugarcane. Sites 105, 106, 108 and 109 are all supplemented by SCARP public tubewells. In the medium-high deficit, the wheat-cotton commands were all evaluated under peak demand conditions and the mixed crop-orchard command has a public tubewell serving two non-perennial command areas. The high-deficit region includes the four rice-fodder commands at site 116 (Thatta) which has excess canal supplies. Farmers on the commands, on the average, apply nearly three times the amounts needed which is one important factor contributing to a bad waterlogging situation.

C. Water Applied and Size of Irrigated Area

Farmers have a good understanding of the time required to irrigate certain fields given an assumed discharge rate for the mogha and or tubewell. Farmers also tend to spread water over as large areas as possible even when irrigations are inadequate. Data in Table 61 show the size of the total unit irrigated evaluated by sample farmers during the irrigation turn and the adequacy of water applied.

Wide ranges in values provide high mean values, therefore, the picture is not clear as indicated by the difference between mean and medians. The trend is for farmers to apply more water than is required at a particular irrigation when the area irrigated is small.

Table 61. Area irrigated by irrigation adequacy percentages.

Area Irrigated (Acres)	No. Farms	Irrigation Adequacy (%) Mean	Median
up to .1	13	231	90
.2- .3	46	152	92
.4- .5	75	134	91
.6- .7	43	100	77
.8- .9	28	102	72
1.0-1.2	45	104	73
1.3-1.5	17	89	59
1.6 and over	42	98	95

D. Human Factors and Adequacy of Irrigation Water Applied

The behavior of irrigators varies. The limited data available presented (see Table 62) show that owner operators applied almost the amount of water that was required to meet the depletion of soil moisture. Tenants and servants especially applied from 74 to 138 percent more than was required. Likewise, those farmers who were careful to inspect for and repair leaks and spills applied amounts closer to that required by about 40 percent than those farmers who did not make checks and repairs for leaks. Also, note that the irrigators who left the field had a mean adequacy measure of 160 percent as compared to 114 percent for those who stayed at the field throughout the irrigation. This suggests that there is a tendency for farmers to overirrigate when they do not provide complete attention to their complex task.

In summary, it is found that farmers serviced by public tubewells tend to apply more water than is adequate to replenish the SMD. Also, farmers on commands with seven or more tubewells apply more water than farmers with less private tubewell equivalents. Farmers also tend to apply heavier irrigations for sugarcane pre-irrigations, and fodder crops (mainly berseem) than for other crops. The size of the irrigated

Table 62. Irrigation behavior of farmer by irrigation adequacy percentages.

Irrigation Behaviors	No. Cases	Adequacy of Irrigation (%)	
		Mean	Median
1. Status of Irrigator			
Operator-Owner	152	104	86
Tenant	39	238	116
Servant	12	174	78
Small Boy	10	134	125
2. Inspects for Leaks/Spills			
Yes	150	123	88
No	59	161	109
3. Repairs Leaks/Spills			
Yes	150	123	87
No	59	163	116
3. Irrigator Leaves*			
Yes	1	160	93
No	134	114	87

*This refers to irrigators who either remained at the fields throughout the irrigation period or who went away after beginning an irrigation.

also seems to influence the amount of water applied for a given irrigation. Also, farmers who are owner-operators, those who inspect and repair leaks and spills, and remain at the field during irrigation periods tend to better match their irrigations to soil moisture deficiencies. Time series data are needed to analyze this problem more adequately.

CHAPTER FIVE

LAND USE, CROPPING PATTERNS AND CROPPING INTENSITIES

This chapter will describe the actual land use patterns for the 40 sample watercourse command areas. These patterns will be examined in regard to authorized and actual cropping areas, factors influencing the percentage of cultivated area in crops, and cropping patterns.

I. DEFINITION OF THE TERMS AND LIMITATIONS OF THE DATA

A. Culturable Command Area (CCA)

This term refers to the portion of a watercourse command area which is supposed to be served by the existing canal water supplies. It is the area for which the mogha is sized. It is land at a topographical level which can be serviced by the canal system. This excludes buildings, roads, and wasteland. It, however, includes land that has gone out of production due to waterlogging and/or salinity. This is often referred to as the "authorized cultivatable area."

B. Cultivated Area (CA)

This is the actual area cultivated sometime within the period of a year, and excludes roads, buildings, nonculturable waste, and culturable barren land. This can change year by year depending on the canal irrigation supplies, rainfall and supplemental sources of irrigation water such as tubewells and Persian wells. It also can vary in relationship to reclamation programs and "Grow More Food Campaigns" for which extra canal supplies are made available for specified periods and crops. This area will also change depending on waterlogging and/or salinity problems from year to year.

C. Seasonally Cropped Area (SCA) and Cropping Intensity (CI)

The seasonally cropped area is the total area in crops as a proportion of the CA for a given season, for rabi as RCA and for kharif as KCA. The cropping intensity is the sum of the cropped area or CA for rabi and kharif seasons at the time of the survey, divided by the cropped area total times 100 to provide a percentage,

$$CI = \left(\frac{\text{rabi acreage + kharif acreage}}{\text{cultivated area}}\right) \times 100 \text{ or } CI = \left(\frac{RCA + KCA}{CA}\right) 100$$

Fruit orchards and sugarcane crops are counted twice because they occupy the land and utilize water the year round. Where three crops (as fodder or vegetables) are cultivated and harvested in one year the intensity increases. For our purposes we include only two crop seasons--rabi and kharif for one year. Intercropping, which we term polyculture, also inflates the cropping intensities and we have not counted these crops twice in the rabi and kharif intensities but have shown the extent of this type of cropping practice for each site.

D. Harvest Intensity

Harvest intensity is the percentage of the CA which has crops that are harvested each season.

A major limitation of the data results from the nature of the survey. Cropping patterns and intensities were mapped in a crop survey for each sample site. These crop surveys were conducted at the particular time of the study and do not reflect the actual areas in crops for both rabi and kharif seasons. Some of the area had not been cultivated at the time of the survey; therefore, the areas shown as fallow on our crop survey maps are inflated. This leads to under reporting the shorter duration fodder and vegetable crops. To partially overcome this problem, a special conceptual grid system was designed for each acre of each sample farm. The farmers were asked to report the area in each crop for their CA for the season at the time of the survey and the one directly preceding the survey. The crop survey data mapped for each command area and village site are shown in the map appendix for the 16 sample sites.

II. AUTHORIZED AND ACTUAL CROPPED AREA OF COMMAND AREAS

The sample of 40 watercourse command areas and the authorized cultivation for each in acres is shown in Figure 21. Several of the command areas are small perhaps due to the location of the distributary, as for the case of watercourse commands 4, 5, 6 and 7.

Table 63 provides additional information about actual cultivated acreage as compared to the authorized CCA. Where possible, farmers extend the cultivated acreage by means of tubewells and Persian wells. The only sites where farmers did not go beyond the authorized CCA (see sites 102, 105, 106, 109 and 111) in cultivation area sites where there are either severe topographical problems or areas where waterlogging limits cultivation. The pressure on the land is great, and at sites 101, 107, 110, 112, and 115 farmers by means of tubewells, Persian wells, and jhallar water lifts have expanded the cultivated area. This is typical of many command areas in Pakistan and has been accelerated by private tubewell developments. As was reported 28 years ago (Roberts, 1951: 167-169) farmers make every effort to extend their cultivated acreages. Site 110 is a special case--there is an essentially noncommanded area with 119 acres which has no canal supplies. All irrigation supplies are from eight private tubewells.

Table 63 provides information about the 16 sample village sites as to the authorized CCA and the actual area cultivated for the commands and the water supply situation. The water supply situation gives the authorized

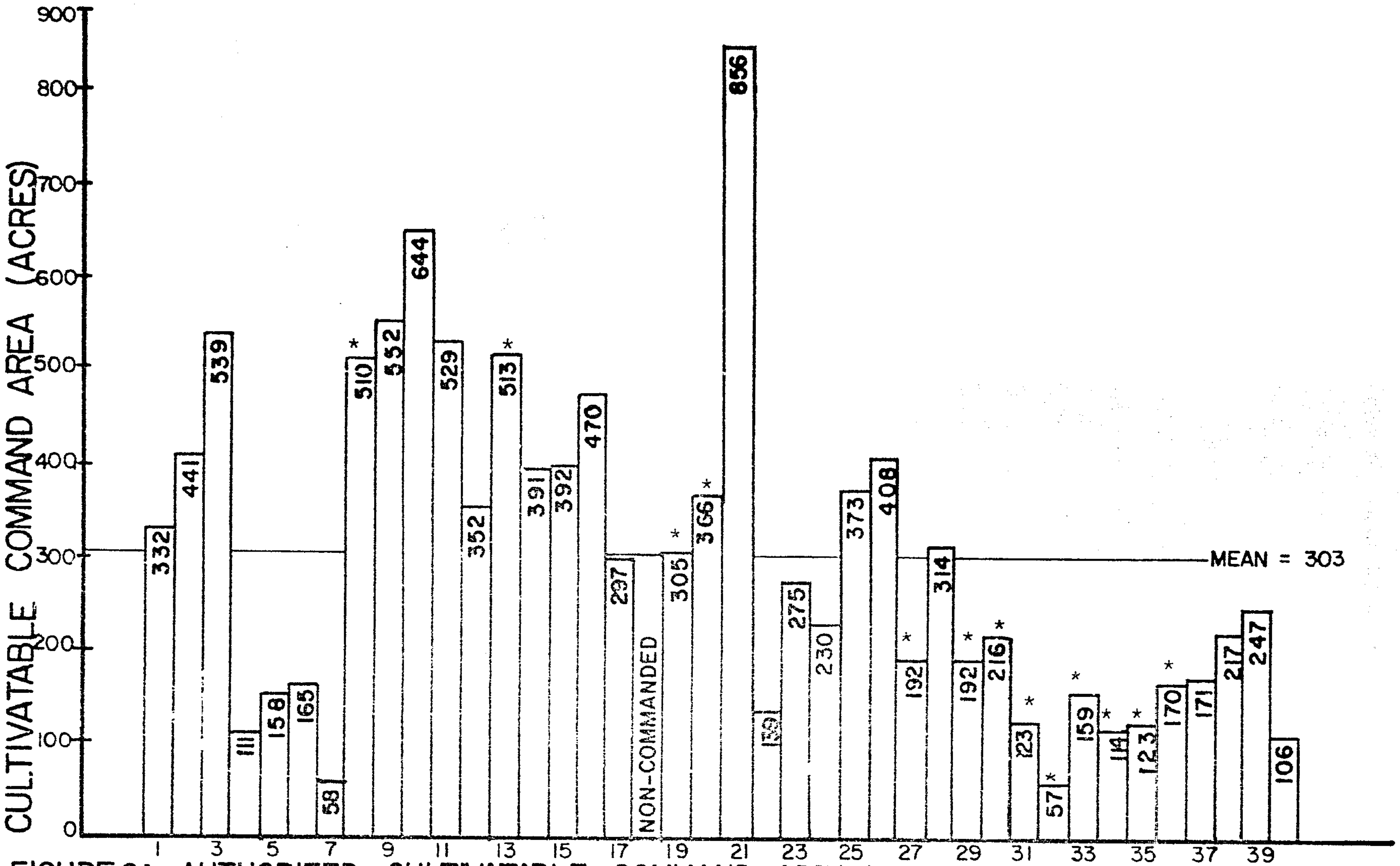


FIGURE 21. AUTHORIZED CULTIVATABLE COMMAND AREA IN ACRES FOR SAMPLE OF 40 WATERCOURSES IN PUNJAB AND SIND.

*Denotes non-perennial commands, all others are perennial.

Table 63. Authorized CCA, actual area cropped with authorized and supplemental canal supplies.

Type command and sites	Cultivated acres		Authorized Mogha Discharge cusecs	Authorized mogha discharge and acres of authorized CCA/cusecs (1÷3)	Authorized canal supplies and acres of actual CA per cusecs (2÷3)	Potential supplemental discharge (cusecs)	Actual CA in acres and potential water supplies acres/cusecs (2÷3+6)
	Authorized CCA	Actual CA					
Perennial							
101-2 wc	773	804	2.39	323	336	1.20	224
102-1 wc	539	528	1.76	306	300	3.60	99
103-1 wc	111	128	.49	227	261	.60	117
104-3 wc	381	378	1.50	254	252	.60	180
106-1 wc	552	492	1.87	295	263	1.27	157
107-3 wc	1525	1625	5.08	300	320	15.60	68
109-2 wc	783	670	2.24	350	299	2.05	156
110-2 wc	767	776	3.49	220	222	15.60	41
*112-3 wc	1270	1127	1.15	1104	980	none	980
113-3 wc	1011	712	3.55	285	201	none	201
116-4 wc	741	505	6.17	120	82	none	82
Nonperennial							
105-1 wc	510	507	2.19	233	232	1.83	126
108-1 wc	513	507	3.00	171	169	3.00	84
111-2 wc	671	444	4.26	158	104	3.40	58
114-4 wc	914	920	5.04	181	183	1.20	147
115-6 wc	746	609	4.56	164	134	2.4	88
Noncommanded							
110-1 wc	none	119	none	none	none	4.8	25

Note: The following types of supplemental supplies are at each site:

Site: 101-2 private tubewells
102-6 private tubewells
103-1 private tubewell
104-1 private tubewell
105-1 public tubewell
106-1 public tubewell
107-26 private tubewells
108-1 public, 2 private tubewells
109-1 public tubewell
110-2 wc, 26 private tubewells
111-1 public tubewell, 2 Persian wells
114-2 private tubewell, 26 Persian wells
115-4 private tubewell, 17 Persian wells

Discharge of private tubewell estimated at .6 cusecs
Discharge of Persian wells estimated at .1 cusecs

*112-1 deleted.

canal supplies in acres per cusec and the supplemental supplies from tubewells and Persian wells. The reader should note the number of watercourse commands for each village site. These data show a wide range in authorized canal supplies or cusecs per area of cultivated acres. The CCA acreages range from 58 to 856 acres for perennial commands and from 57 to 513 acres for nonperennial commands. For the perennial commands, factors which cause some variation are the type of command area and special allotments for reclamation purposes and "Grow More Food" campaigns. For example, site 103 is a jhallar waterlift system and the authorized canal supplies are 227 acres per cusec. At site 104 with 254 acres per cusec, farmers receive extra supplies for reclamation of land by rice cultivation. At site 110 special supplies also are granted for rice cultivation and reclamation purposes. For the nonperennial commands the CCA per cusec ranges from 158 to 233 acres. In Sind (sites 112 to 116) the range in cusecs per CCA in acres is 120 to 285 which indicates a higher average duty than for the command areas in the Punjab. The usual dejure duty in the Punjab is 350 acres per cusec for non-SCARP public tubewell commands and about 150 acres per cusec for SCARP public tubewell supplemented commands.

Wide variation is seen in the potential supplemental supplies for command areas as revealed in Table 63. For example, at both sites 107 and 110 there are 26 and 34 tubewells respectively and for these perennial sites the tubewells alone provide about one cusec per 132 acres at site 107, and about one cusec per 29 acres at site 110. The exceptional case is the noncommanded system 110-3 where there are 8 private tubewells supplying about one cusec of water for 25 acres on the noncommanded area of only 119 acres.

Available irrigation supplies are shown by village site (Table 63) to conserve space and also because, where possible, farmers use water from one mogha outlet to irrigate fields located on other commands. This is an extra-legal practice, but farmers follow this procedure where topography permits and especially when they have fields ideally located on the margin of a command area. At sites 101, 104, and 107 this is a common practice. (See the watercourse maps in Volume VI, Appendix IV-A.) Farmers also utilize tubewells located on one command to service fields on an adjacent command whenever possible.

III. Percentage of Cropped Cultivated Area

The percentage of the actual cultivated area (CA) cropped by farmers in a given season depends on the general water supply situation, the type of crops cultivated, the agro-climatic region, and several socio-economic factors such as size of holding, land tenure status, and distance to market. Cropping intensities here are not to be confused with harvest intensities--the percentage of the CA which has crops harvested each season. Cropping intensities vary from year to year depending on rainfall patterns.

Table 64 shows the potential water supplies available at various types of command areas. With a few exceptions, variations in cropping intensities are not as great as the variations in the available water supplies. Farmers adjust their cropping patterns and intensities to the water they perceive to be available. As will be discussed under cropping patterns, farmers adjust their crops in relationship to crop water demands. For example, whenever supplies of water are short and unpredictable, farmers choose crops such as small grains, millets and maize (used primarily as green fodder) to maintain as high cropping intensities as possible.

Table 64. Summary of potential irrigation supplies (authorized canal supplies plus supplemental supplies) and percentage of total area cropped (1975-76).

Type command and sites	Potential irrigation supplies (acres of CA/cusec)	Number of farms	Percentage of total area cropped (1975-76)		
			Rabi	Kharif	Rabi + kharif
Perennial					
101-2 wc	224	15	86	60	146
102-1 wc	99	9	59	71	130
103-1 wc	117	16	90	65	155
104-3 wc	180	30	84	69	153
106-1 wc*	157	12	87	62	149
107-3 wc	68	54	80	77	157
109-2 wc*	156**	14	94	84	178
110-2 wc	41	20	79	76	155
112-3 wc	NONE**	34	76	57	130
113-3 wc	201**	26	84	61	145
116-4 wc	82**	26	79	86	165
Perennial totals		256	81	70	151
Nonperennial					
105-1 wc*	126 **	8	84	69	153
108-1 wc*	105 **	9	70	45	115
111-2 wc*	55 **	24	76	60	130
114-4 wc	104 **	38	62	58	120
115-6 wc	70 **	39	82	55	137
Nonperennial totals		118	74	57	130
Noncommanded					
110-1 wc	25	16	77	88	165

*Denotes public tubewell supplemented.
**Denotes data awaited to be in final draft.

In summarizing the data on "percentage of cultivated area cropped for the 1975-76 seasons"(Table 64), it is evident that farmers adjust their crops to the available water supplies. Cropping intensities, however, are not static and fluctuate in relationship to the rainfall and problems such as power supplies for tubewells and tubewell breakdowns.

A. Tubewell Supplies and Cropping Intensities

Watercourse commands with public and private tubewells provide increased control over supplies. Control and reliability of water supplies are crucial considerations in making cropping decisions. Given inadequate canal supplies and lack of control over them, farmers have found investment in tubewells to be lucrative. Though tubewells may exist on commands, all farmers do not have equal access to tubewell water. Factors such as distance from the tubewells, ownership of private wells and social power determine the availability of supplemental tubewell water. It is well known that farmers with considerable influence frequently operate public tubewells at will or provide gifts to tubewell operators in return for extra water.

Table 65 provides information on average cropping intensities of sample farms by type of tubewell supplement (see Table 65). The exceptional case of four command areas at site 116 is removed from Table 65 due to excess canal supplies and associated waterlogging problems. Private tubewells do not appear to exert an impact on cropping intensities until a threshold value of about seven or more per command are present. Farmers on such commands have a weighted mean intensity of 157 which is very close to the intensities for farmers on public tubewell commands.

There is little variation between cropping and intensities and type of tubewell supplement. One reason for this is that under "no tubewell

Table 65. Farmers on watercourses and type of canal water supply supplements by rabi and kharif cropping intensity percentages

	CROPPING INTENSITY (%)					
Watercourse command area tubewell supplements	Farms reporting	Rabi season	Farms reporting	Kharif season	Farms reporting	Rabi & kharif seasons
Perennial commands						
1. No tubewells**	101	82	96	61	70	143
2. Only public tubewells	33	89	33	72	33	160
3. Private tubewells						
a. Less than three	30	86	31	61	30	146
b. Three to six	33	75	33	73	33	148
c. Seven or more	45	79	46	78	45	157
4. Both private and public	4*	83	4	63	4*	146
Nonperennial commands						
1. No tubewells	49	71	48	61	48	131
2. Only public tubewells	0		0		0	
3. Private tubewells						
a. Less than three	54	74		54		127
4. Both private and public	16*	78	16	56	16	133
Noncommanded area						
Private tubewells	16	77	16	88	16	165
a. Seven or more						

**Four watercourses in village 116 are removed from this analysis due to excess canal water supplies and waterlogging. Total intensity is 165 for site 116.

*Farms located on watercourse commands with public tubewell supplements and up to two private tubewells for canal supplements.

supplement" sites 114 and 115 have 43 Persian wells or four on each command. The 16 farms on the commands with public tubewells have only one private tubewell per command; therefore, the extra supplement is only about .6 cusecs. The noncommanded area has eight tubewells and the high (165%) cropping intensity.

Since all farmers do not have equal access to tubewell supplies as a result of lack of cash, credit, or influence, each farmer was asked several questions about his perception of tubewell water availability and his use of tubewells. These qualitative questions do not provide answers about the times and amounts of tubewell water utilized but where there are tubewells available there is a strong demand for tubewell water as a means of supplementing canal supplies and for meeting crop demands. As shown earlier, private tubewells are distributed almost equally between head, middle, and tail reaches of command areas, and farmers of all farm size classes make use of tubewells.

Table 66 presents farmers' reports of tubewell water availability. Farmers on public tubewell commands are included under "purchase tubewell water" because the assessment of fees for these tubewells are included in the Irrigation Department abania for canal water assessments.

Farmers who report that tubewell water is easily available, and those who own tubewells have higher cropping percentages.

B. Rabi and Kharif Cropping Intensity Differences

One of the advantages of tubewell supplements is to reduce differences between rabi and kharif cropping intensities. The major means of accomplishing this by farmers is through control of supplemental tubewell supplies of water. Wherever a substantial supply of tubewell water is available, the wide differences in areas cultivated for rabi and kharif seasons are less.

Table 66. Availability and use of supplementary tubewell water by percentage of cultivated area in crops.

Command areas and availability of tubewell water supplies	Total Cultivated Acres in Crops (%)					
	No. farms	Rabi	No. farms	Kharif	No. farms	Rabi and kharif
Perennial commands						
Availability and use of tubewell water						
1. "Not available"	60	86	47	53	47	137
2. "Available with difficulty"	47	74	47	63	47	137
3. "Easily available"	87	83	88	75	87	158
4. "No use"	97	83	93	62	93	144
5. "Purchase tubewell water"	80	83	81	73	80	155
6. "Own private tubewell"	33	78	33	76	33	153
Nonperennial commands						
Availability and use of tubewell water						
1. "Not available"	45	69	45	53	45	124
2. "Available with difficulty"	16	85	17	61	16	146
3. "Easily available"	29	71	28	63	28	134
4. "No use"	66	73	68	56	66	129
5. "Purchase tubewell water"	27	70	26	55	26	125
6. "Own private tubewell"	9	77	9	67	9	144

It might be thought that greater canal supplies available in kharif (summer season) plus monsoon rains from July to August would result in higher kharif cropping intensities. This is not the case however, because of high summer evapotranspiration rates. Atmospheric demands accelerate to such a point that the irrigation water required for a crop is almost double in kharif as compared with rabi season. For example, maize fodder when fall harvested will require about 12" of water from September to the first of December as compared to 33" when planted in March and harvested in June. Likewise, great millet or jowar when spring planted for fodder will require about 30" of water as compared to 16" when fall planted.

Data (Table 67) show differential cropping intensities for rabi and kharif seasons by type of tubewell supplements. Differences between rabi and kharif intensities are less for farms on nonperennial commands with no tubewell supplies. This may result from the fact that there are 45 Persian wells on nonperennial commands at sites 114 and 115.

When both perennial and nonperennial commands are combined, the commands with least difference between rabi and kharif intensities are those with three or more private tubewells. Farms on commands with no tubewell supplements have rabi-kharif differences of 18 percent which is about the same as for farms on public tubewell supplemented commands.

In summary, data on tubewell supplements and cropping intensities support several conclusions. First, farmers on commands with public tubewell supplemental supplies and a medium to high density of private tubewells tend to have higher percentages of total cultivated area in crops than farms where tubewell supplemental supplies are less available. Secondly, farmers who report tubewell supplies easily available, purchase tubewell water, and own private tubewells tend to have higher cropping

Table 67. Water supply situation by percentage of cultivated area in crops for rabi and kharif.

Water supply situation	No. farms	Cultivated Acreage in Crops (%)		
		Rabi season	Kharif season	Difference between Rabi and Kharif
1. Perennial commands				
a. No tubewells*	101	82	61	+21
b. Public tubewells	33	89	72	+17
c. Under 3 private TW	30	86	61	+25
d. 3-6 private tubewells	33	75	73	+ 2
e. 7 or more tubewells	45	79	78	+ 1
f. Public and private	4	83	63	+20
Perennial Totals	246	82	67	+15
2. Nonperennial commands				
a. No tubewells	49	71	61	+10
b. Under 3 private TW	54	76	54	+22
c. Public + private TW	16	78	67	+11
Nonperennial Totals	119	74	59	+15
3. Noncommanded (site 110-3) 7 or more tubewells	16	77	88	-11
4. Perennial plus nonperennial commands				
a. No tubewells	150	78	59	+19
b. Only public tubewells	33	89	72	+17
c. Under 3 private TW	84	78	63	+15
d. 3-6 private tubewells	33	75	73	+ 2
e. 7 or more tubewells	45	79	71	+ 8
f. Public + private TW	20	79	57	+22
Perennial + Nonperennial	365	79	64	+15

*Four commands at village 116 are not included due to an excess water supply situation already discussed. Rabi was 77 percent and kharif fallow was 86 percent for 26 sample farms.

intensities than farmers who have no tubewells available. Thirdly, especially for the perennial command farms, the farmers who have public tubewell supplies or are on commands with a high density of private tubewells show less differences in rabi and kharif cropping intensities than farmers who are not favored with good tubewell supplies. Fourthly, farmers do adjust their cropping intensities to their perceived supplies of irrigation water. Fifth, water supplies alone do not explain differences observed in cropping intensities. Other factors such as agro-climatic region, type of crops cultivated, distance to market and socio-economic factors are also expected to exert some influence on cropping intensities.

C. Cropping Intensities by Agro-Climatic Regions Showing Dominant Crops on Commands

Summary Table 68 provides information about the major crops cultivated on watercourses in relationship to agro-climatic regions. The four climatic zones are based on the estimated annual evaporation and rainfall as defined in the methodology sections of Volumes II and VI. It should be noted (Table 68) that of the 26 perennial watercourse commands 15 are dominated by sugarcane or rice crops with high water demands, while of the 13 nonperennial commands, only 6 at village 115 cultivate large areas of rice due to a good supply of water during the kharif season.

Table 69 shows the percentage of cultivated area cropped for 1975-76 season by crop-dominant watercourse commands. Little variation is observed between the agro-climatic regions and dominant crop commands except for the low annual atmospheric evaporative deficit fodder-wheat commands under (1) and the rice-fodder command under (11) which have cropping intensities of 165 and 168 respectively. At the other extreme are the high evaporative demand commands with cotton-wheat cropping pattern which have a mean

Table 68. Climatic zones based on annual atmospheric moisture deficits by major crops of watercourse commands.

Climatic zones based on atmospheric moisture deficits and village sites (p=perennial,* np=nonperennial)**	No. of WC's	Major crops cultivated						
		Rice and fodder	Cotton and wheat	Rice and wheat	Sugar-cane and wheat	Rice fodder and wheat	Mixed crops and orchards	Fodder and wheat
I-Low moisture deficit (<45"/annum)								
Village 103p	1							X
Village 104p	3					X^{+}		
***Village 110p	3			X^{+}				
Subtotal	7							
II-Low to medium moisture deficit (45-55"/annum)								
Village 101p	2				X^{+}			
Village 105np	1						X	
Village 106p	1						X	
Village 108np	1						X	
Village 109p	2						X	
Subtotal	7							
III-Medium to high moisture deficit (55-65"/annum)								
Village 102p	1		X					
Village 107p	3		X					
Village 111np	2						X	
Village 114np	4		X					
Subtotal	10							
IV-High moisture deficit (>65"/annum)								
Village 112p	3		X					
Village 113p	3				X^{+}			
Village 115np	6			X^{++}				
Village 116p	4	X^{+}						
Subtotal	16							
Totals	40	1	4	2	2	1	5	1

*Total of 25 perennial commands signified by p.

**Total of 14 nonperennial commands signified by np.

***Village 110 has one noncommanded system with 8 private tubewells which is a rice-wheat dominated area.

+Denotes 15 of 26 commands dominated by sugarcane-rice.

++Denotes 6 of 13 commands dominated by rice.

Table 69. Agro-climatic regions with estimated annual evaporative deficit by mean cropping intensities for rabi and kharif.

Agro-climatic regions with estimated annual evaporative deficit (inches)*	Cropping intensity percentages					
	Rabi season		Kharif season		Rabi & Kharif	
	No. of farms	Mean %	No. of farms	Mean %	No. of farms	Mean %
1. Fodder-wheat	16	95	16	70	16	165
Rice-fodder	36	78	36	58	36	137
Rice-wheat	25	80	25	71	25	149
2. Medium low						
Sugarcane-wheat	14	72	14	72	14	144
Mixed orchard	40	79	39	69	38	147
3. Medium high						
Cotton-wheat	94	74	95	74	93	147
Mixed orchard	24	80	24	58	24	139
4. High						
Cotton-wheat	34	72	31	56	31	126
Sugarcane-wheat	26	79	26	61	26	140
Rice-wheat	39	82	37	57	37	140
Rice-fodder	24	81	24	87	24	168

*Estimated annual atmospheric evaporative deficit.
Low=<45"
Medium low=45-55"
Medium high=55-65"
High=>65"

cropping intensity of only 126 percent. The fodder-wheat command areas under (1) are influenced by the Lahore fodder market where farmers cultivate maize, oats, and millets for fodder, and rice-fodder (11) is influenced by Karachi for which berseem is grown. The low intensity at the cotton-wheat command of 126 percent is influenced by the lack of any supplemental supplies to canal water and the fact that 32 percent of the cultivated area is devoted to cotton in a region with a high annual atmospheric evaporative deficit in excess of 65 inches per year.

To summarize weighted cropping intensity percentages for the four climatic zones in Table 69:

Deficit Category	Mean Annual Deficit	No. Farms	Rabi + Kharif intensitied (%)
Low	<45"	77	147
Medium Low	45-55"	52	146
Medium High	55-65"	115	145
High	>65"	118	142
Totals		362	145%

There is little variation among the low to high atmospheric evaporative deficit areas. The major influences on intensities are related to other factors. Whe the commands are grouped into the dominant crop categories one finds the following:

Major crops	No. Farms	Rabi + Kharif Intensities (%)
Fodder-wheat	16	165
Rice-fodder	60	149
Rice-wheat	62	144
Sugarcane-wheat	40	141
Cotton-wheat	124	142
Mixed-orchard	62	144

Again, there is little variation between major types of crops which dominate the 40 watercourse commands. The fodder-wheat watercourses are located near Lahore City in the low evaporative deficit area where there are strong market demands for fodder crops and milch products. Many farmers cultivate as many as three short duration maize fodder crops in one season for marketing in Lahore City. When moisture is insufficient for berseem fodder, farmers shift to millet and oats as fodder crops which require less water than fodder crops such as berseem (Egyptian clover) or alfalfa.

In conclusion, the data do not show that the particular crop dominated commands or the particular regional climate influences the area cultivated for the 1975-76 season. This does imply that farmers do adjust their crops to the particular water supply situation they confront and the markets that are available at a given time. In areas and times of short supplies farmers tend to utilize as much of their cropped areas as possible by switching to crops with lower water demands.

D. Watercourse Location and Percentage of Cultivated Area Cropped

As has been observed in the analysis of watercourse losses, both the delivery efficiencies and the total amounts of water loss in conveyance to farms are higher for farms located along the tail reaches of command areas. Table 70 shows that the overall weighted cropping intensities are about 10 percent less for tail farms as compared to head farms. Note, however, for the perennial commands supplemented by public tubewells the differences are as much as 25 percent. This indicates the greater total losses of large discharge rates into conveyance systems with inadequate cross section and freeboard to convey the relatively large volumes of water. Commands differ in the maintenance of earthen conveyance systems,

Table 70. Water supply situation by differences between cropping intensities for farms at head and tail reaches of watercourse commands

Type watercourse & tubewell supplements to canal supplies	CROPPING INTENSITY PERCENTAGES				
	No. of farms	Tail farm (%)	No. of farms	Head farms (%)	Difference between tail and head farms
1. Perennial commands					
a. No tubewells	32	146	36	151	- 5
b. Public TW only	7	151	10	176	-25
c. Private TW only					
1) Low density	10	127	15	145	-18
2) Medium density	12	142	11	150	- 8
3) High density	12	154	14	165	-11
PERENNIAL TOTALS WEIGHTED	73	145	86	155	-10
2. Nonperennial Commands					
a. No tubewells	15	118	14	130	-12
b. Public TW only	7	149	16	141	+ 8
c. Both public & private	2	88	2	107	-19
d. Private TW only					
1) Low density	10	118	7	124	- 6
NONPERENNIAL TOTALS WEIGHTED	34	123	39	132	- 9
3. Totals	107	138	125	148	-10

but where there are private tubewells the head-tail cropping intensity differential (8-18%) is less than on commands without private tubewells. The weighted mean cropping percentage for these perennial private tubewell commands is about 11 percent less for tail farms as compared to head farms. For the nonperennial command farms with no tubewell supplies the differences are 12 percent less for tail farms. This difference would probably be greater except for the fact that at sites 114 and 115, with 43 Persian wells, 18 are located at the middle of command areas and 15 are located at the tail reaches. Therefore, 33 Persian wells supply water which can be utilized by tail farms. The public tubewell only supplemented commands present an unusual situation. At site 105 the major watercourse losses were observed at the head due to a branch watercourse that was improperly designed with respect to the surrounding topography. Tail farms received relatively more water. Water is ample at this command area with about 1.83 cusecs of public tubewell water.

Whatever the water supply situation, farms located at the tail reaches of commands receive less than their equitable share of the water due to greater conveyance losses. Therefore, they are under the water supply constraint to reduce their cropping intensities from 10 to 25 percent as compared with farmers located at the head of watercourse commands. In Volume VI, Appendix III-D, a list of all 40 individual command areas is given and the differences in cropping intensities for head and tail farms is given with an explanation of differences. Of 24 of these individual commands, the range in differences in cropping intensities between head and tail farms was minus 2 percent to minus 48 percent.

E. Cropping Intensities by Farm Size and Tenure Class

Both farm size and tenure classes are presented (Tables 71 and 72) in relationship to percentage of acreage in crops for the 1975-76 season.

Table 71 provides information about cropping intensities and farm size classes. When both perennial and nonperennial command farms are combined there is little indication that the larger farms have lower intensities. The major explanation is that our sample does not include sufficient numbers of larger farmers.

When cropping intensities are examined in relationship to tenure classes (Table 72) we find that owner-cum-tenants have lower intensities than either owners or tenants for perennial commands. For nonperennial commands, tenants have lower intensities which may reflect the fact that water is a major constraint, especially in kharif season. All tenure classes have about 12-13 percent less cultivated area in crops for kharif season than for rabi. This reflects the very high evapotranspiration ratios in kharif as compared to rabi season.

F. Use of Tractors for Land Preparation and Cropping Intensities

A common problem in Pakistan for increased cropping intensities, other than a shortage of water, is the narrow margin of time in completing the harvest of the crops for one season and the land preparation required for the next crop, especially where seasonal labor shortages and shortage of bullock power are problems. For example, the harvesting of wheat in April and May requires about 42 man hours per acre for harvest (cutting) and about 26 man hours/acre plus bullocks for threshing. The upper Indus study (Gibbs, 1966: 254-278) provides useful data on labor and animal power utilization for crop and harvest activities. A farm with five acres of wheat would require about 26 man days for cutting the grain and

Table 71. Farm size classes for perennial and nonperennial watercourse commands by percentage of cultivated area for rabi and kharif crops (1975-76).

Type of command and farm class sizes (acres)	Percentage of Cultivated Area			
	Farms reporting No.	Rabi %	Kharif %	Rabi & kharif %
Perennial				
Under 2.5	35	85	76	161
2.5-7.49	71	81	65	145
7.5-12.49	75	84	69	153
12.5-24.99	64	76	72	148
25.0-49.99	17	84	72	156
50 and over	7	80	64	144
Nonperennial				
Under 2.5	38	76	55	131
2.5-7.49	22	77	58	136
7.5-12.49	21	65	52	115
12.5-24.99	22	71	62	131
25.0-49.99	0	-	-	-
50 and above	1	44	40	88
TOTALS Perennial and nonperennial				
Under 2.5	73	80	65	145
2.5-7.49	93	80	63	143
7.5-12.49	96	80	65	133
12.5-24.99	86	75	69	144
25.0-49.99	17	84	72	156
50 and above	8	76	61	137

Table 72. Tenure class for perennial and nonperennial watercourses by cropping intensities for rabi and kharif seasons (1975-76).

Watercourse type and tenure classes	CROPPING INTENSITY PERCENTAGES					
	No. farms	Rabi Season	No. farms	Kharif Season	No. farms	Rabi & Kharif Season
Perennial command						
Owner-operators	189	83	187	70	187	152
Owner-cum-tenants	34	76	32	62	32	137) 145*
Tenants	46	80	46	73	45	153)
PERENNIAL TOTALS WEIGHTED	269	82	265	70	264	150
Nonperennial						
Owner-operators	64	74	63	59	63	132
Owner-cum-tenants	21	69	21	60	21	129) 124*
Tenants	19	73	20	47	20	118)
NONPERENNIAL TOTALS WEIGHTED	104	73	104	57	104	129
Perennial Plus Nonperennial						
Totals weighted	373	79	369	66	368	144

*Note cropping intensity percentage differences between owner-operators and the combined values of tenants plus owner-cum-tenants for both perennial and nonperennial command areas.

about 16 man and bullock days for threshing. This is a time when labor and animals are needed in the cotton area, for example, to prepare the seedbed and for planting. These operators require about two man days and four bullock days per acre for plowing and 1.5 man and bullock days for planting the seed. Depending on the soil types, the bullocks, the skill of the operator and crop residues using the traditional plow from 2.5 to 3.0 hours are required for plowing one acre. Farmers in the Punjab especially follow the local idiom. "The more you plow the soil, the greater the produce," and often plow the cotton fields seven or eight times before planting. Much of this is for weed control. Many crops, including wheat and cotton, due to the time constraint, are not sown or planted on time.

One way of relaxing this constraint is to employ tractors for seedbed preparation. Increasingly, farmers are making use of tractors for this purpose. Table 73 provides information about the use of tractors for seedbed preparation and cropping intensities. For example, those who report no use of tractors have a cropping intensity of 146 percent as compared with those who hire tractors of 153 percent, and owners of tractors of 160 percent for perennial commands. For nonperennial commands the relationship is not clear due to only 4 tractor owning farmers, but those who rent tractors have intensities of 135 percent versus those farmers who do not use tractors of 128 percent.

While farmers who own tractors also own more tubewells than other farmers, there is some indication that use of a tractor is related to cropping intensities.

Table 73. Utilization of tractors for seedbed preparation by average cropping intensities.

Utilization of tractor for seedbed preparation and cultivation	AVERAGE CROPPING INTENSITY PERCENTAGES					
	Farms reporting	Rabi cropping %	Farms reporting	Kharif cropping %	Farms reporting	Rabi & kharif combined cropping %
Perennial watercourse command areas						
No use of tractor	120	81	118	65	117	146
Hires tractor	129	82	128	72	128	153
Owns tractor	16	78	16	82	16	160
Nonperennial watercourse command areas						
No use of tractor	69	73	69	55	69	128
Hires tractor	29	74	29	62	29	136
Owns tractor	4	60	4	60	4	120
Totals						
No use of tractor	189	78	187	62	186	139
Hires tractor	158	81	157	70	157	150
Owns tractor	20	74	20	77	20	151

IV. CROPPING PATTERNS OF WATERCOURSE COMMAND AREAS

There are many factors which influence a farmer's choice of cropping patterns from season-to-season and year-to-year--some of the most important include:

- The water supply situation and the control of supplies along with the particular crop irrigation demands.
- The farmer's home consumption needs and the land he has available.
- The tenure status of the cultivator.
- The size of the operation and the socio-economic power of the farmer to command capital and labor.
- The marketing situation.
- Climatic and soil conditions.

Other factors such as tradition and custom also play a role in farmers' decisions to cultivate various crops at a given time.

Crops reported in the text of this report are those for the 1975-76 rabi and kharif seasons. During this period there were canal closures, due to the rationing of canal supplies and floods in the summer of 1976. The unexpected release of Tarbella waters for repair of serious damages must also be considered. The crops reported are only for sample farms. We must depend on farmers' reports for seasons not included in the crop surveys. Volume VI, Table B in Appendix III provides information as to the time of the survey at each site. At some sites, the survey coincided with the period between cropping seasons when farmers had not completed land preparation or harvest of crops. Therefore, we must depend on farmers' report which were obtained by using a grid showing each acre cultivated on each farm. The crop survey data for all sites is reported in Volume VI, Appendices III A to D and IV D. Also, a table is presented which compares the sample farm cropping data with that obtained from the crop surveys for the total command area. Where these differ significantly, it is noted in Appendix III-D. While there are differences for area in some crops, the data reported in the text provides a good approximation of the cropping patterns for the commands investigated; in the presentation of data on cropping patterns, several concepts must be considered. First, the term "cropping intensity" refers to the percentage of cultivated acreage sown to crops for a given season or year. Orchard and perennial crops are counted twice. Secondly, the term harvest intensity excludes perennial crops such as fruit orchard and sugarcane crops which provide only one harvest per year. Third, the tables also show the area in polyculture or intercropping such as gram and wheat, fodder and wheat in orchards. Crops which are intercropped with other crops are not counted separately. Only the major or dominant crop is counted, however, the incidence of polyculture is shown separately at the bottom of each table for each site. Fourthly, data in the tables are usually presented for each sample village sites instead of for each individual command area. The rationale for combining command areas at village sites is that climatic, marketing, land use, and water supply factors are almost identical.

A. Agro-climatic Regions and Command Areas

Tables 74 to 80 provide detailed information on cropping patterns.

(1) Cotton-wheat command areas

These include commands at two sites in Multan District (102 and 107); one site in Bahawalpur District (114) and one site in Tharparker District (112). The last mentioned is located in Sind Province and the others are in the main cotton belt of the central and southern Punjab.

Cropping intensities (Table 74) vary from 122 to 158 percent--the variation can be explained primarily by water supply situations. For example site 114, on a nonperennial command, has an intensity of 122 percent. Of the four watercourses at this site, there are only two private tubewells to supplement seasonal canal supplies. These are located only on 114-1. Note that this site has almost no rice and only four percent of the cropped area in sugarcane. Site 107 has 26 diesel powered private tubewells and an intensity of 158 percent. Site 102 has six diesel powered private tubewells to supply an area of 522 acres plus an authorized mogha discharge of 1.76 cusecs. A serious problem of mogha submergence reduces the actual mogha discharge, thereby decreasing canal supplies. Also many fields have not been adequately leveled since the area was settled in 1948. Site 112 has a relatively low cropping intensity due to lack of supplements to canal supplies.

The presentation of data on cropping patterns (Table 74) also includes information on crop rotations of farmers for command areas in various climatic regions and cropping zones. The major limiting factors to planned rotations in Pakistan are land constraints and control over scarce water supplies. Farmers with limited land and water resources are under strong pressures to increase cultivated acreage as much as possible which results in periods of underirrigation relative to crop needs. Most of the perennial commands without tubewell or Persian well supplements are designed for 50-75 percent intensity. While the farmer can claim this amount by right, the actual intensity is much higher. The canal system limits farmers options in planning rotations (Roberts, 1951: 122). Climate and the relative profitability of various crops, therefore, have only a secondary influence upon crop rotations.

Table 74. Cropping patterns for cotton-wheat dominated command areas.

Season, crops, cropping and harvest intensities	PERCENTAGE OF COTTON-WHEAT DOMINATED COMMAND AREA SITES AND ESTIMATED ANNUAL ATMOSPHERIC EVAPORATIVE DEFICIT IN INCHES			
	Site 102 55-65"	Site 107 55-65"	Site 114 55-65"	Site 112 > 65"
	n=9	n=55	n=38	n=34
A. Rabi season				
1. Wheat	48	53	42	57
2. Fodder	12	12	14	9
3. Sugarcane	1	9	1	8
4. Garden	1	Neg.	3	1
5. Vegetables	-	4	3	2
6. Other crops	-	2	Neg.	Neg.
7. Fallow	38	20	37	23
Cropping	62	80	63	77
Harvest	62	80	63	77
B. Kharif season				
1. Rice	-	1	1	Neg.
2. Cotton	60	41	32	32
3. Fodder	10	19	19	5
4. Sugarcane	1	11	4	14
5. Garden	1	Neg.	1	1
6. Vegetables	1	6	1	5
7. Other	-	Neg.	1	1
8. Fallow	27	22	41	42
Cropping	73	78	49	58
Harvest	71	67	54	43
C. Rabi + Kharif				
a) Fallow	65	42	78	65
b) Cropping	135	158	122	135
c) Harvest	133	147	117	120
d) Polyculture	5	10	5	1

To obtain data on crop rotations, sample farmers were asked to report their actual crop rotations for three to four randomly selected fields for three or four seasons. Since many farmers did not report four past seasons, Table 75 shows crop rotations for three seasons for wheat-cotton command areas. It is not feasible to list all possible rotations, therefore, "no pattern" refers to combinations of many other rotations. The purpose is to show the major rotation patterns (rabi-kharif-rabi) for each major cropping region with a discussion of the water supply situation.

Wheat-cotton commands favor a wheat-cotton-wheat rotation 28 percent of the time. A number of rotations are used with cotton which include fodder-cotton-wheat (10%), fodder-cotton-fodder (3%) and fallow-cotton-fallow (3%). These commands, with the exception of villages 114 and 112 watercourses, have a heavy density of private tubewells ranging from 5 to 13 in number. Cotton can always follow wheat, but timing is important especially at the time of wheat harvest which is also the time for using bullocks and human labor for preparation to plant cotton. Given an increase use of tractors and threshers this constraint is gradually being reduced for tractor utilizing farmers.

On the 281 reported rotations, 75 or about 27 percent contain fallow. The rotations in which fallow is used are strongly related to the general water supply situation. For example, at sites 102 and 107 there are 6 or more private tubewells per watercourse command and only 9 percent of the rotations reported contained fallow. At site 112, with no supplemental supplies, 9 of 41 rotations reported or 22 percent contained fallow. At sites 114 and 115, both of which are nonperennial with little supplements to canal supplies, 42 percent of the rotations reported contained fallow. Farmers tend to limit the use of fallow in crop rotation where supplemental water supplies are available.

Table 75. Crop rotations for cotton-wheat command areas.

Rotation followed by farmers	Number of times reported	Percentage of total reports
Wheat-cotton-wheat	77	27
Fodder-cotton-wheat	30	11
Wheat-fodder-wheat	15	5
Sugarcane-sugarcane-sugarcane	12	4
Fodder-fodder-wheat	11	4
Wheat-fallow-wheat	11	4
Fallow-cotton-fallow	9	3
Fodder-cotton-fodder	8	3
Sugarcane-sugarcane-wheat	8	3
Wheat-fallow-fallow	7	2
Fodder-fodder-fodder	6	2
No pattern	89	31
Totals*	283	99

*Note the lack of fallow included in the rotations above.

The sites shown where farmers cultivate cotton have no problems of waterlogging and all are in climatic regions ideal for cotton production. Cotton is cultivated in these areas due to good soil conditions (light to medium textured) and a good market.

Of the four sites, those with the best supplemental tubewell water supplies have a higher percentage of acreage in cotton. After a farmer has met his home consumption needs for food and fodder crops, the availability of water probably is the prime consideration in decisions about how much cotton to cultivate. This is partially confirmed by farmers' responses when asked how much they would increase their present acreages of cotton given a doubling of irrigation supplies. Fifty-six and 64 percent of the farmers, respectively, at sites 112 and 114 (5-13 tubewells/command) reported acreage increases of 50 percent or more while no farmers at sites 102 and 107 reported increases of 50 percent or more.

Farmers, given pressures on the limited land resources, do not appear to include fallow in rotations except on a limited basis. Rotations do make use of fodder crops, but the emphasis is on as intensive cropping intensities as are possible.

2. Rice, fodder and wheat command areas

Rice is also a cash crop where soils and water supply permits. Farmers who grow rice for market prefer the aromatic Basmati variety which has a strong market demand as a foreign exchange earner. The Basmati variety is characterized by a special fragrance, long grains, and excellent cooking qualities. Basmati is favored over the new HYV of the IRRI type because of the special qualities and the premium price. For example, the procurement price for Basmati rice per maund for the 1974-75 crop was Rs. 90 as compared to Rs. 38 for IRRI 8 rice variety. Yields per acre of IRRI HYV of rice between 1970-1973 averaged 21 maunds as compared to about 11 maunds for Basmati varieties (Saeed, 1974: 3-6). The differential in price is such that farmers in the rice areas who grow rice for market overwhelmingly cultivate the Basmati varieties which provide a gross income of about 25 percent more per acre than IRRI varieties.

Table 76 shows the cropping patterns at five sites. Sites 116 and 110 are those with primarily rice cultivation. Both are located on perennial commands. Fodder cultivation is high at site 116 where berseem is marketed to Karachi by truck throughout the rabi season. Sites 104 and 103 have high percentages of fodder for both kharif and rabi seasons due to a high market demand for fodder in Lahore City. While these two commands have little supplemental irrigation supplies, fodder crops are primarily maize, millets, and oats which have relatively low water demands as compared to berseem and lucerne crops. Site 115 is predominately a wheat-fodder command where only about 4 percent of the area was in rice for kharif 1975.

The major crop rotations followed by farmers at the sites reported in Table 76 are given in Table 77.

Table 77. Major rotations used at sites 103, 104, 110, 115 & 116.

Sites	No. of rotations reported	Major rotations	Percent of total reports
Site 116 (rice-fodder commands)	43	berseen-rice-berseen wheat-rice-wheat	58 33
Site 110 (rice-wheat commands)	108	wheat-rice-wheat wheat-rice-fodder	33 12
Sites 103 and 104 (rice-fodder-wheat commands)	80	wheat-fodder-wheat fodder-fodder-wheat	38 14
Site 115 (wheat-fodder command)	52	wheat-fodder-wheat wheat-cotton-wheat	25 14

Table 76. Cropping patterns for rice and fodder crop dominated command areas

Season, crops cropping intensities and harvest intensities	Rice-fodder Dominated Commands	Rice-fodder-wheat Dominated Commands	Rice-wheat Dominated Commands	Fodder-Wheat Dominated Command	
	Site and estimated annual atmospheric evaporative deficit in inches				
	Site 116 >65" n=26	Site 104 <45" n=30	Site 110 <45" n=20	Site 115 >65" n=39	Site 103 <45" n=16
A. <u>Rabi season</u>					
1. Wheat	32	37	58	49	57
2. Fodder	47	42	11	8	24
3. Sugarcane	-	*	4	3	*
4. Garden	-	4	5	8	1
5. Vegetables	-	*	6	14	4
6. Other crops	-	1	1	1	-
7. Fallow	21	16	15	17	14
Cropping	79	84	85	83	86
Harvest	79	84	85	83	86
B. <u>Kharif season</u>					
1. Rice	87	19	65	4	7
2. Cotton	-	*	*	10	12
3. Fodder		39	4	29	33
4. Sugarcane		3	4	2	3
5. Garden		*	1	9	*
6. Vegetables		*	*	2	5
7. Other crops		4	-	*	3
8. Fallow	13	35	26	44	37
Cropping	87	65	74	56	63
Harvest	87	62	69	45	60
C. <u>Rabi + Kharif</u>					
a) Cropping	166	149	159	139	149
b) Harvest	166	146	154	128	146
c) Polyculture	-	3	*	10	9
d) Fallow	34	51	41	61	51

*Negligible percentage, much less than 1%.

Farmers try to adjust their cropping patterns to the water suppl situation. Fallow is primarily related to available water supplies. Where farmers do not have sufficient water to grow crops requiring relatively high water demands, they shift to fodder crops and gram which demand less water.

3. Sugarcane-wheat commands

Table 78 shows the cropping patterns at two sites where about one-fourth of the cropped area for rabi and kharif are in sugarcane. Both of these commands are near sugar mills where sugarcane growers are given extra incentives such as fertilizer and insecticides against delivery of the crop. Site 113 has no supplemental water supply. The cropping and harvest intensities are lower than at site 101. Site 113 has a higher percentage in fallow given lack of tubewell supplements to canal supplies. Crop rotations reported by farmers for the sugarcane-wheat commands are provided by Table 79.

Table 79. Crop rotations reported by farmers

Sites	No. of reports		Percent of total reports
101	36	sugarcane-sugarcane-sugarcane	19.4
		wheat-fodder-wheat	12.9
		sugarcane-fodder-wheat or fodder	11.1
		no pattern	55.5
		percentage of total with fallow	6
113	55	wheat-fodder-wheat	18.2
		fodder-sugarcane-sugarcane	27.3
		wheat-fodder-sugarcane	5.5
		wheat-cotton-wheat	3.6
		wheat-fodder-fodder	3.6
		no pattern	41.8
		percentage of total with fallow	22

Table 78. Cropping patterns for sugarcane and wheat dominated command areas.

Season, crops, cropping and harvest intensities	Percentage of Sugarcane-wheat dominated command sites and Estimated annual atmospheric evaporative deficit in inches	
	Site 101 45-55" n=15	Site 113 >65" n=26
A. <u>Rabi season</u>		
1. Wheat	41	28
2. Fodder	18	19
3. Sugarcane	23	23
4. Garden	3	11
5. Vegetables	1	1
6. Other	-	2
7. Fallow	15	16
Cropping	86	84
Harvest	86	86
B. <u>Kharif season</u>		
1. Rice	3	1
2. Cotton	2	3
3. Fodder	25	18
4. Sugarcane	25	27
5. Garden	3	11
6. Vegetables	2	-
7. Other	-	1
8. Fallow	40	40
Cropping	60	61
Harvest	32	23
C. <u>Rabi & Kharif</u>		
Cropping		145
Harvest	118	109
Polyculture	21	14
Fallow	55	56

Note in Table 79 that at site 101 sugarcane is carried for three years in 19 percent of the rotations, whereas at site 113 this is not so. As a ratoon crop, yields are usually lowered substantially if carried for the third season.

4. Mixed crops with fruit orchards

Five of the sites (see Table 80) have no definite pattern or crops. All of these sites are served by public tubewells and cropping intensities are high except at site 108 where canal supplies were limited in kharif, 1976. All sites except 111 are in the SCARP areas of Sargodha district. Site 111 is the Muzaffargarh District, the heart of the mango belt. Over 20 percent of the cultivated area at site 111 is in mangoes. Site 109 also has a high percentage of cultivated area in orchards which are primarily citrus. Note that all sites except 111 have a relatively high percentage of cultivated area in sugarcane. This is because a sugar mill is located nearby where special incentives are provided for farmers to grow sugarcane. Polyculture at these sites is primarily related to area in garden and sugarcane. For example, site 109 has 53 percent of total cultivated area in sugarcane and wheat and 57 percent of the area in polyculture. At these sites, polyculture is primarily related to area in gardens where berseem, maize fodder, and other crops are planted in orchard crops. Note that at sites 105 and 108 there is little polyculture and little area devoted to gardens.

The major crop rotations reported at sites 105, 106, 108 and 109 are sugarcane-sugarcane-sugarcane 12 percent of the time and wheat-fodder-wheat 25 percent of the time. At site 111, the major rotations are wheat-fodder-wheat and wheat-fallow-wheat.

Table 80. Cropping patterns of sites with mixed crops and orchards.

Season, crops, cropping intensities and harvest intensities	Percentage of mixed crops with fruit orchards and estimated annual atmospheric evaporative deficit range in inches				
	Site 105 45-55" n=8	Site 106 45-55" n=12	Site 108 45-55" n=9	Site 109 45-55" n=14	Site 111 55-65" n=12
A. Rabi season					
1. Wheat	32	45	23	24	42
2. Fodder	18	19	31	15	10
3. Sugarcane	28	12	13	25	4
4. Garden	2**	9**	-**	28	21
5. Vegetables	4**	1	3	1	*
6. Other crops	*	1	1	1	1
7. Fallow	16	13	29	6	22
Cropping	84	87	71	94	78
Harvest	84	87	71	94	78
B. Kharif season					
1. Rice	22	10	6	2	8
2. Cotton	6	11	8	9	6
3. Fodder	22	19	15	17	17
4. Sugarcane	16	13	16	24	3
5. Garden	1**	9	-**	29	22
6. Vegetables	2**	-	1	1	1
7. Other crops	*	-	-	2	4
8. Fallow	31	38	54	16	39
Cropping	69	62	46	84	61
Harvest	52	40	30	31	36
C. Rabi + Kharif					
a) Cropping	153	149	117	178	139
b) Harvest	136	127	101	125	114
c) Polyculture	5	18	1	57	44
d) Fallow	47	51	83	22	61

*Negligible, meaning much less than 1%.
**These are probably not representative.

5. Incidence of fallow in crop rotations and supplemental irrigation supplies

Farmers leave land fallow for weed control, nitrogen build-up, and because of labor constraints, desire for leisure, and lack of sufficient water supplies. Table 81 shows that the water supply situation is strongly related to the incidence of fallow.

B. Tubewell Supplements to Canal Water Supplies and Cropping Patterns

Table 82 provides information on the percentages of cultivated acreage for selected major crops. In a comparison of overall percentages between perennial and nonperennial command farmers it is expected the former have a higher percentage to wheat, rice, cotton, sugarcane and fodder crops. There is, however, only a slightly smaller percentage of cotton on nonperennial commands.

For sample farmers on perennial commands only public tubewell farmers and farmers with no tubewell supplements report a smaller percentage of total cultivated acreage devoted to wheat. The public tubewell supplemented watercourses are located in the mixed crop region at Sargodha District which cultivate slightly less wheat. Rice cultivation shows little difference between all types of supplemented watercourse commands.

Public tubewell farms for the two seasons have a much higher percentage of cultivated area in sugarcane than do farms on tubewell supplemented watercourse commands. Not only is there a greater volume of water available and more supply reliability, but also there is a nearby sugar mill.

Sample farmers on watercourses with only one or two private tubewells (see Table 82) report 47 percent of their total cultivated acreage for rabi plus kharif in fodder crops. Two of these watercourses, with only one private tubewell per watercourse command, have 32 farmers who have a weighted average of 69 percent of cultivated area in fodder for rabi and kharif. All of these sell both fodder and milk in Lahore City. When these are removed, the percentage of the area devoted to fodder crops for nonsupplemented watercourse commands is decreased to 13.2 as compared to 47 percent. Fodder crops for rabi and kharif combined appear to be influenced by water supply.

When one examines the cropping patterns of nonperennial watercourses (see Table 82) it is obvious that sample farmers on commands with no tubewells devote a larger percentage (45) of total cultivated acreage to wheat than farms on tubewell supplemented commands. Wheat requires much less water than berseem. Sugarcane is significant as a percentage of cultivated acreage only on watercourse commands with tubewell supplements.

C. Cropping Pattern Differences Between Perennial and Nonperennial Commands.

Table 83 provides a summary of the cropping patterns on perennial and nonperennial commands. Cropping intensities of crops with high water demands, such as rice and sugarcane, are from 7 to 13 percent less on nonperennial commands. Rabi and kharif fallow is greater on the nonperennial command areas. Little difference is noted for wheat which is grown widely for home consumption and which can be grown on only two irrigations if water is extremely scarce. Ordinarily, the consumptive use of wheat is from 9-12" of water depending on stress applied, sowing

Table 81. Types of watercourse irrigation supplies by incidence of fallow used in crop rotation.

Types of watercourse command irrigation supplies	No. of observations	No. of rotations in which fallow is included	Percentage of total observations for which fallow is included
Perennial commands			
1. Public tubewells	69	8	11.6
2. Private tubewells			
*a. Low density	161	26	16.1
*b. Medium density	25	5	20.0
*c. High density	247	43	17.4
3. No. TW supplements	94	22	23.4
4. Special cases Excess canal water Villages 113, 116[1]	101	15	14.9
PERENNIAL TOTALS	69'	119	17.1
Nonperennial commands			
1. Public tubewells	17	7	41.2
2. Private tubewells			
a. Low density[2]	125	50	40.0
b. Medium density	0	-	-
c. High density	0	-	-
3. No. TW supplements	45	14	31.0
a. Persian wells 1) Low density			31.0
NONPERENNIAL TOTALS	187	71	38.0
Uncommanded			
1. Private tubewells a. Heavy density[3]	19	0	0
Totals			
All public tubewells	86	15	17.4
All private tubewells	577	124	21.5
All nonsupplement[4]	139	36	25.9

1. Excess canal water in a waterlogged area; farmers in season blocked the mogha and reported abundance of year-round water.
2. Supplemented also with 43 Persian wells for 10 command areas.
3. No canal water but 7 private tubewells.
4. Excludes villages 113, 116 special cases with excess irrigation water.

*Low, medium and high density of private tubewells respectively mean under 3, 3-6, and 7 or more private tubewells.

Table 82. Tubewell supplemented watercourse command areas by percentage of cultivated acreage in wheat, rice, cotton, fodder and sugarcane crops

Tubewell (TW) supplements	No. of farms	Percentage of cultivated acreage in				
					rabi + kharif	
		wheat	rice	cotton	sugarcane	fodder
		Perennial watercourse commands				
No tubewells	101	43	8	11	25*(17)	44**(37)
Public TWonly	33	23	10	9	36	37
Public + private TWs	4	49	2	25	38	26
Under 3 private TWs	54	49	6	10	28	47***(13)
3-6 private tubewells	33	51	9	36	20	24
7 or more private TWs	45	53	9	35	15	31
Overall	270	44	8	18	25	39
		Nonperennial watercourse commands				
No tubewells	48	45	1	24	5	35
Public TW only	32	39	9	6	16	30
Public + private TWs	9	23	6	9	29	45
Under 3 private TWs	54	39	6	11	14	32
Overall	143	40	5	14	12	33

*Percentage in brackets ( ) when farmers of 4 watercourses at villages 101 and 113 are removed which are near sugar mill and have high water tables.

**Percentage when 16 farmers of 2 fodder-wheat watercourses removed near Lahore market.

***Percentage when 32 farmers on 2 fodder-wheat commands with 1 tubewell each near Lahore fodder market removed. Their weighted average in fodder is 69.4 percent.

Table 83. Percentage and percentage differences between cultivated area in major crops for perennial and nonperennial watercourses.

Season and major crops	Perennial (P) and nonperennial (NP) watercourses NP	P	Difference between P and NP watercourse
Rabi	n=268	n=88	- 8.0
Wheat	42.7	44.2	- 1.5
Fodder	12.4	20.9	- 8.5
Sugarcane	2.3	9.8	- 7.5
Garden	6.9	3.7	+ 3.2
Vegetables	7.5	1.8	+ 5.7
Other	.7	.9	- .2
Fallow	27.6	18.4	+ 9.2
		(n=264)	
Kharif	73	81	-12.0
Rice	3.0	15.7	-12.7
Cotton	19.0	16.7	+ 2.3
Fodder	22.7	18.0	+ 4.7
Sugarcane	4.8	11.7	- 6.9
Garden	6.0	3.5	+ 2.5
Vegetables	1.3	2.4	- 1.1
Other	.3	.9	- .6
Fallow	43.2	30.8	+12.4
		(n=263)	
Rabi and Kharif	57	69	
Cropping percentages	130	150	-20.0

date and variety.[10/] Fruit gardens are slightly greater in the nonperennial commands due to a large farmer (over 100 acres) at site 115 who had over 50 percent of his holdings devoted to mangoes.

D. Major Crops and Types of Farm Operations

Land tenure structure and farm size may exert influence on crops cultivated (see Table 84). In rabi season on perennial commands there is no significant difference in area cultivated in wheat.

With improved water control, farmers on perennial commands devote about 16 percent of their cultivated acreage in kharif season to rice while nonperennial command farmers use only about three percent of their acreage to that crop. While rice is consumed on special occasions in Pakistan, it is not the main staple food for large numbers of people. Of the perennial command sample farmers, the smaller the farm size the larger percentage of cultivated acreage devoted to rice. While this does not hold for nonperennial command farmers, this does indicate that small farmers given sufficient water supplies, devote much acreage to this labor intensive crop. There is little difference between the two types of commands in regard to cotton cultivation, but smallest farm category cultivates lesser percentages of cotton than do sample farms in other categories.

E. Tenure Classes and Cropping Patterns

Data relating tenure classes with major crops cultivated are shown in Table 85. Only on perennial commands do tenants cultivate more of their acreage to rice than either owners or owner-cum-tenants. Tenants, however, cultivate slightly less cotton than other farmers which reflects the greater control of private tubewell water and Persian wells by owners.

[10/] Bowers, S. A., CSU Water Management team, private communication, 1976.

Table 84. Farm size class by percentage of cultivated area in wheat, rice, cotton and sugarcane.

Farm size classes (acres)	No. of farms	Percentage of cultivated acreage in selected crops .				
		wheat	rice	cotton	sugarcane rabi	sugarcane kharif
Perennial						
Under 2.5	35	45.8	33.9	13.4	10.3	13.8
2.5-7.49	71	45.3	15.2	16.7	7.3	9.2
7.5-12.45	75	44.6	11.5	16.0	10.6	11.4
12.5-24.99	64	41.9	13.6	19.0	9.7	12.7
25.0-49.99	17	42.9	8.8	17.1	12.0	12.6
50.0 and over	7	40.0	9.6	14.7	19.0	15.8
Perennial Totals Wtd.	269	44.1	15.7	16.6	9.8	11.6
Non-Perennial						
Under 2.5	38	50.7	3.3	10.9	-	1.2
2.5-7.49	22	37.9	1.3	19.9	4.7	2.7
7.5-12.49	21	38.4	5.9	20.3	3.5	6.0
12.5-2499	22	37.0	3.7	20.0	3.1	7.9
25.0-49.99	0	-	-	-	-	-
50.0 and over	1	-	-	-	40.1	40.1
Nonperennial Totals Weighted	104	42.1	3.5	16.5	2.7	4.3

Table 85. Tenure classes by percentage of cultivated area in wheat, rice, cotton and sugarcane,

Tenure classes	No. farms	Percentage of cultivated area in crops				
		wheat	rice	cotton	sugarcane rabi	sugarcane kharif
Perennial						
Owners	189	44.1	14.2	17.2	9.8	10.8
Owner-cum-tenants	34	48.3	8.5	18.6	7.6	9.4
Tenants	45	40.1	27.9	12.6	15.3	17.0
Non-perennial						
Owners	64	43.2	3.2	16.6	3.3	4.2
Owner-cum-tenants	21	40.1	4.1	19.1	1.7	4.2
Tenants	19	40.9	3.6	13.7	2.1	4.7
Both						
Owners	253	43.9	11.4	17.0	8.2	9.1
Owner-cum-tenants	55	45.2	6.8	18.8	5.3	7.4
Tenants	64	40.3	20.7	12.9	11.4	13.3

During the survey, several tenants, when asked their warabundi time period for the allotment of canal water, reported that their time depended on the will of the landlord. Tenants devote a larger percentage of their acreage to sugarcane. This implies that tenants are placing slightly more emphasis on cash crops and are probably pressured in this direction by landlords.

F. Distance to Market and Cropping Patterns

Distance to the nearest market usually influences the cropping decisions of farmers, especially for bulky farm products such as fodder and sugarcane. Table 86 presents information about the percentage of cultivated area in fodder, sugarcane, vegetables and fruit orchards by miles to the nearest marketing point.

Fruit is usually sold as a standing crop to contractors who utilize trucks for hauling the produce to market. No relationship with miles to market is expected. Few of the sample farmers reported cultivating vegetables for the market and those who do reported using primarily tractor trolleys for cartage.

G. Animal Units and Area in Fodder Crops

Among the factors influencing the percentage of cultivated acreage of fodder crops is the number of animal units a farmer must maintain with fresh fodder (see Table 87). Data in Table 87 are inflated by the fact that village 104 with 30 sample farms has an average of 13 animal units per farm. These farmers cultivate an average of about 41 percent of their total acreage to fodder crops each season to maintain their milch animals and bullocks.

Table 86. Distance from nearest market by percentage of cultivated area in fodder, sugarcane, vegetables and fruit orchards.

Miles to Nearest Market (Regulated & Non-Regulated)	# of Farms	PERCENTAGE OF CULTIVATED AREA					
		Rabi-Fodder	Kharif-Fodder	Rabi-Sugarcane*	Kharif-Sugarcane*	Vegetables for Rabi & Kharif	Fruit for Rabi & Kharif**
Perennial							
Distance from Nearest Market							
1. < 2 Miles	40	45.2	14.5	-	3.4	.2	2.9
2. 2.0-4.99	85	18.6	21.8	15.3	15.9	1.4	5.2
3. 5.0 or More	139	16.0	16.2	4.3	4.5	4.0	14.2
Non-Perennial							
Distance from Market							
1. <2 Miles	38	7.9	27.1	3.0	2.4	15.8	17.6
2. 2.0-4.99	57	12.1	19.1	1.0	3.7	2.9	19.1
3. 5.0 or More	7	30.6	14.7	13.1	15.8	3.7	-
All Commands Combined							
Distance from Market							
1. <2 Miles	78	27.0	21.0	1.5	2.9	7.8	10.1
2. 2.0-4.99	142	16.0	20.7	9.6	11.0	2.0	10.8
3. 5.0 or More	146	16.7	16.1	4.7	5.0	4.0	13.5

*For sugarcane we should show distance to the sugar mill but at the time of this reporting these data are not available.

**Denotes area in Rabi plus Kharif.

Table 87. Animal units owned by sample farmers by seasonal percentage of total cultivated acreage in fodder crops.

Animal Unit*	Percentage of Total Cultivated Acreage in Fodder Crops by Season				
	No. Farms Reporting	Rabi Season (%)	No. Farms Reporting	Kharif Season (%)	Both Seasons (%)
Under 4	9	4.5	8	5.3	9.8
4 to 6	13	12.2	11	5.5	17.7
7 to 9	6	18.6	5	2.4	21.0
10 to 12	1	NA	1	NA	NA
13 and above	356	19.0	356	19.5	38.5
WEIGHTED TOTALS	385	18.4	381	18.5	37.0

*Animal units are bullocks, milk cows or buffalo, fodder eating calves, camels, donkeys and horses combined

V. CONCLUSIONS ABOUT LAND USE AND CROPPING INTENSITIES

The data presented in this section lead to several general conclusions:

1. Farmers adapt cropping intensities and patterns to their perceptions of the availability of water. Private tubewells have been a means of farmers increasing their acres cultivated.
2. Tubewells help to smooth out the differences in cropping intensities between rabi and kharif seasons.
3. There is a substantial differential between perennial and non-perennial cropping intensities--about 25 percent. The differences in cropping intensities between head and tail farms is from 10 to 25 percent due to greater losses of water experienced by tail farmers.
4. Given the small number of large farms in the sample no significant difference is found in cropping intensities by farm size except for farms 50 acres or more in size. These few large farms show a tendency for lower intensities. As to cropping patterns and farm size, no important differences are found in major crops grown. Small farmers with good water supplies, however, devote greater acreage to rice than larger farmers. Tenants tend to grow more cash crops than owner-operators probably due to the influence of landlords.
5. Farmers who utilize tractors for land preparation have higher cropping intensities than farmers who make no use of tractors.
6. Distance to market is found to be important for fodder crops and vegetables.

CHAPTER SIX

CROP YIELDS OF WHEAT, RICE, AND COTTON

Average per acre yields for most crops in Pakistan are known to be very low by international standards. For example, Figure 21 provides comparative data for yields of several major crops with those of selected yields of several countries. Wheat yields for 1972-73 are less than half those of Egypt. Rice yields in Egypt are more than double those of Pakistan and Pakistan's rice yields about one-third of Spain's. The thin bar on the bar graph (Figure 22) with the asterisk represents the average yields of sample farmers in the present study.

There are many factors responsible for low crop yields in Pakistan. This chapter presents data relative to the impact of the water supply situation on yields. An intensive accounting system (Lowdermilk, 1972: 441F) was used to estimate the per acre yields. Farmers were asked the acreage of each crop, the amounts marketed, the amounts used for home consumption, amounts paid to labor in kind and amounts in kind paid to village artisans, religious leaders and gifts to minor government officials. Such an accounting system using farmers' reports has shortcomings in comparison with the more accurate procedure of crop cutting experiments and weighing of crops from randomly selected fields. However, the nature of the time constraints dictated the method.

Table 88, while excluding one noncommanded watercourse at Village 110, provides summary information of yields for wheat, paddy rice, and seed cotton for the 16 sample village sites. Across the total sample, wheat yields are 21 mds./acre.[11/] These yields are not representative

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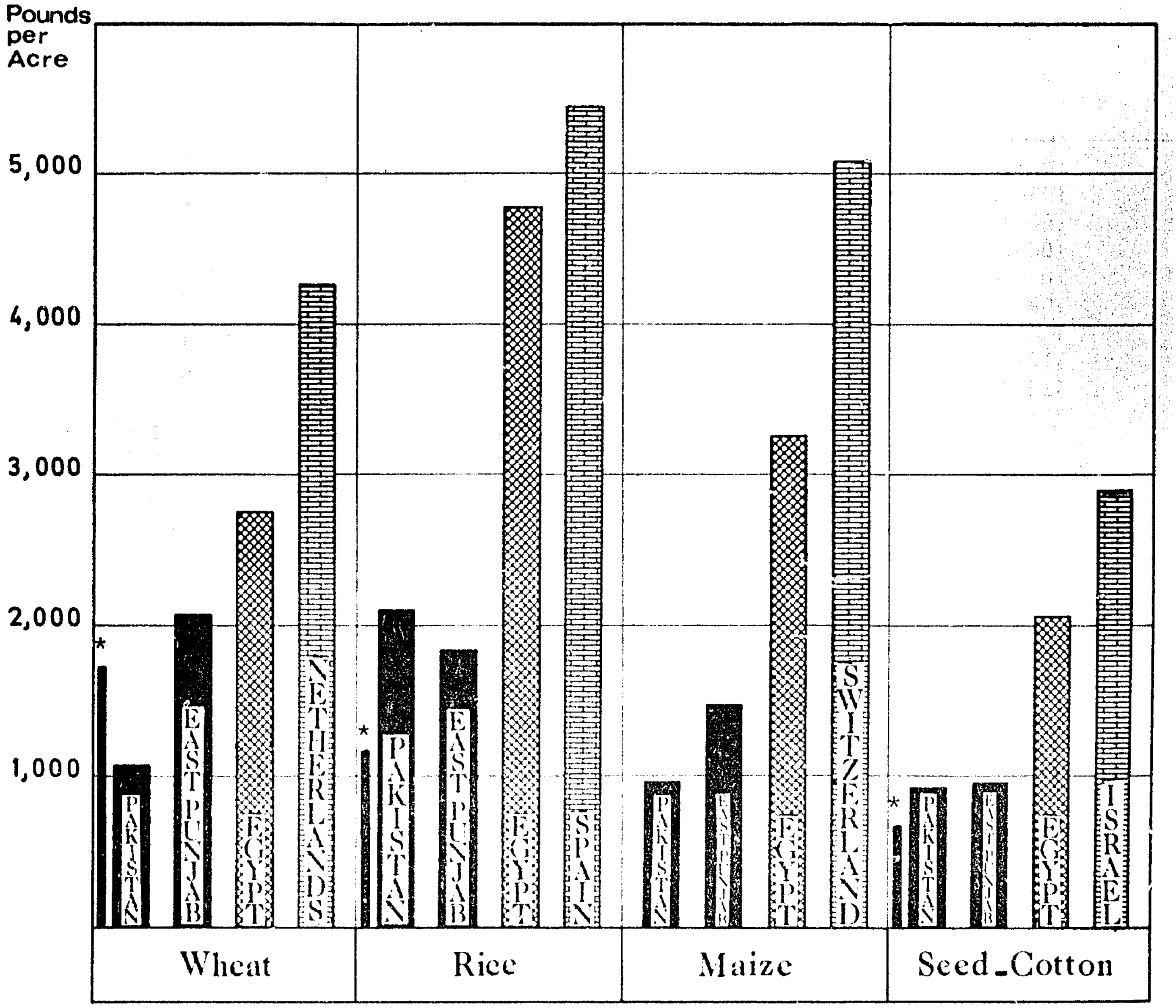
[11/] One maund is equivalent to 82.3 lbs. or 1.0367 of a long ton (27.2 mds. = 1 long ton of 2,240 lbs.)

Figure 22. **COMPARATIVE CROP YIELDS**



Average FY 1972 / FY 1973

* Denotes average yields/acre obtained by sample farmers, 1975-76 - C.S.U. watercourse command field survey

Source: Pakistan - On Farm Water Management Project Paper, Department of State, Agency for International Development, Washington, D.C., June 6, 1976, Annex A, p. 20.

Table 88. Average reported yields by village sites for wheat, rice and cotton for perennial and nonperennial command areas.

Village sites and watercourses	Average reported yields					
	No. of farms	Wheat maunds/ acre	No. of farms	Rice maunds/ acre	No. of farms	Cotton maunds/ acre
Perennial						
101-2wc	15	27	3	13	2	7
102-1wc	9	24	0	-	9	11
103-1wc	15	18	2	10	6	5
104-3wc	27	14	23	15	2	3
106-1wc	12	22	7	23	4	9
107-3wc	52	30	0	-	44	13
109-2wc	14	16	3	15	7	7
110-2wc	20	15	19	23	0	-
112-3wc	29	19	0	-	27	7
113-3wc	24	29	2	20	7	6
116-4wc	11	9	26	13	0	-
Perennial weighted means	228	22	85	17	108	10
Nonperennial						
105-1wc	8	25	3	15	1	5
108-1wc	5	17	0	-	1	4
111-2wc	24	14	13	15	8	4
114-4wc	30	15	5	10	32	7
115-6wc	27	18	7	13	9	11
Nonperennial weighted means	94	17	28	14	51	7
Perennial and nonperennial weighted means	322	20	113	16	159	9

of national averages because they include only irrigated crops (dryland barani wheat brings down the average).

Table 89 provides summary information on yields of wheat, rice, and cotton for the 16 village sites as compared to two World Bank estimated yields. Average yield/acre obtained in the present survey for wheat are higher. This finding is probably due to the fact that included in national yields/acre are the North West Frontier and rainfed areas where wheat yields are much lower than in the irrigated areas of Punjab and Sind.

Table 89. Summary information on average yields of wheat, rice and cotton for the 16 village sites versus two World Bank estimates.

Source of data	Selected crop yields in lbs/acre		
	Wheat	Paddy Rice	Seed Cotton
*World Bank all Pakistan estimate (1973-74)	1490	1234	633
**World Bank all Pakistan estimate (1970-75) (average)	1080	1366	605
CSU watercourse survey (Punjab-Sind)	1722	1230	738

*World Bank Pakistan Agricultural Sector Review, Volume III, appendix.
**World Bank Pakistan Sector Review, Volume I, appendix.

I. AGRO-CLIMATIC REGIONS AND SELECTED CROP YIELDS

As expected, yields of wheat, cotton, and paddy rice show much variation between agro-climatic regions. Table 90 includes the noncommanded watercourse which was excluded in Table 88.

A comparison of the four evaporative deficit regions (see Table 90) wheat yields show less overall variation than paddy rice and cotton crops. Cotton and rice, as wheat, can be cultivated throughout the Indus Basin.

Table 90. Agro-climatic regions by average reported yields of wheat, rice and cotton in maunds/acre.

Agro-climatic* region showing dominant crops and estimated atmospheric evaporative annual deficit (inches)	Average reported yields					
	No. farms reporting	Wheat maunds/acre	No. farms reporting	Rice maunds/acre	No. farms reporting	Cotton maunds/acre
Low deficit <45"						
Rice-wheat	27	16	26	24	0	-
Rice-fodder-wheat	32	14	26	14	2	3
Fodder-wheat	15	18	2	10	6	5
Low deficit weighted means	74	16	54	19	8	5
Medium-low deficit 45-55"						
Sugarcane-wheat	15	27	3	25	2	7
Mixed crops	39	20	13	19	13	7
Medium-low deficit weighted means	54	22	16	20	15	7
Medium-high deficit 55-60"						
Cotton-wheat	91	22	5	10	85	10
Mixed crops	24	14	13	16	8	4
Medium-high deficit weighted means	115	20	18	14	93	9
High deficit >65"						
Rice-fodder	11	9	25	13	0	-
Cotton-wheat	29	19	0	-	27	7
Rice-wheat	27	18	8	14	9	11
Sugarcane-wheat	24	29	2	20	7	6
High deficit weighted means	91	20	35	14	43	8
Total weighted means	334	19	123	17	159	9
Overall range by sites		9-29		10-25		3-11
Overall range by climatic zone		16-22		10-25		5-10
% variation		16=37%		15/10=150%		5/10=100%

*Location of sites:
Low deficit = Villages 110,104,103
Medium-low = Villages 101,105,106,108,109
Medium-high = Villages 102,107,111,114
High = Villages 112,113,115,116

However, both these kharif crops have very high water demands due to the long hot summer days and dry winds. Soil conditions are also important factors in some areas, especially for adequate puddling of rice. In general the particular type of soils and the water supply situation are more critical for rice than for cotton and, in turn, than for wheat. It is evident from the data presented that yields of these three crops do vary between agro-climatic regions.

II. CROP YIELDS AND WATER SUPPLY SITUATION

A major constraint on increased yields is sufficient water and control over irrigation supplies to insure reliability. Table 91 provides information about the different water supply situations and the average yields reported by sample farmers for wheat, paddy rice, and cotton.

Sample farmers on perennial commands report higher yields for wheat, rice and cotton crops than nonperennial command farmers (see Table 91). The primary influence is the increased volume of water available and greater control of water resulting from the presence of private and public tubewells on perennial commands. Of 78 private tubewells on 39 sample watercourse command areas and one noncommanded watercourse, 66 or nearly 85% of these are located on 26 watercourses which have perennial canal supplies.

Average reported yields of wheat and paddy rice are similar for public and private tubewell supplemented commands but private tubewell supplemented watercourses have higher yield in all cases. As for low cotton yields, the public tubewell sites 105, 106, 108, 109 and 111 are not primarily cotton producing areas.

Even on public tubewell supplemented commands, it is not clear that all farmers have equal access to extra water from tubewells. Several

Table 91. Selected types of water supply situations by average reported yields for wheat, rice and cotton.

Water supply situation	Average reported yields					
	No. farms reporting	Wheat maunds/ acre	No. farms reporting	Rice maunds/ acre	No. farms reporting	Cotton maunds/ acre
Type watercourse command						
Perennial	242	21	88	18	112	10
Nonperennial	80	16	23	13	48	7
Noncommanded*	7	19	7	27	0	-
Command totals (weighted)	329		118		160	
Actual tubewell supplements						
None	139	18	62	14	69	7
Public tubewells	33	20	13	19	12	8
Private tubewells	146	21	42	21	72	11
Both private & public	16	13	6	15	7	5
	334		123		160	
Farmers' reports of availability and use of tubewells						
Not available	126	18	58	15	55	7
Available with difficulty	57	21	13	17	36	9
Easily available	122	21	37	21	56	11
	305		108		147	
No use	170	18	75	14	75	7
Hires tubewell	113	21	35	21	54	10
Owns tubewell	42	24	9	23	27	13
	325		119		156	

*For the rice-wheat rotation in village command 110-3 of Gujranwala District, 7 private tubewells serve about 119 cultivated acres.

tenant sample farmers reported that landlords decide how much and when they will receive water supplies. Large landlords also command sufficient power and influence with public tubewell operators to gain special favors in the use of tubewells. Table 91 also shows farmers' reports of "availability" and "use" of tubewell water. It is obvious that there are considerable differences in sample farmers' yields of wheat, rice and cotton in relationship to availability and use of tubewells. Yields increase directly with ease of water availability and use. These sample farmers who reported tubewell water "available with difficulty" identified their constraints as: lack of credit, location of their farm in relationship to tubewells, topographical problems, mechanical failures, and unreliable supply of electricity.

Table 92 examines the density of private tubewells on commands in relationship to average per acre yields for three crops. Density of tubewells varies greatly for commands. For example, 27 of 40 sample commands have private tubewells ranging in number from 1 to 18 per command. Table 92 shows the number of tubewells broken down into four categories. Those watercourse commands supplemented with public tubewells (i.e. sites 105, 106, 108, 109 and 111) are excluded from this analysis. Information presented in the Table 92 shows that all crop yields except for wheat are related to density of tubewells. One explanation for the decrease in rice yields and slight increase in cotton yields is that Village 110, with 3 watercourses and 7 or more private tubewells per watercourse, is predominantly a rice command area where rice yields average about 24 mds/acre when the noncommanded watercourse is included; other commands in other cropping regions have this tubewell density may have very poor yields. Some farm yield weighing based on the number of acres of that crop

Table 92. Number of private tubewells on watercourse commands by average reported yields of wheat, rice and cotton (excludes public tubewell commands).

Number[+] of Private Tubewells for Canal Supplements *	Average reported yields					
	# of Farms	Wheat Maunds/Acre	# of Farms	Rice Maunds/Acre	# of Farms	Cotton Maunds/Acre
None	112	19	49	14(11)**	81	6
Less Than Three (Low)	68	17	22	15	25	7
Three to Six (Medium)	31	25] 23++	7	29] 25++	22	12] 13++
Seven or More (High)	57	22]	19	23]	31***	13]
Totals weighted means	268	20	97	17	159	8

* Excludes commands with public tubewells

** Includes WC rice fodder commands at 116 - 1 to 4 with excess canal water; when excluded, rice yields/acre decrease to 11 Mds.

*** These farms located primarily in Multan cotton-wheat area.

\+ The percentage of total cultivated area of sample farms do not vary greatly as wheat is a crop grown for home consumption in Pakistan. For example, the weighted percentage of area devoted to wheat by private tubewell supplemented commands is as follows: No private tubewells = 43%; Less than 3 tubewells = 49%; 3 to 6 tubewells = 51%; and 7 or more tubewells = 53%. The range for all village sites for percentage in wheat where there are private tubewells is 41 and 58%.

++ Weighted mean yields/acre for private tubewells supplemented commands with three or more private tubewells. The purpose of these data is to show the importance of water control and yields.

cultivated in a village would perhaps remove this aberration. Sample farmers on the high tubewell density commands at site 107 report no cultivation of rice. Likewise, no cotton is cultivated at site 110, therefore, the yields of 13 mds/acre for categorized heavy tubewell density reflects mainly those of sample farms in Village 107.

The conclusion reached from data presented in Table 92 is that the water supply situation is a major factor in the yields of wheat, paddy rice, and cotton. Private tubewells not only provide a greater volume of irrigation to those watercourse commands but also provide increased control and therefore reliability of supplies. A greater density of tubewells indicates, but does not guarantee, more water and more control.

III. LOCATION OF FARM ON WATERCOURSE COMMAND AREAS AND YIELDS

The water supply situation has a strong influence on crop yields. Sample farmers with private tubewells or located on commands with a high density of tubewells (three or more) and those farmers on public tubewell supplemented commands have more control of irrigation water; their yields per acre are on the average higher than those obtained by sample farmers on commands with no tubewell supplements. This type of economic dualism which exists across watercourse commands also exists within typical watercourse command areas--a dualism based on location wherein tail farmers experience greater conveyance losses than do head farmers.

Data presented earlier have shown the differences in delivery efficiencies from the mogha outlet to farms and their location on commands. There are many factors[12] which reduce the variation between water supply and

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12/There is a tendency for private tubewells to be located at tails of command areas as 44 percent, 28 percent, and 28 percent respectively are located at tail, middle and head reaches. For the sample of all commands, 33 percent of the 45 Persian wells are located at the tail reaches, 42 percent at the middle and 24 percent at the head positions.

the various reaches on a typical command area such as location of private tubewells, Persian wells, soil types, and general maintenance of watercourses. Even when all these are not controlled for the 40 command areas, we note from Table 93 that yields are slightly higher for sample farms located at the head as compared to the tail farms of command areas.

Three measures are used for location of farms on the command areas. First, the actual measured location is that used only for sample farms where irrigation evaluations were made. The distance was measured from the mogha along the main and branch watercourses to the tail and the distance in feet was divided into thirds. The second measure, "estimated location" was the position of the farm as estimated by interviewers upon questioning the farmer and consulting the warabundi list and timings. Thirdly, the "adjusted measured position" was developed by taking the distance in feet of the longest watercourse and its branches at each village site, and dividing the total distance into thirds for head, middle and tail positions. Positions for sample farms of all commands located at a given village site were thereby standardized.

When using these three measures, without controlling other variables mentioned such as location of tubewells and soil types, rice and cotton yields are higher for head versus tail farms for the first two measures. The first measure is considered more reliable in that it is an actual measurement unadjusted or standardized for a village site's commands. Yields of rice for head farmers average 20 mds. as compared to 13 mds. for tail farms. This of course is influenced by the fact that of the rice farmers reporting for the three positions only 25 percent were located at command tails.

Table 93. Three measures of farm location on watercourse command reach by average yields per acre for wheat, rice and cotton.

Farm location factors on watercourse command reaches	Average yield per acre					
	No. of farms	Wheat maunds/ acre	No. of farms	Rice maunds/ acre	No. of farms	Cotton maunds/ acre
Measured location on command*						
Head	111	20	25	20	55	11
Middle	94	19	43	20	39	10
Tail	37	22	11	13	22	6
Estimated location on command**						
Head	122	21	48	18	53	10
Middle	81	20	27	19	38	10
Tail	102	19	36	17	58	8
Adjusted measured position on command***						
Head	93	20	38	17	55	10
Middle	74	19	22	16	27	8
Tail	53	22	21	23	23	9

*Distance from mogha outlet to farm along watercourses measured by engineers at time of irrigation evaluations.

**Distance from mogha outlet to farm estimated by interviewer.

***Distance as measured by engineers on maps adjusted in relationship to longest watercourse at the village and branches to the farthest farm unit. Note that sample farms with holdings at more than one of the watercourse positions are not included.

IV. TUBEWELL LOCATION ON WATERCOURSE COMMAND AREAS AND CROP YIELDS

A factor reducing the variation in yields/acre between farms located at various reaches of the command area is the location and density of tubewells. In order to examine this more closely, public tubewells are converted to private tubewell equivalents in Table 94 and added to the total number of private tubewells. We estimate the average discharge of a public tubewell serving one command area as about 1.8 to 2.0 cusecs. When a public tubewell serves two command areas the estimated discharge is 1.00 to 1.5 cusecs based on actual discharge measurements. The average discharge of private tubewells is estimated at .6 cusecs based on actual discharge measurements of private tubewells.

Farms at the middle reaches of command areas as a group have average weighted yields/acre for the three crops very similar to the head farms. Within middle farms there is a clear relationship between number of tubewells and yields/acre.

Tail sample farms also show a general tendency for higher yields of the three crops in relationship to density of tubewells. The small number of farms with 7-8 tubewells presents a problem.

The data presented in Table 94, though not controlled for other factors such as agro-climatic region, soils, fertilizer applications, etc., provide suggestive evidence that both water supply and the control of irrigation water act as strong influences on crop yields. The data also show that farms located at the tails of watercourse commands in relationship to canal supplies are at a definite disadvantage due to the higher average losses of irrigation supplies in unimproved earthen conveyance systems. Even when tubewells are available to provide more water, the extra cost of purchasing tubewell water through pumping groundwater by public tubewells must be entered as a farm expense.

Table 94. Private tubewell equivalents for position of farms on command areas by average yields for wheat, rice and cotton.

Watercourse position and No. of private tubewell equivalents*	Average yields per acre					
	No. of farms	Wheat maunds/ acre	No. of farms	Rice maunds/ acre	No. of farms	Cotton maunds/ acre
Head position farms						
No. of tubewells						
None	49	20	23	16	26	7
1 - 2	48	17	20	18	13	10
3 - 4	17	27	5	19	7	13
5 - 6	0	-	0	-	0	-
7 - 8	8	29	0	-	7	13
Head weighted means	122	20	48	17	53	9
Middle position farms						
No. of tubewells						
None	54	18	23	16	22	8
1 - 2	15	24	0	-	9	13
3 - 4	9	24	1	30	7	11
5 - 6	0	-	0	-	0	-
7 - 8	3	24	3	33	0	-
Middle weighted means	81	20	27	18	38	10
Tail position farms						
No. of tubewells						
None	64	18	29	15	34	6
1 - 2	22	21	5	22	12	11
3 - 4	14	20	0	-	12	12
5 - 6	0	-	0	-	0	-
7 - 8	2	16	2	29	0	-
Tail weighted means	102	19	36	17	58	8

*Private tubewell equivalents combines public tubewells at head positions and private tubewells. One public tubewell serving one command area is counted as 3 private tubewells; one public tubewell serving two command areas is counted as two private tubewells.

V. YIELDS OF WHEAT, RICE AND COTTON, AND FARM SIZE AND TENURE CLASSES

Factors such as farm size and tenure status might be expected to influence crop yields. Both of these variables are indirectly related to the water supply situation in that larger owner operators have more capital to install private tubewells, therefore they have better water control. Of the 78 private tubewells owned individually and jointly by the sample farmers 74 percent are owned by farmers with holdings of 12.5 acres and above. However, smaller farmers can offset this some by their increased labor intensity. Another factor is availability and use of fertilizer which is related to farm size and tenure status.

Table 95 presents data across all sample commands by farm size categories. There is a slight tendency for wheat yields to increase with farm size perhaps because wheat requires a lesser quantity and control of irrigation water and less labor than other crops. Very small farmers (under 2.5 acres) have yields of only about 14 mds/acre as compared to about 19-22 mds for all other farm class sizes, except the few very large farms which report 30 mds/acre. Rice yields show less overall variation. There is only one case of a rice farmer in the 50 and over category; no generalization can be made. Cotton yields are also relatively stable except for the smallest farmer categories.

Table 95 also shows that owner-operators and owner-cum-tenants have higher average wheat yields/acre than tenants for the 334 reporting sample farms. While the yields for rice show less variation--they range from only 16 to 18 mds per acre. Both rice and cotton crops require heavy inputs of irrigation water and control of water--larger landlords have the advantage here along with greater access to fertilizer and insecticides. However,

Table 95. Farm size and tenure classes by average reported yields/acre for wheat, rice and cotton.

Farm size and tenure classes (acres)	Average yields per acre					
	Farms reporting	Wheat maunds/acre	Farms reporting	Rice maunds/acre	Farms reporting	Cotton maunds/acre
Farm size classes						
Under 2.5	55	14	24	15	21	8
2.5-7.49	85	19	30	17	40	10
7.5-12.49	88	21	29	15	42	8
12.5-24.99	82	21	33	20	45	8
25.0-49.99	17	22	6	19	8	9
50 and above	7	30	1	14	4	13
Total weighted means for farm size	334	20	123	17	160	9
Tenure classes						
Owner-operators	222	20	79	17	107	9
Owner-cum-tenants	53	19	14	18	28	9
Tenants	58	16	30	16	25	8
Total weighted means for tenure	333*	19	123	17	160	9

*One farm operated by a contractor is deleted.

this advantage may be partially offset by intensive labor inputs which tenants can provide. Another factor is that the yield potential for basmati rice, local coarse rice and upland cotton varieties are much less than high yielding varieties of wheat which respond more positively to higher levels of fertilizer.

VI. YIELDS AND THE AVAILABILITY OF FERTILIZER AND CREDIT

Yields of sample farms are influenced by the availability of credit for fertilizer and the availability of fertilizer. Availability data for credit and fertilizer are based on farmers' reports. Table 96 presents the data.

When one groups those farmers who took loans for fertilizer from the promising program launched by the National Bank of Pakistan after the Nationalization of Banks one notes the importance of credit, especially for wheat. Rice and cotton show little variation with respect to use of institutional credit.

Farmers were also asked to report perceptions about availability of fertilizer. Those farmers who report fertilizer "not available" face lack of credit. Fertilizer is available at some price in the market. Farmers who report availability with difficulty identify obstacles such as high price, lack of cash or credit, and distance to the fertilizer agency. The categories of farmers who reported fertilizer unavailable have wheat and rice yields of from 4 to 5 mds less than those who gave other reports. Cotton yields show little difference between the types of credit availability.

Table 96 reveals that the greater the availability of credit for fertilizer, the use of credit for fertilizer, and the availability of fertilizer, the greater the average per acre yields of wheat, rice and cotton.

Table 96. Availability of fertilizer and credit and use of institutional credit for fertilizer by crop yields.

Availability of fertilizer and credit for fertilizer and use of fertilizer credit	Crop yields					
	No. of farms	Wheat maunds/ acre	No. of farms	Rice maunds/ acre	No. of farms	Cotton maunds/ acre
Credit availability for fertilizer						
Not available	121	18	61	16	59	9
Available with difficulty	95	19	29	18	46	10
Easily available	96	22	26	17	45	9
Use of institutional credit for fertilizer						
No use	246	19	95	17	118	9
Some use	51	23	17	17	21	10
Fertilizer availability						
Not available	12	15	7	13	6	10
Available with difficulty	122	19	46	18	54	9
Easily available	195	20	68	17	94	9

VII. SUMMARY: MULTIPLE REGRESSION MODELS AND FACTORS EXPLAINING VARIATION IN YIELDS OF WHEAT, RICE AND COTTON

Several regression models were used in an attempt to estimate the major factors responsible for the variation in yields/acre for the three crops. The model used for the wheat yield dependent variable contains a larger number of variables than for rice and cotton because extra data were collected from wheat farmers. In using the regression models several basic assumptions were used. First, variables selected had fairly normal distribution. Secondly, variables were employed which did not have high intercorrelations. In some cases a logarithmic transformation would have reduced the variance of some variables and provided a more normal distribution. However, our purpose here is only to ascertain those variables which explain the major difference in yields.

Table 97 presents the results of the multiple regression analysis of selected factors and yields/acre of wheat. The model used is:

$$y = a + b_1x_1 + b_2x_2 + b_3x_3 + b_4x_4 \;.. + b_{11}x_{11}$$

where a and b are the parameters to be estimated

x_1 = nutrient lbs of nitrogen/acre

x_2 = dummy variable for seeding method with broadcast = 1; kera = 2, pora = 3; drill = 4

x_3 = (dummy variable) tenure status - owner = 1; owner-cum-tenant = 2; tenant = 3

x_4 = dummy variable use of tubewell, no use of tubewell = 0; purchase tubewell water = 1, and ownership of tubewell = 2

x_5 = dummy variable - seeding depth recommendation off by more than .5 inch = 1; within .5 inch = 2; 1.5 to 2.5 depth = 3

x_6 = mass media index scores

Table 97. Summary of multiple regression analyses with selected independent variables and yield/acre of wheat.

Variable	Beta	S.E of Beta	t ratio	Multiple R	R^2	Final F ratio
Level of nitrogen	.064	.018	.28	.434	.188	12.39*
Seeding method	.490	.531	1.08	.442	.199	.85
Tenure	-.136	-.475	3.49	-.446	.199	.08
Use of tubewell	.890	.450	.51	.491	.241	3.91**
Seed depth	.977	.353	.36	.530	.281	7.67*
Mass media exposure	.069	.150	2.17	.540	.291	.21
Extension contacts	3.000	.876	.29	.567	.321	1.75
No. of irrigations	.757	.347	.46	.598	.357	4.77**
Area cultivated	-.022	.014	.64	.602	.363	2.35
Split fertilizer applications	1.250	.631	.50	.616	.380	3.90**
Phosphorus level	.064	.026	.41	.629	.396	5.90**

*Denotes F ratio significance of .01 or higher.
**Denotes F ratio significance of .02 to .05.

x_7 = extension contacts (number)

x_8 = number of irrigations

x_9 = farm size (area cultivated) acres

x_{10} = split fertilizer application (dummy variable) no = 0; yes = 2

x_{11} = level of phosphatic fertilizer nutrient lbs/acre

The variables included which show the highest degree of intercorrelation are phosphorus and nitrogen with a coefficient of .46 and split levels of fertilizer with both nitrogen and phosphorus with coefficients respectively of .51 and .49. Only one other set of variables has a relatively high intercorrelation--the number of irrigations and use of tubewells have a coefficient of .31. With these limitations we will examine the importance of the variables used in the model when other factors are held constant (see Table 97).

Variables which contribute most to the difference in wheat yields are: nitrogen applied, use of tubewells (public and private), depth of seeding, and number of irrigations applied (see Table 97). These four variables together explain about 31 percent of variation in yields. The variables which explain most of the variation in yields of wheat/acre are, in order of importance, level of nitrogen, use of tubewells, seeding depth, and number of irrigations.

Nitrogen use alone explains about 19 percent of the difference in yields followed by use of tubewells, seeding depth, and number of irrigations which explain about 4 percent each or a total of 31 percent of the difference. Level of phosphorus which is intercorrelated with level of nitrogen at .48 when added to the equation explains only about 2 percent of the variation. Farmers who use higher levels of nitrogen also tend to use higher levels of phosphatic fertilizers. Also split applications of nitrogen are intercorrelated with nitrogen at .43, therefore suggesting that farmers who apply more fertilizer tend to split applications. When farmers apply nitrogen and phosphorus, or more than one bag (50.5 nutrient lbs) of nitrogen, they tend to split the applications. Therefore, when other variables are held constant, the level of phosphorus and split applications of fertilizer are not important. Farmers who use tubewells also apply a higher number of irrigations as tubewell use and this variable are intercorrelated (.31). The simple correlation between size of farm and yields is only .10. All 11 variables explain only 39 percent of the yield differences.

A similar regression model was used to ascertain the most important factors explaining differences in cotton and rice yields. Table 98 provides summary information about the results of the regression model for cotton yields. All variables in this equation were also used in the regression model for wheat and, therefore, the variable type has been explained. The only variables that have a relatively high intercorrelation coefficient are use of tubewells and number of irrigations (.44).

The major explanatory variables for cotton yield are use of tubewells, level of phosphorus, farm size, and number of irrigations. These four factors explain about 30 percent of the variation in yields. Level of phosphorus in a sense acts as a proxy for nitrogen in that farmers who use phosphorus tend to utilize more nitrogen. One variable, use of tubewells, alone explains over 15 percent of yield differences. Farm size indicates that larger farmers do not have higher yields than smaller farmers when other factors are held constant. Owner operators have slightly higher yields than tenants though the relationship is not statistically significant or very important. It should be noted that there is

Table 98. Summary information on multiple regression analysis of selected variables with cotton yields.

Variables	Beta	S.E of Beta	t ratio	Multiple R	R^2	Final F ratio
Level of P fertilizer (lbs)	.048	.024	.50	.282	.080	3.86*
Farm size (acres)	.028	.015	.54	.047	.121	3.49[1]
Tenure status	.334	.370	1.11	.375	.140	.82
Mass media exposure	.062	.105	1.69	.376	.142	.34
Level of N for cotton	.003	.013	4.33	.384	.148	.06
Extension contacts	.747	.872	1.17	.386	.149	.73
Use of tubewell	1.465	.360	1.28	.550	.303	16.61**
No. of irrigations	.454	.259	.57	.566	.320	3.07[2]

*Significant at .05 level; ** at .001 level.

1/and 2/Denote significance respectively of only .06 and .08 level.

an inverse relationship between tenure and use of tubewells and tenure and number of irrigations with coefficients respectively of -.14 and -.16. Other variables which explain little or no difference in yields are mass media exposure and extension contacts. Earlier it was estimated that extension had played little or no role at all in improving cotton yields (Gotsch, 1968). Only about 32 percent of the differences in cotton yields are explained by this model. However, our earlier finding about the importance of tubewells is confirmed. Also our earlier indirect findings about use of fertilizer is confirmed.

Rice and cotton are much more complex crops to cultivate than wheat. Good cotton yields, along with efficient and timely irrigations and fertilizer, also requires plant protection measures. However, plant protection is probably more critical for rice than the local upland cotton varieties, such as AC 134 and AC 144. The stem borer represents a major insect problem for rice; it causes major losses in rice areas. Since we do not have data on the type and extent of insect control measures for rice or cotton, the same regression model used for cotton yields is used for rice yields as shown in Table 99.

The major factors to explain differences in rice yields are level of nitrogen and use of tubewells. These two factors explain about 13 percent of the yield difference. These variables are statistically significant. Other variables which explain only one to two percent of yield differences are level of phosphorus, farm size, and number of irrigations. The relationship with farm size is inverse, therefore though the relationship is not significant there is a tendency for smaller farms to have higher yields. This suggests the importance of labor intensity for the rice crop as was also true for cotton. It is interesting that the

Table 99. Summary information on multiple regression analysis of selected variables with rice yields.

Variables	Beta	S.E. of beta	t ratio	Multiple R	R^2	Final F ratio
Level of nitrogen	.072	.035	4.86	.276	.076	4.37*
No. of irrigations	-.694	.745	1.07	.300	.090	.87
Farm size	-.033	.021	.64	.327	.107	2.40
Level of phosphorus	.181	.151	.83	.365	.133	1.46
Use of tubewell	1.78	.983	.55	.424	.180	3.26**
Mass media exposure	.049	.323	6.59	.424	.180	.02
Tenure	.323	.914	2.82	.426	.181	.12
Extension contacts	.089	2.47	27.75	.426	.181	.001

*Denotes significance at .04 level.
**Denotes significance at .07 level.

correlation coefficient between tenure and number of irrigations is a negative one (coefficient = 0.35) which suggests that owners have more water control. Mass media, tenure status, or extension contacts contribute very little to explaining the differences in rice yields. Only a total of .18 percent of the variation in yields is explained by the regression model used. Probable reasons are the lack of data for insect and pest control, soil type, and the loss of nitrates through leaching.

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ENGLISH GLOSSARY

Agro-Climatic Zone - A region where climate makes a well defined demand for water and a general cropping pattern prevails on a majority of the farms.

Alidade and Plane Table - Engineering telescope and table tripod tools used for preparation of maps to scale in the fields.

Alkaline Soil - A high pH soil that contains sufficient sodium to cause deleterious effects on most crops.

Application Efficiency - The quotient of soil moisture deficiency and nakka discharge in inches equivalent multiplied by one hundred to construct a percentage value.

$$Ea = \frac{\text{soil moisture deficiency}}{\text{nakka discharge (in depth of water equivalent)}} (100)$$

Authorized Supply - The design discharge of water from a mogha.

Barrage - Headworks with movable gates that allow flood waters to pass over their crests. Not to be confused with storage dams.

Barren Land - Land which is not cropped due to salinity, waterlogging, lack of water, presence of sand dunes, etc.

Brotherhood (Biradari) - A lineage group of families related as brothers, sons, uncles, etc. typically with common interests on various issues. A subdivision of a caste group.

Bunded Unit - The smallest field unit irrigated as a separate unit, surrounded by a small earthen ridge or bund.

Canal Colony - Large areas of land brought into production by Irrigation Department and settled by cultivators.

Caste - Ancestral, occupational grouping of people implying prestige gradations.

Centrality of Power - The amount of power/influence attributed to watercourse farmers by 25% sample of farmer/judges. A watercourse centrality value expresses the percentage of all farmers who score at a specified level or above.

Command Area - The area served by a watercourse or set of watercourses in a village.

Concentration of Power - The extent to which power/influence is distributed equally on a watercourse.

Conflict Cleavage - Line of division between opponents over an issue.

Conveyance (Delivery) Efficiency - The percentage of water passing the mogha which reaches the field nakka outlet. The nakka discharge is divided by the mogha discharge and the quotient is multiplied by 100 to create a percentage value.

Cropped Area - The sum of the acreage under rabi or kharif crops in a watercourse command area.

Cropping Intensity - The number of crops grown on a given field in a given year times 100 to express a percentage value. Applied to a farm, it is the acreage of all crops grown in a year divided by the area on which they were grown times 100.

Cropping Pattern - The combination and sequence of crops grown on a given farm over a year's time.

Cross Cutting Cleavage - Opponents on one conflict issue are allies on other conflict issues. Makes for cooperation and negotiability of issues.

Cultural Command Area - The cultivated area of a watercourse command area which can be served by gravity irrigation.

Cutthroat Flume - A water measuring flume device especially suited for low gradient watercourse channels.

Delivery Efficiency -- See Conveyance Efficiency.

Delta - Amount of water applied for an irrigation.

Depth of Application - The average depth of water applied to a field obtained as the product of nakka discharge (in cusecs) times the time of application in hours divided by the area irrigated in acres.

Discharge - the volumetric rate of water flow or delivery, expressed as cubic feet per second (cusec)

Discharge Factor - The mogha outlet design capacity from distributary to watercourse expressed as discharge per 1000 acres of command area.

Distributary - The smallest water channel maintained by the government. The size hierarchy of channels would be, in descending order, major canal, minor canal, distributary. Moghas may be placed on any of these channels.

Duty - The area irrigated per unit of water per season of the year.

Evaporative Moisture Deficit - Estimated annual atmospheric evaporation.

Evapotranspiration - The total water lost to the atmosphere via evaporation and plant transpiration.

Farm Irrigation Efficiency - The proportion of water, passing the mogha, which is stored in the root zone of a crop, calculated as the product of the conveyance efficiency and application efficiency times 100 to create a percentage value.

Gross Command Area - The portion of the entire village area that is commanded by gravity canal irrigation; includes roads, schools, graveyards, canals, etc.

Groundwater Recharge - Deep percolation which replenishes the water table.

Headworks - A division with controllable gates on a major canal dividing water into two or more minors.

Landlord - Owner of land who does not cultivate the land.

Link Canal - Largest of the canals -- each carries water from the western to eastern rivers as part of the Indus Basin Replacement Project mandated by the Indus River Treaty with India (1960).

Local (person) - Person living, or whose family has lived, at present location since before partition of British India into India and Pakistan.

Minor - A water supply canal smaller in discharge than a major canal but greater in capacity than a distributary.

Non-perennial - A single season, kharif, water supply situation for a watercourse command area.

Overlapping Cleavage - Opponents on one conflict issue are opponents on all conflict issues. High polarization. Issues become difficult to negotiate. Hurts cooperation.

Percolation - The downward movement of water through soils.

Perennial - A year-round water supply situation for a watercourse command area.

Persian Well - A water lifting device used on a deep open well comprised of a chain of buckets or earthen pots powered by a pair of bullocks or a camel moving in a horizontal circle.

Potential Evapotranspiration - The maximum evaporative demand which a given climate can place on a given crop when there is no constraint on water availability and crop maturity.

Private Tubewell - A small discharge irrigation well individually or jointly owned by farmers.

Province - Administrative unit such as Sind, Baluchistan, Punjab and North West Frontier areas.

Public Tubewell - Large discharge tubewells installed and operated by WAPDA and Irrigation Department.

Refugee - Person displaced from India at partition.

Saline Soil - Soil which contains a sufficient percentage of soluble (non-sodium) salts to impair crop growth.

SCARP - Acronym for the Salinity Control and Reclamation Project areas where public tubewells are used for lowering watertables and augmenting water supplies.

Seepage- The lateral movement of water through soils.

Soil Moisture Deficiency - Estimated inches of soil moisture depleted due to evapotranspiration.

Tenant - A non-landowner who cultivates a block of land on a share-cropping basis with a landlord.

Time of Application - The duration of an irrigation application of turn.

Tubewell - An irrigation well.

Union Council - A governmental subdivision of a tehsil comprised of approximately 8 to 10 villages.

WAPDA - Acronym for the Water and Power Development Authority - a government corporation.

Watercourse - A water supply channel placed on a 16 foot wide government right of way, constructed and maintained by farmers to deliver water from a mogha outlet to a farmers field ditch.

Watercourse Command Area - The area served by the water passing through an authorized mogha.

Waterlogging - Soil condition where water table is at or above the ground surface.

GLOSSARY OF URDU/PUNJAB AND LOCAL ENGLISH TERMS

Abadi - Land set aside for a village site.

Abiana - Water rate.

Agricultural Assistant - Supervisor of field assistant level extension workers in the Agricultural Extension system. Usually has a Bachelor of Science degree in agriculture.

Bagh - Orchard.

Bajra - Spiked millet.

Bakhsheesh - Gratuity.

Barani - Rainfed cropping.

Berseem - Egyptian clover.

Bhusa - Wheat straw used as animal feed.

Biradari - A brotherhood lineage group of families related through brothers, sons and uncles within the same caste. Typically members take common interests on issues.

Bund - Small earth ridge.

Caste - Ancestral, occupational grouping of people implying prestige gradations.

Chaj Doab - Land between Jhelum and Chenab Rivers.

Chak - Block of land set aside as smallest administration unit.

Chula - Earthen hearth.

Crore - Ten million, 100 Lakh.

Dab - Preplanting, irrigation and cultivation to control weeds.

Deh - Administrative division below Tehsil.

Deputy Commissioner - Administrative officer at the district level.

Desi - Indigenous, unimproved.

District Revenue Collector - Revenue officer for the District Revenue Department.

Divisional Canal Officers - Administrative head of a divisional branch of a canal command system.

Doab - Land between two rivers in Punjab.

Executive Engineer - Mid-level Irrigation Department or WAPDA Official.

Field Assistant - Local lowest level extension worker, education usually 10th class plus one or two years of general training in agriculture.

Fasalana - Payment for reduced water rates.

Guara - Cluster bean.

Gur - Indigenously prepared country sugar.

Gunta - 1/40 of an acre.

Halqa - Circle of villages of which a canal patwari is in charge to make water dues assessments.

Hakim - Local doctor.

Hari - Share cropper or tenant.

Henna - English translation "Myrtle" and known by botanical name Lawsonia alba. Used as a local orange dye.

Hukka - Waterpipe.

Hul - Local plow.

Jhallar - Persian well adapted to low water lifts.

Jhenab - Land unit used in Sind for one-half acre.

Jowar - Sorghum.

Kacha - Unripe, unimproved, earthen, random, poor quality.

Kanal - 1/8 of an acre.

Kassi - Hoe-like shovel used by irrigators.

Khal - Watercourse, conducts water from mogha to fields.

Khati - Process of removing silt from the watercourse.

Kharaba - Crop failure, declaration for reduced water rates.

Kharif - Warm season cropping, approximately April-October.

Khasrah - Register on revenue due on units of land.

Kiari - System recommended by Agriculture Department for compartment of a field into very small basins for irrigation.

Killa - Area of land equal to 1.11 acre.

Kistiwar - Random layout of land in bunded units.

Karah - Indigenous two team bullock pulled scraper for moving earth.

Karahi - Same as karah but powered by one bullock team.

Lakh - One hundred thousand.

Lucerne - Alfalfa.

Mal - Property.

Mandi - Chartered market center.

Maraba - A square of land made of 25 parcels, usually acres or squares.

Marla - 1/160 of an acre; 1/20 of a kanal.

Muhavir - Person or family migrated from India.

Maund - Unit of measure, 82.3 pounds equivalent to 40 seers.

Mauza - Village, smallest division of government.

Moeen - Non-agricultural castes who perform services for a share of agricultural produce (also kami).

Mogha - An ungated outlet of fixed size passing water from irrigation canal to a watercourse.

Mukamis - Local resident.

Nakka - Outlet from branch watercourse; inlet to a field.

Numbardar - Village headman -- function of government who collects land revenues.

Nikal Water - Water left in watercourse at the end of a complete rotation of warabundi.

Overseer - Irrigation Department functionary over patwari, responsible for maintenance and repair of moghas.

Pansal Nawees - Irrigation Department gate keeper.

Pahar - Turn of water of five hours.

Patwari - Title of revenue officer for Irrigation Department and Land Revenue Department.

Patti - Division of a village under the responsibility of a numbardar or village leader.

Pora - Seed tube attached behind plow for seeding crops.

Pucca - Ripe, improved, concrete, specified to order, high quality.

Parchas - Chits of paper used for notifying farmer of revenue assessments.

Rabi Hui - Bullock pulled mouldboard plow.

Rabi - Cool season cropping; approximately November-March.

Rauni - Presowing irrigation.

Rechna Doab - Land between Ravi and Chenab rivers.

Rej - Irrigation prior to land preparation.

Rosewari - Irrigation schedule to a particular block of land on a particular day.

Saip System - Traditional system by which village artisans exchange their goods and services with landed agriculturalists for a portion of the crop.

Sarkari Khal - Watercourse constructed by farmers on a 16 foot right-of-way provided by the government for the purpose of conducting water from the mogha outlet to the individual farmers field ditches.

Seer - Unit of measure, smaller than kilogram, 2.08 lb. Forty seer equal one maund.

Sem - Waterlogged soil condition.

Shamlat - Village common land usually used for grazing.

Sohaga - Wooden plank or beam drawn by bullocks used in land preparation.

Square - 25 acre, 27.5 acre of 16 acre block of land depending on location.

Subdivisional Officer - Irrigation Department Official under the Executive Engineer.

Superintending Canal Engineer - Irrigation engineer who heads up a canal command hydrologic unit.

Tehsil - A sub-unit of a district.

Tehsildar - Official at Tehsil level.

Thal Doab - Land between Indus and Jhelum rivers.

Thur - Salinized soil condition.

Tonga - Horse drawn two-wheeled carriage.

Union Council - Political subdivision of a tehsil.

Vattar - Farmers' concept of optimum soil moisture condition for plowing.

Wahn - Watering of a field for first ploughing for seedbed preparation.

Warabundi - Schedule of irrigation turn rotations agreed to by farmers either informally (katcha warabundi) or under formal agreement through the Irrigation Department (pucca warabundi).

Warashikni - Taking irrigation water out of turn.

Zilladar - Junior member of Superior Revenue establishment of Irrigation Department.

Zamin - Land

Zamindar - Landholder - farmer