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MANAGING IRRIGATION FOR ENVIRONMENTALLY SUSTAINABLE AGRICULTURE IN PAKISTAN

Report No. R-77

FINAL REPORT

TOWARDS
ENVIRONMENTALLY SUSTAINABLE AGRICULTURE IN THE INDUS BASIN IRRIGATION SYSTEM

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FOREWORD

This document constitutes the Final Report for the second phase of funding from the Netherlands Development Assistance covering the time period 1 October 1994 to 31 December 1998. This report has been subdivided into three major parts.

Part A Background provides in Section 1 a brief introduction to this research project and a physical description of the Indus Basin Irrigation System, along with the agricultural situation, environmental situation and institutional context in Pakistan. An interesting dialogue regarding principles of institutional determinants for technological advancements is provided in Section 2. The focus for this research project is described in Section 3, which consists of three components regarding operational management, institutional development and salinity management.

The results emanating from this research project is described in Part B, which consists of five sections numbered 4 to 8: (4) Role of Water Users in Decentralized Management; (5) Decision Support Systems for Improved Canal Operations; (6) Watercourse Management; (7) Surface Irrigation Methods and Practice; and (8) Salinity Management. For more detailed information, refer to the list of IIMI publications at the back of this report.

The implications of the research results are described in Part C Epilogue, which also serves as an Executive Summary. Section 9 on Sustainable Agriculture and Section 10 on Farmers First provides a strategy for moving Towards Environmentally Sustainable Agriculture, with a major focus on empowering farmers, who have been the most underutilized resource for improving the productivity and sustainability of irrigated agriculture in Pakistan. This strategy is schematically depicted in the poster located inside the back cover of this report.

All of the IIMI-Pakistan staff are extremely grateful for the support of the Foreign Ministry in The Hague and the Royal Netherlands Embassy in Islamabad. This major research project has significantly contributed to the professional development of staff both from IIMI and our National Partners.

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PART A
BACKGROUND

1. INTRODUCTION

1.1. RESEARCH PROJECT

1.1.1. Project Inception

The International Irrigation Management Institute (IIMI) entered into an Agreement with The Netherland's Ministry for Development Cooperation to conduct the research project, "Managing Irrigation for Environmentally Sustainable Agriculture in Pakistan". Although the Agreement was finalized in May 1995, the study covered a five year period from January 1994 to December 1998, with funding from 1 October 1994 to 31 December 1998.

The reason for this pre-Agreement project initiation was because the project, in fact, is an extension of a previous research activity by IIMI, "Managing Irrigation Systems to Minimize Waterlogging and Salinity Problems" supported by the same source of donor funds. This activity was begun in January 1989 and ended in December 1993. The April 1993 Evaluation Mission commented: "the goals of this project are of great importance to the overall food security objectives of Pakistan and the project has already achieved promising results that have a great potential of making a major impact on improvement of irrigation efficiency and reducing the incidence of salinity and waterlogging". The Mission strongly recommended the extension of the project for another phase of five years. However, the Mission alluded that the success of this work would largely depend on the willingness of the Government of Pakistan to implement the feasible recommendations of IIMI.

Based on further discussions with a Formulation Mission in May 1994 and deliberations with relevant government authorities, the new project's content was broadly classified into three main components: (1) Operational Management; (2) Institutional Development; and (3) Salinity Management. The Operational Management component was further divided into two subcomponents: Main System Management and Watercourse Management, whereas the Institutional Development component was divided into three subcomponents: Water Users Organizations, Institutional Support for Water Users Organization, and Coordinated Irrigation Agriculture Services. The Salinity Management component was also divided into three subcomponents: Soil Chemistry and Groundwater Management, Rechna Doab Salinity Management, and Waterlogging and Salinity Management in the Sindh Province.

1.1.2. Study Locations

The research program was conducted at three large areas. The greatest effort of the Operational Management and Institutional Development components was focused on the Punjab's Fordwah Eastern Sadiqia (FES) Irrigation and Drainage Project area, where more than 200,000 ha cultivated. The major location of the Salinity Management component was the Rechna Doab, the area between the two rivers, Ravi and Chenab, in the Punjab Province, where much of the project's Phase I research took place. This area consists of 2.3 million hectares (ha) of irrigated land. Two research activities associated with Main System Management and Salinity Management were also conducted in the Province of Sindh, with most of the effort focusing on the Left Bank Outfall Drain (LBOD) Stage I Project area having 500,000 ha of irrigated land.

The Main System Management and Watercourse Management subcomponents were quite active in the FES North area since the beginning of 1994. The Water Users Organizations (WUOs) subcomponent under the Institutional Development component was also initiated in February 1994 on the Hakra 6-R Distributary, with the objective of training the field staff and assessing the effects of social organization activities previously undertaken by the OFWM Directorate in that area under the Command Water Management Project. During May-June 1995, efforts were shifted to the Hakra 4-R Distributary, which was selected as the first pilot area for the planned action research on social organization.

1.1.3. The Report

The project generated a large volume of published and unpublished documents. These documents include regular six-monthly progress reports, A Plan of Operation, Research Reports published by IIMI's Pakistan National Program, Research Reports and Working Papers published by IIMI Headquarters in Colombo, externally published papers and Seminar Papers. This present report, as the project's Final Report, synthesizes the research material generated during the project period and presents some suggested strategies for future action to make irrigation management in Pakistan more productive and environmentally sustainable.

The Report starts in its Part A with an outline of the background to the study, and proceeds in Part B to synthesize the research findings of the various components of the project. Part C includes some suggested strategies for action to be initiated by the relevant authorities.

1.2. PHYSICAL DESCRIPTION OF INDUS BASIN IRRIGATION SYSTEM

Agricultural production in Pakistan is conditioned by the water resources and the way these can be harnessed. With an arid to subtropical climate, the natural precipitation is very scanty and rainfed agriculture, restricted to small favorably located areas, presently contributes only 10 percent to the country's total agriculture production. The progressive utilization of the river waters and the exploitation of the groundwater resources has made irrigated agriculture the mainstay of the agricultural economy of the country.

1.2.1. Sources of Water Supply

The sources of surface water supply available to Pakistan are its rivers. Most of these rivers, in the western half of the country, are ephemeral streams that remain dry for most of the year. It is the Indus River and its tributaries with perennial flows that constitute the main source of water supply.

The Indus River and its tributaries have their sources in the Himalayan Mountains and the Hindu Kush, with a total drainage area of 399,000 sq. km, which is larger than that of the Ganges and Brahamaputra. The inflow to these rivers is mainly derived from snow and glacier melt and rainfall in the catchment areas. The tributaries of the Indus, originating in India but flowing into Pakistan are the Jhelum, Chenab, Ravi and Sutlej (with a major tributary Beas). Originating in Afghanistan, the other major tributary is the Kabul River.

Under the Indus Waters Treaty 1960, the flows of the three Eastern Rivers, (Sutlej, Beas and Ravi) have been allocated to India, whereas, with minor exceptions, Pakistan is entitled to all the waters of the Western Rivers (Indus, Jhelum and Chenab). The long term average annual inflow of the Western Rivers at the rim stations, as they enter the Indus Plains is 169.25 billion m^3 (BCM). This constitutes the main source of water supply for irrigation in the country.

In addition to the surface water, groundwater is another important source of water supply. Investigations have established the existence of a vast aquifer with an areal extent of 194,000 sq.km. underlying the Indus Plains, which has been recharged during geologic times from natural precipitation and river flows, but more recently by seepage from the canal systems. Although the quality of the groundwater in the Indus Basin aquifer is highly variable, both areally and with depth, it is estimated that 49.8 BCM of groundwater, representing the recharge, could be withdrawn annually for beneficial uses.

1.2.2. Irrigation Development

Irrigation development in Pakistan, which came about essentially during the last 150 years, has been based on the flows of the Indus River and its tributaries. Initial development consisted of inundation canals which functioned only during periods of high river flow, providing water for summer (kharif) crops and some soil moisture for winter (rabi) crops. Controlled, year-round

irrigation was introduced by the progressive construction of barrages (weirs with gates) across the rivers. Most of this irrigation development took place in the Indus Plains, where the gentle gradients permitted the layout of irrigation systems with long canals in a dendritic pattern, to irrigate large areas.

With no means for the storage of the river waters, the irrigation development had to depend on the run-of-the-river flows, which was characterized by a great seasonal variation – with 84 per cent of the flow occuring during the summer cropping season of kharif (April to September) and only 16 per cent in the winter cropping season of rabi (October to March). This implied that perennial irrigation supplies could be run only in those irrigation systems which first appropriated the meager rabi supplies and the others were relegated as non-perennial canal systems with supplies available for the kharif season, with some to nurture a scanty rabi crop.

At the time of the partition of India in 1947, irrigation systems had been developed in Pakistan for a culturable command area of 13.3 mha out of which 10.9 mha was fed from weirs and barrages across the rivers and 2.4 mha was under irrigation from inundation canals.

At this time, a number of the irrigation systems in Pakistan were an extension of the irrigation systems originating in India, or were dependent on their supplies from headwaters located in India. Moreover, the rivers flowing into Pakistan had their headworks in India. This raised the issue of riparian rights, which was resolved by a Treaty in 1960.

Under the Treaty, India was given the right to the waters of three rivers (Sutlej, Beas and Ravi) and the irrigation systems in Pakistan that were dependent on them, had to be fed from the waters of the remaining three rivers (Indus, Jehlum and the Chenab) assigned to Pakistan. This involved the construction of two storage reservoirs and a number of inter-river link canals along with their headworks. Some of these inter-river link canals had already been constructed pending the signing of the Treaty.

With the implementation of the Treaty Works, which was preceded in the 1960s with the construction of three barrages on the Indus for feeding the inundation canals and extending the irrigated areas, the irrigation systems in Pakistan were all integrated in a network that had the flexibility of switching the river supplies between the different systems. Coupled with the storages, an infrastructure was thus created, which could optimize areally and temporally the utilization of the available river supplies. This network of canals, inter-river link canals and storages is shown in Fig 1.1.

The surface irrigation system as it now exists covers the world's largest contiguous irrigated area (see Fig. 1.2), which is comprised of three storage reservoirs (total original live capacity 18.99 BCM), 16 barrages, 12 inter-river link canals, 2 syphons and 43 main canals. The total designed diversion capacity of the main canals is 7250 cumecs. The total length of the link canals, main canals, branches and distributaries is about 57,000 km. The system has 88,600 outlets for the irrigation of service areas. The length of the farm channels and watercourses is about 1.6 million km. An irrigable area of 14.2 million ha is served by the system.

Apart from the canal systems, a significant feature impacting on the country's irrigated agriculture has been the massive development of groundwater from the Indus Basin aquifer during the last 30 years. Initial development of groundwater, as a supplement to surface irrigation, was an outcome of the Salinity Control and Reclamation Projects (SCARPs) under which large capacity (60-150 liters per second, lps) tubewells were installed in the irrigated area to control waterlogging. Starting from 1963, over 11,000 tubewells were installed up to 1985 in the SCARPs having useable groundwater. At the same time, the demonstration effect of the SCARP tubewells spurred the development of groundwater in the private sector by the use of small capacity (30 lps) tubewells. From 1964 to 1989, the number of private tubewells jumped from 27,000 to 264,000, representing an average growth rate of 9.6 percent per annum.

About 70 percent of these private tubewells are located in the canal commanded areas, providing an opportunity for conjunctive use of surface and groundwater.

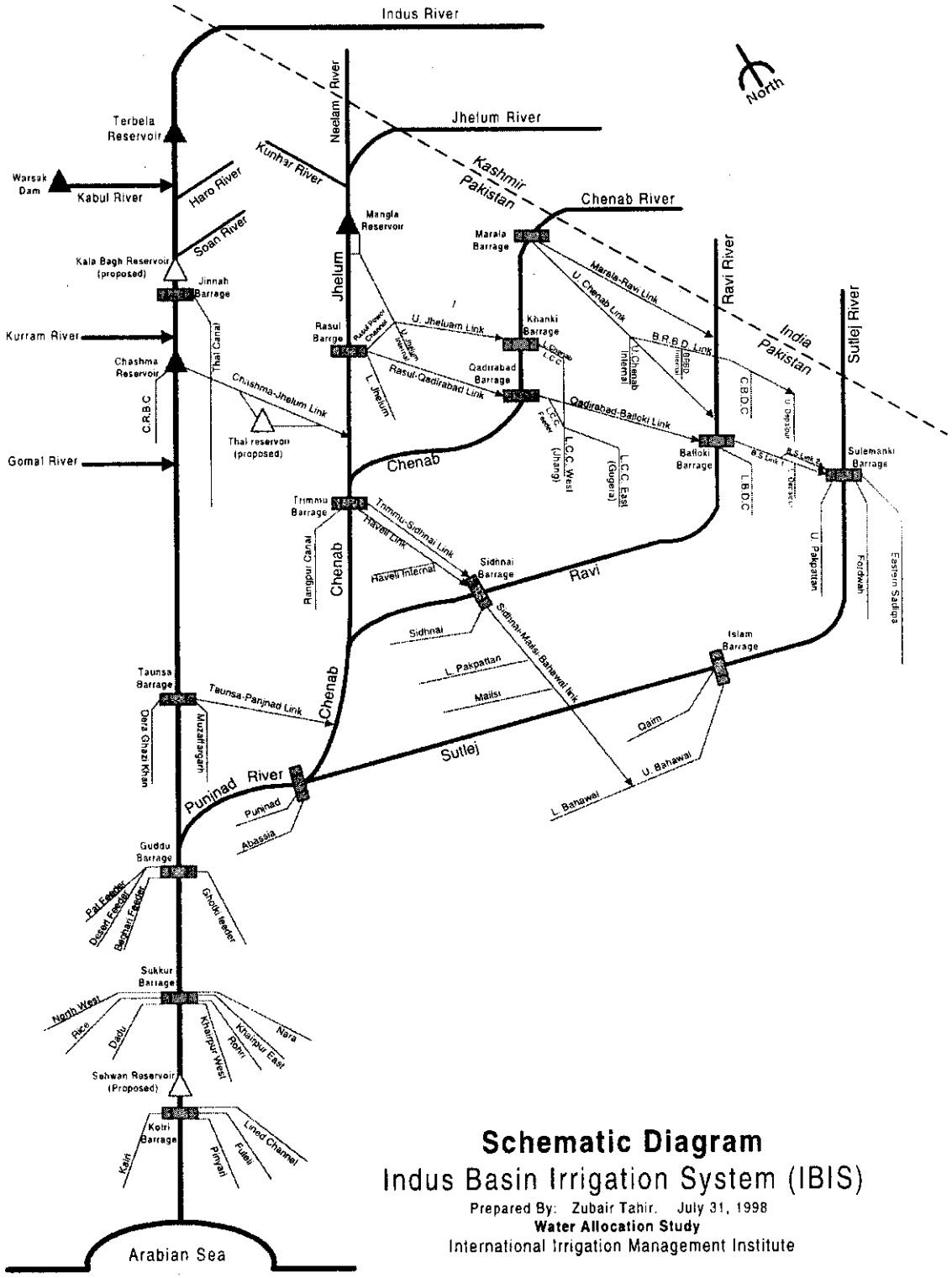

Figure 1.1. Schematic Diagram of Indus Basin Irrigation System (IBIS).

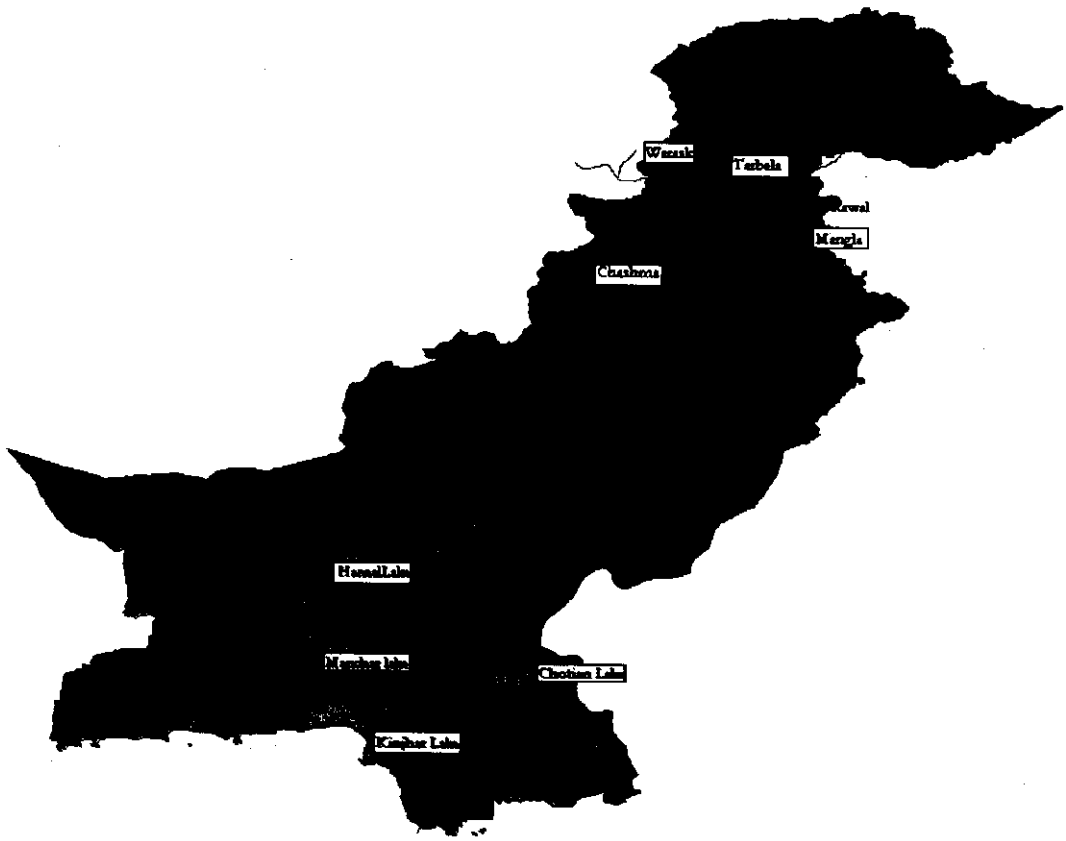

Figure 1.2. Indus Basin Irrigation System (IBIS) Including Existing Surface Storage.

1.3. Land And Water Context of Indus Basin

1.3.1. Land

As per statistics published by the Ministry of Food, Agriculture and Livestock, out of the total geographical area of Pakistan of 79.61 mha, 38 percent of the land (or 30.3 mha) has been classed as culturable, of which 21.44 mha was reported as the cultivated area in 1993-94, with 8.84 mha of culturable waste representing the possibilities for cultivation. However, as water is the limiting factor, land by itself does not constitute a constraint for irrigated agriculture in Pakistan.

1.3.2. Soils

Most of the irrigation systems in Pakistan have been developed over the alluvial Indus Plains, with only some small systems over inter-montane plains or on the piedmonts. While the soils, depending on their modes of deposition, show a wide range in their characteristics, they are not characterized by any conditions that would make them problem soils for irrigated agriculture.

The fluvitile soils of the Indus Plains, although generally silty, can be grouped into the medium to fine textural classes. These soils are normally porous with good infiltration characteristics and have medium to good water holding capacities.

The soils in the inter-montane plains and on the piedmonts display characteristics varying with the distance from the high lands. Soils higher up may display strongly layered cobbles to clay

horizons, while lower down they are of finer texture in the range of silty clay loams to silty clays.

1.3.3. Surface Water Utilization

The average annual surface water balance over an 11-year period (1976 to 1987) is presented in Table 1.1. This shows the average river inflows during two cropping seasons (kharif and rabi) and annually, along with their utilization in the canal system with the operation of the reservoirs.

Table 1.1. Average Annaul Surface Water Balance 1976-1987

Billion Cubic Meters (BCM)

	Kharif	Rabi	Annual
River Inflows	148.56	32.01	180.57
Reservoir operations	(-) 14.26	(+)14.26	--
Canal Withdrawals	82.19	46.88	129.07
System Gains or Losses	(-) 11.11	(+) 2.57	(-) 8.54
Outflow to sea	41.00	1.96	42.96

Based on Table 3.3 WSIPS. Vol I, 1990.

The figures in Table 1.1 show that the total annual canal head diversions averaged 129.07 BCM or 71 percent of total river inflows. However, the rabi diversions amounted to 46.88 BCM against the rabi inflows of 32.01 BCM which was possible due to the inter-seasonal transfer of supplies through the storage reservoirs of Tarbela, Mangla and Chashma augmented with regeneration. On the other hand, the kharif diversions of 82.19 BCM were only 55 percent of the inflows. During this period, the quantity of water that escaped to the sea averaged 42.96 BCM annually, or 24 percent of the inflows.

Considering the highly variable nature of the kharif flows, further capture of surface waters for enhancing dependable irrigation supplies is now greatly limited. Potential increases in irrigation supplies would have to depend on the construction of surface storages.

1.3.4. Groundwater Utilization

Out of the annual potential useable groundwater estimated as 49.84 BCM, the groundwater pumpage in 1984-85 was found to be 10.80 BCM from the SCARP tubewells and 39.35 BCM from the private tubewells. Thus, if anything, there is now a tendency for over-exploitation.

1.3.5. Overall Irrigation Supplies

With the progressive exploitation of groundwater, both in the public and private sectors, the irrigation water availability in the existing irrigation systems has considerably improved. Table 1.2 shows the annual irrigation water availability at the farmgate from the canals and tubewells in the recent past. Of the total irrigation water from tubewells as shown in Table 1.2, 73 percent was pumped by the private tubewells.

Table 1.2. Annual Irrigation Water Availability at the Farmgate.

Billion Cubic Meters (BCM)

Year	Water at Farmgate by Sources		
	Canal	Tubewells	Total
1977-78	75.53	34.32	109.85
1982-83	81.69	44.72	126.41
1987-88	87.87	50.55	138.42
1992-93	97.08	56.74	153.82

Source: Agricultural Statistics of Pakistan, 1992-93, Ministry of Food, Agriculture and Livestock.

1.3.6. Overview

With the existing irrigation systems whereby river supplies can be diverted from control structures at the barrages supplemented by link canals, and through which inter-river transfers of water can be effected, including surface storage waters, an irrigation infrastructure now exists in Pakistan whereby proper management can lead to a highly productive use of the water resources. The presence of useable groundwaters in many of the canal irrigation systems is another highly favourable element, where, with conjunctive water use, can add further to the productive potential of irrigated agriculture.

1.4. AGRICULTURAL SITUATION IN INDUS RIVER BASIN

1.4.1. Crops

Pakistan's agricultural sector has had a historical annual growth rate of 3.7 percent and, in 1991-92, accounted for 66 percent of the value added contribution to GDP, with 49 percent coming from major crops (wheat, rice, cotton, maize and sugarcane) and 17 percent from minor crops (oilseeds and pulses) (IFAD, 1992). Out of the total cultivated area of 21.4 million ha, 77 percent is irrigated and 23 percent is rainfed. In 1994-95, the total cropped areas amounted to 22.44 million ha, of which food grains occupied 65 percent and cash crops 20 percent. About two-thirds of the wheat production increase during the last 15 years have come from improvements in yield, and the balance from areal expansion; comparative figures for cotton and rice are 50 percent and 25 percent respectively, while the yield increase for sugarcane has been much less. The expansion of cropped area has stagnated during recent years because of continuing stress on the distribution of existing irrigation surface supplies.

Cropping patterns have changed over time; rice and wheat account for over 54 percent of the cropped area (an increase of over 10% since the late 1950s), while the area under sugarcane and cotton has also increased [Figure 3 (a)]. The average rates of growth in production of these four major crops between 1985-86 and 1990-91 have been fairly high [Figure 3 (b)]. The yield increases have been largest for wheat, followed by cotton and sugarcane, whereas the yield of rice is declining, reflecting increasing problems of water shortage, salinity and waterlogging in the irrigated areas [Figure 3 (c)]. On the whole, average yields of almost all crops are low when compared with international standards and the achievements of progressive farmers within the country. Given proper agronomic practices and the use of inputs in a timely and proper proportion, average farm productivity can easily be improved by 15-20 percent.

1.4.2. Stagnation

Numerous field studies involving discharge measurements and farmer interviews testify to the high degree of unreliability and inequity of canal water supplies. Water management "blows up" in the secondary canal system consisting of distributaries and minors that feed the tertiary watercourse command areas.

The major causes of inequity and unreliability are the social disease triplets of political interference, rent-seeking and farmer anarchy. Other causes are: (1) discharge ratings for cross regulators and head regulators are not periodically updated so that errors of 10-20 percent in the discharge rates commonly occur; and (2) the lack of communication between gate operators so that each cross-regulator is operated independently, thereby aggravating discharge variability in the branch canals and further downstream in the secondary and tertiary channels. The National Commission on Agriculture (1988) reported four major constraints to Pakistani farmers that hinder increased agricultural production. These constraints could be referred to as "nightmares" for farmers. The four farmer nightmares are: (1) poor quality seed; (2) untimely availability of fertilizers that are also low in nutrients because of "junk" materials mixed with the fertilizer; (3) unreliable and inequitable canal water deliveries; and (4) highly adulterated chemicals (biocides).

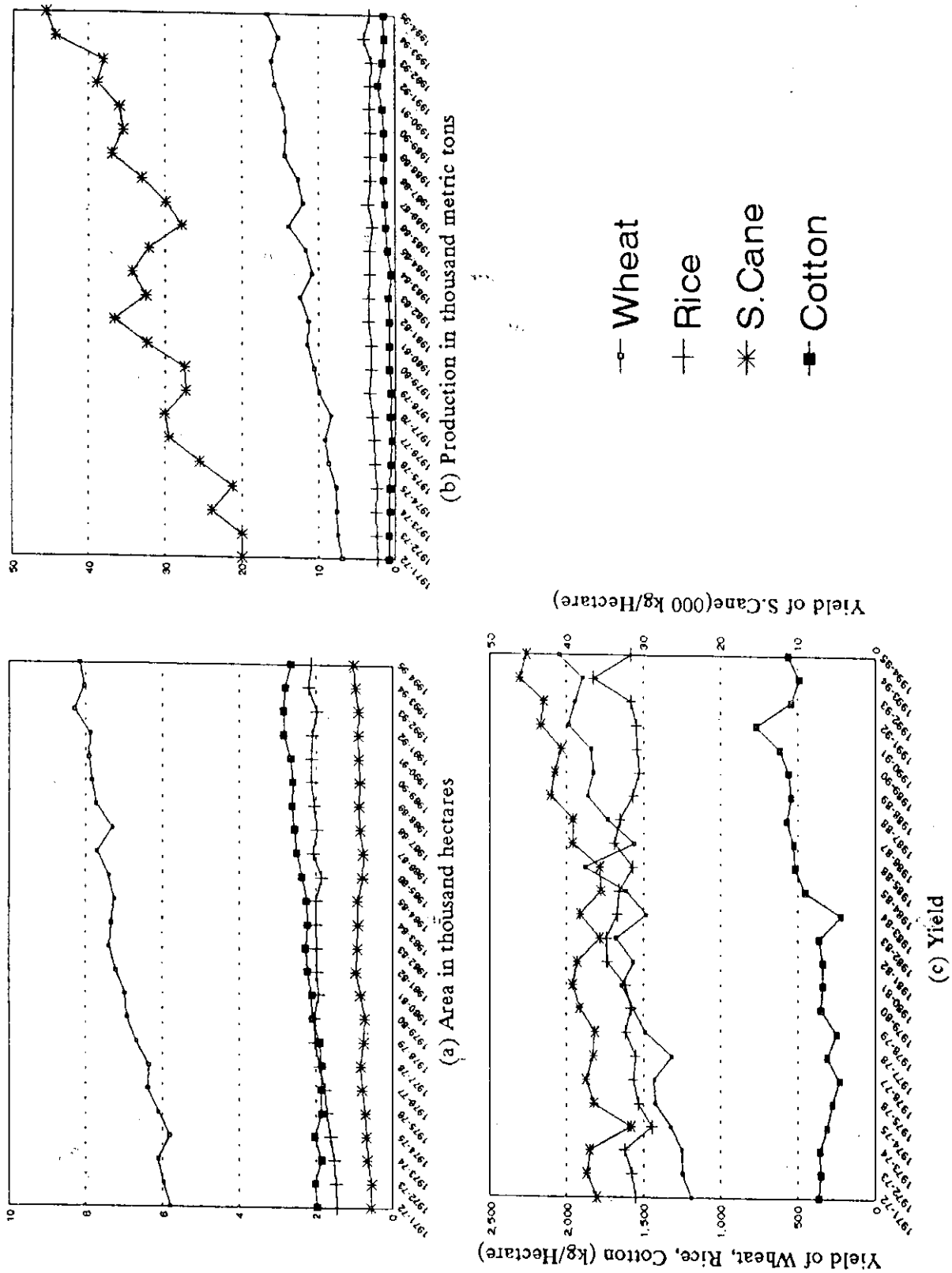

Figure 1.3. Historical Trends in Area, Production and Yield of Major Crops in Pakistan.

The combination of accumulated sediment deposition in irrigation canals, the twin menace of waterlogging and salinity, the social disease triplets, and the four farmer nightmares have resulted in a rather stagnant agriculture. Overcoming this difficult situation will require multiple solutions that address this broad set of constraints. This is not surprising because successfully interlinking the many components of an irrigated agricultural system are required in order to continually increase productivity, while at the same time assuring the sustainability of the system.

The first major criterion for moving the Indus Food Machine forward is to have farmers play a much larger role in managing the irrigation system than is presently the case. Most Pakistani professionals are extremely skeptical about farmers being more heavily involved in the operation of the irrigation system. Certainly, implementation will be very difficult, but it can also be argued that lack of success in this arena will mean that the agricultural system will remain "stuck," with the prognosis being that many more millions of people will live in poverty, even during the near future.

1.5. Environmental Situation in Indus River Basin

1.5.1. Salinity

Soil salinity has long been regarded as a problem affecting irrigated agriculture in Pakistan and was originally considered to be as the outcome of rising watertables creating waterlogged conditions. It was for this reason that when an assessment of the salinity was initiated in 1927 by the Waterlogging Enquiry Committee of the Punjab Government, the survey was confined to the areas where the watertable was within 5 feet of the ground surface (Nazir and Chaudhry 1988). From 1943, these surveys, based largely on visual examination of the cultivated lands were extended to all of the irrigated areas of the Punjab Province as an annual feature termed " Thur Girdawari". For the Province of the Punjab, these surveys over a 30-year period up to 1976 showed a persisting soil salinity trend with areas remaining out of cultivation, as shown in Table 1.3.

Table 1.3. Soil Salinity in the Punjab based on Thur Girdawari.

Survey Year	Salinity Affected Area (Percent of Surveyed Area)		
	Under cultivation	Out of cultivation	Total
1945-46	10.2	8.6	18.8
1955-56	11.6	9.0	20.6
1965-66	9.9	6.4	16.3
1975-76	8.4	5.1	13.5

From Table 2.9: Nazir and Chaudhry 1988.

A country-wide assessment of the soil salinity situation was earlier undertaken in 1953-54 as part of a Reconnaissance Survey of the Landform Soils and Present Land Use in the Indus Plains, which covered the entire irrigated area. This survey, based on aerial photography, indicated that the area mapped as 'predominantly severely saline' was 7 percent, whereas the area in which saline patches were common stood at 16 percent (Fraser 1958). This implied that about a quarter of the land was affected by soil salinity.

Progressive trends in salinity in the 1960's, over all the irrigated areas, became know when the Thur Girdawari was undertaken in all the four provinces forming the one unit of West Pakistan. The salt affected areas, province-wise, termed as Thur affected are shown in Table 1.4.

While the prevalence of soil salinity continued to be regarded as an important factor in the irrigated agriculture, its countrywide quantitative assessment and characterization was only undertaken during the late 1970's when a salinity survey was launched by WAPDA over the 41 million acres of the irrigated areas of the Indus Basin during the formulation of the Revised

Action Program of Irrigated Agriculture. Under this survey (from 1977 to 1979) the salinity of the top soil termed 'surface salinity' was established from field inspections supplemented with field tests and the exact composition of the salts was determined in the soil profiles on a one-mile grid by the chemical analysis of the soil samples to a depth of 72 inches.

Table 1.4. Thur affected areas in different Regions of Pakistan (1961-69)

Year	Percent of Thur in selected area				
	NWFP	Punjab	Bahalwalpur	Sind	Baluchistan
1961-62	3.72	17.63	11.8	14.84	-
1962-63	10.37	17.79	15.3	12.64	4.27
1963-64	9.49	17.75	15.4	15.19	7.16
1964-65	9.47	16.50	15.7	15.24	7.24
1965-66	10.15	16.28	15.9	16.20	7.23
1966-67	10.42	16.15	15.8	16.09	5.21
1967-68	9.73	14.09	15.2	17.08	6.34
1968-69	10.05	15.35	10.1	15.44	5.93

From Nazir and Chaudhry 1988.

As far as the extent of 'surface salinity' is concerned, this survey brought out that 26 percent of the irrigated area was affected by salinity in the categories slightly saline (ECe 4 to 8 mmhos), moderately saline (ECe 8 to15 mmhos) and strongly saline (Ece more than 15 mmhos).The position of 'surface salinity' by the provinces is shown in Table 1.5.

Table 1.5. Province-wise Extent of Surface Salinity in the Irrigated Areas of Pakistan during 1997-1999.

Province	Gross Irrigated Area (million acres)	Percent of Area				Total Salt Affected %
		Salt Free (S1)	Slightly Saline (S2)	Moderately Saline (S3)	Strongly Saline (S 4)	
NWFP	1.52	86.7	8.9	2.2	2.2	13.3
Punjab	25.12	85.7	7.1	4.1	3.1	14.3
Sindh	13.78	51.5	19.6	10.3	18.6	48.5
Baluchistan	0.87	74.0	17.0	5.0	4.0	26.0
Pakistan	41.29	74.2	11.3	6.2	8.3	25.8

Based on Data reported by WAPDA Planning Division (Data Volume 1981).

This survey further highlighted that the extent of salt-affected soils was much larger than what was apparent from the surface. Taking into account the salts in the root zone, the survey indicated that almost 40 percent of the area was affected, not only by salinity, which can be cured by leaching, but also by sodicity. Characterizing the profiles by the worst conditions in layers from the surface to 6 inches, to 12 inches, to 18 inches, and to 36 inches, 27 percent of the profiles had sodicity as against 11 percent with salinity alone.The province-wise breakdown of the profiles into 'saline' (ECe more than 4 mmhos) and sodic (SAR more than 13) is shown in Table 1.6.

Table 1.6. Province-wise Chemical Status of Soil Profiles in the Irrigated Areas of Pakistan during 1977-1979.

Province	Percent of Profiles in Different Categories				
	Non-saline Non-sodic	Saline	Saline-sodic	Sodic	Affected
NWFP	79.8	11.1	7.1	2.0	20.2
Punjab	73.7	7.1	14.1	5.1	26.3
Sindh	38.4	17.2	42.4	2.0	61.6
Baluchistan	35.0	26.0	38.0	1.0	65.0
Pakistan	61.6	11.1	24.3	3.0	38.4

Based on data reported by WAPDA Planning Division WAPDA: (Data Volume 1981).

1.5.2. Agricultural Chemicals

Some research has been done by agricultural universities and research institutes, mostly on nitrogen fertilizers, but very little on the transport of biocides (pesticides, herbicides, etc.) through the soil profile into the groundwater reservoirs, or as return flows to the rivers. There is considerable conjecture about the threat of agricultural chemicals on water pollution, but there are no studies that identify the magnitude of agricultural chemicals impacting the environment.

1.5.3. Biological Wastes

There is considerable evidence of surface water supplies containing human and animal wastes. These biological wastes are discharged both into canals and open drains; however, the open drains discharge into a river, so that these flows are diverted into canals at the next barrage located downstream. These wastes are usually not visible because of the high sediment loads in the canal, except in extreme cases when the water becomes black. Unfortunately, many people drink this water without boiling because: (1) the underlying groundwater is too brackish for drinking; (2) the cost of fuel for boiling water; and (3) a lack of knowledge by many villagers about sanitation.

1.5.4. Industrial Wastes

Potentially, industrial discharges are the most dangerous of all wastes entering the water supply. These industrial wastes are discharged into canals and drains, with many different colors of water. The industrial waste loads in canals presents a tremendous threat to human health. At the same time, there will most likely be groundwater contamination in Punjab Province and further downstream. There is even a serious question regarding toxicity to plants entering the food chain, as well as deleterious effects on the physical and chemical characteristics to agricultural soils, particularly in Sindh Province. Unfortunately, the amount of investigation is very meager for a problem of such significant magnitude.

1.6. Institutional Context in Pakistan

1.6.1. Operating Agency

Pakistan's extensive canal irrigation system is largely managed by the government. The country's constitution provides that irrigated agriculture is a subject devolved on the provinces. Accordingly, the Provincial Irrigation Departments (PIDs) are responsible for the major part of the tasks associated with operating and maintaining the physical systems, while the farmers attend to the maintenance of the tertiary level watercourses. PIDs are large organizations in the provincial administration. For example, Punjab's Irrigation and Power Department has a staff strength of over 50,000 persons.

A hierarchy of organizational units is involved in the operation and maintenance of a typical canal system. An Executive Engineer is in charge of a canal Division, which is the executive unit for operational activities, and he functions under the administrative control of a Superintending Engineer, who is the head of a Circle consisting of two or three Divisions. A Division is further divided into three or four Sub-divisions, each headed by a Sub-divisional Officer (SDO), who is also a qualified engineer. A Sub-division, ordinarily, consists of three or four Engineering Sections and two to three Zilladari or Revenue Sections. The head of an Engineering Section is a Sub-engineer, who is responsible for the distribution of supplies and the maintenance of secondary canals up to about 2 to 4 cumecs (70 to 150 cusecs) discharge. The Sub-engineer is assisted by Masons, Mistries, Mates and Canal Patrols for maintenance and watching channels, and also has Gauge Readers for regulation and observation of water flow. A Zilladari Section is headed by a Zilladar who supervises the work of about 10 Patwaris (Irrigation Record Keepers), each Patwari being required to record the extent of irrigation of 1,200 to 2,000 hectares.

This typical pattern of staff that is required to operate a canal system under the traditional design has remained largely unchanged for a long time. As the system was designed for a low management intensity, the density of irrigation staff is lower in the sub-continent than in many other irrigated areas. The average irrigation staff per 100 irrigated hectares is to the order of 0.3 to 0.5 in many Pakistan and Indian canals, compared to around 2.5 in South Korean canals (Wade, 1988).

1.6.2. Low Institutional Performance

The performance of this massive irrigation system in Pakistan is known to have been on the decline. Although the productivity per unit of water is high, Pakistan's crop yields have remained generally low, or progressed only very slowly when compared to many other countries. According to the Pakistan National Conservation Strategy document, the country's wheat yield is 44 percent of that in Mexico, rice yield is 43 percent of that in Egypt, maize yield is 33 percent of that in Turkey, cotton yield is 75 percent of that in Mexico, and sugarcane is 66 percent of that in India.

Similarly, poverty has stubbornly persisted in rural areas despite their proximity to irrigation. Pakistan's National Commission on Agriculture commented in 1988 that "Input subsidies and price supports for cash crops worked more to the advantage of the large farmers". In Pakistan, the average per capita income in rural areas (where about 70% of the population live) is less than half that in urban areas, and value added per worker in agriculture (which employs about 50% of the work force) is less than one-third of the rest of the economy (Hamid and Tims, 1990). Absolute rural poverty dropped by only one-third in twenty years, a much lower rate compared to achievements in some States of India (John Mellor Associates and Asianics Agro-Dev, 1994).

A more recent evaluation pointed out that poverty considerations were not a priority in Pakistan's irrigation development projects (World Bank, 1996). "While the projects helped alleviate poverty through their effects on farm production, they also provided large and unnecessary transfers of public resources to some of the rural elite". In effect, On-Farm Water Management Projects, the Irrigation System Rehabilitation Project and the Command Water Management Project have all tended to favor the more affluent farmer groups.

Reasons for this performance deficiency are complex. The peculiar irrigation culture, which is formed out of a feudalistic social structure and a formalism introduced by the colonial administration, is a major factor influencing the region's irrigation performance (Bandaragoda, 1996). The long experience in canal irrigation has led to the evolution of a strong irrigation tradition, which has sustained a broad-based community interest in irrigation. In the resultant institutional milieu, a set of formally established irrigation rules and organizations stand side by side with an intricate set of informal social institutions. The two sets act like a dual system, often in conflict with each other.

A largely uncoordinated institutional framework compounds this situation further. Federal responsibility for resource allocation, provincial responsibility for irrigation management, large organizations with centralized administration, large numbers of water users with little involvement in irrigation management decisions, difficult coordination among agencies and their sub-units and functions, numerous laws and procedures mixed with traditional concepts and sporadic amendments by occasional enactments and promulgations, and more importantly, the countervailing forces that act against formal rules, all contribute to this vast complexity of Pakistan's irrigation institutions.

In sum, the following main institutional factors that affect irrigation performance in Pakistan can be identified (Bandaragoda and Firdousi, 1992):

- The overriding effect of socially evolved informal institutions over the formal rules and management decisions;
- The obsolescence of irrigation rules, codes and procedures; and
- The declining relevance of organizational structures in the light of changed circumstances.

1.6.3. Recent Changes in the Institutional Environment

With the post-independence political development, the irrigated agriculture scene underwent some changes. Populist approaches of a newly emerging democracy tended to bring about substantial influence on many aspects of canal administration, which, through a cycle of mutually reinforcing social factors, led to the present situation of rent-seeking and free-riding. Most of the traditional design features have outlived their usefulness in the context of these changed social conditions. The ideas of "protective" irrigation and equitable water distribution embodied in the early design criteria are no longer readily applicable. Some of these interacting changes in the operational environment were:

- increased indiscipline in the operation of the system;
- cumulative effect of poor maintenance;
- increase in the number of small farms;
- demand for more irrigation water and its greater reliability;
- advent of groundwater development;
- increased water supply through reservoir storage;
- increase in cropping intensities (over 100% in many systems); and
- diversification in cropping patterns.

The cumulative effect of these political and socio-economic changes can be seen in the present social setting of Pakistan's irrigation, which has the following main features:

- skewed land ownership pattern;
- increasing number of small landholders due to fragmentation of land;
- the majority of water users are illiterate and poor;
- lack of information sharing;
- centralized irrigation administration;
- lack of accountability;
- rent-seeking behavior is rampant;
- neglect in operation and maintenance;
- political interference in administration of the irrigation systems; and
- inequity in water distribution -- tailend deprivation is a common feature.

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2. INSTITUTIONAL DETERMINANTS OF TECHNOLOGICAL ADVANCEMENTS

2.1. HISTORICAL PERSPECTIVE

In a developing country such as Pakistan, it is useful to relate the present situation to the country's development process. Particularly, the institutional development is an evolutionary process, that takes into account the historical aspects of culture and society, and their interactions with the external world. More importantly, the technological progress in a country has a direct link with this evolutionary process, as much as with its institutional capacity. It depends on the enabling strength of the country's laws, or formal and informal rule systems, and its value systems, and the way they have evolved over time.

2.1.1. Ancient Tradition

As in many developing countries, in Pakistan, the development process has been dominated by government interventions. This public sector dominance, particularly in the irrigated agriculture sector, has its roots in the interest shown by the ancient rulers in water resources development. Although the water users played an important role in operating and maintaining the small irrigation systems at that time, they were guided by the rules of the state for their required contribution. Also, regarding equitable distribution of water, there was state guidance and the water users acted on the decisions of the ruler's representative in the area.

The tradition of compliance comes from over two thousand years of subordination and structured life under the Emperors, Kings, Princes, Nizams and Sultans, and the various warlords and chieftains. Compliance during that time was not understood as total subservience; it was partly seen as a reflection of the work the benevolent leaders did in using their power and resources to provide common goods like irrigation for the benefit of the people, following the general understanding that nation building and social welfare were essentially the ruler's responsibility[1].

These features of the ancient tradition contributed to a supply-oriented administration, which is still conspicuously dominant in public sector management in Pakistan. The remnants of ancient traditions can be seen when those who are responsible for rule application often show a tendency to act like the "rulers" in relation to their water user "subjects".

2.1.2. Colonial Influence

The regimented and formalistic administration of the colonial period was built on the pre-colonial centralism. Through this evolved a dominant public sector with strict administrative discipline and an efficiency-oriented and equity-based value system. The vigor with which the physical irrigation systems were built during the colonial period was matched by an enthusiasm to develop the needed irrigation institutions. In designing new organizational structures and rules, the colonial administration retained most of the old local institutional elements found in the monarchical social systems of the subcontinent. Yet, several improvements were made on the supervision and compliance relationships that existed at the time. Understandably, the centralism in administration was strengthened. Hierarchical structures were established, village leaders were formally appointed, and rules and procedures were formalized.

The institutional framework for irrigation that was finally put in the subcontinent during the period was basically an innovative adaptation to suit local conditions. Detailed manuals of procedure for the conduct of officials, strict supervision, performance-oriented work habits, equity-based water allocation supported by official warabandi schedules, open katcheri system for arbitration and conflict resolution, and the involvement of village leadership for revenue

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[1] Karl Witfogel (1957) saw this as "oriental despotism" in which a social need to control large systems required the "benevolent" monarchies to take responsibility for managing the common goods.

collection are some of the main features in the administration during this period. Strict compliance of "orders" of the superior was generally assumed as a necessary characteristic of the hierarchical officialdom. As for the heritage from this colonial era, the formal rules and bureaucratic practices remain almost unchanged, although rule application and related work ethics have been eroded by political patronage. It is still not difficult to find the "brown sahib" image in the canal administration environment.

2.1.3. Post-Independence Political Modernization

The new nation state of Pakistan retained most of the centralist elements, sans some of the cherished values of colonial administrative styles. This resulted in a conspicuous dualism of ruling classes and poor masses, or the "providers" and the "beneficiaries". Soon after independence, the state embarked on yet another period of concern and attention on irrigated agriculture, on the basis of an often expressed desire to provide food for the growing populations. To promote food production, incentives were built into irrigated agriculture. Support prices, subsidies and other incentives were introduced, the rules were liberalized, and rule application was relaxed. With increased government expenditures on irrigation development, operation and maintenance became a state responsibility. The credit for national development was to be exclusively owned by the government. Almost reflecting the colonial style, the successive governments preferred to maintain central authority. The higher the levels of government investment on irrigation development, the greater was the government's desire to retain irrigation management as a social responsibility. Consequently, the water-related institutional framework became more centralized. In terms of relationships between the government (or its elitist members) and the people, the newly independent state still carried out authoritarian style of the colonial administration and the vestiges of feudalism. In the words of Clifford Geertz (1963), they were the "new states with old societies".

2.2. RIVER BASIN DEVELOPMENT

Pakistan's irrigated agriculture is dominated by one large river basin, the Indus, which accounts for almost 90 percent of the country's total cultivated area. This significant physical characteristic makes Pakistan a typical product of river basin development. This section discusses the evolutionary process of water resources development for a river basin in general, and leads to an inference that can be made in the case of the Indus River Basin.

2.2.1. Primacy of Physical Works in Early Stages

Conceptually, there are a few basic evolutionary steps that can be traced in the development of resources in a major river basin. First, in the early days of development, when the river basin is sparsely populated, people need water mainly for domestic purposes, but in arid areas, they also need water for producing food. Basically, the water needs of the people can be satisfied by moving water from the river or its tributaries to where the people live, which was often very close to the river itself. Thus, the ancient civilizations of Harappa and Mohendojaro were both located close to the Indus River. As people tried to divert water from the river and take it towards their habitats, they constructed some physical structures. In this process, they were concerned with the weather conditions, the soil, and how the water could be conveyed to where it was needed. This is the beginning of "hardware development" related to water resources.

2.2.2. Hardware and Software

As the population of the river basin increased, there was an increasing demand for more hardware development. and the ancient societies supported them with adequate rules related to resources allocation, which became accepted customary practices. Formulation of rules and procedures associated with the operation of physical systems can be described as "software development". In today's context, when the populations have increased in Malthusian proportions, the need to think beyond the physical systems and consider numerous other

complementary measures linked with water resources management involving economics, politics, human relations and organizations, begin to grow in importance. In other words, as the water resources become more and more utilized, there is an increasing milieu of "software" measures that have to be considered and then implemented in conjunction with "hardware" measures.

2.2.3. Software Development under Increasing Exploitation of Resources

Finally, as the water resources approach full utilization (say 85-95 percent), the development efforts have to be guided almost completely by software measures. In fact, hardware is only used to support software development. Thus, the strategy for increasing water resources utilization is entirely focused on software solutions with hardware only being used to support the successful implementation of software. The major issue concerns the status of water resources development in the Indus Basin, where water utilization is approximately 75 percent. How much more emphasis should be placed on software development than has been so far considered? It is in such a carefully considered view that the optimum benefits could be seen of a long tradition of river basin development in the Indus.

The development of irrigated agriculture in most places in the last few decades has focused almost entirely upon the construction of water delivery and water removal subsystems. This preoccupation with the installation of "hardware" results from a naive single-discipline approach to water management (Wiener, 1972). One discipline cannot begin to solve the complex physical, economic, and sociological problems involved. Probably the greatest deterrent to improved water management in most irrigation systems today is the inordinate focus on the water delivery and removal subsystems and the almost complete neglect of other requirements. In reality, though, especially in irrigated agriculture, we come face to face with a wide gap that frequently exists between "hardware development" and the development of all the other requisites for increased agricultural production, namely "software development."

As the water resources become more fully utilized, the necessity for meeting new water demands (along with physical, socioeconomic, and political problems of water quality degradation) requires that much of the conventional wisdom of the past be questioned. It should also be obvious that many developing countries have neither the time nor resources many western irrigated regions had to utilize in their development. Pressures created by rapidly rising populations and corresponding water scarcity will force them at some point to re-evaluate their approaches.

In contrast to the mere development of water resources approach, the "management" approach attempts to achieve water development objectives by applying a variety of measures after studying the entire system, thereby attempting to modify the total system to meet new and changing demands as well as estimated future demands. Therefore, instead of constructing new engineering works to meet new demands, the focus should be upon water resources management, with construction works considered only as a tool when necessary to meet water management objectives (Wiener, 1972). Unfortunately, in most cases, water management and the many disciplines required to produce efficient management are relegated to the postanalysis of engineering works, which aggravates not only the implementation of technology, but really constrains or makes extremely difficult the implementation of a host of services requiring strong institutional measures (Skogerboe, 1991).

2.3. Recent Irrigation Development in Pakistan

Recent development efforts were mainly through the World Bank-sponsored Indus Basin Project (IBP), which consolidated more than a hundred years of consistent heavy investment in irrigation in Pakistan. The IBP of the 1960s resulted in an increase in the total annual water supply for irrigation from about 79 billion cubic meters at the time of independence to almost 135 billion cubic meters by the end of the IBP effort. It has become customary to refer to this

Indus River Basin System as the largest contiguous irrigated area in the world, served by 43 large canal systems. In addition, substantial donor funds were invested in on-farm water management programs in various selected canal commands to improve the farm-gate supply of irrigation water.

2.3.1. Emphasis on Physical Work

Contrary to the basic principle of increased value on software development as water resources development was approaching full exploitation, the influence of the more recent "development era" was characterized by its emphasis on physical infrastructure. This misplaced emphasis on hardware development and its "projects" modus operandi, came with massive support from overseas development assistance (ODA). As ODA flowed into Pakistan along with the Indus Basin Project, in which a number of large link canals were to be constructed to transfer water from western to eastern tributaries in the Indus River Basin, there was a tendency to favor a technocratic emphasis in administration, and to provide greater opportunities for handling large-scale capital intensive activities. The government's enthusiasm on physical infrastructure development was motivated by a great political concern to rectify a situation caused by the closure of eastern water sources after partition. The technocratic approach saw a definitive tilt in the administrative style towards planning, construction, engineering, and financial management skills, causing a relative neglect of basic economic and social aspects of water resources management.

2.3.2. Relative Neglect of the Social Aspects of Water Management

The Provincial Irrigation Departments, which had evolved from the colonial period, were partially dismantled to form a larger, more powerful and resourceful para-statal body (WAPDA), mandated with infrastructure development objectives. The emphasis on technical processes polarized a decline in attention on the social side of irrigation management. While the construction emphasis enriched the new organization, the rest of the institutional framework failed to capture the opportunity to develop other useful emphases. For example, while developing a plethora of state agencies in the post-independence period, there was no organizational unit mandated with the responsibility for providing assistance to social organization in irrigated agriculture. Also, there was no serious attempt to have a coordinated institutional set up for irrigated agriculture. With the initial emphasis shifting to resource base development, a real interest on resource management never surfaced. Being the most recent influence, the emphasis on technical processes seems to have remained as a conspicuously dominant feature of the present irrigated agriculture administration.

2.3.3. Watercourse Lining Program

USAID funded an On-Farm Water Management Pilot Project (OFWM) from July 1976 to June 1981. The major target was the improvement of 1,500 watercourses scattered throughout Pakistan. The major emphasis was upon earthen improvements by the farmers, followed by brick-and-mortar lining of 10 percent of the watercourse length. The lining could be located anywhere along the watercourse, which was expected to be through the village (for health and social reasons) or at the head of the watercourse. Almost universally, the lining was done at the head in order to gain support from the farmers located in this area, who otherwise would not have benefited. Prior to watercourse improvement, the water losses were measured and this information was shared with the farmers. In addition, considerable effort was expended in developing training courses for OFWM staff. Eventually, there were also research activities associated with the program.

The Water Management Research Project staff (4-7 faculty) of Colorado State University (CSU) were in Pakistan from June 1970 to November 1979, when they had to depart because of the Pressler Amendment. At their time of departure, the highest priority research activity was to sustain and strengthen water users associations so that they would maintain their improved

watercourse. A part of this effort was to provide a legal basis by having each provincial assembly enact a Water Users Association Act. This finally occurred during the period 1980-82.

Surprisingly, the target of improving 1,500 watercourses was achieved by June 1981. Then, the World Bank provided loan funds for OFWM-I in July 1981. This was followed by OFWM-II and presently, OFWM-III. In addition, the Asian Development Bank has also been providing loan funds for very similar projects. Also, Canada and Japan have been supporting OFWM projects.

The OFWM program has been very popular with farmers. They have been clamoring for this program. Certainly, this has been one of the most popular development activities in Pakistan. Unfortunately, this highly successful program has been steadily degenerating through the years.

Presently, watercourse losses are not measured by the OFWM staff. Also, farmers no longer rebuild their earthen watercourse. Instead, the focus is almost entirely upon watercourse lining. This emphasis is also recognizable by the almost total lack of sustainable WUAs. A common statement is that WUAs have nothing to do after watercourse lining is completed. This is true because the only purpose in organizing the farmers was to get the lining underway. There was very little concern about creating sustainable WUAs that would maintain their improved watercourse, along with making more effective use of any water savings through improved water management (including agronomic) practices. From the very start, the major emphasis was focused upon the targets for improved watercourses. This emphasis was reinforced by the donors. In the end, the emphasis was largely confined to watercourse lining.

The most important lesson to be learned from the OFWM program is that when the emphasis is upon civil works, then the institutional component is relegated to such a low priority that it is unlikely to be successful. On-Farm Water Management became a misnomer as the program steadily degenerated into a Watercourse Lining Program. In future development projects, the institutional component needs to lead the way with the physical component following in a manner that supports the institutional component.

2.4. Motives for Technological and Institutional Changes

Institutions in a given society at a given time are related to multiple interests of different stakeholders of that society at that particular time. The economic, social and political viability of a package of technological interventions, therefore, would depend on the interplay of existing institutions, which in turn would depend on their ability to satisfy the overall interests of the concerned stakeholders. Any institutional change required by new technologies is yet more critically dependent on the power of those who can use it.

2.4.1. Resistance to Change

Some of the stakeholders obviously benefit from the status quo and, therefore, resist change more than the others. For instance, some influential landowners gain from the existing situation of inequitable water distribution; they are the most vociferous opponents of institutional reforms. Similarly, the water users in the head reaches of a distributary, who gain from inadequate maintenance, may be the reluctant participants in collective action. The case of some agency staff may be the same with respect to changes in the present institutional structure. Similarly, a change in the existing cropping pattern for saving water would be resisted by those who stand to gain from the current pattern of major crops, or their personal gain associated with post-harvest activities of such crops.

Theoretically, a potential for improvement in the existing (socio-economic) situation will be the critical incentive for accepting change. The main issue is to what extent this potential can be identified by the stakeholders. Is there a good potential for improvement in terms of efficiency, equity, cost recovery and accountability, the four most quoted criteria of benefits for

institutional change in water resources management? Finally, is there a potential for improvement in the returns to investment in the system as a whole? Until positive answers become clearly discernible, the resistance to change would continue to be a real impediment to change.

2.4.2. Understanding the Need for Re-Orientation of Roles

Recently, the water users' participation in operating and maintaining water resources infrastructure has been advocated as the main focus of the needed institutional reforms. Popular participation is believed to be a strategy to increase the probability of establishing infrastructure people want, in ways people can and will manage them (Mienzen-Dick et al, 1995). This approach implies a new role for the water users. They are expected to have a major attitudinal change from being mere "beneficiaries" of government assistance to sharing responsibility for managing infrastructure. More importantly, the water users have to change to a new situation in which they think and act as groups rather than individuals.

The success of this approach requires a redefinition of the roles of the other actors as well. Redefinition of roles while focusing on users' participation implies that the government's operating agencies and their staff will have to empower the water users for undertaking new management responsibilities; the regulatory and enforcement agencies and their staff will have to recognize these changed roles of various actors; the agriculture extension agencies and their staff will have to support the organized water user groups; and the big landlords and other rural-based influentials will have to acknowledge a new power base emerging in the water users' organizations.

2.4.3. Complexity of Rules-in-Use[2]

Since irrigation is associated with fairly complex social systems, the institutions operative in the context of irrigated agriculture in rural societies are profoundly complex. The major part of this complexity lies in the society itself; farmers are of different distinct social groups with different sets of goals and objectives, and different alliances. The formal rules designed to govern their conduct in an orderly manner give way to flexible informal rules (Bandaragoda and Firdousi, 1992). For instance, a recent study in a sample of twenty-two watercourses in the Punjab did not find a single pucca warabandi in practice as officially designed (Bandaragoda and Rehman, 1995). Similarly, forces of tradition, such as feudalism, caste and biraderies have a greater influence over people's lives than the written codes of law. In these deep rooted informal behavioral patterns, giving or accepting a bribe has become an accepted norm, rather than a crime punishable by law. Taking more water than assigned, or tampering with irrigation structures, are routine occurrences.

By nature, institutions are intrinsically inter-linked. In the present context, these linkages are criss-crossing various categories and groups of people, adding to the complexity. For instance, some farmers are more closely linked with agency staff than with the farming community; people shift their political alliances when their feudal lords change parties. Politicians from rural electorates have an urban bias in their policy preferences. Because of this inter-linked network of relationships, a change in one institutional aspect requires or generates corresponding changes in others. Giving recognition to this concept means that the planners need to think of an integrated package of institutional reforms, rather than of isolated items in an ad-hoc manner.

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[2] Ostrom (1992) defined institutions as basically the rules-in-use, and therefore, irrigation institutions can be described as the sets of working rules for supplying and using irrigation water (Ostrom, 1992).

2.5. CURRENT STATUS OF IRRIGATION MANAGEMENT

Pakistan's irrigated agriculture sector is mainly constrained by three factors:

- a general shortage of good quality canal water, which becomes more pronounced during peak periods of crop water requirements;
- a maintenance-related deterioration in physical conditions of the canal system, which reduces the water delivery efficiency, while aggravating the water shortage situation; and
- a centralized and rather static administrative system which cannot fully cope with the increasing difficulties of effecting both proper operation and maintenance of the physical system, as well as equitable water distribution.

The three main constraints are further compounded by environmental problems associated with waterlogging, soil salinity and capacity limitations of the conveyance system. The combined effect of these problems amounts to an increasing inequity and a declining productivity in the irrigated agriculture sector.

2.5.1. Erosion of Equity

The present inequity is, primarily, the cumulative effect of a number of recurrent institutional and management deficiencies. At a glance, they all appear to be related to technological defects, the problems of maintenance and operation of the canal system, but in fact, they are mainly manifestations of a general breakdown in accountability at all levels in the system.

Maintenance is basically a support activity to facilitate operating the irrigation system, and the two activities need to go hand in hand for the system to perform according to its design parameters. The original design of Pakistan's irrigation systems, as well as of the institutional arrangements for their operation and maintenance, was characterized by features aimed at equitable water distribution. With the gradual decline in the quality of physical and management conditions, this design stage objective of equity steadily eroded, leading to the present situation of near anarchy in the irrigation canal environment. Today, equitable water distribution has been replaced by a blatant behavior of water misappropriation. Some water users appropriate the share of the others by taking advantage of the deterioration in both physical and management conditions in the system. When design assumptions for distributary outlets (such as continuous full supply water level in the canal and outlet modular conditions) were no longer valid, the distribution of water among the outlets was found to be substantially inequitable.

In the irrigation scene in Pakistan, a fairly common picture emerges that represents the interactions referred to above, between maintenance, operations and related social behavior. When the canal is silted, its upstream outlets tend to draw more water than their design discharges. This is simply a hydraulic phenomenon, which however has an impact on social behavior; it discourages the upstream farmers from promoting maintenance activities in the canal. In a seminar held in Karachi, mention was made that some influential farmers in such advantageous locations in a canal command had brought tractor loads of removed silt back into the canal, immediately after a major desilting effort by the government. Laxity in canal operations also promotes anarchy in the field; there are many instances of breaching of canal bunds, installing of unauthorized outlets, pumping and siphoning of canal water, and tampering with outlets and other canal structures. These acts in turn exacerbate the maintenance problems. In the overall, the effect of this "free rider" behavior, in which some individuals try to get more than their due share at the expense of the others, is that the tail-end sections of the canal system suffer from water shortages. Both under normal supply and acutely shortage conditions, generally the upstream water users receive more water than their due share, while those in the tail reaches of the canal command receive less.

Surprisingly, there are also instances where the tail-end watercourses in some canals have been reported as receiving more water than their head-end watercourses. This unusual "reversed inequity", which was observed in Puran and Nari Distributaries in the Punjab, is attributed to an overall over-supply of water to the canals. A similar anomaly was seen in a study in the Lower Swat Canal in the North West Frontier Province, where its downstream Sheik Yousaf Minor was drawing more excess water relative to the design discharge than its upstream Distributary No. 3. It is reasonable to believe that an over-supply in part of a system under conditions of general shortage of water in the system can occur only with some serious human interventions.

2.5.2. Breakdown in Accountability

Conditions of scarcity and poor reliability of supply normally encourage the individual water user to engage in various malpractices for maximizing personal gain. A long period of this behavior results in a "syndrome of anarchy" (Hart 1978, Wade 1987), which is a product of mutual mistrust between the water users and the operating staff. The users lack the confidence that if they refrain from stealing water, or breaking the structures, they will get their entitled water on time, while the officials lack the confidence that if they apply themselves properly to somehow get water on time, the users will refrain from breaking the rules. The problem is, where and how to break this vicious circle. As long as the offenders are the majority in either group, enforcement is not possible as any law can be effective only when a small minority of the population tends to break it. Over the years, this vicious circle has resulted in a breakdown in the whole accountability system. Both the agency staff, as well as the water users, have ceased to become accountable for any task, or to any source of authority.

Another major reason for the breakdown in accountability is the dispersion of responsibility for sustainable irrigated agriculture, which is exacerbated by poor inter-agency coordination. Apart from the traditional demarcation between irrigation and agriculture agencies, the fact that irrigated agriculture is conducted with very little consultation with other related agencies, such as those responsible for public health, primary education, internal and external trade, tends to make irrigated agriculture unsustainable on many criteria. In the final analysis, there will no single agency who will be accountable for any part of the overall functions.

2.6. Rationale for Institutional Change

A strategy that is likely to help in this situation is to approach the problem from the demand side of the irrigation management equation. This strategy has not been fully explored so far in Pakistan, where a supply-sided bureaucracy has consistently been playing a dominant role. The proposition here is that the "syndrome of anarchy" leading to inequity can be resolved by an institutional change initiated by the water users, which will later involve appropriate and corresponding institutional changes for improved accountability in the delivery organizations.

The present problems of irrigation management in Pakistan typically call for such institutional solutions. The main reason for this thinking is the understanding that, hitherto, the country's irrigation development has been overly technology oriented, and pursued with a pre-occupation in expanding the resource base. The commendable work done so far in technology application and resource base expansion is now clearly facing a decline in its productive value. Yields of the main crops under irrigated agriculture in Pakistan are either stagnant, or declining. The Pakistan National Conservation Strategy, a recently published government document, points out that Pakistan's average yields of all main crops are considerably less than the average yields achieved by other countries. The 1990 Water Sector Investment Plan of Pakistan predicts a shortfall of about 10 percent by the year 2000 and 25 percent by 2013 in the country's future food and fiber production needs, even if the Plan's proposed targets of resource base and performance improvements are met. This represents an increase in the food deficit from 24 percent to 36 percent during this period. Thus, the low productivity of irrigated agriculture in Pakistan represents a major threat to the country's food security.

Low productivity of irrigated agriculture would also mean a decline in the financial sustainability of irrigation systems, and in turn a fast flow of capital and labor away from the rural areas. Unless this situation is arrested, the potential role of irrigation as an engine of growth in Pakistan's rural sector is likely to diminish rapidly.

The present levels of low productivity in Pakistan's irrigated agriculture are mainly attributable to poor irrigation management. The state institutions in the country's irrigated agriculture sector are seen as having already become obsolete in view of new demands and the changed scope of irrigation management. As in the case of crop yields, the performance of Pakistan's irrigation related institutions in general has also become sluggish. While there has been a considerable amount of research conducted on Pakistan's irrigated agriculture, not much of its results has been adequately captured by policy, and consequently, they have not led to any meaningful institutional reform. The time has come, therefore, for policy to take account of this fast deteriorating situation and make even a rather belated attempt to reverse the process. It is time to seriously think about some of the essential institutional requirements that would normally complement the efforts in establishing physical infrastructure for sustainable development.

3. RESEARCH FOCUS

3.1. OBJECTIVES OF PHASE I

The Project, "Managing Irrigation Systems to Minimize Waterlogging and Salinity Problems" implemented during 1989-1993 was a field research program designed to identify the linkages between existing irrigation system management processes and the incidence of waterlogging and salinity problems and to develop irrigation management techniques and strategies to mitigate waterlogging and salinity problems in irrigated areas of the Indus Basin.

The general notion of the project was that a combination of physical works and changed management practices, plus their effective integration, offers a greater likelihood of success in addressing the range of existing and potential waterlogging and salinity conditions in the Indus Basin than can physical works or management changes alone.

The overall objective of this project was to develop and implement, using action research, a set of improved management strategies and techniques to mitigate incipient waterlogging and salinity, and to leave a persistent institutional commitment for continued implementation of management strategies as developed in the project.

Specific objectives of this project were:

1. Define system management practices, which impact upon waterlogging and salinity;
2. Define the array of possible physical and management solutions, which have potential for minimizing irrigation's contribution to waterlogging;
3. Identify irrigation system operational strategies for the kharif and rabi seasons at various levels in the system, i.e., main, branch, distributary, and watercourse, that have promise of minimizing irrigation's contribution to waterlogging and salinity;
4. Develop specific analytical methods to assess irrigation's contribution to waterlogging and salinity vis-à-vis other sources of the problems;
5. Based on field information, quantify the relative contributions of various sources, e.g. rain, rivers, main canal system, watercourses, farmer's ditches, and fields;
6. Identify farmer mechanisms for coping with excess surface water, high water tables and salinity, e.g., providing on-farm drainage work, changing crops, modifying cropping calendars, land levelling; and
7. Evaluate under field conditions the environmental and agricultural productivity impacts of irrigation system management strategies with potential to reduce waterlogging and salinity.

3.2. PHASE I RESULTS

3.2.1. Accomplishment of Project Objectives

The various studies conducted in the Punjab on operations and performance of irrigation systems at the main and secondary canal levels, on salinity, water and salt balances at the watercourse and field levels, on conjunctive use of surface and groundwater, as well as water markets, produced the location-specific research findings on waterlogging and salinity issues. Though these findings were based on the studies undertaken on limited irrigation environments and sample watercourses, fields, and number of farmers interviewed, they also provided enough generic conclusions on irrigation's contribution to the incidence of salinity and its impact on agricultural productivity of the irrigated areas.

The studies on effect of physical and management interventions (canal lining, desilting and operational management) on the irrigation system performance partially satisfied project objectives (1), (2) and (3).

Modeling studies were undertaken on assessment of current irrigation system performance and improved performance as a function of various operational and maintenance inputs. Salinity modeling studies were conducted for simulating profile salinity in irrigated soils and the effect of salinity on crop yields, along with salt and water balances. These studies served to satisfy objective (4).

Water balance studies conducted at the watercourse level to quantify the various components of a water balance and their contribution to the rise of the groundwater table, fulfilled objective 5.

A report on *Mechanisms for coping with salinity and waterlogging problems* explains farmers' perceptions about waterlogging and salinity problems and various measures being adopted by farmers to manage these problems. This report, along with other IIMI studies on these issues, were aimed at objective 6 of the project.

The work done on development and field testing of various management interventions during this project was not enough for making concrete recommendations on implementation of these interventions for ID and policy makers. Still, substantial work needs to be done on the development of effective management alternatives. Field testing their impact on system performance, along with obtaining a strong commitment from irrigation agencies and policy makers for their implementation, are time consuming efforts. However, the achievements of this project (Phase I) was mainly in making inroads into the bureaucratic consideration of these issues.

3.2.2. Complementary Research Activities

During the course of the project, some additional studies not directly linked to the stated objectives were also conducted. Studies on water markets, gender issues, institutional study of the Directorate of Land Reclamation (DLR), annual desilting program, warabandi and farmers organizations and conjunctive use of canal water and groundwater were the additional activities that served the projects overall objectives.

Water markets are considered by policy makers and donor agencies as a solution to irrigation constraints (insufficient and unreliable irrigation water supplies) for irrigated agriculture, which increases the efficiency of the water allocation system and increases agricultural productivity. This prompted IIMI to conduct research on water markets issues in the research sites in order to investigate the existence of water markets, feasibility of their development, and their potential for improving irrigation services and agricultural productivity.

Keeping in view the importance of gender issues in irrigated agriculture, IIMI's management decided to include a gender component in its ongoing and future research programs in its various country programs. IIMI Pakistan launched research on gender issues (role of women in irrigated agriculture) in order to explore the possibility of incorporating the gender component in IIMI Pakistan's ongoing and future research projects.

Research on warabandi, DLR operations and farmers organization were conducted in order to study their functioning and to study how they could contribute to improve system performance and minimize irrigation's contribution to salinity problems.

During Phase I, when it became clear that groundwater is contributing significantly to the total irrigation supplies, while its increased use with poor quality water is causing soil salinity

problems, it was felt that research on groundwater issues (groundwater quality, use of groundwater with surface water (in mixed or cyclic form, types of tubewells, tubewell density, operations, etc.) should be conducted for arriving at concrete conclusions and recommendations on conjunctive groundwater management for its sustained use over a long period of time.

3.2.3. Summary of Recommendations

The main conclusions from Phase I of the project conducted during 1989-1993 are:

- Inequity in surface canal water distribution and heavy use of marginal to poor quality groundwater for irrigation are the main contributors to the irrigation-induced salinity. Water shortage, poor operation and maintenance of the irrigation system, weak institutions, and illegal cuts and breaches by the farmers having large land holdings cause inequity in canal water distribution.
- Currently, the irrigation systems in the Punjab are not managed in a way to achieve the objective of equitable distribution of canal water in all reaches (head, middle and tail) of the secondary canals. This fact is reflected by poor conditions (or non-existence) of control structures in the irrigation system, outdated rating curves for flow measuring structures with the ID operating staff, significant sediment deposition in canal beds, large variations of discharge rates in the main channels, and weak institutions incapable of enforcing rules and regulations.
- Salinity is disassociated from waterlogging because the waterlogging occurrence has been significantly reduced by the operation of public and private tubewells. Salinity problems are still increasing due to inadequate amounts of irrigation water for leaching salts from the root zone and also due to use of pumped groundwater of poor quality for irrigation.
- The farming community in the tail reaches of the watercourse command areas depend heavily on groundwater supplies for irrigation due to inadequacy, or non-availability, of canal water. The conjunctive use of canal water and groundwater contributes to irrigation-induced salinity. In some cases, groundwater accounts for 50 to 70 percent, even 100 percent, of the total irrigation supplies. Also, irrigation water is posing a soil sodification hazard, which is a tremendous problem for the long-term sustainability of irrigated agriculture.
- In general, farmers are aware of the adverse effects of salinity on agricultural productivity and many farmers have the capacity of managing successfully field-level salinity by modifying their farming and irrigation management practices, keeping in view the inequity in canal water distribution and the resulting effects on soil salinity. Though farmers seem to have an idea about soil sodicity caused by using sodic groundwater, they are not able to mitigate this problem.
- Presently, the Directorate of Land Reclamation (DLR) operations are not performed as they were intended. The procedure of selecting the lands for reclamation is subjective and does not follow the criterion for salinity status of the lands. In addition, farmers are using the additional water supplies (reclamation shoots) for irrigating other lands, rather than the leaching of saline croplands, as intended.
- The groundwater markets generally improve the quality of irrigation services available to, and the agricultural productivity of, farmers involved in these markets. However, the private tubewell owners realize greater agricultural production due to their having more control over groundwater supplies.
- Institutional and management capabilities of the PID need to be strengthened in order to improve the hydraulic performance of the irrigation systems, which currently causes inequity in surface canal water supplies and increased

dependence of especially tail end farmers on pumped groundwater of poor quality, thereby causing the occurrence of more soil salinity problems. Improved irrigation system management would increase equity, reliability, and reduce the variability in canal water distribution in the irrigation system.

- Computer models are invaluable predictive tools for studying the long-term salinity trends and impacts of various salinity management alternatives upon an irrigated area. The model predictions provide guidelines that can be used to make decisions about implementation of salinity control technology in an irrigated area. However, extensive and reliable field data are essential for reliable model predictions in order to make sound decisions regarding salinity control technology implementation.

The main recommendations on the issues that need further research are:

- Because pumped groundwater is heavily used for irrigation purposes in irrigated areas, there is a need to manage effectively the conjunctive use of canal water and groundwater for minimizing the groundwater salinity/sodicity contribution to irrigated lands. More research on conjunctive use management of canal and groundwater is recommended to be undertaken in order to establish conjunctive use management requirements for safe use of groundwater for irrigation.

- Farmers organizations could prove to be more effective in increasing irrigation efficiencies by maintaining watercourse as well as distributary physical infrastructures and sustaining improved water distribution and allocation. Though some work was done on types and functioning of Water Users Associations in Phase I, further research needs to be done on this issue.

- Under inequitable and unreliable water distribution conditions prevailing in the irrigated areas, water markets offer greater potential for improved irrigation services. For arriving at concrete conclusions about the increased irrigation efficiency and agricultural productivity impacts of water markets, there is need of further research on water markets related issues.

- The management intervention implementation program should have a monitoring program to monitor and evaluate the effectiveness of the various measures being implemented, but more importantly, to refine the implementation of the management interventions.

- Cost-effectiveness analyses on various management interventions should be performed in order to find both technologically and economically feasible measures for improving the management of the irrigation systems.

- The constraints on implementation of management changes by responsible agencies need further research to arrive at concrete conclusions and consequently development of appropriate management alternatives for improving irrigation system performance. Still, a lot of work is required to have a strong institutional commitment from ID for implementing, as well as monitoring and evaluating the effectiveness of various management interventions.

3.3. PHASE II OBJECTIVES

As this Phase I was nearing its completion, the need to continue with the process of testing management interventions was widely acknowledged. The work on three management interventions was already underway. Delivery Accountability, Irrigation Management Decision Support System and Irrigation Management Information System were the three interventions started in 1992 to be completed in 1993.

The report of the Review Mission (April 1993) on the Phase I Project had raised the issue, "whether a productive agriculture can be sustained without any further damage to the environment" and added that it is a "subject that requires further monitoring and continued evaluation of the impact of changes". The Phase II Project titled, "Managing Irrigation for Environmentally Sustainable Agriculture in Pakistan", was designed to at least partially seek clarifications on this vexing issue. The new project intended to address this question and identify management interventions, which would not only try to mitigate salinity, but also promote water use efficiency and yield increases.

The broad purpose of this Phase II project remains the same as for Phase I, to develop and implement through action research a set of improved management strategies and techniques which can reduce the aggravating effects of irrigation on waterlogging and salinity; to expand the institutional capacity to effectively manage the solutions; and to maximize the role of farmers and rural communities in irrigation management for increasing agricultural production. The Project Document (pp. 5-6) lists a number of short-term and long-term objectives as derived from an overall appreciation of Phase I findings and Phase II intentions. Activities which aim to bring about institutional and management improvements in the irrigation systems of Pakistan for sustaining irrigated agriculture form the context of this project. The distribution of project objectives among these project components (as given in the Project Document) is listed in Table 3.1.

The overall activity plan of the project, including the items under the above mentioned three categories and those related to information dissemination are as given in Table 3.2 (adapted from page 21 in the Project Document). Although some activities related to this project were started in January 1994, substantive project activities for 1994 as they appear in the project document were placed in full gear only during the second half of the year. The major reason for this is that certain resource mobilization commitments had to await the formal acceptance of the project proposal. Apart from this limited cautious action, the project schedule covers a full five-year period from 1994 to 1998, despite the fact that the formal project Agreement provides for a project duration of 4 years and 3 months from 1 October 1994 to 31 December 1998.

3.4. PHASE II COMPONENTS

The objectives stated above clarify two basic propositions of this project. One proposition is that the effective management of water entering the soil can play a substantial role in reducing the adverse effects of irrigation induced problems of salinity and waterlogging, and that a concerted effort to manage the water inputs to the system would ensure the economical and sustainable use of fragile soil and scarce water resources of Pakistan. The other proposition is that an appropriate strategy for achieving this effective water management is to improve the quality and coordination of present irrigation-related institutions in Pakistan, particularly with an increased participation by water users in the management process.

Thus, the project through its three main components--operational management, institutional development and salinity management--seeks to identify measures for making a more productive use of irrigation waters, removing constraints on agricultural production, and maintaining a productive environment. A combination of field investigations, socio-economic evaluations and action research activities were planned to be undertaken within these three main project components, but the project plan recognizes the importance of having to integrate the components and sub-components of the project through areas in which common linkages can be identified.

Table 3.1. Phase II Project Objectives.

Specific Project Component Objectives	Short-Term Objectives (Main Activities Areas)
Component I. Operational Management	
Ia. Create a "visible success story" on Decision Support System for Main System Management that can be disseminated among all of the Provincial Irrigation Departments	Main System Management - Decision Support System, Punjab * Imlproved main system operations, practices in FES (550, 000 ha) with the provincial Irrigation Department (PID) in the Punjab Main System Management - Decision Support System, Sindh * Improved main system operations practices at three pilot areas in Sindh with PID
Ib. Develop irrigation management practices at the watercourse level that will alleviate trends in soil salinity and groundwater quality that threaten the sustainability of irrigated agriculture in Pakistan.	Watercourse Management - Irrigation Practices * Application of state-of-the-art technology in surface irrigation to small bunded fields for improving water and salinity management practices in FES (South) Irrigation and Drainage Project with Mona Reclamation Experimentation Project (MREP), PAD, and the Centre of Excellence in Water Resources Engineering * Application of low cost pressurized irrigation technologies for tubewell water in FES (North) with the Water Resources Research Institute (WRRI) * Improved water and salinity management practices for watercourses in the two pilot distributaries in FES(South) with PAD. The approach will be tested in FES (North) Watercourse Management - Water Markets * Improved water market practices for tubewell water in FES (North)
Component II. Institutional Development	
IIa. Develop feasible irrigation management strategies regarding Water Users Organizations that will alleviate trends in soil salinity and groundwater quality that threaten the sustainability of irrigated agriculture in Pakistan.	Water Users Organizations * Learn "how" to organize farmers as Water Users Associations (WUAs) at the watercourse level and Water Users Federations (WUFs) at the minor and distributary level with PAD and PID in the Punjab.
IIb. Create institutional support for water users organizations at both the watercourse and distributary, along with strengthening the interaction between farmers and government agencies.	Institutional Support for WUOs * Strengthen the cooperation between PIDs and PADs, as well as the interactions with WUAs and WUFs at the two pilot distributaries in FES(South) and the three pilot minors or distributaries in the Sindh. * Promote institutional measures with the provinces of Punjab and Sindh that will strengthen WUAs and WUFs.
IIc. Explore institutional arrangements for coordinated irrigation services by the provincial agriculture and irrigation departments.	Coordinated Irrigation Agriculture Services * Promote institutional arrangements with the provinces of Punjab and Sindh that will enhance government services for irrigation.
Component III. Salinity Management	
IIIa. Assist in establishment of the physical and chemical (salinity) processes occurring in: (a) the unsaturated soil profile between the ground surface and the groundwater table; and (b) the spatial and temporal variation of salinity in the groundwater reservoir resulting from pumping.	Soil Chemistry and Groundwater Management * Develop salinity analytical tools in collaboration with IWASRI/NRAP for salinity management study.
IIIb. Identify salinity management alternatives for the Rechna Doab in the Punjab using Phase-I research results and Phase II results on salinity processes in the unsaturated soil profile and the groundwater reservoir, which could then be considered for implementation by GOP in collaboration with farmers.	Rechna Doab Salinity Management * Develop groundwater management alternatives for the Rechna Doab with WAPDA.
IIIc. Assess potential opportunities for alleviating extreme condition of waterlogging and salinity in the province of Sindh that would result in environmentally sustainable agriculture for production.	Sindh Waterlogging and Salinity Management * Develop an implementation strategy for environmentally sustainable agriculture in the Indus Basin Irrigation System. * Study existing irrigation development projects in Sindh and identify ways in which severe problems of waterlogging and salinity can be more effectively managed.

Table 3.2. Overall Project Schedule

SCHEDULE OF MAJOR ACTIVITIES						
Obj	**Activity**	**1994**	**1995**	**1996**	**1997**	**1998**
Ia	Decision Support System – Punjab					
Ia	Decision Support System – Sindh					
Ib	Watercourse Management					
IIa	Water Users Organizations (WUOs)					
IIb	Institutional Support for WUOs					
IIc	Coordinated Irrigation Agriculture Services					
IIIa	Soil Chemistry and Groundwater Management					
IIIb	Rechna Doab Salinity Management					
IIIc	Sindh Waterlogging and Salinity Management					
	Workshops					
	National Conference					
	Final Report					

A strong link exists between the Watercourse Management sub-component and the Water Users Organizations sub-component, as the related set of research activities and the set of social organization measures can mutually reinforce each other. A similar strong link exists between the Main System Management sub-component and the Institutional Development component. The pilot projects attempting to establish viable water users organizations for O&M responsibilities in the distributaries and watercourses can benefit very much from the project's research on decision support systems being tested upstream from the pilot distributaries.

These linkages are not surprising since each sub-component is a subsystem of an entire irrigation system. The productivity is located on the croplands, but the operating characteristics upstream dramatically impact agricultural productivity. Thus, it is usually essential to diagnose the entire system in order to develop cost-effective solutions for increasing agricultural productivity that will ensure the long-term sustainability of the system.

A schematic diagram depicting the Activity Framework for this project is shown in Figure 3.1, which illustrates the: (a) physical system; (b) operational responsibilities; and (c) project activities. The Decision Support System activities in the Punjab and Sindh are being undertaken with the PIDs to improve the timeliness of water deliveries and reduce the daily discharge variability in canals and branch canals, both of which significantly affect irrigation practices and subsequently, crop yields. The second component on institutional development is concerned with organizing farmers at the distributary and watercourse levels so that they can achieve better equity in water distribution among watercourses, as well as better water distribution to farmers along watercourses.

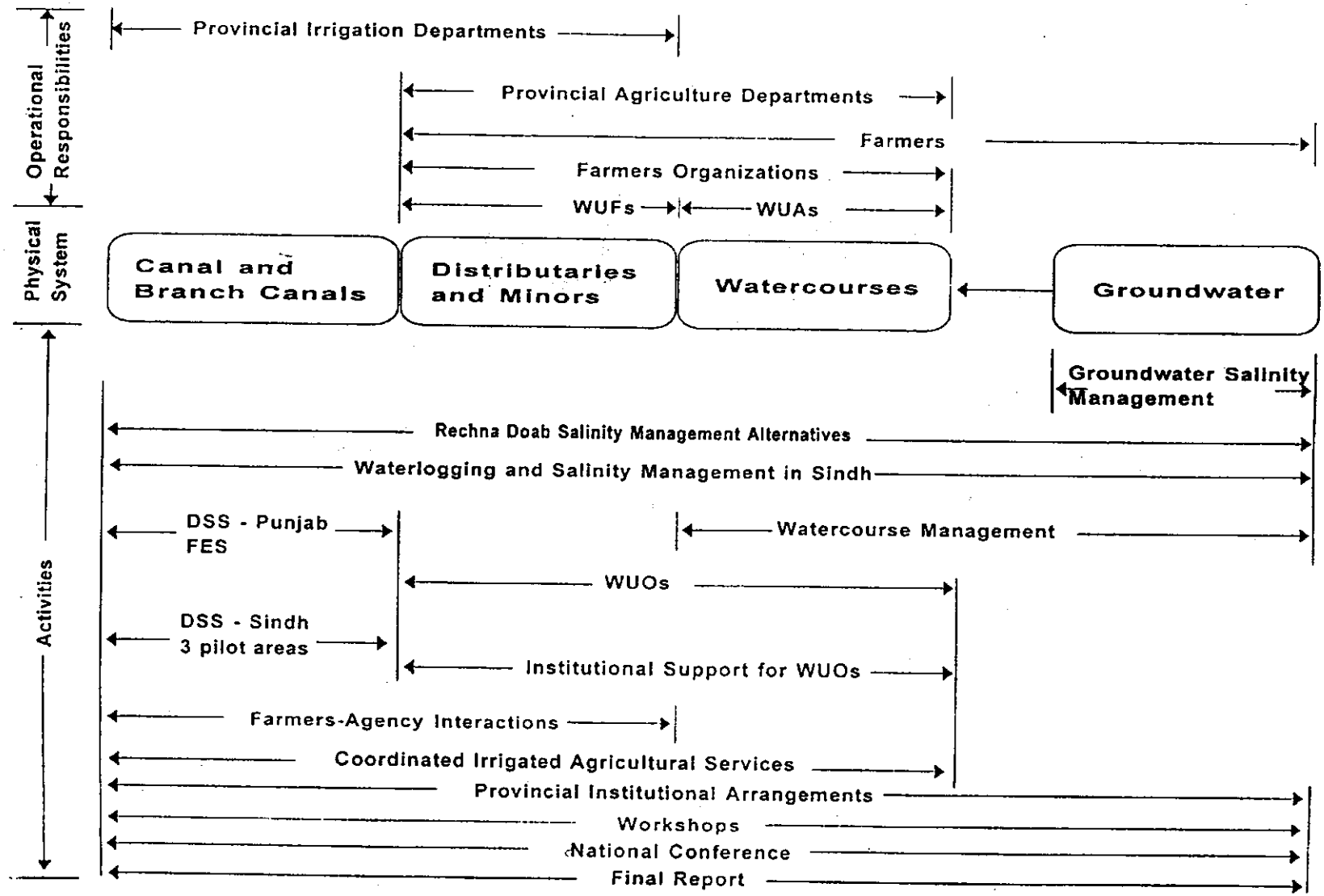

Figure 3.1. Framework for Project Activities.

PART B
RESEARCH RESULTS

4. ROLE OF WATER USERS IN DECENTRALIZED MANAGEMENT

4.1. DECENTRALIZATION OF MANAGEMENT

4.1.1. Increased Centralism

In developing countries such as Pakistan, water resources development for irrigation and other water uses has shifted from small systems built, owned, operated and maintained by local communities during ancient times to large systems constructed and managed by a central agency. These large systems were built by governments of these countries with the financial and technical assistance of donor organizations or colonial governments. Over time, these management agencies of the government have gradually become more centralized and further removed from the water users.

Ironically, while the irrigation management has become more centralized, the authority of centralized management agencies has declined as societies and economies have become more liberalized. Structurally, the state irrigation agencies are authoritative, and hierarchically ordered, but functionally, they have become less effective, as they are rigid in procedure and static in management style. Many agree that the continued centralized management approach is one of the main reasons for low and declining returns on investment in irrigation, and has been one of the major concerns among the donors and governments of developing countries. The most recent response to this concern is the movement to *privatize* or *turn over* the responsibility of large portions of water delivery and drainage systems to water users groups.

4.1.2. "Turnover" of Irrigation Systems

The turning over of irrigation systems, or parts thereof, to water users groups is a top-down approach, and is popularly referred to as a process of "privatization". Despite many attempts at "turnover" or "privatization" in various parts of the developing world, there has been limited success in establishing a viable institutional framework that is responsive to current needs for sustainable development. This failure can be attributed to the following factors:

- The term "privatization", in developing countries, is often associated with industrial privatization, which, in many cases, has the stigma of favoring a few privileged individuals.
- The capability of water users to manage large systems is often limited. Large proportions of water users in developing countries are socially vulnerable, politically unorganized and economically weak.
- The top-down strategy of imposing institutional changes on management groups and water users is often resisted by the strong technocratic and administrative culture that exists in the region, and resented by an uninformed community of water users who are accustomed to receive benefits from subsidized irrigation management.
- Water users see no meaningful incentives for taking over additional responsibilities for water management.

4.1.3. "Decentralization" as an Alternative Strategy

An alternative to the "privatization/turnover" approach is a strategy of decentralizing the management of water resources. The decentralization for water management can be considered a confluence of interest of the government as well as the water users. This strategy can be most effective if it is implemented in a gradual manner, allowing the various actors to participate in its planning process. The main reasons favoring such an approach are that:

- the authority to enforce top-down rules from the center is declining;

- the direct cost recovery is in disarray and the capacity to subsidize is also declining;
- a local level decision to take over part of the system is most likely to be based on local capacity to mobilize resources; and
- the transfer of knowledge and technology can be more effective through decentralized units.

Most top-down planning decisions to turnover irrigation systems are often taken without much consultation with the water users groups. In contrast, a strategy to decentralize the management strategy would be done in a participatory mode and include the following key elements:

- Assessing the capacity and the willingness of water users to manage parts of the water delivery/drainage system;
- Providing empowerment (enabling legal framework, training and other incentives) from the "top" to those who are to manage the system;
- Decentralize to a level where effective local management is possible, and decentralize those functions that cannot be effectively managed by the center; and
- The process and levels of decentralization should be developed through negotiations by the various groups so that consensus can be reached before implementation.

4.2. USERS ORGANIZATIONS IN DECENTRALIZED MANAGEMENT

4.2.1. Theoretical Justification

Organized water users form an essential part of the improved institutional framework in a strategy of decentralizing irrigation management. An appropriate short definition of the word "institution" in this instance is the one chosen by John R. Commons in 1934; "an institution is collective action in control of individual action". The word "control", which is used in a broader connotation here, means a number of measures that a group collectively takes, and relates to individual action for the purpose of improving the group's overall benefit. Generally, the group tries to enhance individual action, but considering the fact that some persons' enhanced actions can adversely affect the welfare of the others, the group also has to restrain individual action whenever necessary. Thus, as derived from this particular definition, "an institution is collective action in restraint, liberation and expansion of individual action" (Parsons 1984:28).

The view of a water users organization as an institution, based on the definition adopted above, is of special relevance to the context in which the users organizations have to be considered in Pakistan's irrigation canal systems. With the social conditions prevailing in Pakistan, any useful collective action in the canal system should necessarily mean a combination of both the liberation and the restraint of individual action. For example, while individual action has to be expanded for undertaking maintenance work, and liberated for realizing individual rights and effectively interacting with officials, it also has to be restrained for reducing anti-social and "free-rider" behavior among themselves. Provided that such a perception can be built among the water users community, the definition used by Commons suggests that the users organizations can serve as a very valuable institutional remedy to address the present situation in Pakistan's irrigated agriculture in taking over part of the management responsibility.

Viewed this way, an effective water users group should be able, not only to mobilize its individual members for expanding and liberating their production oriented action, but also to agree for restraining their action to ensure equity-oriented behavior. An appropriate

combination of the two functions would then serve to increase the overall benefit of the group. Within a channel command, there can even be a small group of people who tend to exploit the others. An important issue is whether they can be absorbed into collective action for common benefit. The possibility lies in what Gandhi once said. "Exploitation of the poor can be extinguished not by effecting the destruction of a few millionaires, but by removing the ignorance of the poor and learning how to resist the actions of their exploiters. That will convert the exploiters also."

4.2.2. Past Experience

Past experience in state sponsored interventions to organize the water users in Pakistan has not been a great success. One reason for this failure may be associated with the project-based bias towards the more tangible, target-oriented and engineering-related activities by the water users. Once this limited involvement in lining and improving watercourses, a task that was purportedly used as an incentive for social organization, was accomplished, the "WUA" that was formed for the purpose collapsed. In fact, the activity itself was a doubtful incentive for the farmers to organize themselves for collective action. As the task of improving watercourses could have been undertaken with minimum organized behavior by the individuals, it did not lead to sustainable organizations.

Based on this experience, Pakistan may test the proposition that managing water as a resource is itself an important task to be gainfully accomplished through collective action by the organization. One of the important objectives of any future interventions in organizing water users in Pakistan should be to test whether organized water users can manage water more productively and more equitably, if they were to be given the responsibility, not only at the watercourse level, but also at the distributary canal, or even higher levels.

4.3. Action Research on Water Users Organizations

4.3.1. Action Research Objectives

The main objective of the action research program was to test the viability of farmers organizations managing parts of the water resource system so that more efficient and equitable allocation of water can be achieved. In order to achieve this objective, five main activities were planned:

1. gain an understanding of the existing internal social dynamics of the community in the pilot area;
2. help establish water users organizations (WUOs) in selected distributary canal command areas using a slow step-wise social organization process;
3. train the members of the WUOs in conducting meetings, identifying and planning maintenance activities, financial management, and taking collective choice decisions related to water resources management;
4. assist the WUOs in undertaking distributary canal level water resource management in the pilot sites with the maximum involvement of the individual farmers on the basis of joint management agreements between WUOs and irrigation authorities; and
5. identify legal requirements and institutional processes that would be necessary for effectively organizing and strengthening WUOs on a wider scale.

As indicated earlier in Section 4.1.1, the broad conceptual approach underlying the pilot project had more specific expectations for the future progress of participatory management:

- that the WUOs would eventually be accountable for the water received at the head of distributary canals;

- that the WUOs would be responsible for distribution of water among the member water users associations (WUAs) at the watercourse level according to their own agreed allocation rules;
- that the WUOs and their member WUAs would be responsible for managing groundwater levels in their respective command areas;
- that the WUOs would reach an agreement with their members, as well as with the agencies, for assessment and collection of appropriate water charges and/or operation and maintenance (O&M) costs of irrigation and drainage facilities in their distributary command areas; and
- that they will undertake the collection of water/drainage charges, improve water management practices and other activities related to the use and disposal of irrigation water, including the maintenance of irrigation and drainage facilities.

To realize these expectations, the action research design further conceptualized that the WUOs would be able to develop and enforce appropriate internal by-laws, which will be binding on their members, and resolve any water-related disputes that may arise among them. It was envisaged that some "social engineering" by the social organizers would be able to catalyze this process so that the WUOs and their members would agree upon a set of rules, rights and responsibilities.

4.3.2. Hakra 4-R Distributary: the Pilot Site

In selecting an appropriate pilot site for this purpose, the following criteria were developed in consultation with the operating agencies:

1. Working in a distributary within the World Bank-funded Fordwah Eastern Sadiqia (South) FES(S) Irrigation and Drainage Project area could help IIMI to associate this work closely with the pilot projects undertaken by the OFWM Directorate for similar work under the FES(S) Project;
2. Preferably, the selected distributary should not be too small or not very large so that the pilot effort will be with average physical and socio-economic conditions;
3. Selecting a distributary where IIMI or any other agency or research institute had not intervened recently would provide a more receptive farmer group;
4. The distributary should preferably have farmers of a mixed background - - a mixture of local people as well as old and recent settlers;
5. A distributary having a number of hydraulic structures would help the water users groups to monitor the discharges in terms of space and time;
6. A distributary in which watercourses had not been completely improved under the OFWM program would allow the water users to see the need for physical improvement as an incentive for organization as WUAs at the watercourse level; and
7. A distributary having a sizable minor would allow two secondary systems to be used for pilot experimentation within the same distributary command area.

On the basis of these criteria, Hakra 4-R Distributary, located within the FES(S) project area, was selected for the action research. The presence of two minors and a number of hydraulic structures along the main distributary channel made it possible to have monitorable water flow regimes for different sections of the command area.

The Distributary No. 4-R in the Hakra Branch Canal of the Fordwah Eastern Sadiqia irrigation system is one of the larger distributaries in the Punjab Province. It has a total discharge of 5.46 cubic meters per second (cumecs), or 193 cusecs, and a total of 123 irrigation outlets (watercourses) serving a command area of nearly 18,000 hectares. Within this distributary

system and its two minors are 1RA Labsingh, with a discharge of 0.6 cubic meters/sec (22 cusecs) and 16 watercourses, and 1R Badruwala, with a discharge of 1.22 cubic meters/sec (43 cusecs) with 33 watercourses.

The study area, which is located in the south-eastern part of the Punjab Province, covers parts of the tehsils Haroonabad and Bahawalnagar of District Bahawalnagar. The average annual rainfall ranges from 125 mm to 250 mm. A hot and dry climate, low rainfall and unfit underground water necessitates an ensured and regular supply of surface irrigation water.

Some details of the pilot distributary are given in Table 4.1.

Table 4.1. Some Details of Hakra 4-R Distributary.

Channel	Length (Kms)	Design Discharge cumecs (Cusecs)	Authorized Withdrawal cumecs (Cusecs)*	No. of Outlets	CCA (Acres)	No. of Shareholders
Main distributary channel	36	5.6 (193)	3.0 (106)	75	27,100	2,775
1-RA Minor Labsingh	7	0.62 (22)	0.6 (21.8)	15	6,100	565
1-R Minor Badruwala	15	1.22 (43)	1.13 (40)	33	10,200	1,350
Total	58		4.73 (168)	123	43,400	4,690

Cropping Pattern: The yearly variation in the cropping pattern is generally non-existent. For the *kharif* or summer season, cotton, sugarcane and rice are the most popular cash crops. Sorghum, Bajra, Maize and Jantar are sown as fodder.

Occasionally, vegetables are also sown. During the winter or *rabi* season, wheat, although less profitable, is the most popular crop, while berseem is the main fodder crop generally sown for feeding the domestic livestock. Some of the farmers also cultivate vegetables and oilseeds, and on a few farms, orchards, especially of the citrus family, can also be seen.

Groundwater: Groundwater in this area is generally considered unfit for irrigation. However, due to a shortage of canal water, and inequity and unreliability of canal water supplies, farmers have been compelled to look for groundwater. About 237 shallow tubewells are located in the distributary command area.

Canal Water Supplies: In a water measurement test conducted on 26 October 1995, the Hakra 4-R Distributary received a discharge of 6.6 cumecs (232.7 cusecs) against the sanctioned discharge of 5.48 cumecs (193 cusecs), roughly a 21 percent increase. All the outlets were calibrated and discharge measurements were taken. Against the authorized discharges of 3.01 cumecs for the main distributary outlets, 0.62 cumecs in Minor 1RA and 1.14 in Minor 1R, the actual withdrawals were 3.58 cumecs (an increase by 19%), 0.69 cumecs (115% increase), and 1.71 cumecs (50% increase), respectively.

The People: The rural life in this part of the Punjab Province is very hard indeed, mostly due to scarce canal irrigation resources, unfit underground water, and the so-called twin menace of waterlogging and salinity. The Hakra 4-R Distributary command area consists of about 40 villages including small deras (hamlets), having a population of about 66,945 according to the census of 1981 (the projected population for 1995 for this area is about 101, 880). The majority of these people are settlers and migrants. The major castes are Rajput, Arian, Jat, Joya and Watto.

The baseline socio-economic survey conducted during July-August 1995 on a sample of 367 respondents selected from 13 out of the 123 watercourse commands provided some information about the socio-economic features of the pilot site. The following are some of the main features that could be identified.

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- The average family size was 9, out of which school going children were 2.
- Land is a major determinant of farm income, and control over land has a strong association with the adoption of new farm techniques. A majority of the farmers (55.9%) owned up to 5 acres of land on the Hakra 4-R Distributary, whereas 6 percent owned land of 25 acres or above.
- A majority of the respondents (61.6%) were found to be illiterate.
- The organizational behavior of the sample farmers was clearly evident on two issues i.e., the maintenance/construction of mosques and the maintenance of watercourses. The respondents showed considerable organized behavior; 94 percent had participated in collective action in maintaining or constructing the village mosque, 90 percent in maintaining the watercourse, and 20 percent in desilting the distributary.
- About 69 percent of the respondents were dependent on state assistance; they felt that the unsatisfactory water distribution situation could be solved by the agency staff, if they wished to do so.
- About 45 percent of the respondents reported inequity among distributaries, and of this, 23 percent attributed the problem to the "influentials".
- About 80 percent referred to inequity within the distributary, and this number ranged from 67 percent in the head reaches to 84 percent in the tail reaches; most of the respondents attributed the problem to big landlords and irrigation officials.
- None reported inequity within the watercourse.
- The cropping intensity was 122 percent higher at the head reaches (147%) when compared to the tail reaches (97%).
- The average farm income was Rs. 78,963 for an average operated area of 13.25 acres, as reported by the respondents.

4.3.3. Methodologies to Suit the Context

Considering the large command area and its large population, the action research design sought to adopt a methodology of facilitating a social organization process, which, if found to be successful in the pilot area, could be easily replicated on a wider scale.

Many people, both within and outside the country, asserted that organizing water users for distributary level management in Pakistan was a very difficult task; some believed that it was impossible. Most of the contextual factors described in the earlier sections of this report contributed to this perception. Preliminary field investigations also indicated that organizing water users for a federation at the distributary level was going to be an enormously difficult task. Only some of the watercourses in the pilot area had experienced the formation of WUAs sponsored by the OFWM, and these WUAs were already defunct. The water users in these watercourses were particularly hostile to the idea of yet another attempt to "organize" them. People in the area appeared to be overwhelmed by problems of salinity and unproductive farming, and showed little patience to listen to possible long-term solutions.

4.3.3.1. Methodological Features

The given social context demanded a fairly cautious and slow process of social organization, carefully designed with adequate trust-building strategies, whereas, the physical context of the large contiguous canal irrigation system called for designing a method of appropriately sharing the management responsibility. On the basis of these two main requirements, four special methodological features emerged as significant contributions from this action research: 1) deployment of small social organization field teams consisting of persons with a

strong local background; 2) use of community-based volunteers; 3) non-dependence on externally funded physical improvements as an incentive; and 4) a step-wise social organization process.

Locally Recruited Small Field Teams as Catalysts: The preliminary stages of the action research program found that a community that is normally suspicious about outsiders, strangers, and new ideas, preferred to listen to local opinion leaders. The project staff who were directly involved in field activities were all locally-recruited, and were able to break this barrier of mistrust. Two other characteristics of the field teams helped in this process. The field team at each pilot site was kept at a minimum size of five, with a combination of formal training background of social science and agriculture engineering. The disciplinary combination helped in handling the strong socio-technical linkage that characterizes water resource management for irrigated agriculture, whereas, the small size field teams were successful in maintaining close interactions with the community. The small size of the team also meant easy replicability of the catalytic effort on a wider scale. The training given to the Social Organization Field Teams[3] on project objectives and methodologies became an asset when they had to reflect the special features of the project design in their field work. A fair understanding of the institutional implications of irrigated agriculture was considered important in motivating people to see the value of social organization. This training also helped the staff in undertaking self-assessment of their field operations and collective action.

Community-Based Social Organization Volunteers: To supplement the small field teams, a strategy was adopted to use community-based volunteers in social organization work. Initially, the project decided to call these volunteers "contact farmers" because they had to play a pivotal role as a contact between the field teams and the community. Selecting some suitable persons from the local community to be deployed as "contact farmers" was an important strategy in the social organization process. The term "contact farmers" was found to be associated with the "influentials", big land owners and farmer leaders of the T & V system adopted by the Agricultural Extension Directorate. Since the use of these elitist contact farmers had not resulted in the proper functioning of the T&V system, the term had an unfavorable connotation. In order to avoid farmers' mistrust from the start, the term "contact farmers" was replaced by the term "Social Organization Volunteers" (SOVs).

Training as a Motivating Influence: An idea drawn from international experience was the value in "putting people first" (Cernea, 1985). During the reconnaissance surveys in the pilot project area, many water users inquired about the package of physical incentives planned for the project. They were accustomed to the government subsidies on watercourse lining and tubewell development, etc. A considerable effort was spent to convince the water users of the need to get organized first so that a form of collective action could benefit more from whatever the government could deliver, or from their own resource mobilization initiatives. They were eventually convinced of this approach towards self-reliance.

Non-dependence on Externally Funded Physical Improvements: The project did not have access to funds allocated for any physical improvements to be effected in the pilot sites. This was a major deviation from the usual social organization project designs adopted earlier in Pakistan and elsewhere in the region. Both OFWM and CWM programs had physical improvements as the main task, and the associated institutional development component was to enable this primary task. Consequently, both programs could not achieve any meaningful results from the second objective. Instead of physical incentives, this action research program planned to use training as an incentive for organizational interactions. The participatory approach adopted throughout the project period typically suited this strategy, and a series of

[3] The term "SOFTware" was coined by the IIMI's staff in the Hakra 4-R Distributary pilot project in Punjab to distinguish these Social Organization Field Teams from IIMI's other teams engaged in more technical work.

training programs and similar interaction programs were helpful in maintaining a steady level of enthusiasm among the water users.

The motivational effort, through training and information sharing, was also to engage the water users in building awareness, confidence and mutual trust. There was no monetary incentives and no promises of physical assets. The training inputs were incorporated into other social organization activities, the interventions being in a slow process, monitoring the effect of each step and building on it. The strategy was also to share project-related information with the water users in frequent meetings with small and large groups in places considered "neutral", such as schools, mosques, playgrounds and other community meeting places. Water users showed a greater interest in learning about the physical aspects of the irrigation and drainage systems than about proposed organizations. This was quite natural as the physical sub-system of an irrigation system would be foremost in the minds of the people. They would like to hear about quantity and quality of water they receive, sedimentation in their canal system, and the conditions of the structures. They are also keen to know about new crop varieties, agricultural inputs and modern cultivation methods for conserving water.

Step-Wise Process: In this scenario, taking some preliminary steps to assess the existing potential for change before embarking on introducing new institutions was considered a prudent strategy. There was a need to first "sense the environment" and assess the pulse of the people regarding institutional change, and then identify the scope and content of possible change and determine the style of interactions with the community before even deciding on a time-frame for project activities. Most of these steps were taken collectively with the water users themselves.

4.3.3.2. Process for Organizing Water Users

In the gradual step-wise approach chosen by the project, the process of organization of water users was designed to encompass four phases:

1. Support mobilization;
2. Initial organization;
3. Organization consolidation; and
4. Organizational action.

A flow chart of this four-phase process[4], which was developed during project inception was a guide to implementing project activities. This flow chart is reproduced in the Annex of this report.

The support mobilization phase was a "get set" stage during which the field teams were mobilized and trained, initial collaborative arrangements were discussed with the staff of OFWM, PID and other irrigation-related agencies, selection of the pilot sites was finalized, members for a field level coordination committee were identified, and initial baseline information was collected.

In the second phase (initial organization phase), some progressively advancing steps in interacting with the community were taken. The core social organization field activity was implemented during this phase. Starting from a familiarization program, the field teams and the social organization volunteers proceeded through three other series of interactions, and finally reached the culminating step of forming the water users federations.

The organizational consolidation phase included a series of capacity-building programs to provide WUO leaders and their members with the necessary knowledge and skills to engage in actual water resources management tasks. Registration of WUOs with the OFWM Directorate

[4] This four-phase process for water users organization activities in Pakistan was adapted from the M & O guidelines given in Skogerboe et al (1993).

under the Water Users Ordinance, and the preparation of joint management agreements (JMAs) between the distributary level water users federations and the PID were two important tasks undertaken during this phase. The last phase is meant to give effect to the provisions of the JMAs.

In this organizational development process, many actors would need to contribute. A design team coordinated the planning effort, and collaborated with the social organization field team located in the pilot site. The selected SOVs and a Field Implementation Coordination Committee (FICC) were the other partners in the field. The FICC consisted of representatives from various agencies providing irrigated agriculture services to the farmers, including the civil administration, and selected farmer representatives. Social organization activities were supported by some collaborative activities by various agencies. The idea of conducting collaborative activities was to maintain the water users' interest on the action research program. A facilitator, such as IIMI, would play a catalyst role in bringing various line agencies and other service delivery groups to the water users on their request. The overall process described above is depicted in Figure 4.1.

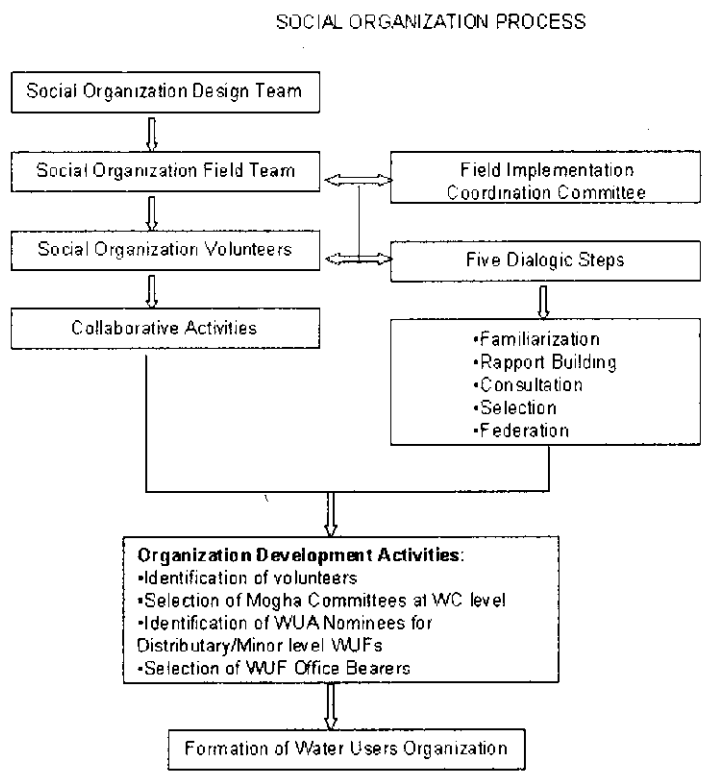


Figure 4.1. Social Organization Process.

4.3.3.3. Five Dialogic Steps

An important feature of the iterative process was the progressively enhanced interactions in a series of meetings with the water users, which culminated in forming a water users federation in the pilot area. Adopting a step-wise approach, and building on the steps already taken, the process advances towards the group behaving on mutual trust, sharing information, consulting for consensus, developing options and implementing an appropriate organization design. Since the interactions were between the catalysts and the water users, the stages of this iterative process of social organization was named "Five Dialogic Steps" as indicated below.

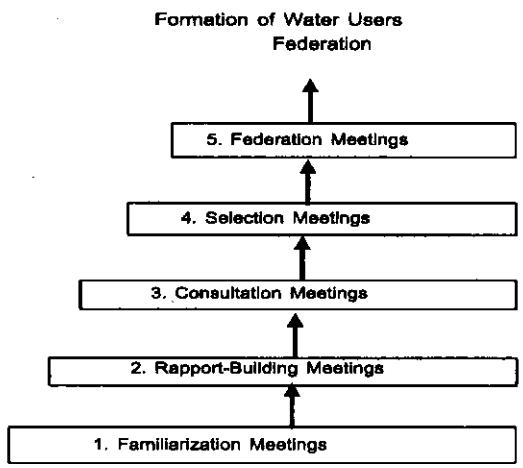


Figure 4.2. Five Dialogic Steps Leading to the Formation of a Water Users Federation.

First Dialogue: A series of "familiarization meetings" to get to know the area and the people in general, and to introduce the purpose of the field team's visit to whomsoever were met in the command areas, the idea of the pilot project, and its proposed activities.

Second Dialogue: A series of "rapport-building meetings" to meet with the identified SOVs and a few other water users in small groups. The main purpose was to explain the objectives, status and programs of IIMI and build up fellowship with the SOVs and their colleagues.

Third Dialogue: A series of "consultation meetings" to consult as many water users as possible to develop tentative plans for establishing water users organizations. The meetings were to be in groups larger than those used for "rapport-building" meetings. These consultation or planning meetings formed a crucial step in the social organization process to ensure that the water users knew the project objectives clearly, and to follow up on earlier rapport building meetings for clarifying any misunderstandings among the people regarding the program.

Fourth Dialogue: A series of "selection meetings" for the purpose of discussing the process for selecting or electing organizational leaders at the primary (watercourse) level. After clarifying the elements of a democratic method for this purpose, meetings were held for each watercourse to select the organizational leaders. With wide publicity and extensive personal interactions, an attempt was made to have the maximum number of water users in each watercourse to participate.

Fifth Dialogue: "Federation meetings" to initiate the identification of office bearers for the pilot Water Users Federation. During these interactions, the water users were encouraged to select the watercourse nominees, who would form the general body of the federation in the pilot area, and then proceed towards selecting the WUF leaders.

4.3.3.4. Three-Tier Structure As a Strategy

One of the project objectives has been to ensure maximum participation of the water users in irrigation management decision making. Past experience shows that water users' participation at the tertiary level can accomplish satisfactory results in mobilizing resources and making decisions related to short-term objectives, such as watercourse lining or improvement.

However, after the completion of this task, the water users associations were no longer sustainable. The main reason was the lack of a long-term purpose for organized collective action. If the organizational effort is moved upstream to a higher level (distributary or minor level), the assumption is that more meaningful and longer-term purposes for organization could be found. For instance, a water users organization at this higher level could achieve the maximum possible participation in "joint management" of the irrigation system. Logically, users' participation would contribute to improving the efficiency, equity, reliability, productivity and sustainability associated with the use of irrigation water resources. In considering the large size of the Hakra 4-R Distributary, two planning objectives emerged:

1. In the context of a large number of water users, how best can they be offered an equal opportunity for participation in the process of selecting their leaders and eventually forming water users associations (WUAs) and the water users federation (WUF)?
2. How best could the size of the command area be used in identifying longer-term functions for the water users organizations[5] (WUOs)?

The traditional way of organizing water users associations (WUA's), one for each watercourse, and then federating them to form a water users organization at the distributary level was considered too time-consuming, and likely to delay the process of accomplishing project objectives. To optimally use the time available, and limited resources, it was necessary to think of an appropriate alternative method for reaching the distributary level fairly quickly. A different approach also would help to avoid the perceived "WUA images" associated with the government sponsored water users associations.

Considering these project constraints, the chosen alterative approach was to define a set of intermediary sub-systems within the Hakra 4-R Distributary, between the watercourses and the distributary, for organizational purposes.

Five logical sub-units or sub-systems were identified. This division was based on the existence of two minors in the distributary, and the possibility of dividing the main distributary channel into three reaches i.e. head, middle and tail, preferably in terms of hydraulic structures along the main distributary. The five sub-systems seemed to be appropriate units for social organization action research, for the following reasons:

1. The division of the distributary on the basis of hydraulic structures would help in monitoring the discharges in terms of time and space;
2. Medium sized groups would be more suitable for effective social organization at the initial stages;
3. Initial representation at this intermediary sub-system level would enable an equality of opportunity to be achieved by the water users in gaining membership in executive committees for participation and decision making;
4. Water users groups can be identified in terms of clusters of watercourses (in each sub-system), which would help in arranging meetings, discussing problems and resolving disputes more effectively; and
5. The initial identification of these sub-systems would help in generating common interests on possibly common problems.

Specifically, the following division was adopted in consultation with the water users:

Sub-System 1 -- RD 00 To RD 46.30 on the main distributary channel;
Sub-System 2 -- RD 46.30 To RD 72.10 on the main distributary channel;

[5] WUOs is the generic term to mean WUAs and WUFs. In this instance, the organization at the intermediary level of Sub-system or Zone is referred to as Sub-system WUO, or Zone WUO.

Sub-System 3 -- RD 72.10 To RD 112.05 on the main distributary channel;

Sub-System 4 -- Minor 1RA – off-takes at RD 23.2 on the main distributary channel (Length: RD 00 to RD 22 on Minor 1RA); and

Sub-System 5 -- Minor 1R – off-takes at RD 72.10 on the main distributary channel (Length: RD 00 to RD 50.623 on Minor 1R).

Important characteristics of these sub-systems are given in Table 4.2.

Table 4.2. Important Physical and Social Aspects of Identified Sub-systems of the Hakra 4-R Distributary.

Sub-system	No. of Irrigation Outlets	Lined Watercourses	Gross Command Area (acres)	Culturable Command Area (acres)	Authorized Withdrawals (cusecs)	Number of Tubewells	No. of Share-holders@
1 Head	25	6	10,350	9,435	34.97	43	735
2 Middle	23	17	8,190	7,030	29.13	45	1,010
3 Tail	27	16	12,220	10,635	41.95	82	1,030
4 Minor 1RA	15	6	6,930	6,100	21.85	16	565
5 Minor 1R	33	21	11,650	10,200	40.24	51	1,350
Total	123		48,250	43,400	168.14$	247	4,690
Avg/outlet			392	353	1.34	2	38

@ The number of shareholders have been extracted from the outlet register of the Irrigation Sub-divisional Office at Haroonabad. As these figures are not frequently amended, recent sub-division of land due to transfer of ownership may not be accounted for in many of the outlets.

$ Total authorized discharge of the distributary is 193 cusecs. Here, only authorized withdrawals for different outlets have been summed up and do not reflect the seepage allowance and withdrawals by municipal water supplies.

In terms of WUO functions, the sub-system organizations would be able to monitor more closely the water distribution among the watercourses within their respective sub-system areas. Maintenance of the distributary or minor also would have a more intimate supervision and an organizational attention. The office bearers of each sub-system will have responsibilities for resource mobilization for this purpose, a function they have to accomplish in very close collaboration with individual member WUAs. The only difficulty is that these sub-system organizations need to be legally recognized.

Dividing the distributary command area into five sub-systems facilitated the process of organization. The water users of each watercourse were to meet separately and identify one nominee to be their representative at the sub-system organization, and the members of each sub-system organization were to identify five representatives from each sub-system group to serve on the Water Users Federation. Finally, the twenty five members of the distributary level organization would select their office bearers. The three-tier structure can be seen in Figure 4.3.

4.4. Farmers Organizing Farmers: the Role of SOVs

Organizing people is a socially sensitive and politically vulnerable activity. This is not a task to be solely undertaken by an international institute like IIMI; rather, it should be the responsibility of local people (i.e. local agencies and the water users) themselves. An internally generated demand for social organization has a greater chance of making these organizations productive and sustainable. IIMI, as an agent of change, or a catalyst, could only provide a facilitating role in this process, based on its international experience, by helping the organizers to proceed in both a professional and a systematic way.

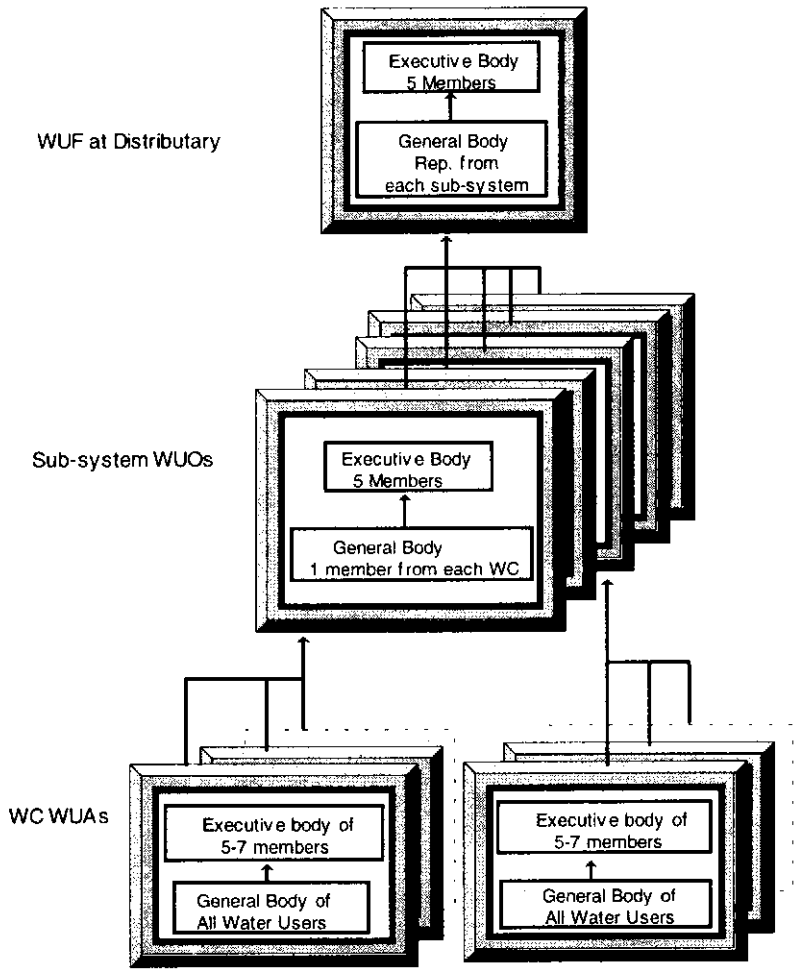


Figure 4.3. Three-tier Structure for WUOs.

IIMI's decision to look for assistance from the community itself for reaching the community at large was compatible with this thinking. IIMI did not exclusively rely on the water users alone, but identified members of the community in general who were adequately informed about the community and its needs, and prepared to assist IIMI's field team. The members of this extended field team were based in the community, knew the people fairly intimately, and shared their language, beliefs, traditions, rituals, needs and problems. The methodology had the following advantages:

- **Interventions could be routed through local people, causing little room for mistrust;**
- **The SOVs could reach the community in the large pilot distributary command area fairly quickly, partially meeting the project's time constraint; and**
- **As SOVs were deployed on a voluntary basis, the method was cost-effective and could easily be applied on a wider scale.**

As the activity of organizing water users involved a complex social organization process, it was important to select the correct type of persons as SOVs. For this reason, a number of factors had to be considered. The main criteria for selecting SOVs were that an SOV should:

- **be imbued with an initiative for working with the community, and should see the value in collective behavior for a common good;**

- be honest so that water users would believe him;
- possess communication skills, a willingness to engage in a two-way communication so that the SOV could disseminate the SOFTware messages to the community, and also be able to communicate effectively with the outsiders who came to collaborate with the local people;
- be well informed about the area, local languages, castes, traditions, rituals, and other community characteristics, and details on water and land resources in the area, and generally about irrigated agriculture;
- be a non-controversial person and not anti-social in any way;
- be educated, having potential and ability to be trained to become a community based social organizer;
- have experience in speaking at a public gathering (an added advantage);
- not necessarily be a farmer, a big land owner, or an influential; and
- not be an aspirant to any office of the WUO, nor expect any reward from SOFTware for services rendered.

After the new methodology for identifying SOVs to help the field team was introduced in December 1995, the process started to take off smoothly. By mid-May 1996, the SOVs were identified in all of the 41 villages. The number of identified SOVs varied between 2 and 6 per village; two in cases where the village was small and homogenous, and more as the heterogeneity within the village increased. In most of the villages, the number of selected SOVs was between 4 and 5. However, no strict criteria were followed for deciding on the number of SOVs per village. The distribution of SOVs by sub-system is given in Table 4.3.

Table 4.3. Details of Social Organization Volunteers.

Sub-system	Number of Villages	Number of W/Courses	Number of Water Users Contacted	Number of Persons Referred as SOVs	Number of Persons Selected as SOVs
1	9	25	146	159	29
2	9	23	132	120	30
3	8	27	63	108	32
4	4	15	83	28	13
5	9	33	61	140	54
Total	396	123	486	555	1587

Table 4.4 reveals that almost all of the SOVs owned some land. Some of them had their own land and also cultivated land on rent or share-cropping. Only two SOVs belonging to the middle reach did not own any land. Understandably, in general, the people had preferred to select those who own some land as they believed that the persons who did not own land could not understand the problems related to irrigated agriculture, or their interests might be different. The caste structure indicates that the water users from each of the sub-systems preferred SOVs predominantly from one or two castes. It appears that each village had to some extent one caste as the major caste and most of the farmers tended to prefer people from that major caste as SOVs.

[6] Apart from these big villages, there are many small additional settlements called azafi basti or tibba (farm houses and hamlets).

[7] After the initial selection, adjustments were made, including some additions and deletions to this number during the awareness building meetings.

Table 4.4. Important Socio-economic Characteristics of the Social Organization Volunteers Identified by Sub-system.

Characteristics	SUBSYS1 Head Reach	SUBSYS2 Middle Reach	SUBSYS3 Tail Reach	SYBSYS4 1RA Minor	SUBSYS5 1R Minor	Hakra 4-R Disty
SOVs (Number)	29	30	32	13	54	158
Average Size of Operational Holding (Acres)	47.22	39.23	20.42	23.46	35.70	34.38
Owner-Cultivators (Percent)	100	93	100	100	100	99
Educated (Percent)	66	80	75	77	80	76
Matric & Above (Percent)	31	53	41	38	52	45
Resident within Village or at Farm (Percent)	100	97	100	100	98	99
Politically Neutral (Percent)	27	33	81	69	11	37
Community/ Collective Workers (Percent)	86	47	75	69	74	71
Local Leaders (UC/DC/Zakat etc.) (Percent)	10	20	19	8	7	13
Caste Jat (Percent)	3	17	34	0	13	15
Caste Arain (Percent)	3	30	38	0	53	32
Caste Rajput (Percent)	66	23	6	0	4	19
Others Castes (Percent)	28	30	22	100	30	34

A majority of the selected SOVs were educated. Almost half of the selected SOVs have reached the educational standard of matric and above; this proportion did not drop below one-third in any Sub-system. Perhaps the farmers believed that the educated persons had a better understanding of the common problems and could communicate these better.

The majority of the selected SOVs were not opposed by other water users, indicating their neutral status and their potential of being apolitical and commonly acceptable. This is further supported by the fact that most of the referred and selected SOVs have already played some role in community/collective work previously. The proportion of local level leaders, such as members of Union/ District Councils, Ushar and Zakat Committees, as well as members of the old Basic Democracy system, is very low, ranging from 7 percent in Sub-system 5 (Minor 1R) to 20 per cent in Sub-system 2. This indicates a preference by the water users to avoid such traditional leaders.

4.5. Lessons from Action Research

The action research program conducted at Hakra 4-R Distributary found that organizing water users at the secondary level of Pakistan's contiguous canal irrigation system was socially feasible. This was contrary to the popular belief that existed both within and outside Pakistan. The popular notions related to constraints of an integrated socio-technical system, illiterate farmers, social pressure from big landowners and obstacles caused by the hierarchical society, were proven to be invalid under conditions of a participatory process of social organization. The methodologies used had the common focus on building self-reliance among the farmers, and using field training and other forms of capacity building as the major motivating influences. A Field Implementation Coordination Committee consisting of representatives of all service delivery agencies working in the area, along with selected water users, highlighted the needed farmer-agency coordination, and greatly facilitated an incentive mechanism through collaborative activities within the pilot sites. This combined effort successfully achieved the formation of a number of water users associations (WUAs) at the tertiary (watercourse) level, and a Water Users Federation (WUF) at the secondary canal (distributary) level at the selected pilot site.

The emerging results of this social experiment were encouraging. The new WUF was able to take collective decisions to negotiate with the provincial irrigation authorities regarding a joint management agreement (JMA) for managing water resources in the canal system. Although the JMA was not made immediately effective due to a procedural difficulty imposed by the present legal framework, the WUF proceeded to test their capacity in undertaking a planned maintenance program during the canal closure period, and also initiating a maintenance-related infrastructure improvement program. Replicability of this social organization program lies in the methodology adopted: the deployment of small field teams and the use of local volunteers. The step-wise social organization process is meant to enhance sustainable interest of all the actors involved.

One drawback in the pilot efforts, however, has been the lack of full commitment from the related government agencies, which have to take the initiative for empowering the water users organizations. However, both the enthusiasm and the capacity demonstrated by the water users in social organization for collective action are considerable, and show a good potential for further progress. Very likely, the demand generated at the local level could facilitate a process of bureaucratic reorientation, which in turn would provide the necessary institutional support for the new water users organizations.

5. DECISION SUPPORT SYTEMS FOR IMPROVED CANAL OPERATIONS

IIMI has been working with two Provincial Irrigation Departments (PIDs) in undertaking the development of a decision support system (DSS). An irrigation circle is first divided into divisions and then sub-divisions. The sub-division is the basic field organization for daily operation and maintenance (O&M) activities.

For example, the Bahawalnagar Circle in southeastern Punjab operates both Fordwah Canal and Eastern Sadiqia Canal. The Fordwah Division has three sub-divisions; namely, Minchinabad, Bahawalnagar and Chishtian. The Chishtian Sub-division (which has a culturable command area (CCA) of 67,000 ha) is the lower portion (tail) of the Fordwah Branch Canal that off-takes from the tail of the Fordwah Canal (Figure 5.1). The hydraulic performance assessment of the Chishtian Sub-division has been reported by Habib and Kuper (1998).

In the Sindh Province, IIMI has been working with the Sindh Irrigation and Power Department in the Mirpurkhas Sub-division (Figure 5.2), which is located in the middle of five sub-divisions for the Jamrao Canal Division of the Nara Circle. The Culturable Command Area (CCA) of the Jamrao Canal is 935,000 acres (374,000 ha) and the CCA of the Mirpurkhas Sub-division is 236,612 acres (95,410 ha). The operational performance of the Mirpurkhas Sub-division has been reported by Khan, et al (1998).

5.1. HYDRAULIC SITUATION

The results from the studies in the Chishtian Sub-division (Punjab Province) and the Mirpurkhas Sub-division (Sindh Province) will be used to illustrate the hydraulic situation in the Indus Basin Irrigation System (IBIS). These results are quite compatible with similar studies by others (but not reported) in other portions of the Punjab Province, as well as the North West Frontier Province (NWFP).

5.1.1. Variability of Canal Water Deliveries

For Kharif 1994, the variability in seasonal planning, the scheduled indent, and the actual water supply is shown in Figure 5.3 at the head (RD 199 of Fordwah Branch Canal) of the Chishtian Sub-division. Figure 5.3 shows that no defined preference pattern is obvious from the actual flow hydrograph. The water shortage is a permanent feature, but not very severe quantitatively. The sub-division receives higher than 70 percent of the design discharge most of the time, but never more than the design discharge. However, the variability of flows is quite high and inflow into the sub-division remains fluctuating most of the time. The two low supply periods in April and August are when there was either a low demand or supplies were lowered for safety purposes during the rains

The water supply delivered to the Chishtian Sub-division (Figure 5.3) is, at best, 90 percent of the indent. However, at times, the water supply is only 50 percent or less, of the indent. Most of all, the high degree of discharge fluctuations wreaks havoc with the irrigation practices of the farmers. For example, if a farmer receives only half of the normal water supply, then less than half as many bunded fields can be irrigated during a water turn (warabandi), so that only one-third or one-fourth as many bunded fields are irrigated. In addition, the frequent discharge fluctuations can result in some farmers being denied water during the warabandi.

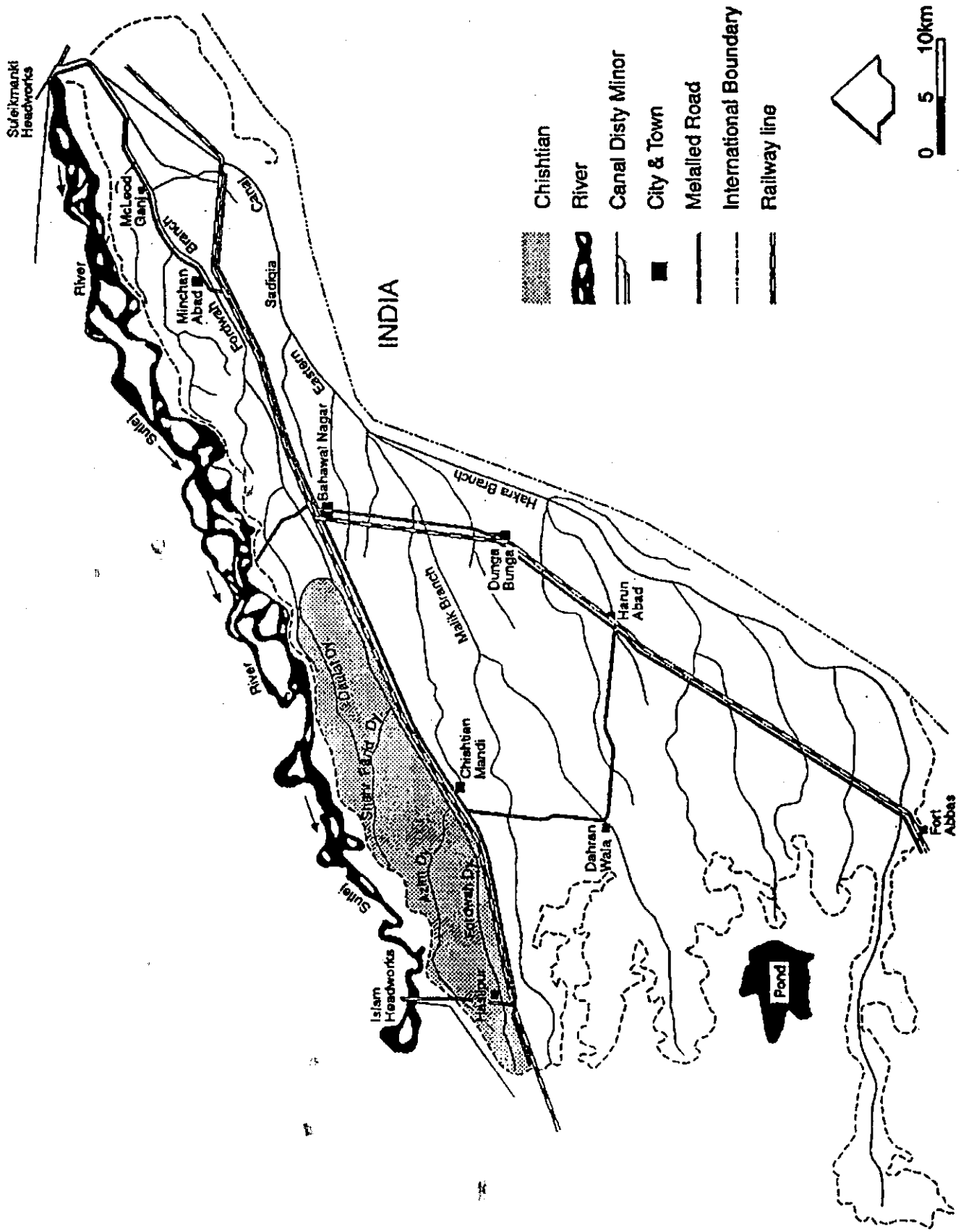


Figure 5.1. Fordwah Chanal and Eastern Sadiqia Canal Systems.

Figure 5.2. Jamrao Canal with the Boundaries of the Five Sub-divisions.

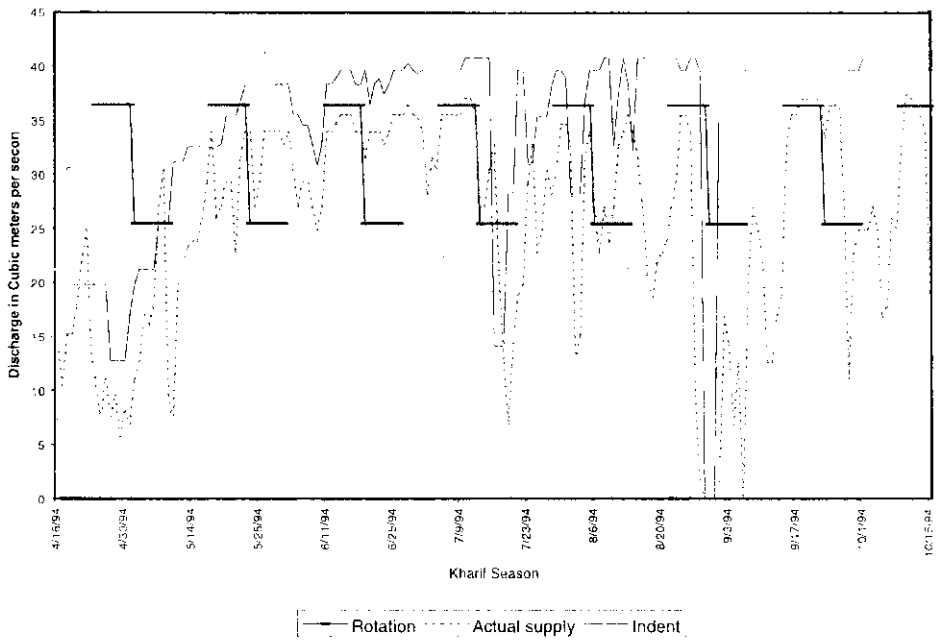


Figure 5.3. Seasonal Planning, Scheduled Indent, and Actual Water Supply at the Head of Chishtian Sub-division for Kharif 1994.

Although both the Jamrao Canal Section (RD 291 to RD 443) and the West Branch Canal Section (RD 0 to RD 143) are parts of the Mirpurkhas Sub-Division, however, a close look to the average seasonal discharge for the off-takes of both the sections reveal that they are different and independent systems. Normally, the average seasonal discharge for rabi is lower than the kharif average discharge and gives a considerable difference, which is true to a greater extent for the Jamrao Canal System. But, the situation in the West Branch Canal system is quite different (Table 5.1). For the West Branch Canal off-takes, the seasonal discharge for both of the seasons gives a mixed situation. For three channels, the rabi discharge is higher than the kharif discharge (e.g. Sangro Distributary, Daulatpur Minor and Bellaro Minor). One of the reasons that could be attributed to this situation is that some of the West Branch Canal off-takes have experienced longer rotational closures than the Jamrao Canal System. The maximum and minimum discharge drawn by each off-take in both of the seasons is also given in Table 5.1.

Table 5.1 The Seasonal Average, along with the Maximum and Minimum Discharges, of Major Off-takes in Mirpurkhas Sub-division.

Parent Channel	Offtake	Average Q (cfs)		Maximum Q (cfs)		Minimum Q (cfs)	
		Rabi 96-97	Kharif 1997	Rabi 96-97	Kharif 1997	Rabi 96-97	Kharif 1997
Jamrao Canal	Mirpurkhas Disty	69.26	70.96	99.21	99.61	25.70	23.32
	Doso Dharoro Disty	50.26	77.03	98.99	121.33	12.12	20.73
	Kahu Visro Minor	16.37	19.38	29.20	31.28	6.23	5.35
	Kahu Minor	42.41	49.67	65.79	75.94	23.0	4.43
	Bareji Disty	63.10	61.01	80.879	86.324	39.932	48.146
	Sanro Disty	51.13	52.49	83.525	102.05	11.04	37.016
West Branch Canal	Lakhakhi Disty	57.99	67.77	97.49	134.13	21.40	32.22
	Bhittaro Minor	16.99	16.04	18.51	19.06	13.10	14.37
	Sangro Disty	131.39	123.64	184.90	163.37	92.77	76.48
	Daulatpur Minor	38.93	36.30	57.94	57.81	20.73	31.74
	Bellaro Minor	59.39	51.29	70.980	75.24	45.21	48.21

Because of the improper, illegal or merely malicious gate operations by the field staff of the operating agency and/or the farmers, water level fluctuations occur all along the Mirpurkhas Sub-division. For this study, water depth variations have been studied at two points: (1) RD 343 of Jamrao Canal where the Mirpurkhas and Doso Dharoro Distributaries off-take, which are the first major off-takes of the Mirpurkhas Sub-division in the Jamrao Canal Section; and (2) RD 38 of the West Branch Canal Section.

Figure 5.4 shows the daily water level variations in the Jamrao Canal at RD 343, both for Rabi 1996-97 as well as for Kharif 1997. The water levels are changing almost daily. There is no particular trend of rise or fall in this variation; however, the fluctuations are usually in the range of 0.10 to 0.20 foot. Other important information revealed by Figure 5.4 is that water levels both for rabi and kharif are also almost the same, except in October 1997, when these levels have increased for about a two-week period. One of the reasons could be that the cross regulator at RD 292 is usually not operated and the discharge increases in the main canal are diverted to the West Branch Canal during kharif.

Figure 5.5 shows the daily water level fluctuations in the West Branch Canal at RD 38. The water depth has been changing nearly every day during both of the seasons, except for some parts of February and March 1997. There is a drop of about one foot in the water level during the last two weeks of March, when wheat is ripe in this part of Sindh and water is not much needed. The water level has increased by about one foot during kharif, however, the fluctuations are also higher than Rabi 1996-97.

5.1.2. Equity of Water Distribution

Equity, or fairness of distribution, is the most discussed performance measure for large-scale supply-based irrigation systems. These systems have long and complex conveyance networks, which carry a limited amount of water to a vast command area. Two forfeitures of these systems are that extra supplies to one section of a canal can cause a water shortage in another section, and that deteriorated maintenance conditions can disturb the water-carrying capacity of the canal. To confront these limitations, the equitable distribution of water has been presented as a primary measure with its specific meanings in the context of Indus Basin systems. All design documents, O&M manuals and guidelines for canal regulation discuss equity of water distribution by supplying the design discharge. The measures suggested to achieve equity are:

(i) Appropriate planning of water regulation and distribution (through scheduling) at the divisional, and sub-divisional, levels;
(ii) Appropriate maintenance and operation of the irrigation network; and
(iii) To help and guide water users to follow a strict predefined water-turn roster called *warabandi*.

For the manager of the Chishtian Sub-division, the target is to deliver an authorized discharge to each distributary, or to achieve a delivery performance ratio (actual/design discharge) equal to one. The relevant characteristics of each distributary are given in Table 5.2. The delivery performance ratio (DPR) varies from 0.43 to 1.57, which is a tremendous variation. Some secondary canals are receiving 50 percent more water than targeted, while other secondary canals are only getting half of the water supply that they should be receiving.

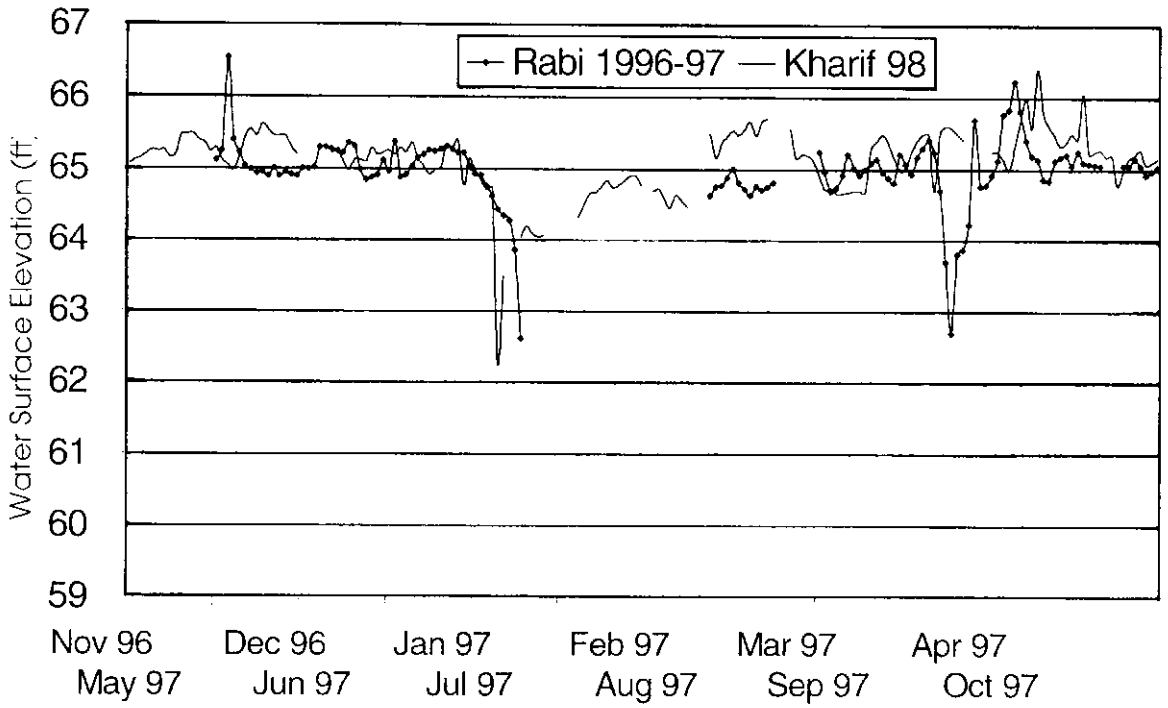


Figure 5.4. **Water Level Fluctuations in the Jamrao Canal at RD 343 of Mirpurkhas Sub-division.**

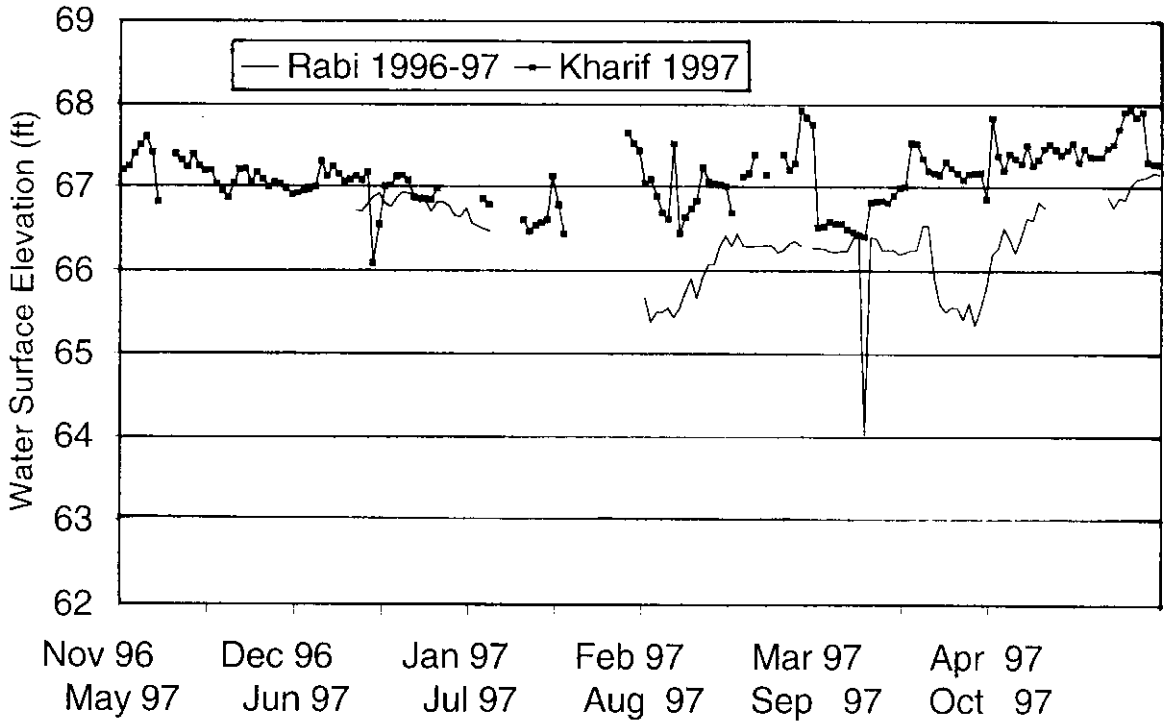


Figure 5.5. **Water Level Fluctuations in the West Branch Canal at RD 38 of the Mirpurkhas Sub-division.**

Table 5.2. The Division of Fourteen Distributaries into Quartiles with Reference to DPR and WD, Kharif 94, Chishtian Sub-division.

Distributary	CCA (ha)	Irrigated Area (ha)	Average Water Depth (WD) (mm)	Average Delivery Performance Ratio (DPR)
Daulat	32718	24335	681	.73
3-L	4451	1247	918	.45
Mohar	2973	2216	1000	.53
Phogan	2213	1742	1410	1.31
Khemgarh	5057	2975	763	.69
4-L	2055	1932	602	.66
Jagir	4451	2761	1203	1.03
Shahar Farid	24913	15095	843	.75
Masood	8106	5627	580	.83
Soda	10122	4865	1099	.62
5-L	885	619	1094	1.57
Azim	30485	22780	505	.43
Fordwah	36709	31266	364	.65
Mahmud	2008	1350	932	1.44

The delivery performance ratio (DPR), which is the ratio of the off-takes duty to the system duty, has been used as a measure to assess equity in water distribution along the Jamrao Canal and the West Branch Canal. The average of the seasonal water duty of the respective channels of the Jamrao and West Branch Canals has been taken as the duty of the system. Inequity could be associated with different factors like the lack of maintenance of the irrigation system, lack of interest of the operating agency, theft of water by the water users, lack or non-existence of objective-oriented operations, and rent-seeking. This inequity is neither site-specific nor time-specific and could be observed any time at any point along the system. Monthly DPR computed from the daily values, for all of the off-takes, is given in Table 5.3. Only Doso Dharoro and Sanro Distributaries have DPR values significantly less than one.

Table 5.3. Monthly DPR of the Mirpurkhas Sub-division Off-takes.

Month	Mirpur Disty	Doso Dharoro	Kahu Visro Mr.	Kahu Minor	Sanro Disty	Bareji Disty	Lakhakhi Dy.	Bhittaro Mr.	Sangro Disty	Daulatpur Minor	Bellaro Minor
Nov96	1.26	0.64	1.47	0.92	0.88	1.24			1.30	1.23	1.02
Dec96	1.21	0.73	1.25	0.93	0.92	1.25	1.25	1.34	1.37	1.28	1.02
Jan97	1.00	0.59	1.28	1.10	0.94	1.32	1.16	1.28	1.23	1.20	0.93
Feb97	0.76	0.58	1.05	1.18	0.51	1.16	1.04	1.21	1.06	0.68	0.80
Mar97	1.2	0.33	1.15	0.90	0.96	1.24	0.64	1.20	0.92	1.03	0.93
Apr97	1.06	0.71	1.20	0.84	0.98	1.27	0.73	1.26	1.14	0.69	0.97
Average	1.08	0.60	1.23	0.98	0.86	1.25	0.96	1.26	1.17	1.02	0.94
May97	1.21	0.66	1.43	1.02	0.84	1.06	1.12	1.32	1.13	1.12	0.74
Jun97	1.04	0.70	1.23	0.95	0.70	1.16	1.02	1.21	1.21	0.80	0.95
Jul97	0.86	0.83	0.92	0.75	0.65	1.03	0.61	0.88	0.91	0.94	0.44
Aug97	0.79	0.83	1.21	1.12	0.91	1.17	1.07	1.21	0.93	0.91	0.77
Sep97	1.05	0.86	1.52	1.14	0.86	0.89	1.19	1.03	1.15	0.78	0.99
Oct97	1.10	0.97	1.38	1.11	0.91	1.15	1.21	1.36	1.12	0.90	0.97
Average	1.01	0.81	1.28	1.02	0.81	1.08	1.04	1.17	1.07	0.91	0.81

5.1.3. Hydraulic Performance of Selected Canals

The Coefficient of Variation, C_v, is the most used statistical measure of a distribution function, and is defined as:

$$C_v = \sqrt{\frac{\sum_{I=1}^{N} X_I^2 - (\sum XI)^2}{n(n-1)}} \Bigg/ \frac{\sum xi}{n}$$

Where, x_I and x are as defined in the previous section, and n is the number of units.

Cv takes care of the inequality of a distribution, irrespective of its average level, by dividing the standard deviation of a sample by its mean. The important characteristic of the coefficient of variation is its sensitivity for extreme values.

For water scarce irrigation systems, where zero, or low supplies could not be avoided, Cv varies over a large range. This variation indicates the level of *non-uniformity* over time and its pattern characterizes the pattern of supply, or scheduling. In itself, Cv is not a real measure of fairness, especially for those systems where supplies can fluctuate between extreme values.

Figure 5.6 shows that the spatial coefficient of variation (Cv) for *Kharif* 94 varies in a range of 0.4 to 1.05, with its value being higher than 0.6 during the rains, and low demand periods (the unstable periods). Even during the most stable period, it varies between 0.4 and 0.5, indicating daily fluctuations in the system.

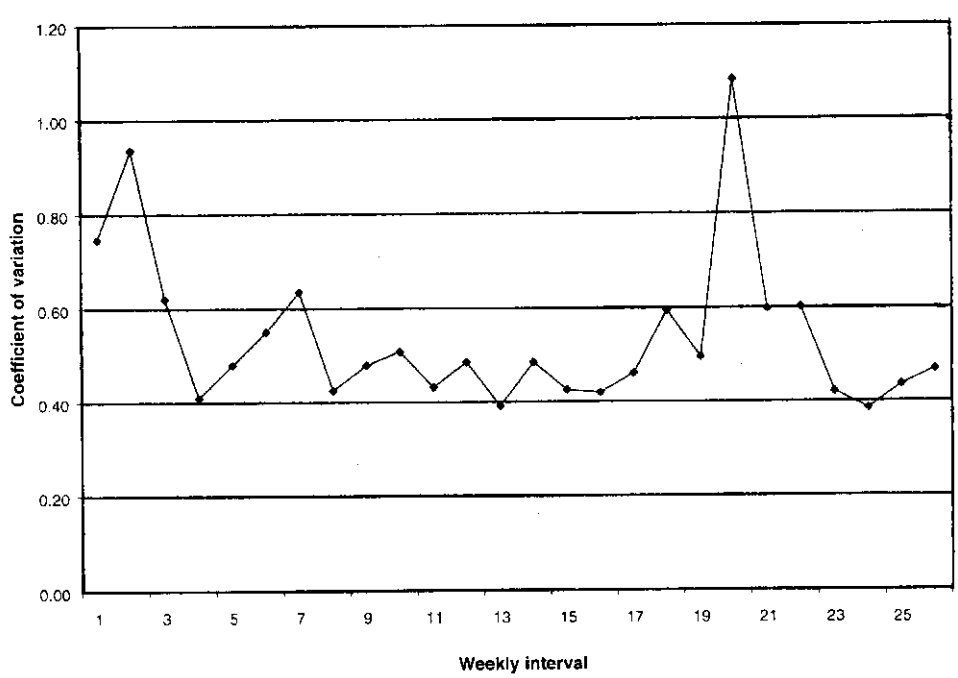


Figure 5.6. Weekly Variation of Spatial Equity Measured by the Coefficient of Variation for the Chishtian Sub-division.

The volatile nature of Cv can provide a good preliminary insight into those systems where a good knowledge and comprehensive information are not already available. The sharp peaks and valleys indicate that the extreme variations, or abnormal behavior, is evident, which can be further explored.

Rotation schedules are supposed to be implemented when water supplies are below 70 to 75 percent of the expected levels, which is not really the case in the Mirpurkhas Sub-division. Similarly, upstream water level fluctuations and unplanned gate operations have their own contribution to flow variability. The Jamrao Canal and the West Branch Canal Sections have

been studied separately for two seasons. The first three months (November 1996 to January 1997) of Rabi 1996-97 have comparatively minimum variability of flow deliveries in the Jamrao Canal Section, which was caused by gate adjustments and upstream water levels as there had not been rotational closures (Figure 5.7). The Mirpurkhas Distributary was closed for six days during February 1997 when the variability reached 73 percent. With the start of rotational closures in March, the variability increased to as high as 95 percent for the Doso Dharoro Distributary, which was closed for 13 days against the official schedule of 7 days. Overall, the Bareji Distributary has performed much better than others during rabi. The months of November and December 1996 have less than 10 percent variability for all the off-takes of the West Branch Canal, except the Lakhakhi Distributary (Figure 5.8). The Daulatpur Minor was closed for 8 days each in February and April 1997, while flow variability in the Lakhakhi Distributary increases continuously from January onward to April (75 percent when it was closed for 10 days). The Bhittaro Minor has been the best: (1) for having no rotational closures; and (2) being a fixed orifice, there were no gate manipulations.

5.2. Canal Operation Management

5.2.1. Structure Calibrations

All essential flow control structures should be field calibrated to develop discharge ratings. These structures would be the canal headworks, each cross-regulator, each distributary head regulator and each escape, as well as all of the direct outlets.

Discharge measurements using a current meter are preferably done during steady-state flow conditions. However, the canals in Pakistan are usually operating under unsteady flow conditions. A technique has been developed (Khan, et al, 1997) for correcting current meter measurements taken during unsteady flow conditions.

The procedures to develop discharge ratings for flow control structures have been reported (Skogerboe and Merkley, 1996). These procedures can be used to systematically develop all of the required discharge ratings for a canal network.

5.2.2. Canal Conveyance Losses

A good technique is to use the inflow—outflow method under steady-state flow conditions. For each reach between two flow control structures (e.g., cross-regulators), the conveyance losses should be measured as the difference in the discharge rates at the upstream and downstream flow control structures. This should be done for at least three different water levels in the reach that essentially covers the range of operating flow conditions. The wetted perimeter for the reach should be measured for each water level. The seepage loss rate, Q_{slr}, can be expressed in cubic meters per day of conveyance loss divided by the square meters of wetter perimeter, which can be reduced to millimetres (mm) per day or feet per day. In the Indian Sub-continent, the seepage loss rate is expressed in cusecs of conveyance loss divided by million square feet (msf) of wetted perimeter, which is calculated from an inflow-outflow test as:

$$Q_{slr}(cusecs/msf) = \frac{Q_u(cusecs) - Q_d(cusecs)}{WP(ft^2)/1{,}000{,}000} \qquad (7)$$

Where Q_u is the discharge rate measured at the upstream flow control structure, Q_d is the discharge rate at the downstream flow control structure, and WP is the wetted perimeter for the reach. The seepage loss rate will increase as the water levels increase. An example of a typical seepage loss rate curve is shown in Figure 5.9. In any reach, there is a water surface gradient, so a water surface elevation has to be selected at any desired location, where often the water surface elevation selected is either: (1) a short distance downstream from the flow control structure at the head of the reach, which is termed a downstream gauge; or (2) immediately upstream from the flow control structure at the tail of the reach, which is an upstream gauge.

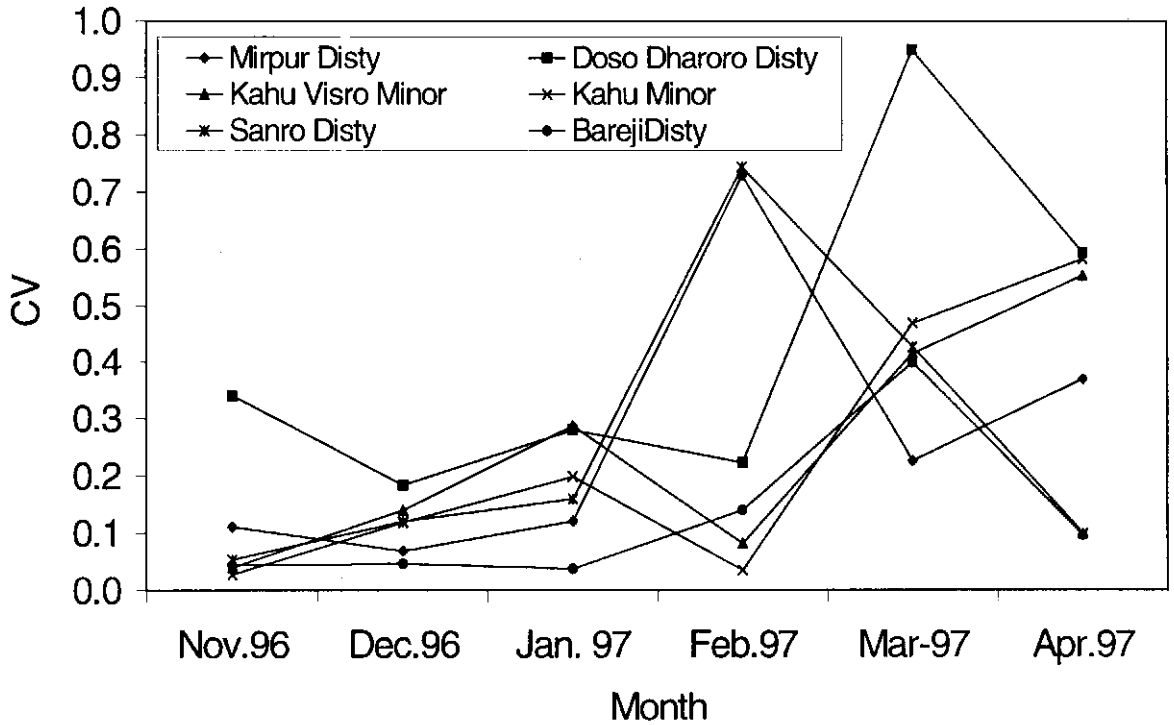


Figure 5.7. Variability in Water Distribution along the Jamrao Canal, Rabi 1996-97.

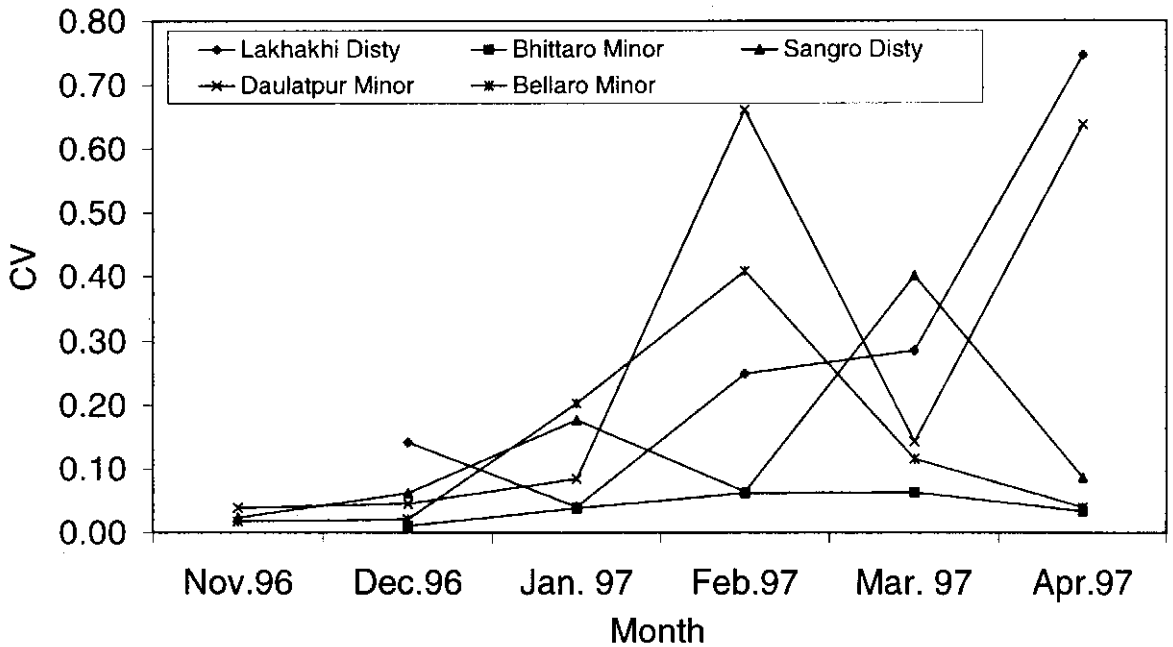


Figure 5.8. Variability in Water Distribution along the West Branch Canal, Rabi 1996-97.

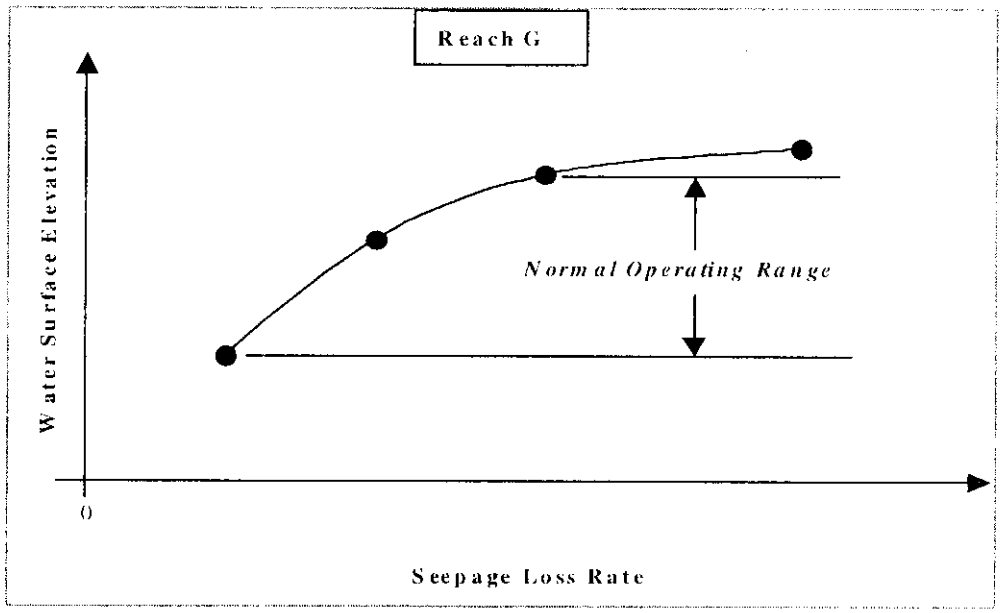


Figure 5.9. Example of a Seepage Loss Rate Curve for a Canal Reach.

5.2.3. Developing Downstream Gauge Ratings

Most irrigation canals have a substantial number of structures for controlling water levels and discharge rates throughout the system. Many of these flow control structures use gates for regulating the water. A common practice throughout the Indian Sub-continent and many other locations, is to place a vertical staff gauge downstream from the flow control structure. Then, a stage-discharge relation is developed using current meter measurements. This relation is prepared as a rating table that provides the gate operator with the required water level on the downstream gauge for any discharge rate specified by the irrigation manager.

After calibrating numerous flow control structures, it was discovered that the actual discharge rate is usually 15-25 percent less than the downstream gauge rating. Hydraulics is a fairly exact science, so such discrepancies are considered huge.

A downstream gauge rating is normally developed using the KD-formula:

$$Q = KD^n = K\,(G - \Delta G)^n$$

Where Q is the discharge rate, K is an empirical coefficient related to the cross-sectional area of flow, D is the hydraulic depth that is equal to the gauge reading, G, minus a gauge correction, ΔG, and n is an exponent affected by the channel cross-section geometry and the degree of nonuniform flow (n is around 5/3 for uniform flow).

The Manning-Strickler equation is commonly used to describe uniform flow. However, nonuniform flow usually occurs almost everywhere in a canal reach. But, when the KD-formula is combined with the Manning-Strickler equation, an equation for the coefficient, K, can be derived. For each periodic current meter measurement, the value of K can be calculated. As long as K remains constant, the downstream gauge rating is still valid. This led to the first major finding of this research: downstream gauge ratings often require a significant adjustment (10-20 percent) after only a few months. Also, if the irrigation channel is experiencing sediment deposition, then the downstream gauge will indicate a discharge rate that is greater than the actual discharge. Likewise, if scouring occurs in the channel, the actual discharge will be greater than indicated by the downstream gauge rating.

When developing a downstream gauge rating, the field measurements consist of: (1) the gauge reading, G, corresponding with the water surface; and (2) the current meter measurement that provides the discharge rate, Q. Thus, there are three variables in the KD-formula (K, ΔG and n), which has four possible combinations for analysis: (1) one variable approach with K as the variable; (2) two variables approach with K and ΔG as the variables; (3) two variables approach with K and n as the variables; and (4) three variables approach with K, ΔG and n as the variables.

The single variable approach provides the simplest and most straightforward downstream gauge rating, but suffers from a high degree of empiricism. The three variables approach provides the most accurate rating, as expected, but often amounts to "curve fitting" as disclosed by derived values of the gauge correction that lack physical meaning. Another important finding was that a linear relationship exists between the gauge correction, ΔG, and the exponent, n, which is unique for each channel, where n decreases as ΔG increases. This finding, along with recognizing that n= 5/3 only for uniform flow and with the use of hydraulic radius, R, as the depth parameter, indicated that a method was required for specifying the gauge correction that had a physical meaning. After considerable effort, the hydraulic mean depth, D_{hy}, was selected that can be obtained from a current meter measurement as the cross-sectional area of flow, A, divided by the top width of the water surface, W_T , which is then subtracted from the gauge reading to solve for the gauge correction ($\Delta G = G-D_{hy}$). The value of ΔG will vary some for each current meter measurement, so the average value is selected. This, in turn, results in the conclusion that the two variables approach with K and n as the variables provides the most physically meaningful downstream gauge rating.

The major conclusion from this research is that the KD-formula is appropriate for developing downstream gauge ratings. What is frequently inappropriate is the application of this technology. The reason that large discrepancies are often encountered between the downstream gauge rating and an actual discharge measurement is the failure to periodically adjust the downstream gauge rating.

Because of the need to frequently adjust the downstream gauge rating, it is recommended that the discharge rating for the flow control structure should also be undertaken. Both ratings can be done simultaneously, with the only additional field work being the measurement of water levels and gate openings at the flow control structure. Since the structure rating will be valid for a number of years, it can be used to provide the discharge rate periodically in order to adjust the downstream gauge rating for the benefit of the gate operators.

5.2.4. Steady and Unsteady Flow Simulation

In the DSS research program, a hydrodynamic model called Simulation of Irrigation Canals (SIC) is used to calibrate an irrigation canal. To accomplish this, the first step is to measure cross-sections at many locations along the full length of the canal, including elevations, which are inputted into SIC.

First of all, the results from the field calibration of the flow control structures (Section 5.2.1) will be inputted into SIC in order to replace the design discharge equation for each structure. Also, the results from measuring canal conveyance losses (Section 5.2.2) will be incorporated into SIC to replace the design conveyance losses. At the same time, the water levels recorded while conducting the inflow-outflow test (Section 5.2.2) will be used to calibrate the steady state version of SIC.

Now, SIC can be used to predict lag times between any two cross-sections along a canal for a wide variety of operating conditions. These lag times can be incorporated into the daily operating schedules. Also, these lag times can be checked during actual operations to determine whether any adjustments are required.

Next >>

5.2.5. Irrigation Management Information System

The results from calibrating SIC for various researches of the canal and branch canals is used to formulate a simple steady state water balance for each sub-division in a canal command area. This water balance constitutes an Irrigation Management Information System (IMIS) that is used by the irrigation manager, who is the sub-divisional officer (SDO).

The IMIS software has been periodically improved during recent years, with a Windows version available since 1997, which has been partially employed at Malik Sub-division in southeastern Punjab, however, there have been difficulties because of Irrigation Department field staff being inexperienced with using computers. Thus, simpler approaches have been sought similar to the representation in Figure 5.10 (Rey et al 1993). The most significant improvement would be telecommunications rather than mail or hand delivery of information.

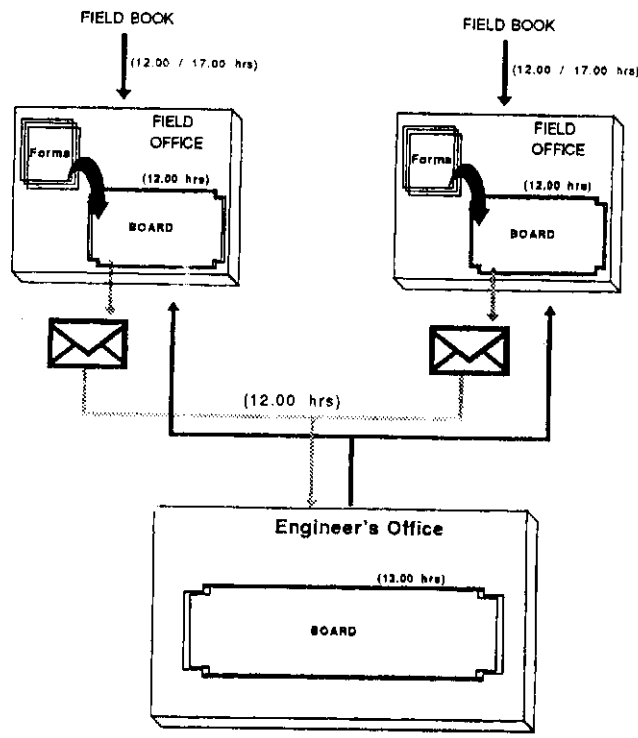


Figure 5.10. General Layout of a Field Collection and Communication Network.

5.2.6. Irrigation System Communications

First of all, there is a need to have adequate, but not necessarily sophisticated, communications equipment between the most important flow regulating structures and the office of the SDO. This would be done for each sub-division. Secondly, a communications network is needed between the sub-divisions and the division offices and from there to the office for the canal command.

A good example is the Nara/Jamrao Canals remodeling under the LBOD Stage I Project. A sub-project for installing a Nara Circle telecommunication system was envisaged in order to provide modern telecommunication facilities after the capacities of this irrigation system are increased. Under the original plan, automatic data loggers were to be installed at strategic points in the Nara Canal Circle, which would be directly linked to the base station in Mirpurkhas. The communication between the base station and the field staff was planned to be through a microwave radio system. However, this project has not been implemented as

originally planned and now only the radio system has been installed at the divisional and sub-divisional turnover points during December 1997.

In the Mirpurkhas Sub-division, where IIMI has been working on DSS, this facility has been provided in the form of three base station units at turnover points, plus two mobile units. The base station units have been installed at the following points as shown in Figure 5.11: (1) RD 291, Mitho Machi Cross Regulator, upstream turnover point from Jhol Sub-division; (2) RD 448 of Jamrao Canal, turnover point to the downstream Kot Ghulam Muhammad Sub-division; and (3) RD 143 of Wwest Branch Canal, turnover point to Digri Sub-division. In addition, a central base station has been established at Mirpurkhas, which serves as the main station for both, the Jamrao Canal System as well as the Nara Canal Circle. Other control structures (cross regulators and head regulators of off-takes) in between the turnover points are still without any electronic or mechanical facility for data transmission. One mobile unit has been provided to the SDO and another one to the Executive Engineer. Hopes are high that this modern telecommunication system will significantly contribute to better management of the system.

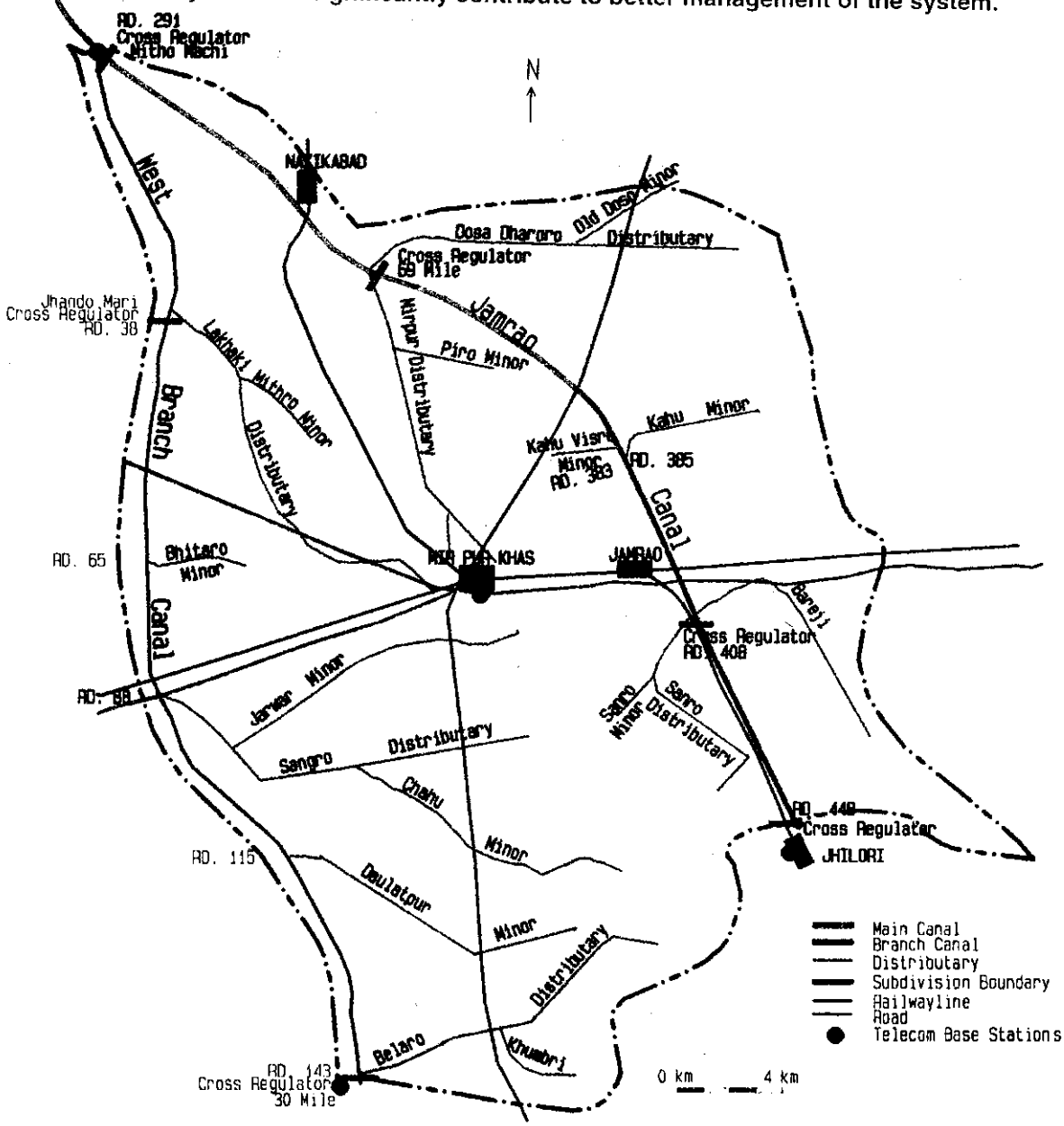


Figure 5.11. Telecommunications Base Stations in the Mirpurkhas Sub-division.

6. WATERCOURSE MANAGEMENT

6.1. FARMER BEHAVIOR

6.1.1. Warabandi

Warabandi, as it has been institutionalized in Pakistan, is a rotational method for distribution of irrigation water, with fixed time allocations based on the size of landholdings of individual water users within a watercourse command area. It presupposes an overall shortage of the water supply. The primary objective of the method is to distribute this restricted supply in an equitable manner over a large command area. For warabandi to achieve this main objective, it needs to be supported by a set of physical and institutional conditions, which form the environment of warabandi, covering the inside boundaries of the tertiary system in which warabandi is actually applied. As the system has been designed with minimum control to allow a "free flow" of water into the outlets, these conditions require that the flow rate of water in the canal system should be uniform so that each water turn receives its proportional share. This is achieved by maintaining the main canal's distributing points and the distributary canals themselves at a predetermined water supply level. Also, all of the outlets in a distributary should operate at the same time, each outlet discharging a constant flow of water into the watercourse, so that the warabandi roster would not be disturbed. The field-level warabandi operations, along with these necessary conditions, constitute a warabandi system, which implies in its design an equitable distribution of water so that each farmer receives the total allocated flow of the watercourse for a fixed duration proportional to the farm area. The successful application of this procedure requires a well-maintained physical system and a high degree of cooperative behavior among the water users.

The origin of warabandi has to be placed somewhere in the precolonial period. When the British started to build the canal irrigation network, warabandi was adopted from existing practices as a water distribution method at the watercourse level. The time allocation schedule was locally determined and mutually agreed upon by the farmers in the watercourse command. However, with changes in social conditions, intermittent water-related conflicts among the farmers led to increased official interventions in this original farmer-managed kachcha (unofficial) warabandi tradition, resulting in the widespread conversion of kachcha warabandi practices into more rigid pucca (official) warabandi schedules. Today, there are only a few watercourses in the Central Punjab that are not covered by pucca warabandi. Field observations reported by Bandaragoda and Rehman (1995) revealed that, in actual practice, most of the theoretical characteristics of official warabandi no longer hold. The reality that emerges in the field contrasts with several myths associated with the popularly known concepts of warabandi, which are commonly shared by many, including some staff of operating agencies, professionals of research institutes, and members of foreign missions.

Foremost among these myths are two interrelated notions. One is that warabandi in practice corrresponds to an equitable distribution of water. The other common assumption, not validated by field observations, is that warabandi in operation is a totally fixed and rigid water distribution practice.

The principle of equitable water distribution underlying the design of warabandi is eroded by an increasing variability in the water flow in the canals, as well as by the nonadherence to standard operational rules, both of which are in turn related to a combination of physical and institutional factors. Poor maintenance due to lack of funds combined with low institutional accountability, maintenance-related physical deterioration of the canal system, and operational deviations caused by the power and influence of some water users characterize this practical field situation. In sum, these are changes in the necessary conditions of a warabandi system. The changes that occur in the operational conditions above the outlet tend to induce corresponding behavioral changes related to warabandi operations below the outlet.

The majority of watercourses in the Punjab Province have an official warabandi established by the Provincial Irrigation Department (PID) at the request of the farmers, which prescribes the time allocation among each of the landholdings for the water supply entering the watercourse command area. This official warabandi is the only record of a "water right" held by each landowner, so it also has importance for settling disputes by arbitration.

Farmers exchange water turns quite often. Sometimes, they sell a water turn. However, for the canal surface water supply to the watercourse, the exchange is more common than selling, whereas the opposite is the case for tubewell groundwater supplies.

The major finding of this applied field research is the high degree of inequity in the water supply entering the watercourses, which is more than a single question of head versus tail watercourses along a minor or distributary. Within each watercourse command area, there are significant deviations in the list of water users, the timing of water turns, and the duration of water turns, as well as deviations in day turns and night turns.

All of the deviations cited above are further accentuated by the variability of the discharge rate throughout the day at the mogha (outlet) structure serving the watercourse. The combination of warabandi deviations and discharge variability is a major constraint to achieving reasonably good irrigation application efficiencies when irrigating the croplands, resulting in significant reductions in crop yields.

The most essential solution involves social organization. Well-organized, viable farmer groups have the best potential for resolving the problems of inequity. Farmers need to be organized into a legal water users' association, for which there exists legislative ordinances. However, there is a need to "learn how to organize" farmers both at the watercourse and distributary levels. This has been the highest research priority in this research project.

The observed deviations from the officially fixed warabandi procedures represent an inequity that cannot be conclusively described as commonly accepted, or as arising from mutual agreement. This inequity generally affects the poorer and less-influential landowners. Generally, the policymakers and planners perceive equitable allocation and distribution of the limited supply of irrigation water as a desirable feature that positively contributes to overall production goals. Thus, the reality of the warabandi that is practiced today should cause some concern in terms of equity, and thereby, its contribution to declining overall system performance.

6.1.2. Water Management Activities[8]

Water management activities that farmers undertake to manage water below the mogha include (re)allocation of canal water, water distribution, watercourse maintenance and water acquisition.

6.1.2.1.(Re)allocation of Canal Water

In Pakistan, canal irrigation water is allocated to the farmers through a warabandi, which by definition is the method of allocating water proportional to the land size (Bandaragoda and Rehman, 1995). In this case, warabandi provides the rules to be followed during the actual distribution of water along a watercourse. In the Punjab Province, most of the tertiary units have an official (pucca) warabandi; however, in the presence of pucca warabandi, farmers make some changes, but following the same allocation rules (i.e. min/acre). This is referred to as (re)allocation of water.

Contributed by Robina Wahaj, IIMI-Pakistan.

Farmers (re)allocate water:

- To include their tenant's water turns since they are not included in the pucca warabandi.
- To have one longer water turn in case a farmer has more than one parcel of land in the same watercourse command area;
- To make adjustments like trading the whole, or part, of the water turn of a farmer and by acquiring water turns allocated for Government land (i.e. forests and schools); and
- To incorporate decisions about the rotation within a square (25 acre parcel of land) to equitably distribute advance (khal bharai) and recession (nikal) time for the group of farmers sharing a non-official (channel that does not belong to the Government) branch of a watercourse to convey canal irrigation water.

A pucca warabandi already allocates water on a time-sharing basis to the owners of the land of a watercourse command area. In (re)allocating water turns, only concerned farmers discuss the options and decide about the (re)allocated schedule for water distribution. Therefore, it is mostly a group or an individual activity (individual in the case when an individual farmer deals with the department people for use of a water turn allocated for Government property).

Farmers expect the following gains from reallocating water:

- Agreed-upon water distribution schedule for the whole watercourse including tenants;
- Every water user gets the information about the timing of his/her water turn;
- Buying and selling of a whole water turn makes it easier to get the idea of the amount of water (at least maximum and minimum) a farmer will most probably get during the next season, on the basis of this information, farmers can plan which crops to grow under how much area; and
- By having rotation within a square among the smaller group of farmers, the bharai and nikal time is equitably shared by the group of farmers taking water from the same official nakka, therefore, everyone gets more or less the same amount of water.

There is almost no negative effect of the (re)allocation of water on the farmers. In terms of the loss of water for crops that is actually allocated for orchards, this is in a way a misuse of a facility that could deprive other farmers of this water. Similarly, the use of water for crops that is allocated for Government property is a misuse of this water and can damage the property itself.

6.1.2.2. Water Distribution

Water distribution is referred to as the activity with which water is brought from the outlet to the farm gate. With the help of warabandi, farmers systematically distribute canal water. This includes all of the ad-hoc exchanges of canal water turns, or purchase and selling of tubewell water. This activity is mainly done at the individual or group level. Farmers distribute water in a systematic way to have more efficient water distribution.

During their wara turn, farmers take the following actions:

- Bring water from the nakka along the watercours to the farm gate.;

- Check the water level in the watercourse and the distributary before their own irrigation turn;
- Patrol along the watercourse to check its condition;
- Borrow a full or part of a water turn (if needed);
- Buy tubewell water (if needed); and
- Farmers close the *mogha* (outlet) during the times when they do not need water.

These actions are expected to provide farmers the following gains.

- By looking at the level of water in the distributary and the watercourse, a farmer can estimate how much of the land could be irrigated or not; thus, a farmer can take a decision about availing his water turn (for instance, to borrow an irrigation turn, to buy tubewell water, or to leave his irrigation turn and not irrigate at all;
- Patrolling along the watercourse helps a farmer to take care of any breach in the channel, upstream nakka leakage, water stealing, or any other obstruction that could reduce the amount of water; therefore, this activity helps a farmer to save water from wastage and to make irrigation more efficient;
- Borrowing a full, or part of, the water turn from other farmer(s) helps to complete the irrigation of a required area; a farmer who gives water knows that in time of need he could also get the same time from the wara turn of the farmer who is borrowing water; thus, this happens out of mutual understanding and the faith that the other farmer will also help;
- Trading of tubewell water gives additional water to the farmer, who buys it and gives money to the farmer who sells it; thus, both benefit from this activity; and
- By closing the mogha during times that water is not needed lessens the damage to crops by over-irrigation, as well as helping to reduce the threat of waterlogging.

The actions that farmers take to adapt the warabandi to their needs are mostly beneficial for all of the farmers within a tertiary unit. However, some of their actions could create problems for the farmers further downstream in the system. For example, if a farmer closes the mogha during his water turn and other farmers downstream do the same, they shift their problems to the tail enders who have no capacity to deal with this excess water in the absence of drains. This can also create a breach in the distributary, ultimately causing loss to the farmers whose land will be flooded with this water.

6.1.2.3. Watercourse Maintenance

Farmers regard watercourse maintenance as one of the most important activities that happens. However, maintenance of a lined watercourse is much easier than the maintenance of an unlined watercourse (Figure 6.1).

Farmers maintain their watercourse:

- To improve the water supply, especially at the tail of the watercourse;
- To save water; and
- To prevent any (legal or illegal) conflict. In case of a breach along the watercourse, the affected person (whose crop is damaged because of water flooding) can go to the court.

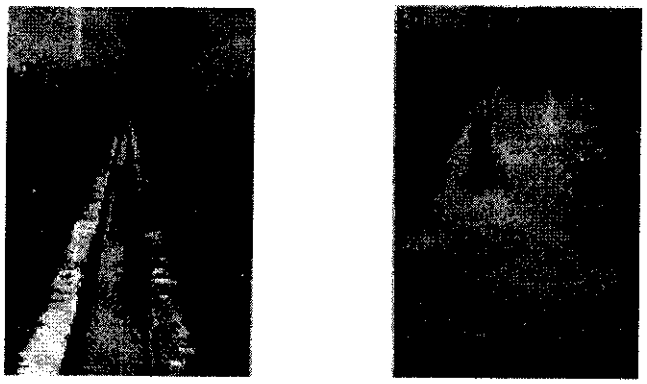


Figure 6.1. Lined and Unlined Watercourse.

The actions farmers take to maintain their watercourses are listed below.

- Desilting of the watercourse. Desilting of the watercourse takes place more often in an unlined watercourse when compared to the lined watercourse because of more sediment deposition (siltation). This action is taken collectively in the case of the main watercourse, with a group of farmers in the case of a branch watercourse; and individually in the case of farmers' channels (Figure 6.2).

Figure 6.2. Desilting of Watercourse.

- Removal of weeds. Weeds in the bed and along the banks of the watercourse obstruct the water flow and, therefore, it is important to remove them. This action is done together with the desilting of the watercourse (Figure 6.3).

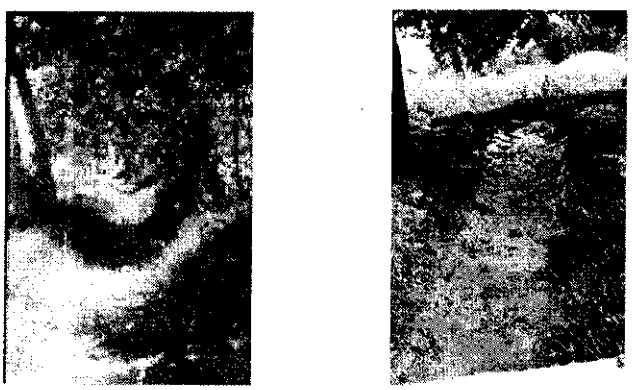


Figure 6.3. Watercourse with Weeds, and then, Cleaned Watercourse.

- Repair and installation of nakkas. Pucca nakkas (concrete) are easier to handle and are more efficient in terms of water saving through reduced nakka leakage. Therefore, farmers prefer pucca nakkas, though they are more expensive than to have katcha nakka (earthen). The installation of pucca nakkas in the main watercourse is mostly a collective activity (Figure 6.4).

Figure 6.4. Pucca Nakka

- Repair of banks and bed of the watercourse. The banks and bed of the watercourse are repaired whenever needed, along with the desilting activity. This action is done collectively in the main watercourse by a group of farmers in a branch of the watercourse, and individually in farmers' channels. This action controls overtopping of the watercourse and reduces the risk of breaching the watercourse.
- Construction of culverts. At the points where cattle or carts cross the watercourse, culverts are needed; otherwise, they could damage the watercourse that ultimately ends up in a loss of precious canal water. This action is undertaken collectively.

The benefits to farmers by undertaking maintenance activities are listed below.

- Maintenance of the watercourse saves water by reducing overtopping from the watercourse, leakage from the watercourse and nakkas, and decreasing seepage losses from the bed and the banks of the watercourse. Thus, it improves the conveyance efficiency of the watercourse.
- In the case of a mogha that draws water from the distributary or minor under submerged flow conditions, watercourse desilting at the head of the watercourse will result in increasing the discharge by lowering the level of the watercourse bed, and thus, provide a comparatively larger hydraulic head.
- More water available to the farmers at the tail of the watercourse because of less obstruction to the flow. The velocity of water increases with the desilting of a watercourse.
- Farmers can irrigate more area during their water turn.
- Construction of a culvert or nakka saves water, as well as making it easier for villagers to walk; these structures facilitate patrolling along the watercourse.

6.1.2.4. Acquiring Additional Water

In the supply-based canal system in Pakistan, water acquisition is not considered a responsibility of the farmers, but they still acquire additional water. Some of the reasons why farmers try to acquire more water are:

- Because the present canal irrigation water supply does not meet perceived crop water requirements for an existing cropping pattern; and
- To ensure timely availability of irrigation water.

The actions farmers take to get additional water can occur at different organizational levels.

- Collective Action (Figure 6.5).
  - Enlarged mogha (Figure 6.6).

Figure 6.5. Collective Decision Making.

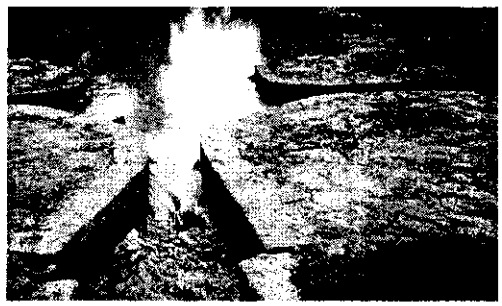


Figure 6.6. Tail Cluster of Moghas.

- Group Action
  - Installation of a tubewell owned by a group of farmers.
  - Water trading (buying and selling canal and tubewell water, or rotation within a square among a group of farmers).
- Individual Action
  - Tubewell installation (Figure 6.7).
  - Siphoning.
  - Water trading (buying and selling canal water and tubewell water; exchange of canal water turns).
  - Using water allocated for Government property (like school, forest).
  - Obtain higher water allocation for orchards and use it for crops.

Figure 6.7. Tubewell.

Figure 6.8. Irrigating a Crop.

The expected benefits to farmers in acquiring additional water are listed below.

- Farmers can grow water-sensitive cash crops like sugarcane and rice. They can also increase the cropped area under these cash crops Figure 6.8).
- An enlarged mogha means more canal irrigation water for all of the farmers in a tertiary watercourse, provided that there is water in the distributary.
- Tubewell installation helps in reducing the risk of crop failure due to unreliable canal irrigation water supplies.
- Water trading helps in obtaining water at the time it is needed and increases the certainty of irrigation water supply. Moreover, for farmers who have more irrigation water then they need, they can either earn money by selling or get water later when they need in the case of exchanging a water turn.
- Individual farmers get more water from the distributary into the watercourse during their water turn at night by siphoning.

Figure 6.9. Rice and Sugarcane Field.

- Some farmers get water allocated for Government properties like a school or forest, by either paying some money to the Department officials, or by just starting to use this water. This gives extra time, and thus, additional water to these farmers.
- Another action for acquiring additional water is to obtain a higher allocation for the orchards, which disappear after some time and the land is cultivated with crop(s), but this higher allocation remains the same and, therefore, more water is available to grow crops.
- Some of these activities, on the one hand, improves the timely availability of irrigation water to the farmers, while on other hand, they reduce the water available to the downstream farmers, since water in the tertiary watercourse sub-system remains the same, but its distribution changes.

The activities that particularly influence the downstream farmers and their effects are listed below.

- Enlarged mogha. The enlarged mogha increases the discharge and, thus, the amount of water available to all of the farmers of that tertiary unit, which ultimately decreases the discharge in the distributary. Thus also, the amount of water available to the downstream farmers. In this way, these farmers improve the adequacy for their own crops, while deteriorating the adequacy for the other downstream farmers.
- Siphoning. Siphoning happens mainly at night, which increases the water available to the farmer who takes this action, but this act reduces the water available to the downstream farmers for the time period that this action continues.

6.1.3. Social Organization

6.1.3.1. Informal Organization for Maintenance Activities[9]

In the Canal and Drainage Act, 1873, it is stated that 'The Government is not responsible for the maintenance of the watercourse, but that it is the responsibility of those who use it, whether on existing Government, or private, land'. A watercourse is defined as 'any channel that is supplied with water from a canal, but that is not maintained at the cost of the Provincial Government, and subsidiary works belonging to any such channel'. The watercourse excludes the 'sluice or outlet' through which water is supplied to such channels.

Maintaining a watercourse is one of the main irrigation management responsibilities of the farmers. Since, normally, a group of farmers share the right to the water supply through the watercourse, maintenance becomes a group responsibility.

6.1.3.1.1. Watercourse maintenance and performance of the system

The need for maintenance at the watercourse level: The watercourse carries the water from the outlet to the farmers' fields, and therefore, is of indispensable importance to irrigated agriculture. Researchers indicate the necessity for proper maintenance of the tertiary canals. Sediment, that is drawn along with the water from the parent channel, deposits on the bed and along the sides of the watercourse, resulting in distortion of the cross-section, and therewith, a reduction of its carrying capacity. The embankments of the watercourse need strengthening to avoid breaches and leakage. Furthermore, vegetation in the watercourse hampers the flow of water, leading to an inadequate discharge capacity (Skogerboe and Merkley, 1996).

The need (and, thus, also the amount of labor and financial inputs required) for watercourse maintenance depends on several factors. These may be the slope of the bed of the watercourse, whether the watercourse is lined, or unlined, the length of the watercourse, the amount of sediment in the parent channel, and the actual discharge at the outlet.

Farmers' perceptions of required routine maintenance: The need for watercourse maintenance is recognized by (at least most of) the farmers. During the annual canal closure meant for maintenance of the major canals and water control structures, watercourses do not receive water from the parent channel. During this period, farmers have the opportunity to perform routine maintenance activities. Maintenance works, that farmers (would like to) carry out during the year, but especially during this period, are:

1. Cleaning of the main watercourse. This entails removing sediment (usually called silt) from the bed and sides of the official (main) watercourse and removing weeds from the official watercourse. In lined watercourses, with a good slope and a high discharge, sedimentation is less, and due to this, less vegetation grows in the watercourse. Desilting and removing of weeds therefore, becomes less important in these channels.
2. Cleaning the banks of the watercourse. Removing weeds and bushes from the banks of the watercourse. This maintenance activity was found to be important in all of the watercourses.
3. Repair of the banks of the watercourse. This includes filling of the banks in those watercourses where (e.g. due to high banks) earth eroded, and removal of silt from the banks in those watercourses where emergency maintenance made temporary deposition of silt on the banks necessary.
4. Repair and installation of *nakkas* along the main watercourse. This includes repair, or replacement, of both officially approved and unofficial *nakkas*, and *pakka* (concrete) and *katcha* (earthen) *nakkas*, that are found to be in a poor

[9] Contributed by Cris de Klein and Robina Wahaj, IIMI-Pakistan.

condition. Especially in the case of *pakka nakkas*, for its construction, there should be no water in the watercourse and, therefore, this maintenance can best be done during the annual canal closure period.

5 Repair of the bed of the watercourse. Sometimes the bed of the watercourse is damaged, but it was not possible, nor desirable, to repair it immediately. This work, then, is postponed until the annual closure period.

6 Construction and repair of culverts.

7 Desilting and cleaning of farmers' watercourses. Although this is regularly done by individual farmers during the year, it can be done more profoundly, and easily, during the canal closure period when the soil is dry.

8 Desilting of the parent canal. Some of the farmers mentioned that their village participated in the desilting of the distributary under the Chief Minister's Campaign a few years back. Although this is not maintenance at the watercourse level, the communities of the tertiary units were organized to perform this task.

Furthermore, farmers mentioned that the tasks of the Irrigation Department during the annual canal closure period 'on their watercourse' are: repair of the outlet and changing the size, or the type, of the outlet.

6.1.3.1.2. Watercourse investigations

Maintenance activities on selected watercourses located in southeastern Punjab were investigated by deKlein and Wahaj (1998). The qualitative data were collected from July 1996 to February 1997 in the watercourses along the Hakra 6-R Distributary and from January to October 1997 in the watercourses in the tail distributaries of the Fordwah Branch Canal. The quantitative data were collected before, during and after these time periods.

Most of the information on the organization and implementation of maintenance activities was collected through interviews with farmers. In the initial stage of the research, semi-structured and informal interviews were conducted at the time of, and in between, desilting activities. These informal encounters took place during the daily visits of the field staff to the watercourses. During these visits, the watercourse situation and on-going activities could be monitored. In each of the watercourses, farmers were asked about, among other things, the need and program for desilting and the problematic reaches along the watercourse in terms of the deposition of silt and vegetative growth.

In each of the watercourses, key-informants were interviewed following a structured questionnaire in the case of the watercourses along the Hakra 6-R Distributary, and with the use of a checklist in the watercourses served by the Fordwah Branch. The key informants were those who were found to be the most active persons with regard to watercourse desilting activities. In a later stage of the research, structured interviews were also conducted during the desilting activities.

Farmers were asked to clarify the pattern of allocation of work (stretches to be cleaned) by use of a map showing the layout of the watercourse and branches. This was done for three of the watercourses along the Hakra 6-R Distributary (detailed) and for four watercourses served by the Fordwah Branch Canal. Quantitative data were mainly related to the layout of the watercourse, conveyance losses, and elevations of the watercourse bed, banks and fields along the watercourse.

The actual occurrence of collective action for watercourse maintenance depends on various factors. Collective action here is defined as an organized activity among a number of people in order to reach a common goal, and in which all participants share an understanding of, and follow, the rules. Collective action is required for watercourse maintenance. One person cannot

do the job. Even in watercourses where not all of the shareholders clean at the same time, the ultimate goal remains the same, and (maybe even more) rules need to be developed and followed by the shareholders. Therefore, 'need for maintenance' and 'need for collective action for maintenance' are practically one and the same thing.

Demand for water. By far the most important factor that encourages farmers to maintain their watercourse is the need for water. Farmers recognize that a better maintained watercourse improves the water supply to their fields. A high water demand leads to a higher need for watercourse maintenance. Although crop water requirements were not calculated, the water allowances indicate that the water supply in the sample watercourses is relatively scarce. In many cases, the farmers managed to reduce this scarcity by increasing their outlet size, which can be seen from the (higher) actual allowances.

The need for water is not the same throughout the year. Farmers will organize themselves only for watercourse cleaning if the growing stage of the crop demands. When the cropping pattern does not differ much within the watercourse command area (which is likely to be the case in such a local system), the demand for water, and thus the interest in watercourse cleaning, will be similar for all of the shareholders.

Next to (growing stage of) the cropping pattern, the need for water is defined by some other factors. In the few watercourses where timely maintenance is not executed, income from off-farm activities, or from land outside the sample watercourse, is higher than in the other watercourses. Sixty percent of one watercourse command area is affected by waterlogging and salinity; the owners of the land complain that due to this, they can no longer get tenants to cultivate their land; for only 44 percent of the cultivators, income from crops in this watercourse command area is the main source of income.

Condition of the watercourse. The layout of the watercourse has a direct effect on the need for watercourse cleaning. The slope of the bed, the length of the watercourse, whether the watercourse is lined or not, are factors that separately, or in combination, influence siltation and weed growth. If an unlined watercourse is elevated compared to the field level, rat holes may endanger the condition of the banks. In general, it was found that farmers are well aware of the physical condition and constraints of the watercourse and the maintenance required for each. Especially in the improved watercourses, farmers have a good knowledge of the slope of the watercourse, the quality of the materials used (sand-cement ratio), the condition of the banks and bed, etc.

Social capital. Awareness of the need for watercourse maintenance does not necessarily lead to collective action. A whole set of conditions must be favorable to make it work. Although, in most of the watercourses, less maintenance is done than required and desired by the shareholders, overall, the farmers manage to organize themselves for this activity. The sample of watercourses is too small to show any unconditional correlation between separate social variables and the potential of collective action. On the other hand, the sample is diverse enough to show that different settings can lead to similar outcomes, and that, more or less, similar conditions can lead to different patterns of organization. One of the main conclusions is that no single social factor (be it cultural, institutional, economic or political) can determine the outcome. Realizing the shortcomings of considering each variable in isolation of the rest, an attempt will be made to mention some of the main conditions that are assumed to be of importance for the organization of watercourse maintenance.

Clear set of rules. Legally, it has been determined that each shareholder is jointly responsible for maintaining the watercourse. This rule is internalized to such an extent that farmers feel accountable to their fellow farmers, more than towards the Irrigation Department. The rules for division of the work are clear to all of the shareholders of all the watercourses. The farmers themselves make these rules, as the Canal and Drainage Act does not at all indicate how the

implementation of watercourse maintenance should be done. In all of the watercourses, the rules in use are the same as those introduced by their forefathers. In a single case, where, since the improvement of the watercourse, no desilting is required anymore, the rules are no longer in use (though still remembered). In another watercourse, farmers think about changing the rules, because since improvement of the watercourse, there are many absentees. In a branch of this watercourse, no division of work is made (so actually there are no rules for it) and now they are considering making a division of the work, so that each individual can be held responsible. In conclusion, it can be said that a 'sense of ownership' of the rules, as well as respect for traditions, makes rules acceptable to all shareholders. The basic rules are simple:

1. Each farmer cleans a stretch of the watercourse that is in correspondence with his land holding size;
2. Each farmer cleans up to his last nakka; and
3. The sequence of stretches to be cleaned follows the warabandi schedule.

Because the number of shareholders and the area of a watercourse is limited, everyone knows more or less how much land everyone has, where that land is located, and the *warabandi* sequence. The person who allocates the shares (on the basis of these rules) is expected to be even more knowledgeable about land holding sizes and the *warabandi* schedule. In conclusion, it can be said that the set of rules is simple and clear to all of the persons concerned.

Leadership and authority. Most shareholders say that there should be a leader to organize the desilting activity, but that there isn't one. A good leader is someone who is respected by the other shareholders and 'who can ask others to do something'. Such a statement also indicates that oftentimes, persons who do not expect to gain an immediate benefit, are expected to participate. In many cases, the leading person has inherited this 'position' from his father. Someone who takes the initiative for watercourse cleaning is not necessarily considered a leader. Most often he is just a shareholder who faces problems during his irrigation turn. Only if that person also takes the decision to actually plan the desilting activity, makes the announcement and motivates the others, is he then considered a leader. The person who divides the work, allocates the shares, and supervises the activity is normally selected by all of the shareholders before the start of the activity. This person is considered a leader (at least for that moment). To ensure that the basic rules of division of work are clearly followed, only 'honest persons' will be selected.

In all of the watercourses, farmers can tell about the rules in use to deal with absentees in desilting activities, like the type of punishment, or under what conditions these sanctions are to be applied. Sometimes, it is even told exactly when these rules were discussed and decided upon, and who took the initiative. But, if asked about the actual situation, they cannot clearly indicate the steps taken against absentees. Sanctions for absentees are very difficult to enforce. In some cases, this is said to be due to the absence of a leader. It seems to be difficult to have a leader, because no one accepts someone else above him. In other cases, leading figures do not have the authority to enforce sanctions. Social, or moral pressure from the group is one of the main mechanisms that makes, people participate. This is found especially if all shareholders belong to the same caste.

The conclusion is that only in rare cases will there be leaders that are accepted by all shareholders and given the authority to enforce rules. In general, farmers feel a need for a leader who can organize the entire desilting activity and maybe other activities in the watercourse command area.

Decision-making. Watercourse maintenance in the sample watercourses could not be observed long enough to see how different decision-making processes have emerged and which impact the different decision-making processes have on the performance of the system. Normally, if a

person wants the watercourse to be cleaned, he will contact any of the leading persons of that watercourse to consider this and to make an announcement. In most of the cases, before making an announcement, the person who has to arrange the announcement will consult with a few others whether they also find it necessary and what would be the best day to undertake the work. Where cleaning of the watercourse is a laborious job, and with a relatively high number of absentees, it may take a long time before the decision is taken, since the willingness of more people needs to be checked.

For the allocation of shares to be cleaned, a person is selected at the spot. Even if this is, more or less, the same person every time, farmers are still of the opinion that they have a say in this. They demand an honest and knowledgeable person and would never accept someone who has a bad reputation. No one forces himself on others as being the right person for this. In some watercourses, the process of how the work will be divided is discussed and an agreement is reached before the actual division starts. Everyone will see to it that the actual allocation is fair. In case of disagreement (which happens only rarely), farmers will refer to the basic rules.

Cost and benefits. Farmers in the tail end invest more time in cleaning than farmers who have their land in the head reach of the watercourse command area. Not a single time was this complained about. This 'inequity' seems to be accepted for two reasons: 1) in most watercourses, tail enders benefit more from cleaning the watercourse than head enders. This does not count in those watercourses with a bad slope, where the head reach easily overflows when the water turn is in the tail; and 2) because it has always been like that (tradition). Therefore, the authors would argue that a difference in workload is not an inequity (contrary to the lower amount of water tail enders get due to conveyance losses, even after a desilting operation). In two of the four watercourses, in which farmers do not organize (properly) for watercourse maintenance, there is no need for more water, and thus, benefits (more water) of desilting will not outweigh the cost (the effort). In two other watercourses, dependency on income from sources other than cultivation may be the reason that farmers are less concerned with maintaining their watercourse.

Izzat and zid. These concepts seem to be inherent in rural Punjabi culture, which also affects watercourse maintenance. Izzat may be glossed as 'honor, 'esteem', 'reputation', 'status' or 'face'' (see Merrey, 1979). Farmers were asked about the meaning of izzat and they mostly exclaim it as 'respect'. As Merrey already indicated, one can distinguish between positive and negative izzat. A person who manages to create fear among others, can have negative izzat. People will still show respect, but only do that because they fear that person and are afraid that, if they don't show respect, he might turn his bad deeds towards them. So, it is false Izzat. This is not sincere respect, but just a manner to 'remain on the safe side'. 'Doing zid' can be defined as 'being stubborn', 'being destined', or 'being insistent upon doing something'. Doing zid means that a person is so persistent in acting upon one's words, so that he does not care about the consequences, even if he will harm others, or himself. Like izzat, there is positive and negative zid, though none of them is false. Zid is negative if its aim is to obstruct others. Positive zid may be displayed by those who try to do something good for the community, but are obstructed by others. To counteract the negative zid of the other party, they themselves will also become very persistent in reaching their goal, and are also prepared to pay a higher price for it.

Zid and *Izzat* are two concepts that cannot be understood in isolation from each other. Zid includes both, goal (objective), and a way to reach it. The goal is to bring down someone's izzat and the manner to do it is to obstruct him. The word zid is used mainly to refer to the manner, or way, the objective has to be reached. Once it failed, or succeeded, the objective disappears and it is no longer a matter of zid (zid also disappears). The objective of doing zid (in a negative sense) is to bring someone else down, to give him a bad name, or at least make sure that he does not get a better name. So, zid is used in the game for izzat.

Recommendations. The focus of this study was the organization of watercourse maintenance in twelve watercourse command areas in Pakistan's Punjab. Different methods of data collection and analysis were used to understand and to integrate the technical and social aspects of one of the main water management activities at the tertiary level. Based on their findings, the authors would like to make the following recommendations.

1. There is no need for external intervention to motivate farmers for watercourse maintenance. In general, shareholders of a watercourse perform this task whenever benefits outweigh the costs. Farmers are knowledgeable about these benefits and costs.
2. A clear set of simple rules is needed to facilitate collective activities. Farmers usually build upon existing rules, such as those coming forth from the warabandi. Rules are best understood and acted upon if developed by the farmers themselves.
3. Leading persons are needed to motivate group members to perform certain tasks collectively. These 'leaders' can perform their tasks best if the group members trust and respect them, so that they have sufficient authority. In general, farmers are well aware of who the leading persons in the watercourse command area are and whether or not they need a leader, or will accept someone as a leader. However, insiders do not easily reveal information about leadership to outsiders. This is mainly because current group thinking about leadership and authority cannot be isolated from past experiences, which are often both, complex and sensitive. A good understanding of leadership patterns is indispensible if one wants to mobilize farmers for a collective activity, but also difficult to gain. Watercourse maintenance is one activity that could be taken as an entrance point to come to know the leading persons in a watercourse and to get a first hand understanding of decision-making processes in the group.
4. Izzat' and 'zid' are inextricably woven into Punjabi culture. An awareness, as well as an understanding, of the functioning of these concepts will be helpful in grasping people's enthusiasm, or reluctance, to participate in any collective activity.

6.1.3.2. Formal Organization for Equitable Water Allocation

As described above, farmers generally have informal arrangements among themselves for maintaining their watercourse. If the farmers are formally organized as a Water Users Association (WUS), they would likely be able to more equitable distribute the water supply received at their mogha. Also, they may be able to make some improvements regarding maintenance activities.

Organizing a WUA is considerably more important when every watercourse served by a distributary has been organized then federated into a farmers organization covering the entire distributary, with the membership of the executive body of the Water Users Federation (WUF) having one or two representatives from each WUA. Then, each WUA would be in a strong position for assuring that they receive their equitable share of the water supply received at the head of the distributary.

Likewise, if each distributary along a broad canal, or canal, is organized, then federated into a canal farmers organization, each WUF will be able to assure their equitable share of the branch canal, or canal, water supply. In turn, each WUA under the canal command can demand their fair share of the total water supply.

6.2. WATER SUPPLY CHARACTERISTICS

From 1991 to the present, IIMI has undertaken extensive studies in the Fordwah Canal and Eastern Sadiqia Canal networks in southeastern Punjab. Earlier, from 1989 to 1993, IIMI was heavily involved in Rechna Doab, the land between the Ravi and Chenab Rivers. Although there are differences in the research results, the conclusions are very similar. To illustrate the water supply situation that farmers must manage, Fordwah Distributary offtaking from the tail of Fordwah Branch Canal will be used. There are other distributaries that are better off than Fordwah Distributary, as well as worse off, but they must all contend with highly fluctuating water supplies.

Sarwar, Nafees and Shafique (1997) reported on hydraulic performance data for Fordwah Distributary during the five-year period of 1992-96. They studied the occurrence of discharge fluctuations at the secondary canal level, which are the result of upstream gate operations, on the fluctuations in the tertiary watercourse channel.

6.2.1. Reliability of Canal Water Supplies

The study by Sarwar et al (1997) first undertook an analysis of the discharge fluctuations at the head of Fordwah Distributary. The initial analysis is based on one discharge observation each day. Some sample years are shown in Figures 6.10 and 6.11, where the monthly coefficient of variation (C_V) is shown. The ideal value of C_V is zero, which indicates no variations in the deliveries for different months within and over the years. Kuper and Strosser (1992) have reported some reasons for these fluctuations as the overall shortage of water in the system, along with changing water requirements, with the added disadvantage for Chishtian Sub-division to be at the end of the system. Only when the water requirements upstream in the system have been satisfied is water conveyed downstream to the Chishtian Sub-division. This means that the problems of supplies and fluctuations for the Fordwah Distributary is further amplified because of being located at the tail end of the Chishtian Sub-division.

The figures clearly show that during a slack period in the month of May due to wheat harvesting, less discharge fluctuations occur, indicating less interference in the upstream channel. In this way, it seems to be mainly an operational problem and can be rectified to some extent with effective control over the system. Figure 6.12 presents the seasonal coefficient of variation for the deliveries at the distributary head. There is no particular trend of C_V variation for the rabi and kharif seasons over this period of analysis. However, the overall C_V is significantly high, which is not good for a canal water distribution system and subsequent farm irrigation management.

Water supplies at the Fordwah Distributary head and its availability at the tail (Tail Wet) in terms of days during the last five-year period are analyzed and the results are shown in Figure 6.13. The simulation results by Hart (1996) shows that the tail falls dry at a discharge of 83% (131 cusecs) of the designed capacity, which is used as an upper limit to sort the daily data. Two more ranges of greater than and equal to 60% (95 cusecs) and 40% (63 cusecs) of the designed discharge are used to categorize the inflow data at the distributary head. Water supply at the tail is assessed by counting the number of days in which the tail was wet irrespective of the levels. The following results can be identified from the summary of this analysis presented in Figure 6.13

1. Overall water supply to the distributary has a decreasing trend in each successive year.
2. Water deliveries in terms of different discharge ranges have mixed patterns. The total number of deliveries greater than or equal to 83% of the designed discharge have a systematic decreasing trend, 60% are scattered, and 40% have increased over the analysis period.

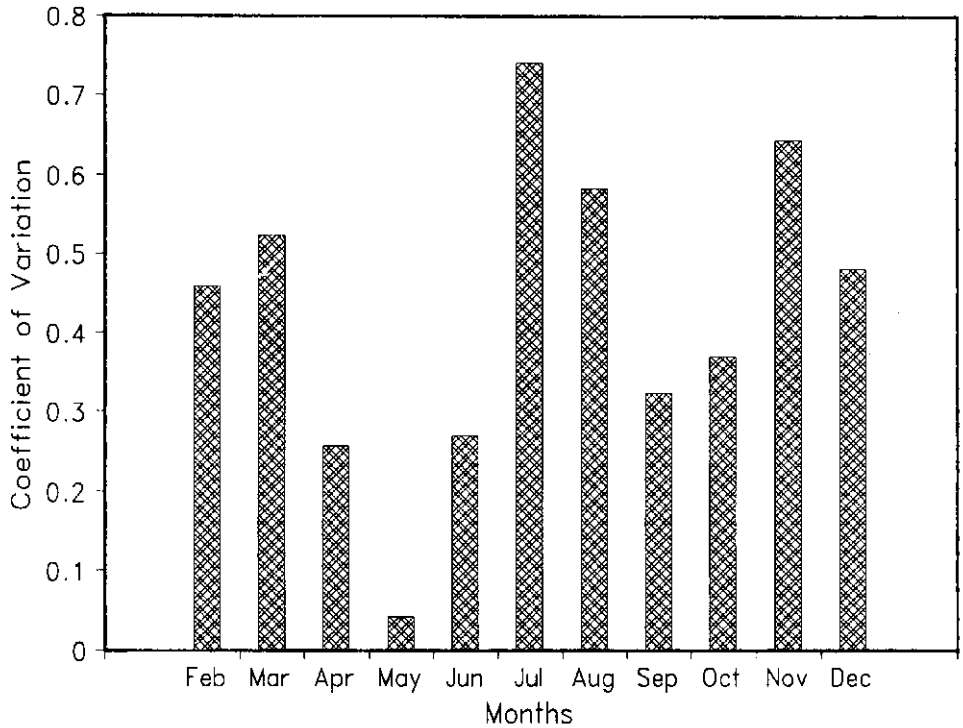


Figure 6.10. Temporal Coefficient of Variation at Fordwah Distributary Head, 1993.

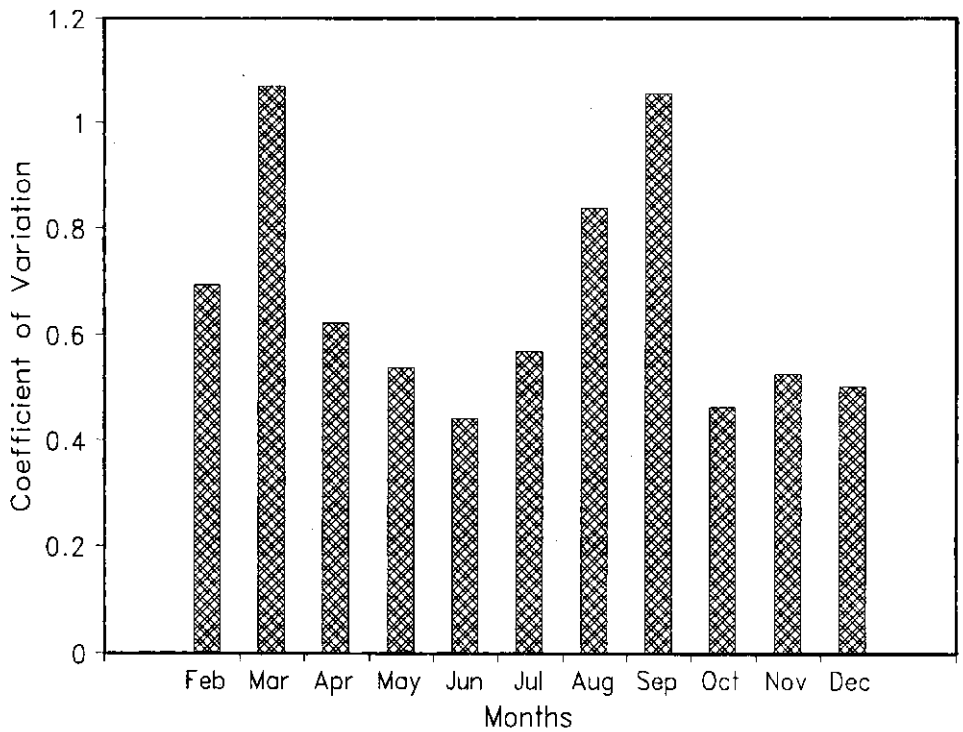


Figure 6.11. Temporal Coefficient of Variation at Fordwah Distributary Head, 1994.

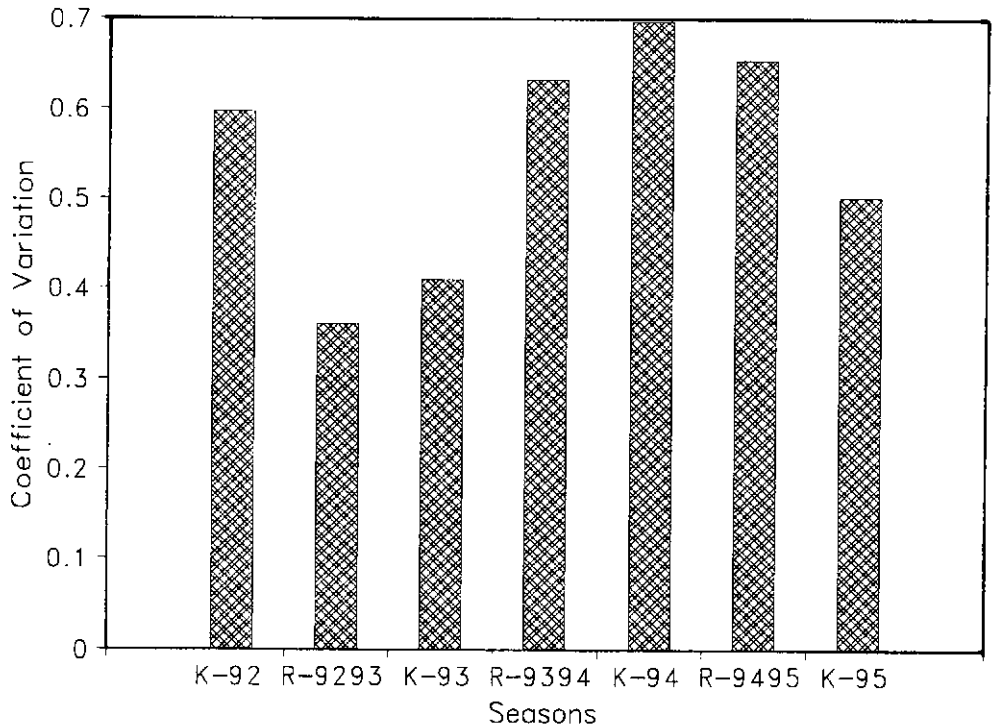


Figure 6.12. Temporal Coefficient of Variation at Fordwah Distributary Head, 1992-1995.

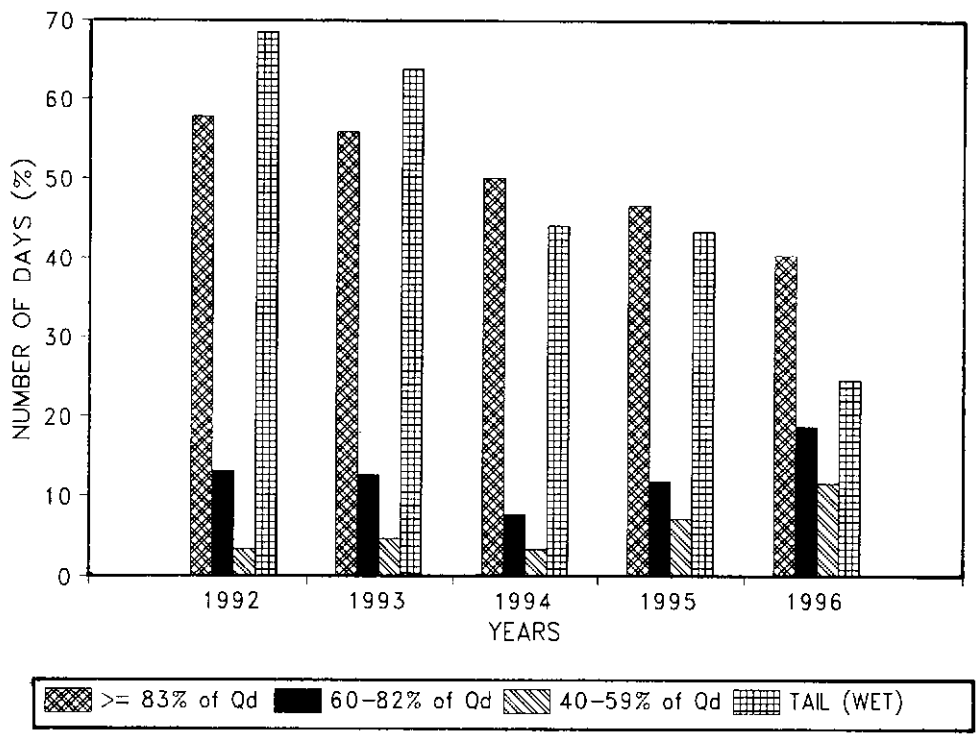


Figure 6.13. Canal Water Supplies at Head and Tail of Fordwah Distributary.

3 The water availability at the tail of the distributary has sharply decreased over the study period. In the years 1992 and 1993, the tail was receiving water during a greater number of days than the upper limit of 83% of the designed discharge at the head. This means that water was reaching at the tail even with the water deliveries less than 83% of the designed discharge. But in the following three years, 1994-96, water supply to the tail end has a decreasing trend with an acute shortage during the last year.

The problems of tampered outlets and siltation already investigated by Hart (1996) and Tareen et al (1996) are some of the reasons for the tail dry problem. The distributary was desilted and maintained in the annual closure of Rabi 1991/92 under the self-help desiltation campaign by the government and the farmers. This shows a positive impact on the water availability at the tail in the initial years, which started decreasing with the passage of time. In addition, the data analysis has also revealed that with the increased number of fluctuating deliveries at the head over different discharge ranges also contributed to the problem.

A more recent study (Wahaj, unreported) shows in Figure 6.14 the discharge fluctuations at the head of the Fordwah Distributary from February 1997 (after canal closure) to April 1998 (wheat harvest). During February-May 1997, there was a tremendous amount of discharge fluctuation with a number of days having zero discharge, while the same time period in 1998 had discharges in excess of the old design discharge and very few days with zero discharge. During Kharif 1998, there is a tremendous amount of discharge variation, including many days with zero discharge, but the majority of days experienced discharges near the target indent (old design discharge).

6.2.2. Watercourse Discharge Fluctuations

Four watercourses located along Fordwah Distributary were intensively studied; namely, Watercourse (WC) Fordwah 14-R, WC Fordwah 46-R, WC Fordwah 62-R and WC Fordwah 130-R (located at the tail of Fordwah Distributary). The notation 14-R means that the outlet is located on the right bank a distance of approximately 14,000 feet from the distributary head regulator. The temporal coefficient of variation for seven seasons is shown in Figure 6.15 for the four selected watercourses, that illustrates tremendous discharge variability.

The Molden and Gates (1990) performance indicators were used to assess the dependabiliy (PD) and equity (PE) of water deliveries to the four sample watercourses along the Fordwah Distributary. The selected performance indicators have been defined as:

- Dependability is the temporal uniformity of the ratio of the delivered amount of water to the required or scheduled amount; and
- Equity is the spatial uniformity for the ratio of the delivered amount of water to the required or scheduled amount.

The following performance classes have been used as standards.

INDICATOR		PERFORMANCE CLASSES		
		Good	Fair	Poor
1	Dependability	0.00-0.10	0.11-0.20	>0.20
2.	Equity	0.00-0.10	0.11-0.25	>0.25

The combined computed values of these performance indicators for the four selected watercourses are listed in Table 6.1. There are a few months where good or fair performance was achieved, but for most of the months from May 1992 to December 1995, the performance was poor.

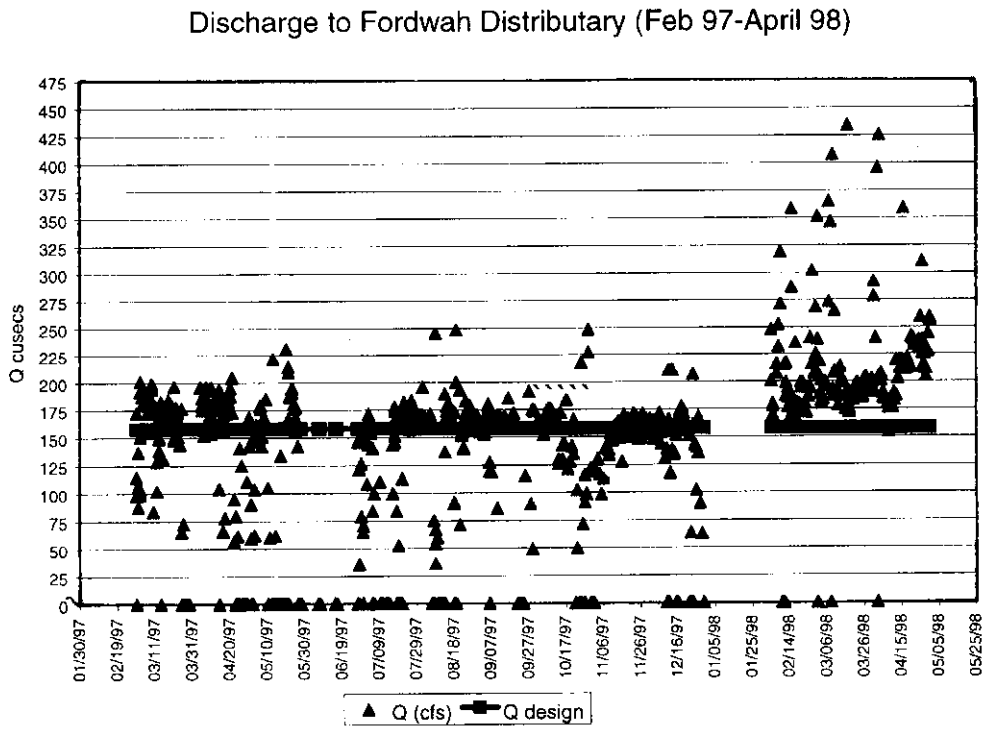


Figure 6.14. Discharge to Fordwah Distributary (Feb 97-April 98).

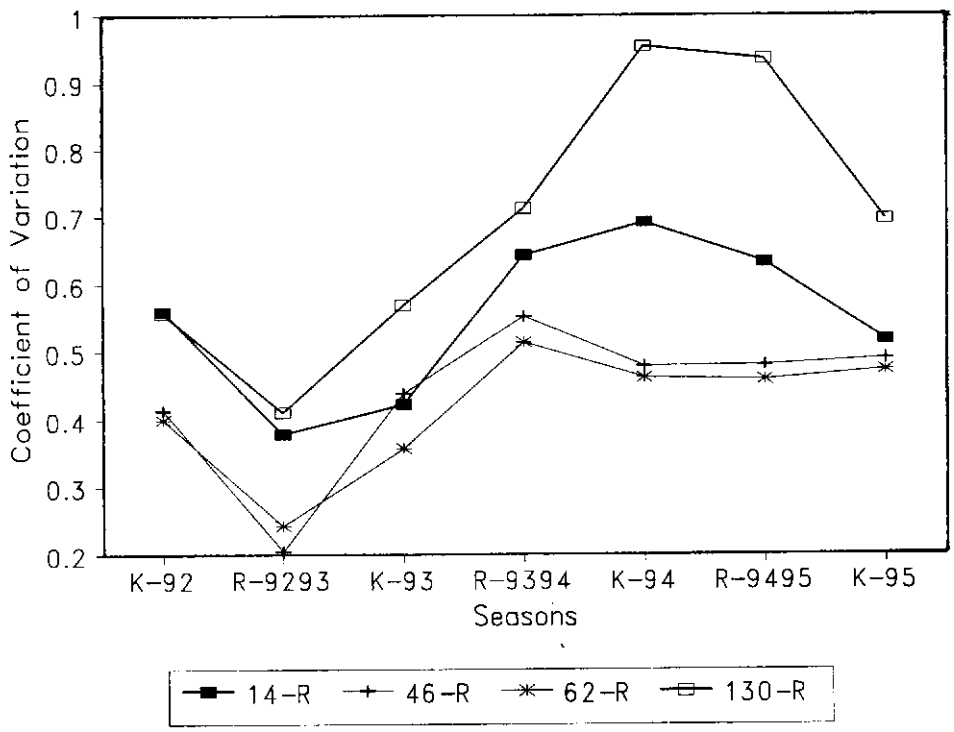


Figure 6.15. Temporal Coefficient of Variation at Sample Outlet Head, 1992-1995.

Table 6.1. Performance Indicators Calculated for the Sample Outlets (14-R, 46-R, 62-R & 130-R) along Fordwah Distributary.

MONTH	YEAR 1992		YEAR 1993		YEAR 1994		YEAR 1995	
	PD	PE	PD	PE	PD	PE	PD	PE
February			0.37	0.40	0.63	0.32	0.54	0.51
March			0.41	0.42	0.97	0.29	0.83	0.43
April			0.20	0.27	0.48	0.54	0.71	0.43
May	0.07	0.20	0.14	0.27	0.51	0.44	0.19	0.29
June	0.49	0.38	0.32	0.37	0.33	0.40	0.43	0.43
July	0.53	0.40	0.75	0.41	0.46	0.56	0.37	0.39
August	0.46	0.33	0.63	0.58	0.81	0.38	0.68	0.69
September	0.52	0.24	0.31	0.33	1.21	0.54	1.09	0.36
October	0.38	0.34	0.43	0.48	0.40	0.50	0.27	0.37
November	0.10	0.28	0.62	0.34	0.41	0.47	0.89	0.43
December	0.32	0.30	0.47	0.39	0.51	0.56	0.70	0.46

SEASON	DEPENDABILITY	EQUITY
Kharif 1992	0.48	0.33
Rabi 1992-93	0.31	0.34
Kharif 1993	0.45	0.38
Rabi 1993-94	0.61	0.36
Kharif 1994	0.65	0.49
Rabi 1994-95	0.63	0.50
Kharif 1995	0.54	0.42

While planning the data requirements, a monitoring exercise for the complete day and night time of a week from September 17 to 24, 1996 was planned. The objective was to collect data about the water distribution patterns at the secondary, tertiary and farm levels at the same time along the sample distributary. With an interval of one hour, discharges were measured at the distributary head, sample outlet heads and all of the farm gates of the sample watercourse command areas. The measurement of discharges means that water levels were recorded for the calibrated structures at the head of the distributary and sample outlets, which were used to calculate the discharges. The farm gate flows were measured insitu using Cutthroat Flumes and current meters. To avoid submergence problems with the flume, farm gate measurements were made at the square level, which is normally considered an official point for diverting water to irrigate a farm.

The average discharges at the head of two of the sample watercourses and the farm gates of their respective command areas are shown in Figure 6.16 for WC Fordwah 62-R and Figure 6.17 for WC Fordwah 130-R. For WC Fordwah 62-R, the farm gate discharges are roughly 5-20 percent less than the outlet discharge, except for the farm located 2,000 m from the outlet where the farm gate discharge was 40 percent less. The discharges at the outlet of WC Fordwah 130-R were roughly one-eighth of the outlet discharges for WC Fordwah 62-R, which is a dramatic decrease.

6.3. Flow Measuring Devices

In order to improve watercourse management, there is an essential need to have appropriate devices for measuring discharge rates. There is a definite value in having farmers know the quantities and volumes of water that are being managed. Most importantly, farmers can be trained to measure water. Zaman et al (1998) reported the training of 132 farmer leaders of the WUF for Hakra 4-R Distributary as an exercise under this project to strengthen the social organization of the WUF.

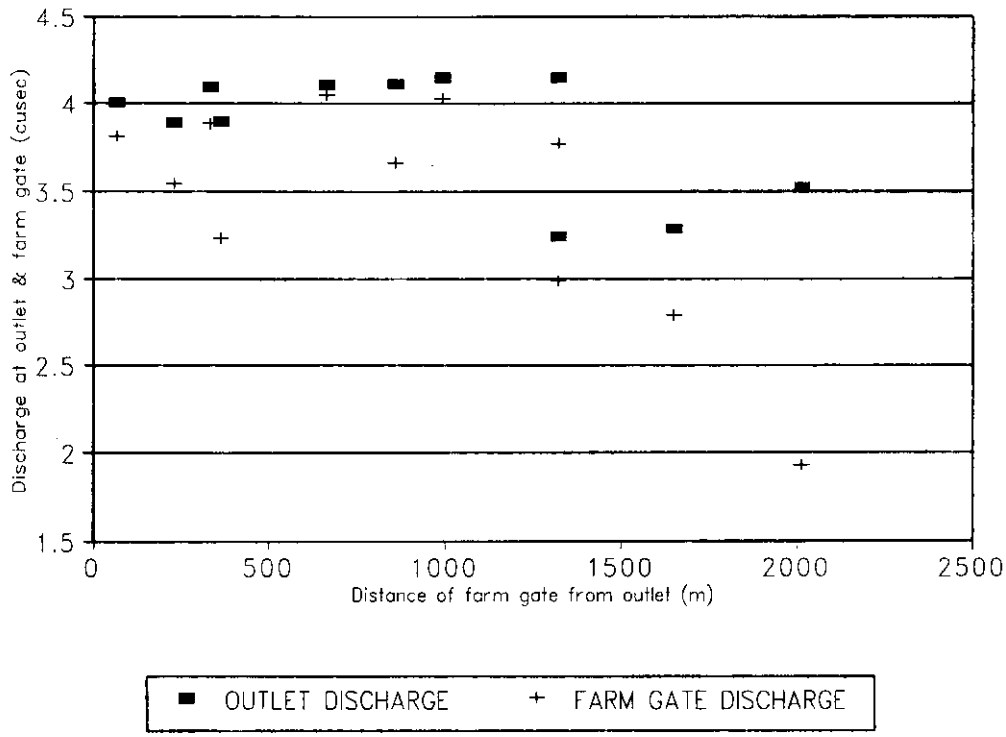


Figure 6.16. Discharge at Outlet 62-R/Fordwah and Farm Gates (September 17-24,1996).

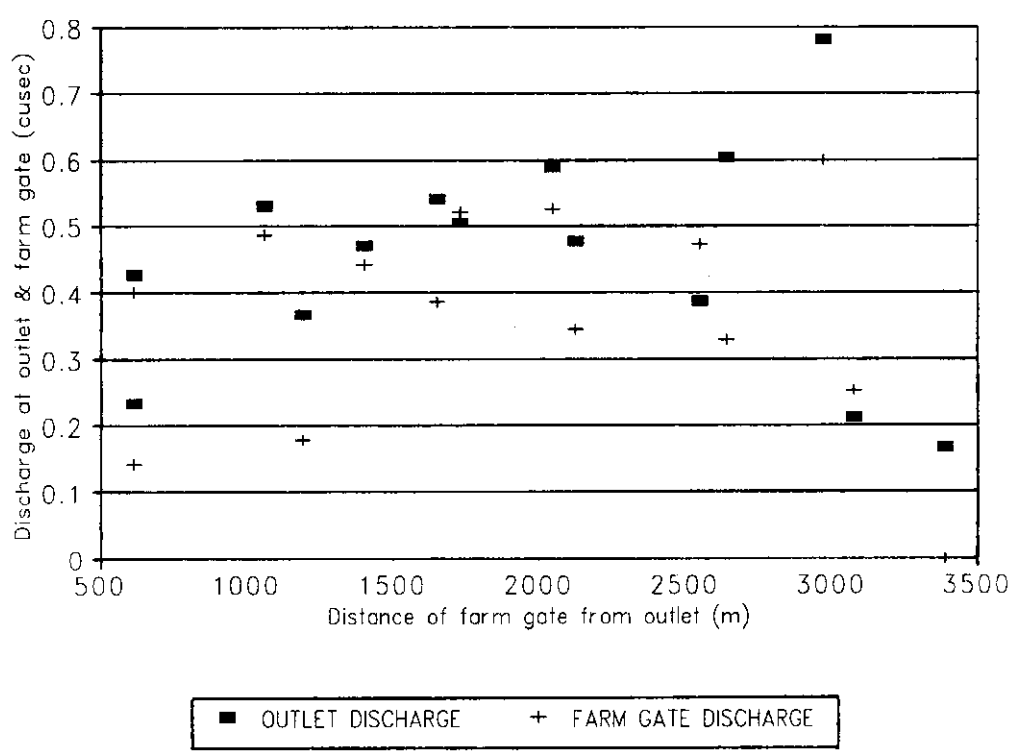


Figure 6.17. Discharge at Outlet 130-R/Fordwah and Farm Gates (Sep 17-24,1996).

Next >>

Of the flow measuring devices to be discussed below, the Pygmy Current Meter has been available for many decades. The Cutthroat Flume was first introduced in Pakistan during November 1973 and is used by many government entities. Under this Dutch-funded project from October 1995 to December 1998, two flow measuring devices have been developed: Rectangular Channels for measuring farm water deliveries and a Pitot Tube for measuring tubewell discharges. This combination of flow measuring devices provides the necessary tools for use in watercourse command areas.

6.3.1. Pygmy Current Meter

A current meter is used for measuring the velocity at a point in flowing water. By measuring the velocity at many points in a cross-section, as well as the area, the discharge rate can be calculated. In fact, the discharges of most rivers around the world are measured utilizing a current meter. For measuring the discharge rate in a watercourse, the commonly used current meter is too large. Consequently, a much smaller model is used that is called a Pygmy Current Meter. The two types of current meter are shown in Figure 6.18.

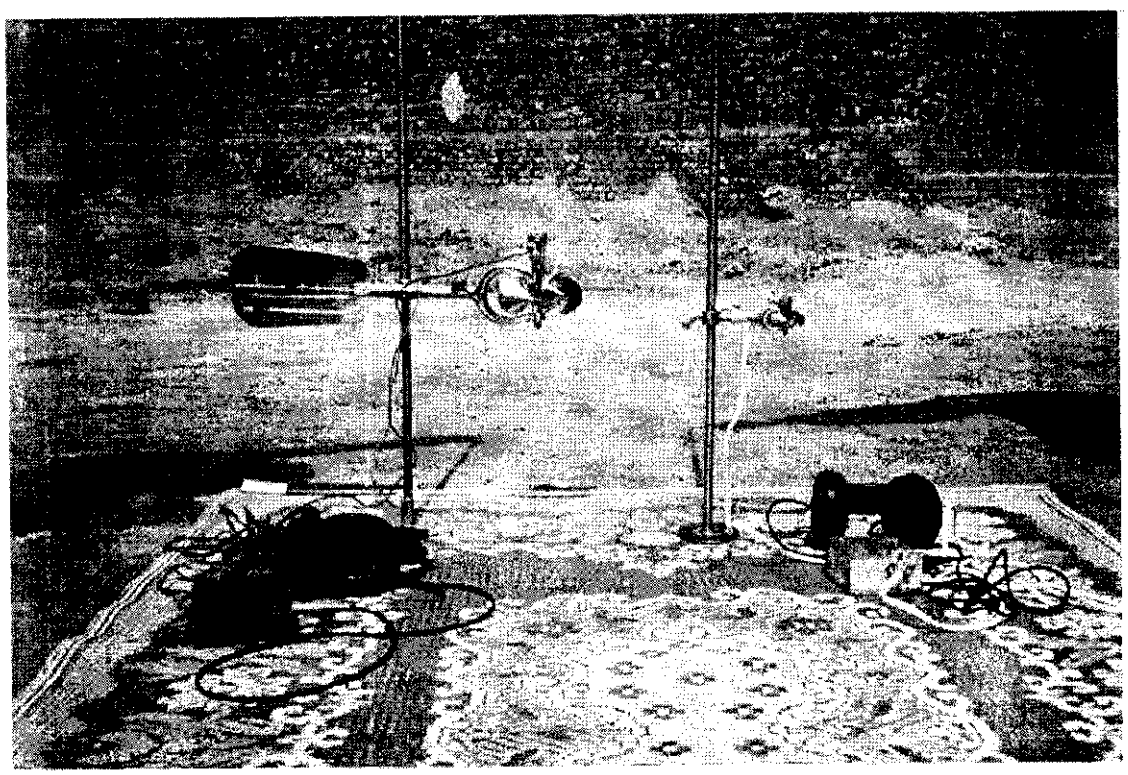


Figure 6.18. Comparison in Size of a Pygmy Current Meter with a Commonly used Current Meter.

6.3.2. Cutthroat Flumes

The Cutthroat Flume has been a popular device for measuring watercourse discharges in Pakistan. The principal advantages of a Cutthroat Flume are: (1) simple fabrication; (2) a level floor so it can be placed on the channel bed; (3) a range of sizes covering discharge rates from less than one cusec to nearly 200 cusecs; and (4) discharge calibration for submerged flow as well as free flow. The principal disadvantage of a Cutthroat Flume is that by constricting the cross-sectional area of flow, the water level upstream is raised, thereby increasing seepage losses for upstream earthen channels. Farmers do not mind having a temporary installation for one or two hours of a Cutthroat Flume, but they are not in favor of a permanent installation. A temporary installation of a Cutthroat Flume is shown in Figure 6.19.

Figure 6.19. Temporary Installation of a Cuthroat Flume for Measuring the Watercourse Discharge Rate.

6.3.3. Rectangular Channels

To overcome the disadvantage of using a Cutthroat Flume, various sizes of Rectangular Channel have been calibrated (Bukhari et al 1998) under this project. The size of a Rectangular Channel is specified by the width, W, and the height, H of the vertical walls. All other dimensions are based on W. To determine the discharge rate, two measurements are required: (1) the depth of water in the stilling well attached to one of the walls; and (2) the velocity at mid-depth in the middle of the Rectangular Channel using a Pygmy Current Meter as shown in Figure 6.20. The principal advantage of a Rectangular Channel is that a width, W, can be selected that very nearly corresponds with the width of the watercourse channel, so that the flow is not constricted and the upstream water level is not raised.

6.3.4. Pitot Tube

There are at least 30 million pumps around the world used for lifting irrigation water. In developed countries, some of the pumps are equipped with good quality flow measuring devices. But the discharge rate of pumps in developing countries are rarely measured. A major accomplishment of this project was to complete the development of a low-cost, easy-to-use Pitot Tube (Shafique et al 1998) for measuring pump flows discharging into the atmosphere, which is the case for most tubewells. The Pitot Tube is placed in the center of the pipe as shown in Figure 6.21. The measured velocity head is converted into a velocity that is divided by a coefficient established in the laboratory, then multiplied by the cross-sectional area of flow in the pipe to arrive at the discharge rate.

6.4. Improving Watercourse Operations

Improving the management of watercourse operations requires water measurement if significant progress is to be achieved. Farmers have a keen interest in being able to measure water. Under this project, 132 farmer leaders of the Hakra 4-R Distributary received water measurement training (Zaman et al 1998). There was a high degree of enthusiasm and they were quick to learn. Also, they helped each other. Some of the WUF leaders became resource

persons to assist IIMI staff in training others. This created a tremendous amount of transparency about water distribution throughout the command area. Most importantly, these six training courses clearly demonstrated that illiterate, as well as literate, farmers can readily learn. This feat amazed the farmers, themselves; they are extremely proud about attaining these skills.

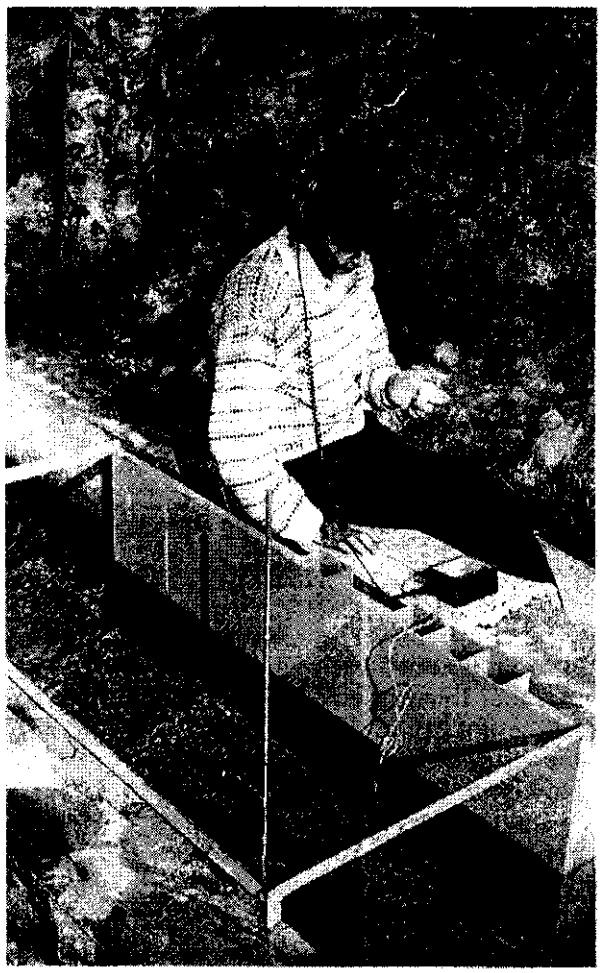


Figure 6.20. Pygmy Current Meter Measurement in an Experimental Rectangular Channel.

6.4.1. Field Calibration of Moghas

At the head of each watercourse is a structure called an outlet or mogha, which are not regulated by gates. In most cases, the mogha is a orifice of fixed dimensions, except at the tail of a distributary or minor, where open flume outlets are used. For an earthen watercourse, a Cutthroat Flume can be temporarily installed a short distance downstream from the mogha; a single discharge measurement will allow the discharge rating for the mogha to be derived. For a lined watercourse, a Pygmy current meter can be used. Having a mogha discharge rating is valuable for all of the farmers in a watercourse command area; however, it is even more valuable if all of the moghas along a distributary, including minors, have been field calibrated so that it becomes possible to achieve equitable water allocation at the watercourse outlets.

Figure 6.21. Photograph showing Proper Placement of the Low-cost Easy-to-use Pitot Tube at the end and in the Center of the pump Discharge Pipe.

6.4.2. Equitable Water Distribution

In general, equitable water distribution along the watercourse is rarely achieved. First of all, farmers have to judge the amount of water by observing the water level in the watercourse channel at their nakka, which serves one square (25 acres or 10 ha). The water level is observed as being normal, or higher or lower than normal. But the discharge rate, in the vast majority of cases, is never measured. The installation of a Rectangular Channel at each nakka (commonly, there are 12-18 nakkas along a watercourse) would certainly provide considerable transparency among all of the water users. This exercise would be even more beneficial if the farmers are organized as a Water Users Association (WUA).

6.4.3. Tubewells for Supplemental Water

Every tubewell owner can afford to either fabricate or purchase a Pitot Tube in order to periodically measure the tubewell discharge. This is valuable for long-term monitoring to establish whether or not the pump capacity is declining. Also, such measurements can be used to monitor irrigation applications on various crops. Finally, a Pitot Tube measurement provides a firm basis for selling tubewell water to other farmers.

6.4.4. Water Markets

In the watercourse command areas, water markets presently exist. The canal water is sometimes sold, but mostly water turns are traded. However, tubewell water is frequently sold. By being able to measure these flows, there will be a much firmer basis for both buyers and sellers in transacting water sales. Thus, water markets will flourish more with water measurement, which will be of significant benefit for increasing agricultural productivity.

7. SURFACE IRRIGATION METHODS AND PRACTICES[10]

7.1. INTRODUCTION

On a world-wide scale, concern exists about the sustainability of natural water resources; during recent years, the emphasis has become more focused on efficient use of natural resources. This is a generic issue, which concerns many countries, western as well as developing countries, as well as those for which agriculture is an important source of income, who depend to a large extent on the existing natural soil and water resources. However, due to increasing population, the competition for the water resources between agriculture and industry, urban use, navigation and recreation (e.g. artificial lakes) continually increases.

To achieve sustainable development in irrigated agriculture stresses on the one hand, is the need for using natural water resources in an efficient manner in order to avoid over-exploitation, and to deal with water scarcity. On the other hand, however, sustainability is embedded in a more complex structure that includes physical, economic and social factors. The technology to sustain irrigated agriculture exists, but its use is limited by a number of factors, such as: lack of economic incentives for irrigators; lack of education on best management practices; the high cost of improving structures, pressurised irrigation systems, and drainage systems; institutional constraints, such as water rights and water transfers; and the effects of irrigation return flows on the environment (ASCE 1990).

Many irrigated areas in the world are suffering from waterlogging and salinity problems (of the world's cultivated lands, about 23% are saline and 37% sodic). Waterlogging has resulted in severe salinity problems and declining yields. The main cause of waterlogging is excessive water inputs into a system that has finite storage and limited natural drainage capacity (Hoffman et. al. 1990). It is important to recognize that inefficient irrigation is the major cause of salinity and shallow water tables in most irrigation projects of the world and that the need for artificial drainage can be substantially reduced through improvements in irrigation management (ASCE 1990).

Presently, there is a need to address the farmers' role in the debate on sustainable irrigated agriculture. Hence, to investigate the debate from the angle of possible potential solutions on improved on-farm water resources management, adaptable by farmers, taking farmers' constraints into consideration. Further, there is a need to investigate the importance and role of institutional arrangements to facilitate on-farm water resources development and to make long-term sustainable improvements.

This section of the report discusses the research on surface irrigation methods and practices, which is Sub-component Ib of the Dutch-funded Project "Managing Irrigation for Environmentally Sustainable Agriculture in Pakistan". This section presents findings on current irrigation practices in Pakistan (Punjab), research approach and objectives, technical and management interventions (results and conclusions), research constraints and limitations, future scope for research, and implementation efforts pertaining to surface irrigation. At the time of writing this report, further results pertaining to the surface irrigation research are awaited, which will be completed by August 1999.

7.2. IRRIGATION PRACTICES IN PAKISTAN

Dealing with the field and farm level with a perspective towards improving water resources management, a considerable amount of water is wasted at this level of the irrigation system due to improper operation and management practices. As observed in South Punjab, farmers generally apply irrigation water using the basin irrigation method, whereby water is applied to bunded units, often not properly leveled, resulting in long irrigation events and a poor water

[10] Contributed by Ineke M.Kalwij and Shahid Sarwar, IIMI-Pakistan.

uniformity, often leading to over-irrigation. Early research in the seventies already revealed low irrigation efficiencies at the field level. For example, Clyma et. al. (1975) described that at the field level, the application of water in the field was found to be very inefficient in Pakistan, with irrigation application efficiencies less than 30%, where the common practice appears to be over-irrigation. As further mentioned in Clyma et. al. (1975), most of the additional tubewell water is lost due to inefficient operation and management practices; only 12 percent of the tubewell water was effectively used. This low efficiency suggests why the SCARP program has not been completely successful in lowering the water table. Much of the pumped water, as well as the canal water, goes to the groundwater to maintain a relatively high water table (Clyma et. al. 1975).

These findings are supported by quite recent studies in the Punjab. Kalwij (1996) reports several cases of over-irrigation for selected basin cotton fields, ranging from 70 percent to 23 percent in application efficiency for over-irrigation cases. More severe over-irrigation cases were reported by Sarwar and Shafique (1997), for basin cotton fields (1996), whereby 50 percent of the 16 analyzed irrigation events, encompassing three fields, showed severe over-irrigation (72 % - 0.37% application efficiency). Kalwij (1997) discusses the irrigation performance for wheat and cotton fields, and concluded that overall excessive irrigation is being practiced; however, one field with loam soil and an alkali crust suffered heavily from under-irrigation due to the low infiltration rate. Despite early efforts on improving on-farm water management, farmers are still facing problems in using water efficiently. Although techniques, such as laser-leveling and furrow irrigation, had been introduced to the farmers in the seventies, very few have benefited from these efforts; moreover, it has not been adopted widely, and mostly by large landowners only.

In recent years, an awareness among farmers is growing, especially among large farmers in trying to find means and ways to achieve more efficient water use and yield enhancement. Based on a study by Berkhout et. al. (1997), which elaborated farmers' perceptions on different irrigation methods and farmers' interest in improved practices, most of the farmers are aware of the advantages of improved irrigation practices (e.g., using the bed-and-furrow irrigation method), but lack of exposure and familiarity, along with existing constraints, make them hesitant for trying alternative options.

Irrigation practices refer to the actual execution of the irrigation event(s) at the field and farm level. To achieve good irrigation performance, it is a necessity to know: (i) when to irrigate; (ii) how long to irrigate; (iii) how much water to apply; and (iv) how to irrigate (i.e. operation and management). For an average farmer in Pakistan, these things are difficult to know, since they do not know the exact amount of water they have at their disposal; also, they do not know the actual crop water requirement. Their knowledge is based solely on observing the crop and soil conditions, which is certainly very helpful, but insufficient for moving to higher levels of management and the subsequent benefits of increased agricultural productivity and higher farm incomes.

7.3. Research Approach and Objectives

The approach is the so-called: "action research", which means that the technical interventions are tested on farmers' fields. This approach has several advantages, such as direct interactions with the farmers, resulting in direct feedback from the farmer and a more objective assessment of the suitability of the technical intervention from a physical point of view (soil type, soil and water quality, water availability, etc.). Furthermore, the exposure to the new technology by other farmers becomes easier, since the technical intervention is tested in their area. A constraint of this approach is the high risk of unexpected events, which makes the data collection incomplete, such as unexpected irrigation events or cattle eating the crop. Further, it is difficult and very time consuming to select a site and to include sample fields with different physical characteristics. Further, farmers are sometimes quite hesitant in allowing their fields to be used for experiments. Often, because of the risk involved, farmers sometimes become

tired during the season of the constant presence of people walking in the field and taking soil samples.

The main objective is defined as to develop improved surface irrigation practices for water and salinity management, applicable to irrigated agriculture in Pakistan. The research is categorized by several research activities:

1. Design and Management of Traditional (Basin) Surface Irrigation Systems (Ph.D. research);
2. Improved Irrigation Practices Using the Bed-and-furrow Irrigation Method; and
3. Surface Irrigation Scheduling.

The application of a surface irrigation simulation model (SIRMOD), developed at the Department of Biological and Irrigation Engineering, Utah State University, plays an important role in the research for evaluating irrigation events, along with the development of alternative management options (Walker 1993). This is a one-dimensional model, which simulates the sub-surface (water infiltration into the soil) and the surface (advance and recession of the water) irrigation processes. The model simulated the irrigation process for basin, furrows and borders. The model involves a numerical solution for the equations of continuity and momentum (Saint-Venant Equations). Three mathematical approaches for solving these equations are integrated in SIRMOD:(1) Full Hydrodynamic Model (which uses the complete form of the Saint-Venant Equations); (2) Zero-inertia Model (which deals with a simplification of the equations); and (3) The Kinematic-Wave Model (which deals with a further simplification of the equations). The full Hydrodynamic and Zero-Inertia Models are used in this research. SIRMOD requires input data, such as the field water inflow, topography, flow cross-section, irrigation duration, downstream boundary condition, flow regime, calibrated Modified Kostiakov-Lewis infiltration function and the target depth of application at the end of the field. Output with respect to performance assessment are: (1) application efficiency (ratio of water stored in the root zone to the total application); (2) requirement efficiency (ratio of water storage to the total root zone capacity); and (3) distribution uniformity (average depth of water applied in the last quarter of the field divided by the average depth applied to the entire field).

Section 7.4 presents the results regarding the design and management of traditional (basin) surface irrigation systems and improved irrigation practices, followed by Section 7.5 using the bed-and-furrow irrigation method.

7.4. Design and Management of Traditional (Basin) Surface Irrigation Systems

7.4.1. Introduction

The basin irrigation method is most commonly used for surface irrigation of crops in Pakistan. Average lower and upper limits of the farm size are 5 and 15 acres in the study area. The basic land division is the acre (0.40 ha) and its boundaries are normally kept permanent during the land preparation operations. After sowing, this land unit is further divided into 1 to 6 small basins, defined here as bunded units (BUs). These bunded units are prepared by constructing dikes lengthwise dividing the width of an acre. This process creates bunded units of an average length 65 m and the width varying from 10 to 60 m.

The field channels to deliver irrigation water are usually designed in between the adjoining acre boundaries serving both sides. These field channels are connected to the main watercourse through a *nakka* (farm gate) that serves the farms in squares of 25 acres (10 ha). In turn, the *nakka* receives water from the tertiary watercourse that receives water through the *mogha* (tertiary outlet) located along the distributary canal. The canal water is distributed through tertiary outlets by a weekly warabandi (water turns) among the landholders of the command area and its duration is normally fixed by the Irrigation Department in proportion to an assessed culturable command area (CCA) of the farmers (Latif and Sarwar, 1994). Private

tubewells are installed at a proper place within a farm to combine this water with their canal turn, or to use it separately depending upon the requirement.

7.4.2. Concepts

The technical principles of irrigation are fairly well developed, understood, and modeled. Most research and development efforts are aimed at refining and expanding engineering, soil and plant science, and economic knowledge of individual processes and interactions that are already well defined. The weakness, therefore, in irrigation science application lies primarily in the management of the irrigation system as a whole and not the design and operation of the irrigation system's individual components (Walker 1989). Or at least, it necessitates studying a part of the system at the time when being designed and then operated by a sole decision body, like a farm is managed by a limited number of leading members mostly having a common interest for good production with minimal expenditures.

Optimization and control of surface irrigation efficiency is a crucial agricultural activity. Although computer models have been developed so that the problem can be studied in a more precise and inexpensive way, these models require knowledge of field parameters that are very difficult to obtain in practice. The underlying assumptions that are implicit in the models, the dynamic character of the field parameters, and the need for a qualified engineer to interpret the results and implement the necessary alterations, has rather seriously delayed the spread of mathematical models for surface irrigation in practice (Katopodes and Tang, 1990).

Boote et al. (1996) have emphasized the need for site-specific or prescription farming, which is optimizing profit and production for a field (or farm) by managing a farm in as many small units and optimizing management for each individual unit's characteristics. This key issue is addressed here to identify the potential use of state-of-the-art knowledge in surface irrigation management within the existing limitations of the agricultural system in Pakistan. The tendency to optimize the use of total available water often conflicts with the tendency of the individual farmers to overuse water. This is more noticeable in situations where farmers are not charged for water on a volumetric basis and the system practices permit such overuse (Sritharan et al. 1988). However, in an environment of deficit canal water supplies, the problem becomes of real importance for the farmers also in order to avoid extra costs incurred on developing and operating the alternative groundwater resource.

The quality, quantity, and temporal distribution characteristics of the source of irrigation water have a significant bearing on the irrigation practices (Walker and Skogerboe, 1987). The low efficiencies of surface irrigation systems are, in part, the result of a faulty assumption made by system designers and managers concerning the supply system, as well as the on-farm system operation. That assumption is that water control – the ability to regulate both the rate and duration of flow – is both practical and practiced (Wattenburger and Clyma, 1989). The problem is even more important for the study area, where the monthly coefficient of variation of the flow rates in a year at the tertiary outlets are observed to be varying from 0.1 to 1.20 due to water fluctuations in the delivery system (Sarwar et al. 1997), with the ideal value being zero and less than 0.2 is considered good performance.

7.4.3. Research Framework and Methodology

Farmers have adopted the existing farm designs, the layout of fields (acres), bunded units within the acres and the serving field channels, with a long experience of irrigating these farms. It means that they have maintained the size and slope of the field channels to deliver the available amount of water for its onward application to different bunded units. It is also perceived that the farmers have a fair qualitative knowledge of the soil types, infiltration, roughness and other factors affecting surface irrigation advance and recession patterns. However, they lack in knowing the "exact" values of these parameters; even, they don't have the means and expertise to measure and further process such information for efficient

irrigation design and management. Therefore, the purpose here is to evaluate the opportunities for irrigation management on these farms, while working with the existing limitations of the farmers and the system.

The study area is located in the south of the Punjab Province, which is served by the Fordwah/Eastern Sadiqia Canals off-taking from the Sulemanki Headworks on the Sutlej River. The area falls in the cotton-wheat zone of the country, which are also the respective main crops during the kharif (summer) and rabi (winter) seasons. The average annual rainfall (250 mm) is very low when compared with the evaporation (2400 mm). Farmers augment the limited canal water supplies with private tubewells in order to satisfy the crop water requirements, which have different marginal water qualities. As a result of the excessive use of tubewell waters, secondary soil salinity and sodicity problems are increasing in this area.

Sample farms representative of the physical environment, as listed in Table 7.1, were selected for in-depth data collection on the existing and proposed farm irrigation practices. An initial assessment of the existing irrigation performance was made during the Rabi 1995-96 and Kharif 1996 seasons for the wheat and cotton crops, respectively. Based on the analysis of the existing crop cultivation systems and their irrigation performance, the study has developed shallow and deep corrugation interventions for close growing crops (wheat) and row crops (cotton), respectively. During the seasons of Kharif 1997 and Rabi 1997-98, the proposed interventions were demonstrated as appropriate water saving measures for irrigation applications throughout the cropping seasons. These interventions are easily adaptable with the available machinery and they can be integrated with the existing sowing and irrigation practices of the farmers. The state-of-the-art zero-inertia technique was adapted for simulating the different irrigation phases and to predict the post-irrigation performance. This computer-based mathematical model was calibrated and tested with actual field data.

Table 7.1. Characteristics of the sample Farms Selected for Evaluating the Basin and Basin-with-Corrugations Irrigation Methods.

Season	Farm ID	Location	Farm Area (acre)	Soil Type	Water Source
Rabi 1995-96	1	FD-14R	12.5	Silt loam	Canal + Tw
	2	FD-62R	10	Sandy loam	Canal + Tw
	3	AZ-111L	6	Loam	Tw
Kharif 1996	4	FD-14R	12.5	Silt loam	Canal + Tw
	5	FD-62R	10	Sandy loam	Canal + Tw
Kharif 1997	6	FD-14R	7.5	Sandy loam	Canal + Tw
	7	FD-14R	13	Clay loam	Canal + Tw
Rabi 1997-98	8	FD-62R	6	Loamy sand	Canal
	9	FD-14R	12.5	Silt loam	Canal + Tw
	10	FD-73R	30	Sandy loam	Canal + Tw
	11	FT-109R	12.5	Sandy loam	Canal
	12	Vill. Bahad.	25	Loam	Tw
	13	FD-90L	12.5	Sandy loam	Canal + Tw
	14	Vill. Bahad.	25	Loam	Tw

Following guidelines from Walker and Skogerboe (1987) regarding data requirements for field monitoring to evaluate a surface irrigation system, a certain number of bunded units scattered in the sample farms were selected to continuously observe the irrigation events during the cropping seasons. The data collection included observations of inflow, advance, recession, infiltration tests, and gravimetric soil moisture analysis before and after the successive irrigation events on the fields selected for in-depth monitoring. Further, the inflow during the whole canal turn, or from separate use of tubewell water, on the sample farms and its application to different fields according to farmers' strategies were also observed. The soil

surface roughness characteristic for different irrigation events was noted by visual observations for using values reported in the literature.

The performance of surface irrigation systems is not predictable without assessing the individual system (Walker and Skogeboe, 1987) and realizing such requirement, the analysis work for this field-oriented research was done in various steps to reach the findings. These steps are listed below.

1 The soil moisture deficit before irrigation and its replenishment after the irrigation event on the sample bunded units are computed up to 91.44 cm (3ft) depth of the soil profile while using the respective gravimetric samplings and measured bulk densities. To avoid the assumptions about water movement above or below the root zone at different crop growth stages, this depth (91.44 cm) is considered as an absolute reference for the target and infiltrated water during irrigation. Normally, this is also the maximum effective rooting depth under local conditions with shallow-cultivated soils.

2 Best-fitted advance and infiltration functions are selected based on calculations by different methods given in the literature (Shafique and Skogerboe, 1987; Walker and Skogerboe, 1987, and Walker 1989). Advance functions (parameters of a simple power function) calculated by the "least squares regression technique" were more reliable than the "two-point method" results. Similarly, the infiltration functions (parameters of the Modified Kostiakov Equation) derived by the "alternative technique" using the observed irrigation data were more consistent than the ones which were obtained from the cylinder infiltrometer test results.

3 The above data set, with additional information on the size of each bunded unit, roughness and inflow for particular irrigation events, was used to test SIRMOD (Walker 1994) under local conditions. The model predictions were fairly matched with the observed field data and the model performance error always remained within the limits of 5 percent or less. However, some significant differences, greater or less than 15 percent in the recession times were found only at the grid points having major topographic undulations as compared with the general field level.

4 Finally, the impact of the proposed interventions was evaluated in terms of the relative water application ratios and the productivity of water.

7.4.4. Technical Interventions: Action Research Results

7.4.4.1. Surface Irrigation Management for Close Growing Crops

Wheat, pulses, oilseeds and almost all kinds of fodder are dense crops, which are sown on a basin. In this irrigation method, field topography governs the advance and recession patterns, which ultimately affects the infiltrated depths. Even in laser-leveled fields, surface microtopography is a key variable affecting basin irrigation performance (Playan et al. 1996). The minimum depth of irrigation water applied to a basin is dictated by covering the 'high spots' so that they do not become saline (Walker and Skogerboe, 1987). Consequently, instead of applying the irrigation requirement, much greater depths are applied, particularly in the early part of the season. Table 7.2 shows the performance analysis of traditional basin irrigation for wheat. Nearly half of the monitored irrigation events turned out as insufficient or excessive irrigations (Kalwij 1997).

Table 7.2. Irrigation Efficiencies on Sample Bunded Units During Rabi 1995-96.

Event	Date	Z2 (mm)	SMD (mm)	DPR (mm)	Stored (mm)	Ea (%)	Es (%)	DU (%)
W/C Fordwah 14-R; Field 3								
Event 1	(14-01)	104.35	51.89	-52.46	51.89	49.73	100	85.52
Event 2	(06-02)	57.86	57.70	-2.16	55.70	96.27	100	95.33
Event 3	(29-02)	70.69	59.99	-10.70	59.99	84.86	100	91.42
Event 4	(12-03)	56.06	48.63	-7.43	48.63	86.75	100	92.80
W/C Fordwah 14-R; Field 33								
Event 1	(23-01)	140.03	51.93	-88.10	51.93	37.08	100	95.46
Event 3	(29-02)	88.02	63.20	-24.82	63.20	71.80	100	98.96
Event 4	(12-03)	84.57	59.79	-24.78	59.79	70.70	100	99.16
Event 5	(28-03)	92.84	40.88	-51.96	40.88	44.03	100	99.32
W/C Fordwah 62-R; Field 8								
Event 2	(06-02)	80.70	54.65	-26.05	54.65	67.22	100	99.73
Event 4	(07-03)	73.57	63.11	-10.46	63.11	85.78	100	99.68
Event 5	(27-03)	22.12	75.08	52.96	22.12	100.00	29.46	99.40
W/C Azim 111-L; Field 4								
Event 1	(19-01)	105.34	77.06	-28.28	77.06	73.15	100	98.14
Event 2	(07-02)	50.57	69.31	18.74	50.57	100	72.96	99.14
Event 3	(02-03)	49.31	54.95	5.64	49.31	100	89.74	99.37
Event 4	(17-03)	53.37	61.33	7.96	53.37	100	87.02	99.67
W/C Azim 111-L; Field 6								
Event 1	(18-01)	147.61	52.20	-95.41	52.20	35.36	100	98.26
Event 2	(07-02)	96.60	55.89	-40.71	55.89	57.86	100	98.67
Event 3	(02-03)	100.11	54.10	-46.01	54.10	54.04	100	99.43
Event 4	(17-03)	109.47	69.75	-39.72	69.75	63.72	100	99.38

There are different concepts for controling the infiltration phenomena to achieve a uniform irrigation. Where it is possible to have proper control on the inflow, surge or cutback irrigation can give good results, mainly in the graded surface irrigation systems. In Pakistan, the farmers don't have much control on the inflow to the farm from the existing rotational system (warabandi). Also, small farmers do not have access to the laser land leveling equipment. In this situation, a simple intervention of 'basin-with-shallow-corrugations' was tested in comparison with the existing 'basin' irrigation method during Rabi 1997-98. Irrigation with shallow corrugations on a flat basin is based on the hypothesis that shallow corrugations facilitate the development of a uniform advance front that ultimately increases the irrigation performance. Figure 7.1 shows photographs of the preparation of an experimental basin with shallow corrugations. Shallow corrugations are made at the end of the wheat sowing operation by using the traditional plank with some pegs on its bottom. Further details of the experiment are given in a pamphlet (Shafique et al. 1998).

Some results on the performance of the comparative irrigation methods -- basin and basin-with-shallow-corrugations -- are given in Table 7.3, which shows the crop yield, applied volume of water, and the productivity of water and is based on the data for the complete cropping season. The comparison of yield per unit area has not shown a significant difference. However, the productivity of water varies from 0.21 to 2.61 kg/m^3 in the basin method, and from 0.25 to 3.95 kg/m^3 in the basin-with-shallow-corrugations method. Percentage increases in the productivity of water, [(S.C.– Basin)/Basin] x 100, varies from 19 to 54 percent. An example of further simplified analysis of the observed data is shown in Figure 7.2, which compares the application time in min/ha during different irrigation events for an experimental site. There is a higher potential of water saving in the 1st irrigation event and the remaining events contribute, more or less, in a scattered pattern. The same analysis for all of the sites over the entire season have shown a water savings ranging from 3.17 to 45.24 hr/ha, in the case of the basin-with-shallow-corrugations method as compared with the basin method. The saving in the time of application, when multiplied by the respective discharge rate, is equivalent to water savings varying from 324 to 4615 m^3/ha over all of the experimental sites.

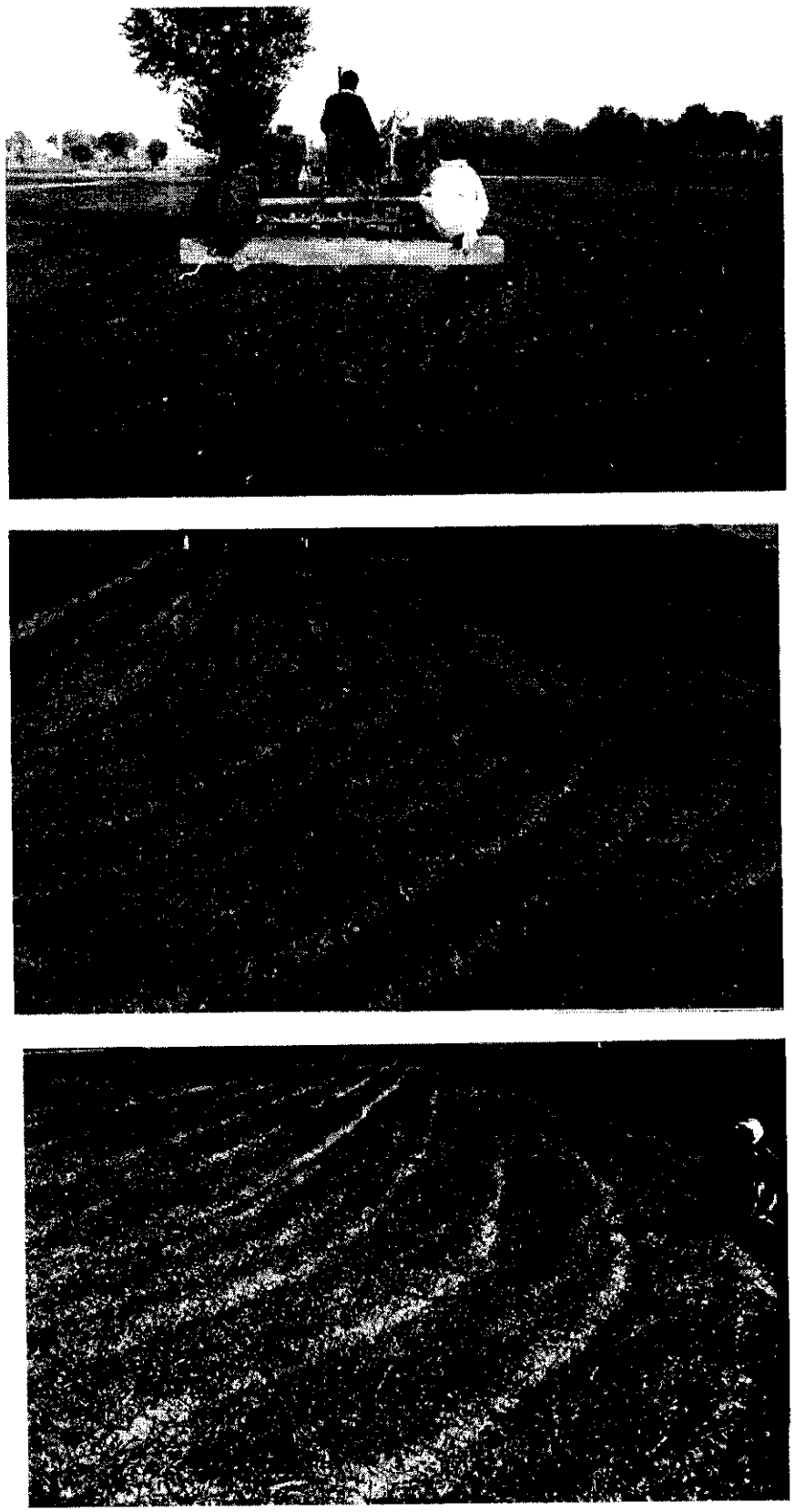


Figure 7.1. **Land Preparation of an Experimental 'Basin-with-Shallow Corrugations'.**

Table 7.3. Comparative Performance of 'Basin' and 'Basin-with-Shallow Corrugations Irrigation Methods.

Farms No	Average Yield (kg/ha)		Volume of Water Applied (m3/ha)		Productivity of Water (kg/m3)		Increase in Productivity of Water
	Basin Field	S.C. Field	Basin Field	S.C. Field	Basin Field	S.C. Field	%
8	3355	3411	6982	5392	0.48	0.63	31
9	2411	2362	6812	4708	0.35	0.50	43
10	4055	4831	2990	2311	1.36	2.09	54
11	4328	3978	20339	15724	0.21	0.25	19
12	4431	4165	4760	2928	0.93	1.42	53
13	3448	3935	1319	995	2.61	3.95	51
14	4041	3473	5921	3501	0.68	0.99	46

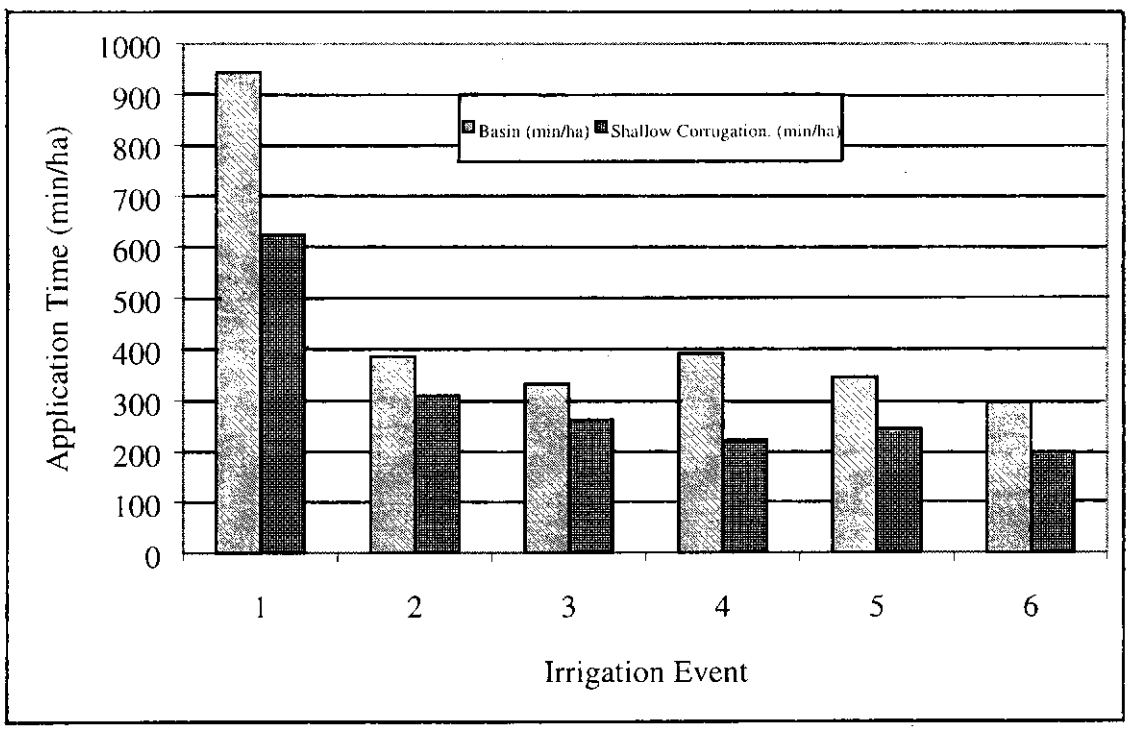


Figure 7.2. Irrigation Application Times for Separate Irrigation Events, Farm 10, Rabi 1997-98.

7.4.4.2. Surface Irrigation Management for Row Crops

Cotton and sugarcane are typical examples of row crops. Under existing practices, these are sowed in rows with different techniques and are irrigated like a basin. In the case of cotton, farmers start its sowing on a flat basin in rows with uniform spacing by a drill machine. Then, they start the hoeing operation before the first irrigation event. The farmers continue the hoeing operation after each irrigation event with a chisel plough. At a certain stage of crop height, hoeing operations are ended with earthening up the crop by a ridger, which creates deep corrugations connected at the head and tail ends.

The irrigation process in this condition starts with the water advancing in the corrugations. After some storage, the flow at the head of the bunded units becomes basin flow, while the advancing front keeps on moving in the corrugations. Ultimately, the irrigation is completed as a basin fully or partially covered with water depending upon the farmer's intention for the

particular situation. Summarized results of irrigation evaluations during the Kharif 1996 season are given in Table 7.4.

Table 7.4. Irrigation Efficiencies on Sample Bunded Units with Cotton (Kharif 1996).

BU No.	Irrigation Event	Applied Flow (l/s/m)	Required Irrigation. Depth (cm)	Application Efficiency (%)	Storage Efficiency (%)	Distribution Uniformity (%)
2	1	1.18	7.01	68.6	100.0	94.0
	2	4.50	5.91	72.1	100.0	98.7
	3	1.28	4.11	72.4	100.0	95.5
	4	1.63	5.57	100.0	87.5	93.0
25	1	6.28	6.31	36.8	100.0	97.6
	2	5.73	4.61	64.6	100.0	97.3
	3	1.63	3.10	30.9	100.0	96.9
	4	1.79	5.28	60.5	100.0	98.8
	5	1.86	5.21	59.5	100.0	99.3
31	1	3.05	8.51	80.7	100.0	95.5
	2	2.93	9.58	100.0	79.5	97.3
	3	3.97	7.46	78.9	100.0	98.4
	4	2.55	5.65	100.0	96.0	99.0
	5	3.71	4.81	78.8	100.0	99.2
	6	6.89	5.33	67.9	100.0	99.4
	7	4.40	4.52	88.5	100.0	99.4
32	1	3.05	12.16	98.5	98.9	94.4
	2	2.93	9.64	100.0	99.9	97.1
	3	3.97	10.41	100.0	99.7	96.1
	4	2.55	8.00	100.0	81.7	98.6
	5	3.71	6.49	100.0	93.1	99.2
	6	6.89	5.74	64.2	100.0	99.4
	7	4.40	5.74	100.0	100.0	99.3

The parameters shown in Table 7.4 are defined as follows:

- **Applied Flow is the water application rate per unit width of the field;**
- **Required Irrigation Depth is the deficit with respect to the field capacity before the respective irrigation events;**
- **Application Efficiency is the ratio of water stored in the root zone to the total application;**
- **Storage Efficiency is the ratio of root zone storage to total root zone storage capacity; and**
- **Distribution Uniformity is the average depth of applied water in the last quarter of the field (or least watered end of the field if the inlet receives less water than the downstream end) divided by the average depth applied to the entire field.**

Clearly, from Table 7.4, there is no problem of irrigation uniformity in the existing small bunded units. This may occur because of the small differences in the infiltration opportunity times over the area of the existing bunded units. Bunded Units 2 and 25 belonging to Sample Farm 4 with a heavy soil that shows a problem of over-irrigation. The reason is just the farmer's perception of good irrigation by completely ponding the fields. Bunded Units 31 and 32 in Sample Farm 5 received some efficient irrigations, but still indicate mostly over-irrigation under the existing practice of the farmers. The crop was severely damaged by a virus disease and the yield assessment could not be made during this season.

In a step to improve the irrigation efficiency of the cotton crop, 'alternate-corrugation' and 'bed-and-corrugation' systems were developed before the first irrigation event in collaboration with the farmers of Sample Farms 6 and 7. Because the first irrigation event was late in the case of basin cultivation of cotton and the crop height (about 30 cm) in both of the cases provided an advantage for studying alternatives from the beginning of the season. The alternate-corrugation system was prepared by using the existing ridger machine with three tines to create corrugations (Figure 7.3) and then manually blocking the head and tail ends of every other corrugation. The bed-and-corrugation system was established with the same ridger by removing its middle tine. Both interventions could only be established separately on the two farms, due to the farmers' interest in different systems. The scheduling for irrigation and other agronomic practices during the season was left with the farmers to involve their perceptions for managing the new interventions.

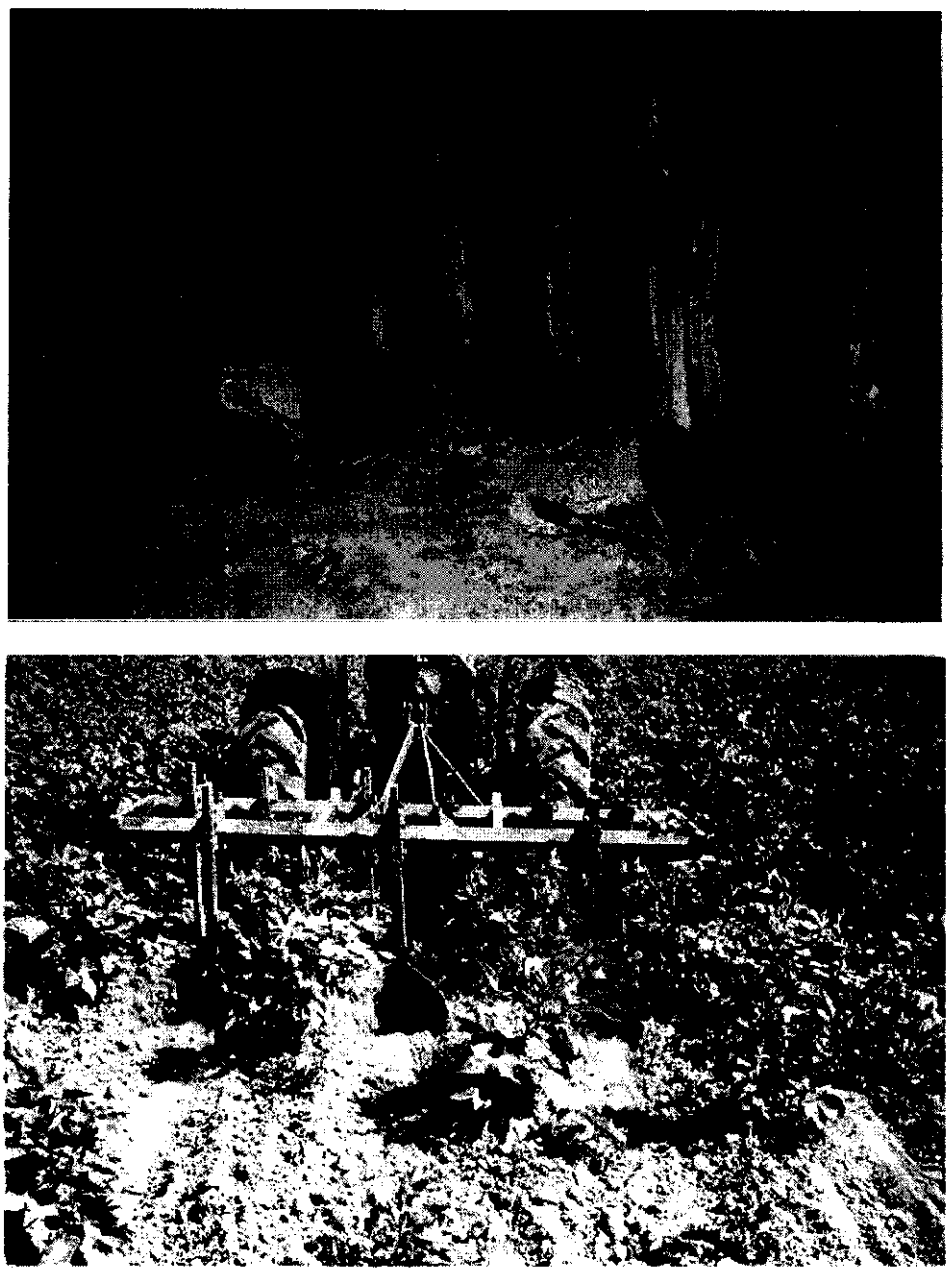


Figure 7.3. Ridger for preparing corrugations.

A simple comparison in terms of the ratio of water applied to the existing system and the alternative systems is shown in Figure 7.4. In the case of Figure 7.4a, the existing basin irrigation system is compared with the alternate-corrugation system the relative water application ratio, (basin-corrug)/basin, on different irrigation events varied from 8 to 68 percent with an average of 41 percent. In the second case (Figure 7.4b), the comparison shows the basin system versus the bed-with-corrugations system; the ratio varies from 10 to 70 percent for the initial nine irrigations with an average of 48 percent. The 1.0 values for Irrigation Events 6 and 9 means that the same amount of water is applied in the basin and corrugated fields. This is attributed to the high flow rates available for these irrigation events and the application of a high flow rate per unit width of the bunded unit flooded the corrugation system just like a basin. As a result, bed-with-corrugations system id not perform as well as the alternate – corrugate system, but improved management practices would likely alter these results.

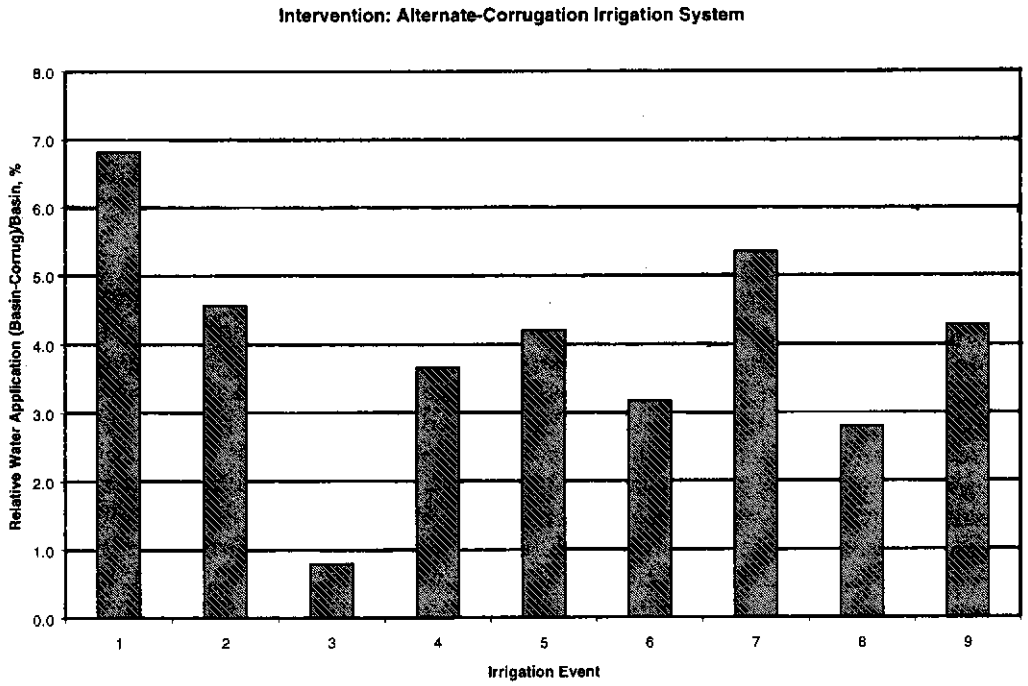
The alternate-corrugation system has shown a water saving of 41 percent, while the bed-with-corrugations system had a 33 percent water saving, both are in comparison with the existing basin irrigation bunded units observed on the respective sample farms. Moreover, observations on crop development during the season and, ultimately, the yield, have not shown a significant difference between the fields of existing and changed irrigation practices. Again, during the Kharif '98 season, the crop was partially affected with a virus so it is not be reliable to interpret the yield per unit of area or per unit of irrigation water application.

7.5. Improved Irrigation Practices by using the Bed-and-Furrow Method

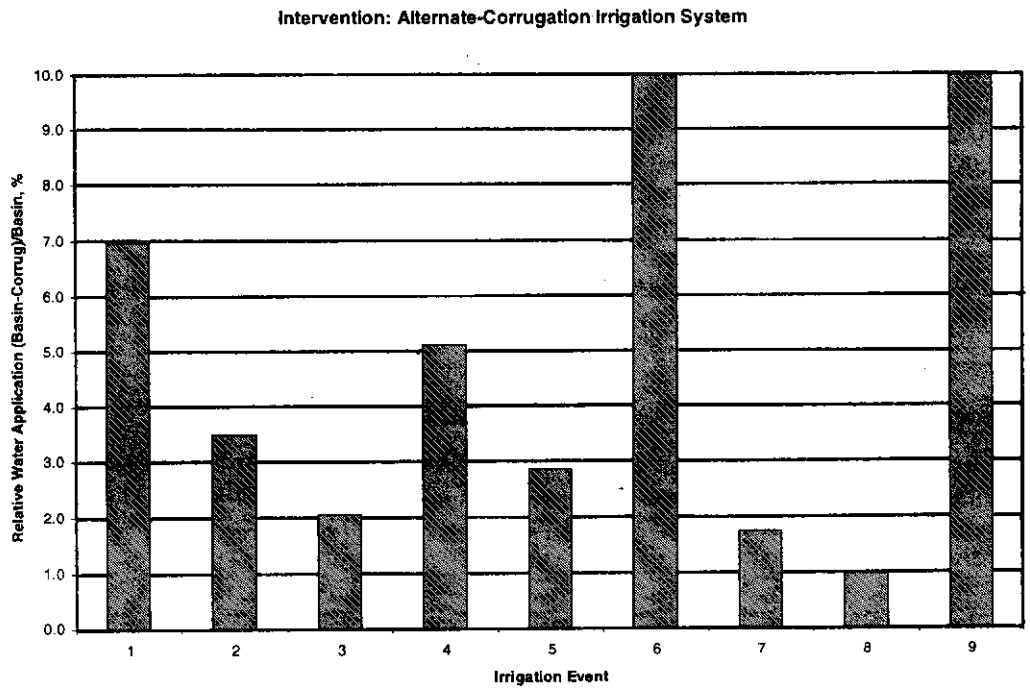
7.5.1. Background

Traditionally, farmers in Pakistan are using the basin irrigation method, whereby the water is controlled by constructing earthen dykes around the fields, which usually results in small bunded units. In the past few years, however, larger farmers have developed an interest in searching for more water saving techniques, which would allow more rapid irrigation of the fields and, consequently, to irrigate more acres of land during their *warabandi* turn (canal water turn). The introduction of furrow irrigation methods found its origin in Pakistan during the early seventies, whereby, through USAID financing, On-Farm Water Management focused on providing extension and knowledge to the farmers about on-farm water management improvements through improved irrigation practices. Despite these efforts, farmers' remained confined to the basin irrigation method for the major crops. However, over the years, farmers' use of the furrow irrigation method for vegetables (on beds) and potatoes and corrugations (small shallow furrows) for sugarcane, maize and cotton have become standard practices used by farmers.

During Kharif 1997, IIMI's involvement started in pilot-testing the bed-and-furrow irrigation methods on farmers' fields in the Fordwah Distributary command area (Fordwah-Eastern Saddiqia Irrigation System). Prior to this season, some activities were initiated, which contributed to the refinement of the research approach. IIMI's involvement in a Cotton Agronomy Research Project at a large farm near Lodhran (Ali Tareen Farm), provided insights into how the farmer manages the irrigation water. Also, the opportunity was there to undertake a comparative study between the water use efficiencies for the basin and bed-and-furrow irrigation methods. Results reveal a relative better water use efficiency for the cotton crop cultivated in bed-and-furrow systems when compared with the traditional flat basin irrigation system. For Kharif 1995, the average WUE for cotton, using the bed-and-furrow irrigation method was 0.54 kg/m^3, and the average value for the basin irrigation method was 0.375 kg/m^3. In 1996, these values were 0.43 kg/m^3 and 0.323 kg/m^3 for the bed-and-furrow and basin irrigation methods, respectively (Iqbal 1997).



(a). Alternate-Corrugation Irrigation System, Farm 6, Kharif 1997.



(b). Bed-with-Corrugations Irrigation System, Farm 7, Kharif 1997.

Figure 7.4. Relative Water Application Ratios for Bed-with-Corrugations and Alalternate-Corrugation Irrigation Systems.

In order to help farmers become more familiar with improved irrigation practices, IIMI's field staff from Hasilpur organized a farmers' excursion (30 farmers from the Fordwah Distributary command area) to a progressive farmer (Bilal Farm near Khanpur). This progressive farmer has used the bed-and-furrow irrigation method for cotton production during recent years. Aalso, he has designed and fabricates the required farm implements (bed-and-furrow shaper and hoeing machine) himself. For farmers, this visit was an eye-opener and certain misconceptions became clear. As commented by farmers: "*more water does not mean more yield*" and "*unnecessary ponding of water is not good for cotton*".

During Kharif 1997, about 15 farmers from the Fordwah Distributary command area experimented with the bed-and-furrow irrigation method. The bed-and-furrow shaper and hoeing machine was provided by IIMI. With respect to water use and yields, farmers' results turned out to be quite satisfactory. Preliminary results reveal that on an average the advance time is reduced by using the bed-and-furrow irrigation method instead of the basin irrigation method, ranging from 8 to 80 percent decrease in advance time depending on the irrigation event and soil type. The effect is higher for the first irrigation event when compared to later irrigation events. The average water application depth is less for the bed-and-furrow irrigation method, resulting in a 11 to 45 percent water saving. However, a constraint felt by the farmers was the overall increase of irrigation events for the bed-and-furrow irrigation method (5 to 11 irrigation events) compared with the basin irrigation method (3 to 10 irrigation events). This more frequent irrigating often conflicts with the timing of the *warabandi* and perhaps irrigating other crops. Out of the 12 farmers checked on yield information, 9 farmers obtained a better yield for cotton cultivated in the beds-and-furrows, whereas 3 farmers faced a yield reduction (Kalwij et. al. 1998). Farmers experienced constraints, mostly related to the required farm implement (bed-and-furrow shaper). Most of the farmers considered the required farm implements as too big and heavy. Their suggestions were taken into consideration and smaller and lighter farm implements were fabricated for the next *Kharif* 1998 season.

A different strategy has been adopted for the research on the bed-and-furrow irrigation method during Kharif 1998. The research area was expanded to other command areas (Hakra-4R Distributary and Bahadarwah Minor), part of a Joint Research Dissemination Program[11], and closer collaboration was established, particularly with OFWM and MREP. The expansion of the research area allows a more objective view on the transferability of the bed-and-furrow technology to (smaller) farmers under different socio-economic, environmental and physical settings. Further, more comprehensive data collection activities were initiated in order to be conclusive about the performance of the bed-and-furrow irrigation method and the potential of transferability of the bed-and-furrow irrigation method to the farming community in South Punjab.

7.5.2. Concept of the Bed-and-Furrow Irrigation Method

During an irrigation event, the crop is flooded in basins surrounded by dykes and the water remains ponded in these bunded units (fields) after an irrigation, reducing the soil aeration and root respiration for those crops that are sensitive to flooding and ponding, like cotton, maize, and groundnuts.

The main characteristics of the bed-and-furrow irrigation method is that furrows are made in a basin at a 2.5 feet space interval (i.e. a 2.5 feet furrow spacing), whereby a bed arises between the furrows. With these dimensions, the tractor wheels match the furrows. The dimension, however, may be different for different systems. The seeds are sown in two rows near the edge

[11] The research on the irrigation trials of the bed-and-furrow irrigation method for the cotton crop is part of the Joint Research Dissemination Program (JRDP) for Fordwah Eastern Sadiqia (South) Irrigation and Drainage Project (FESS). This Program is a joint effort between: Mona Reclamation Experimental Project (MREP), WAPDA; On-Farm Water Management Wing (OFWM) of the Agriculture Department; Agricultural Extension and Adaptive Research Wing (AE&AR) of the Agriculture Department; and the International Irrigation Management Institute (IIMI).

of the bed. Figure 7.5 presents the cross-section of a beds-and-furrows design. Figure 7.6 presents the preparation of the beds-and-furrows and Figure 7.7 presents the final result being irrigated. With respect to the field design, mostly the furrow length will not cover the entire length of the basin, but a space is left at the head and tail reach of the field, either left like a basin or furrows are created perpendicular to the direction of the flow. Since the field (or bunded unit) is entirely dyked and the field slope is negligible, the method can be interpreted as basin - bed-and-furrow irrigation. The bed-and-furrow irrigation method is suitable for crops like cotton, vegetables, groundnuts, maize and sugarcane.

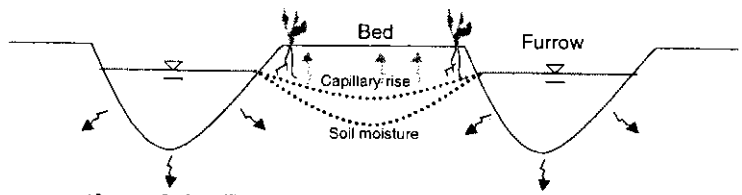


Figure 7.5. Cross-section of the Beds-and-Furrows (not to scale).

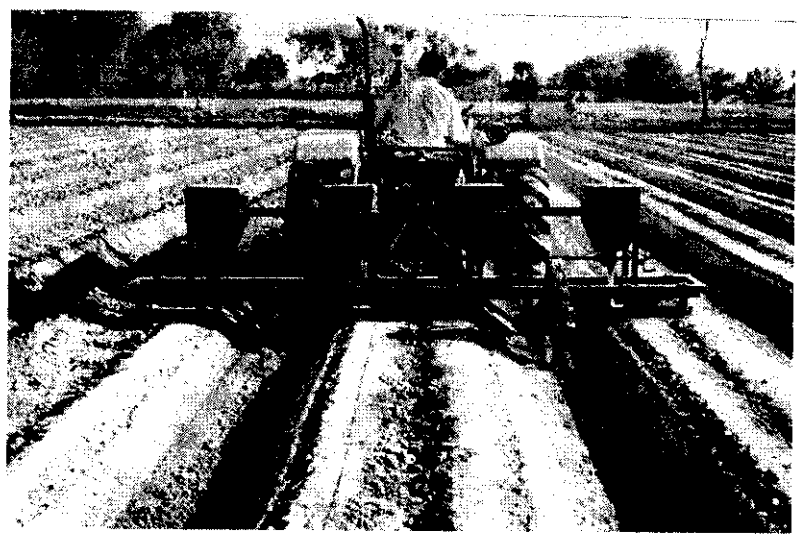


Figure 7.6. Preparation of the Beds-and-Furrows.

Figure 7.7. Irrigation of the Beds-and-Furrows.

Farmers who are using the bed-and-furrow irrigation method recognize a number of advantages, such as: (i) better crop protection for climatic circumstances; (ii) better crop development; (iii) water savings; and (iv) yield enhancement (Berkhout et. al. 1997).

Additional advantages are mentioned by the Director General Agriculture (Water Management, 1997, for example: (i) minimum tillage/seedbed preparation reduces overall energy requirements at the farm; (ii) minimum chances of plant submergence and damage due to excessive rain or flood; (iii) compacting the furrows with the tractor wheels results in minimizing deep percolation and increased lateral movement of irrigation water; (iv) better seed germination and root growth as traffic and root zones are permanently separated; (v) due to the early maturity of cotton in 30 days, the number of pesticide sprays are decreased and it is convenient to sow wheat well on time, with resulting better yields; and suitability for saline and sodic soils as crusting does not occur around plants as a result of irrigation.

The main concept behind having the water channeled through furrows across the soil surface is to facilitate the advance process (i.e. covering the soil with water) and, consequently, the infiltration process. The faster the water reaches the downstream boundary of a field, the faster the infiltration process starts and, thus, the required water depth is more quickly achieved at the lower end of the field. Also, a faster advance process results in a more uniform infiltration distribution, which minimizes the deep percolation losses.

Figure 7.8 presents a computer simulation of the advance and infiltration behavior. The filling of the downstream required water depth starts when the advancing water front reaches the end of the field (tail reach). Figure 7.9 presents a comparison between the advance time for beds-and-furrows and basin fields.

When discussing this principle with farmers, they do realize the difference in water flowing over the field between the basins and furrows. The water arrives quicker at the end and, thus, the farmers' response is to shut down the irrigation supply to the field earlier. Farmers use as their main criterion on how long to irrigate, the time when water reaches the end of the field.

7.5.3. Research Concepts

The research pertaining to the bed-and-furrow irrigation method has two interrelated focuses:

- the technical (hydraulic) aspects of improved on-farm water resources management; and
- the transferability of the bed-and-furrow irrigation method for achieving improved on-farm water resources management in the farming community.

The research was designed around field level experiments on farmers' fields. During Kharif 1995, about 15 farmers joined the experiment (results have been used as an illustration in Sub-section 7.5.1). In Kharif 1998, there were around 160 farms, with about 90 farms for sample purposes divided among Fordwah and Hakra 4-R distributaries and Bahadarwah Minor. A comparative study was conducted between a bed-and-furrow field and basin field (ranging from a field size of 0.25 – 1 acre). The data collected on the sample farms (i.e. one basin and one bed-and-furrow field, generally of a size of 1 acre for each field) was regarding irrigation and cultural practices, agronomic aspects, expenditures (inputs), output (yield), characterizing the socio-economic environment and physical setting. The data analysis relates to: (i) water application (irrigation frequency and water depth applied); (ii) crop development; (iii) production data; (iv) water use efficiency; (v) influence of waterlogging and salinity; (vi) farmers' perceptions on the bed-and-furrow irrigation method; (vii) cost-benefit analysis; and (viii) role of the Farmer Organization (required institutional arrangements).

The water use efficiency is defined as the ratio of the production (kg) per total volume of water applied to the field (m^3), which is used as an indicator for expressing the water productivity.

Further, the research includes an assessment of farm level implications when integrating the bed-and-furrow irrigation method along with improved practices (operation and management of the water resources). In other words, the research aims at quantifying the increased effectiveness of a warabandi turn if an improved method, along with improved practices, is introduced at the farm. For this exercise, two farms have been selected in the command area of Fordwah Distributary (Kharif 1998). Data on irrigations, cultural practices, agronomic aspects, expenditures and output (yield) are collected for each bunded unit. Data collection activities were continued till December 1998.

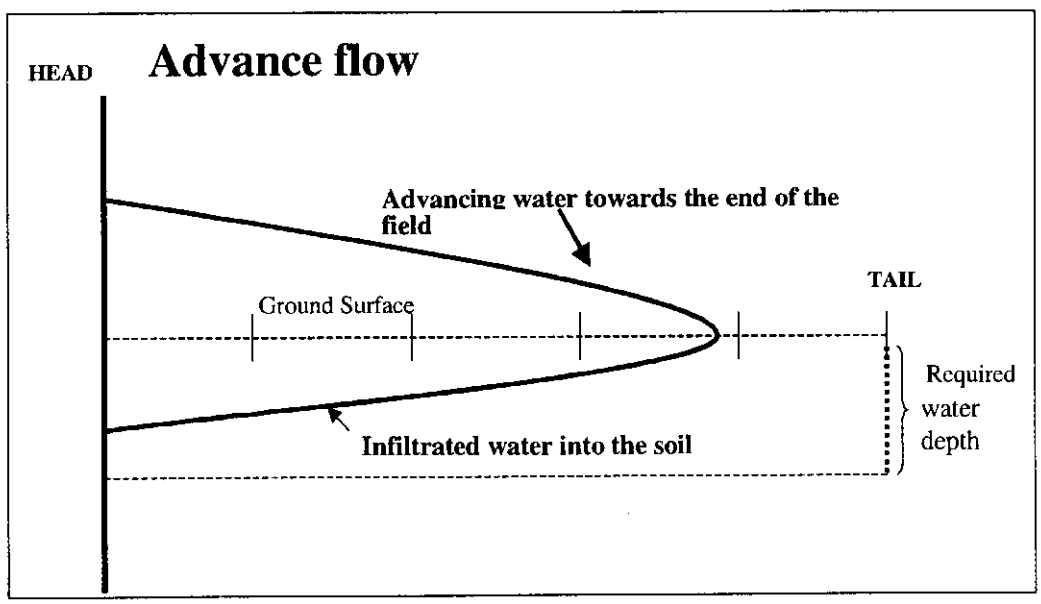


Figure 7.8. Real-time Computer Simulation of the Advance and Infiltration Process.

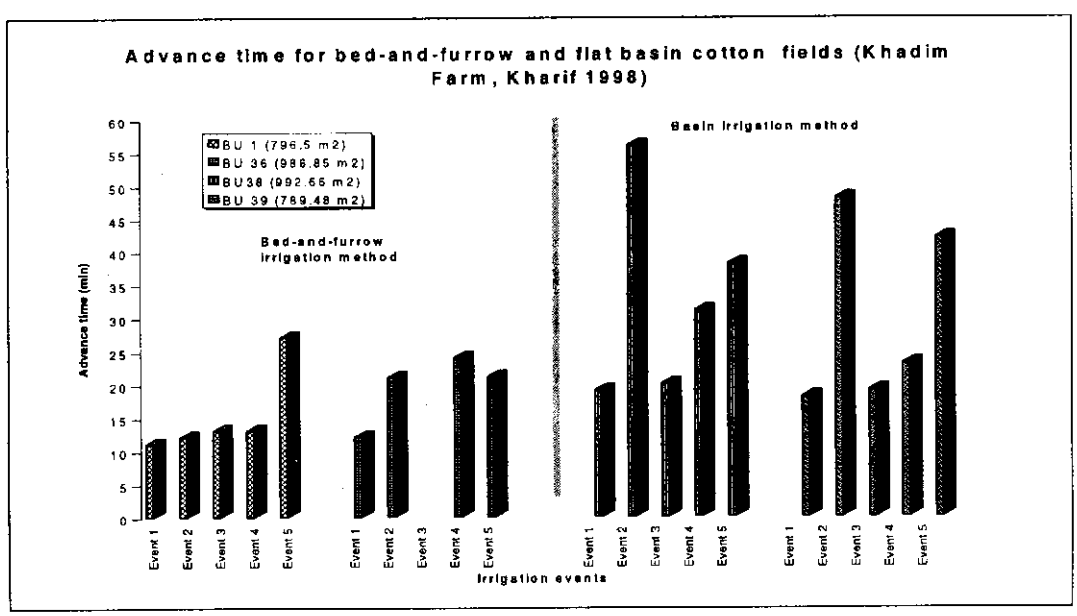


Figure 7.9. Comparison in Advance Time between the Bed-and-Furrow and Basin Irrigation Methods.

At the field level, the mathematical model will be applied for the hydraulic performance assessment (application and requirement efficiencies and distribution uniformity) and improved management scenarios are developed. Once selected fields are calibrated for the model, extrapolation of field level results to other fields can be presented. This is a time consuming process and is not discussed in this report.

7.5.4. Research Results

7.5.4.1. Water Application: Irrigation Frequency and Water Depth

Results, pertaining to the irrigation frequency, reveal an overall increase in the number of irrigation applications for the cotton crop using the bed-and-furrow irrigation method. The variation, however, ranged from just 1 irrigation application difference up to a difference of twice as much. The larger difference in irrigation applications has been more clearly observed in the command areas of the Hakra 4-R Distributary and Bahadarwah Minor, and to a lesser amount in the command area of Fordwah Distributary. An example is taken from two farms of W/C's along the Fordwah Distibutary (Table 7.5), which indicates a relative modest variation (between 1 to 3-4) in irrigation applications between the basin and bed-and-furrow irrigation methods.

Table 7.5. Number of Irrigation Applications between the Basin and Bed-and-Furrow Irrigation Methods on Two Sample Farms under Fordwah Distributary.

Khadim			Josuph		
Acre	Method	Irr. Appl	Acre	Method	Irr. Appl
22	b/f	11	9	b/f	10
8	b/f	12	1	basin	10
9	b/f	11	2	basin	10
10	b/f	11	10	basin	10
3	b/f	12	26	basin	9
4	Basin	8	25	basin	10
7	Basin	8	24	basin	8

Figures, however, from the Bahadarwah Minor show a tremendous difference in irrigation applications between the basin and bed-and-furrow irrigation methods (Figure 7.10).

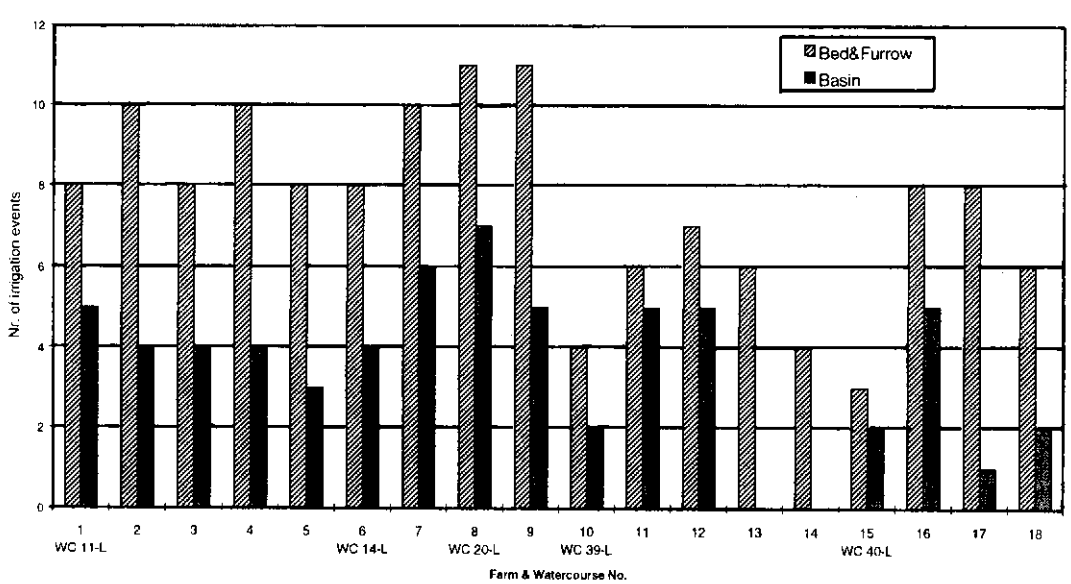


Figure 7.10. Number of Irrigations for the Bed-and-Furrow and Basin Irrigation Methods (Bahadarwah Minor).

Figure 7.10 shows the number of irrigation applications for the basin and bed-and-furrow irrigation methods. In most instances, the number of irrigation applications has increased when using the bed-and-furrow irrigation methods. Feedback from the farmers on this observation revealed that farmers consider this as a disadvantage and impractical, especially when one considers the unreliable water supply from the main system. Farmers related the increase in water applications to more water use. Figure 7-11 presents the total water application depths, which confirms the farmers comment (i.e. more water is used by the bed-and-furrow irrigation method as compared to the basin irrigation method for most of the selected sample fields). Farmers in the area of the Bahadarwah Minor were used to only 4 to 5 irrigation applications (on an average) for cotton sown in basin fields. One main factor influencing the irrigation application is the water table depth. The Bahadarwah Minor has a lower water table when compared to, e.g. Fordwah Distributary. It is assumed that the contribution of capillary rise allows farmers to irrigate less frequently; however, with the bed-and-furrow irrigation method, farmers perceived a quick drying of the soil surface and in response, applied more irrigations. That the difference in water application depths is a spatial variable can be derived from Figure 7.12, based on sample fields located at one farm in the Fordwah Distributary command area (middle section). The graph clearly shows a lesser application depth for the bed-and-furrow irrigation method as compared to the basin irrigation method. In this area, the water table depth is below 30 feet and from the graph can be derived that the farmer applied 9 irrigation events to the basin fields, and 11 irrigation events to the bed-and-furrow fields.

7.5.4.2. Production Data

During Kharif 1997, the collected field data on cotton yields generally showed positive results for the bed-and-furrow irrigation method. Table 7.6 presents the yield data for the cotton crop, obtained from the farmers for the bed-and-furrow and basin bunded units, which represents average figures. Nine farmers obtained a good yield increase when using the bed-and-furrow irrigation method, ranging from a 30 to 250 percent increase. Three farmers, however, faced a yield reduction while using the bed-and-furrow irrigation method.

Some reasons for the yield increase were provided by the farmers such as "the crop stand was better in the bed-and-furrow crop"; or "the germination was much better in the bed-and-furrow fields", and "the average yield in the bed-and-furrow field was better than for basins because the plants received proper moisture for development". The bed, being soft and dry, allows much heavier root growth and provides a better plant growth. Additionally, farmers indicated that during the monsoon season, the crop is less affected by the rainfall (i.e. the ponding of water in the furrow does not hamper the soil aeration). Farmer Aslam indicated that better and more cotton bolls developed in the bed-and-furrow field. With respect to yield decreases for a few of the bed-and-furrow fields, it's only known from Farmer Waris that he used a lower quality seed (other variety) in the bed-and-furrow field as compared with the basin fields.

Overall, however, the yield of Kharif 1997 in Pakistan was relatively low, not so much due to virus attacks, but due to heavy and unexpected rainfall in October, which delayed the harvesting; moreover it damaged the crop, which resulted in lower yields. This was an unexpected turning point, since overall farmers were pleased about the cotton season, not too much affected by virus attacks. 1997 was announced to be The Cotton Year, and higher yields than ever were expected, which did not occur because of the heavy rainfall during October (a frequent statement by Pakistanis is that "it never rains in October").

Next >>

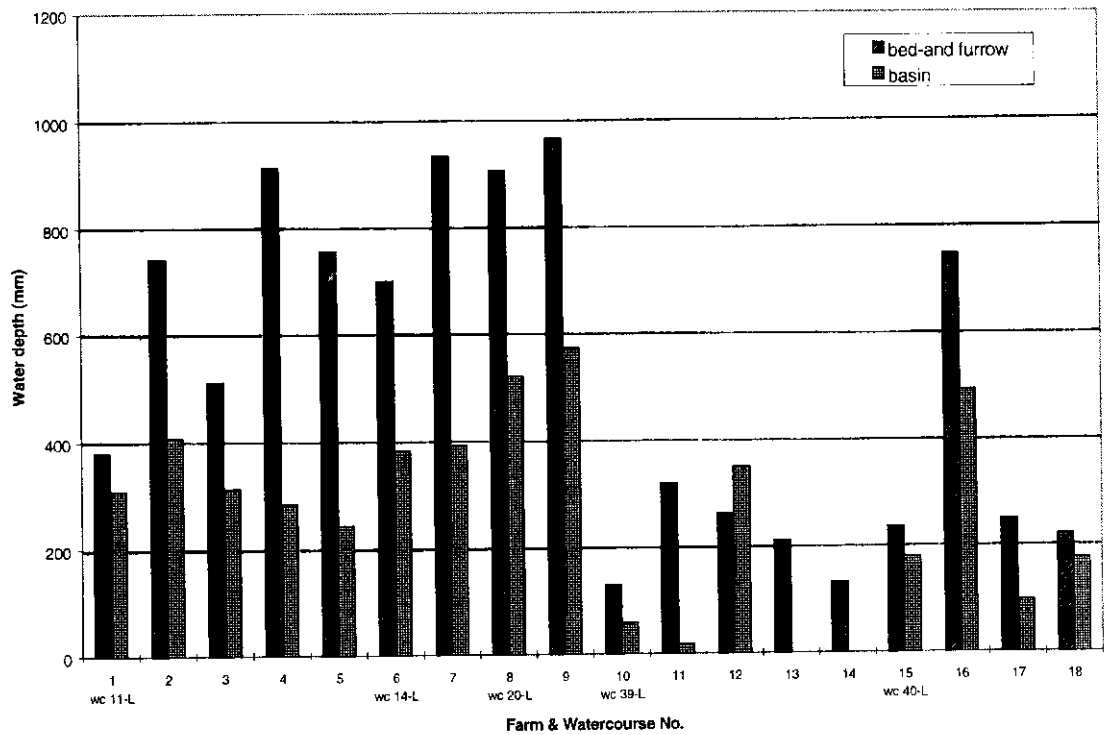


Figure 7.11 **Total Water Depth Applied for the Basin and Bed-and-Furrow Irrigation Methods (Bahadarwah Minor).**

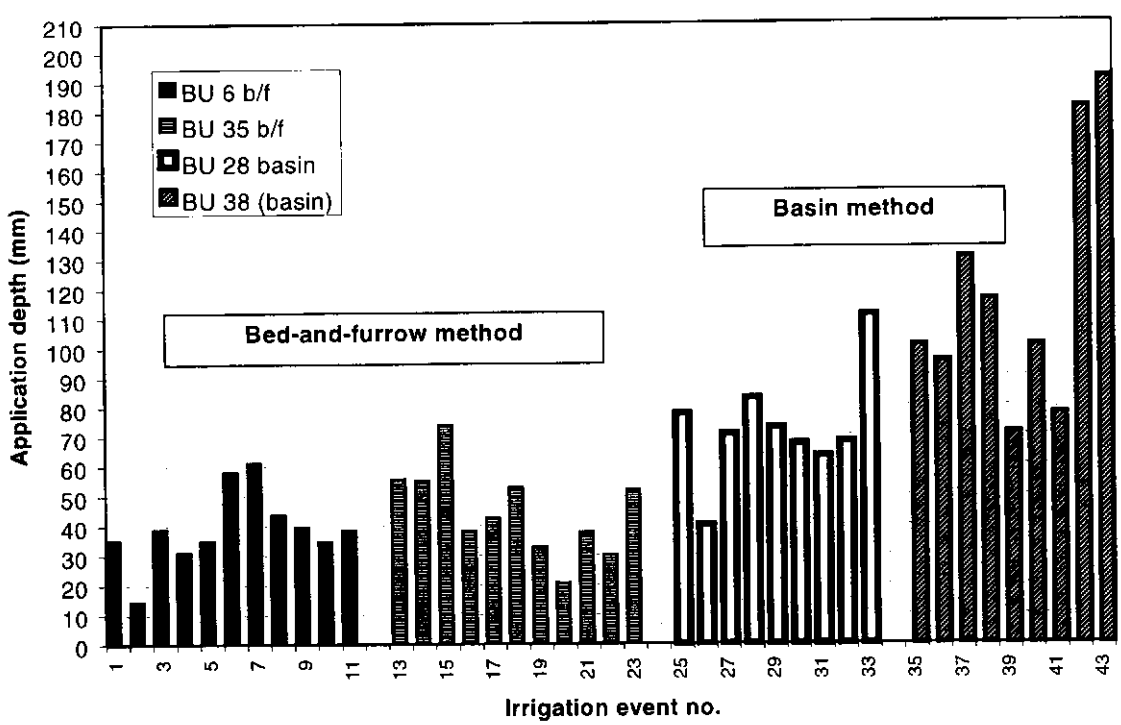


Figure 7.12. **Water Application Depth for Selected Bunded Units at Khadim Hussain Farm Kharif 1998, Fordwah Distributary.**

Table 7.6. Cotton Yields for the Bed-and-Furrow and Basin Irrigation Methods (Kharif 1997).

	Kharif 1997	Bed-and-furrow irrigation method		Basin irrigation method		
	Farmer	Yield maunds/acre	Yield kg/acre	Yield maunds/acre	Yield kg/acre	Increase %
1	Rana Waris	20	800	23	920	-13
2	M. Iftikhar	14	560	4	160	250
3	M. Boota	9	360	6	240	50
4	M. Yaqoob	25	1000	30	1200	-16.7
5	M. Mazhar	11	440	20	800	-45
6	H. Bashir	24	960	17	680	41.2
7	Syed H. Akhatar	26	1040	20	800	30
8	A. Hameed	20	800	15	600	33.3
9	Gh. Mustafa	20	800	15	600	33.3
10	Gh. Hussain	22	880	15	600	46.7
11	A.ul-Haq	22	880	15	600	46.7
12	M. Aslam	22	880	12	480	83.3
13	Jameel	-	-	-	-	-

Crop yields: Preliminary figures on cotton yields for the basin and bed-and-furrow irrigation methods are presented in Figure 7.13 and Table 7.7. Figure 7.13 presents cotton yields (kg/acre) for selected acres at Khadim Hussain Farm and Josuph Farm (W/C's along Fordwah Distributary). Overall, the results reveal higher yields for the bed-and-furrow irrigation method when compared with the basin irrigation method. The Khadim Hussain Farm has been highly productive, where yields for bed-and-furrow fields exceeds more than twice the yields for the basin fields. Similarly at the Jospuh Farm, the yields for the bed-and-furrow acres are more (about 25%) when compared with the basin fields.

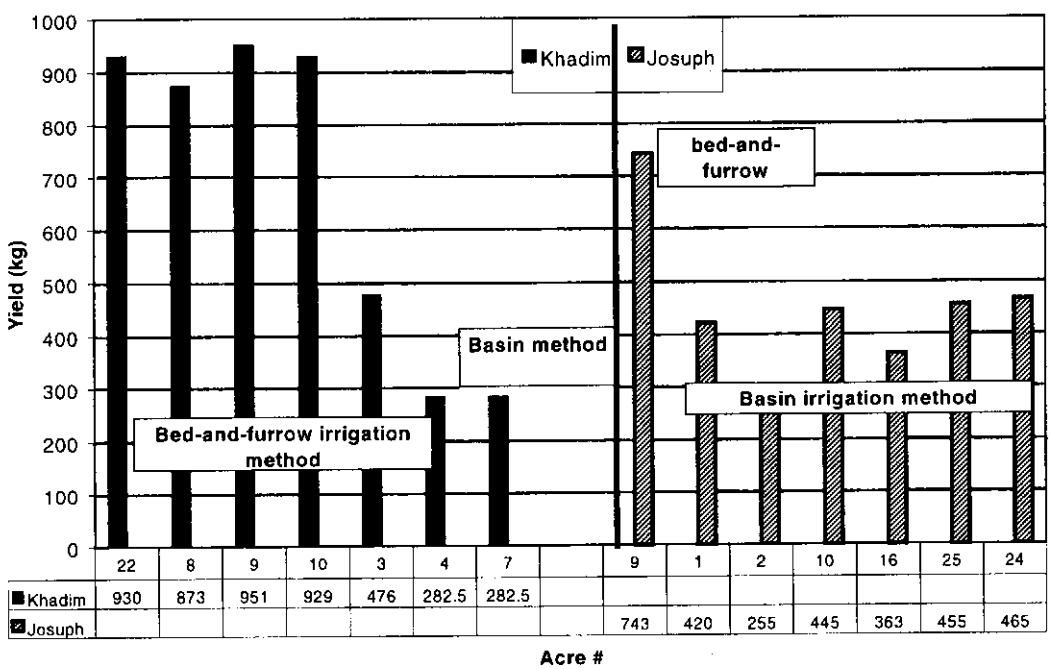


Figure 7.13. Cotton Yields at Khadim and Josuph Farms (Kharif 1998).

Table 7.7 presents preliminary yields for other selected fields in the Fordwah Distributary area (only 6 farmers have completed the pickings up till now). Results reveal a variation in yield

difference between the bed-and-furrow and basin irrigation methods, whereby the (positive) difference is less apparent.

Table 7.7. Cotton Yields for the Basin and Bed-and-Furrow Irrigation Methods.

Hasilpur area	Basin	B/f
	yield (kg)	yield (kg)
1	507	433
2	560	793
3	757	682
4	371	639
5	479	264
6	1081	935

Water use efficiency. Relating yield (kg) and water use (cubic meters of water applied) provides insights into the water productivity (i.e. yield per cubic meter of water applied). The obtained ratio is used as an indicator to quantify the water productivity. Overall, results (presented in Table 7.8) reveal that a higher water use efficiency (WUE) can be achieved for the bed-and-furrow irrigation method when compared to the basin irrigation method. More data, however, is required in order to verify this for other farms and areas (Hakra-4R, Bahadarwah Minor, Fordwah Distributary). It is expected that the WUE for more saline and waterlogged areas, and under more water constraining conditions, is less clear for distinguishing between the basin and bed-and-furrow irrigation methods. In fact, considering the high amount of water applied in the Bahadarwah Minor area, it is expected that the WUE will, overall, be less for the bed-and-furrow irrigation method than for the basin irrigation method. In other words, existing physical factors have a great deal of impact on the WUE, which is not solely dependent on the irrigation method. Table 7-8 presents some results from 1998 and previous seasons.

Table 7.8. Water Use Efficiencies for the Cotton Crop.

Khadim Farm	*Method*	*Volume*	*Yield*	*WUE*	*No. irrigations*
FD-83700R 1998		*m3*	*kg/bu*	*kg/m3*	
Bu 6 (a#9)	bed-and-furrow	461.55	237.75	0.52	11
Bu 35 (a#22)	bed-and-furrow	483.52	232.5	0.48	11
Bu 38 (a#21)	basin	838.7	-		9
Bu 28 (a#4/7)	basin	5082.18	565	0.11	9
Tareen Farm 1996 Lodrn					
S2-1	bed-and-furrow	550	2964	0.45	11
S2-2	bed-and-furrow	630	3102	0.405	12
S2-3	basin	600	2460	0.303	8
S2-4	basin	700	2568	0.348	7
Tareen Farm 1995					
S4-2	bed-and-furrow	532	2800	0.53	6
S4-3	bed-and-furrow	596	3291	0.55	8
S4-5	basin	750	2965	0.4	4
S4-6	basin	905	3133	0.35	5

7.5.4.3. Crop Development: Examples from Fordwah Distributary and Hakra 4-R Command Area

One of the advantages mentioned for the bed-and-furrow irrigation method is that the crop development is better over the season and that crop maturity is reached faster. During the irrigation season (*Kharif* 1998), close observations were made regarding the crop cover, plant height development and appearance of bolls (fruit formation). Results from the Fordwah Distributary command area reveal that the bed-and-furrow irrigation method has a positive effect on the crop soil cover, plant height and boll appearance; however, factors like cotton variety and soil quality may influence the examined aspects, which are not considered in this particular analysis. It has been estimated that the crop matures one to three weeks earlier for the cotton crop sown on beds. Table 7.9 summarizes the results. The observations are based on examining 25 cotton basin fields and 25 cotton beds-and-furrows fields.

Table 7.9. Effect of the Bed-and-Furrow Irrigation Method on Crop Cover, Plant Height and Boll Appearance (Fordwah Distributary, 1998).

	Crop cover	Plant height	Boll appearance
Positive effect	46%	50%	41%
No effect	18%	23%	37%
Negative effect	37%	27%	23%

Table 7.10. Effect of Irrigation Method on Boll Opening (Hakra-4R Distributary, Kharif 1998).

Farmer	Sowing date		No. of opened bolls		Date of Observation
	Beds-and-Furrows	Basin	Ceds-and-Furrows	Basin	
1	8/6	3/6	10	14	30-Oct
2	21/6	18/6	5	4	30-Oct
3	27/5	28/5	12	4	30-Oct
4	19/5	19/6	13	15	30-Oct
5	19/5	21/5	26	12	30-Oct
7	19/5	22/5	16	9	30-Oct
9	27/5	17/5	5	4	30-Oct
29	2/6	8/6	9	0	30-Oct
36	21/5	27/5	28	25	2-Nov
37	19/5	25/5	13	30	22-Oct
34	22/5	27/5	5	10	12-Oct

Table 7.10 presents results regarding the number of opened bolls at a specific time period, chosen late in the season before the cotton pickings. Representative plants were selected in each field for the purpose of observation and counting. The time of sowing at the basin and bed-and-furrow fields are quite near each other (i.e. less than a week's difference), except for the fields of Farmer 9, where the difference in sowing time is ten days. For four experimental locations, there is a clear difference in the number of bolls between the basin and bed-and-furrow irrigation method, whereby more bolls are opened at the bed-and-furrow fields; for 3 locations the opposite result occurred, and in four locations there was hardly any difference.

7.5.4.4. Influence of Waterlogging and salinity: Example from Bahadarwah Minor Command Area

Waterlogging. Three farmers, who have land in a waterlogged area, were interested in using the bed-and-furrow method. It was possible to make one bed-and-furrow field for one farmer. However, the seed failed to germinate in this field so that the farmer decided to abandon the bed-and-furrows and plant rice (see also Box 1). In one other field, the tractor failed to pull the

bed-and-furrow shaper. The last farmer who was interested refused to use the bed-and-furrow method after observing the results in the two fields of the other farmers.

Waterlogged condition have several effects on land preparation:

- A moist soil is heavier then a dry soil. A moist clay or loamy soil is more cohesive than a sandy soil. Therefore, it is not possible to plough the soil well with the conventional method used in the area, oxen or a light tractor. A moist silty loam soil, which is common in the research area, can only be ploughed properly with heavy traction equipment.
- With oxen or a light tractor only, the top soil (approx. 1 foot) can be well prepared. However, the top soil may remain moist through capillary rise. The soil layer below 1 foot of the soil surface may be compacted.

Box 1. Operation of bed-and-furrow shaper in a waterlogged area.

The field of Mr. Abdul Razzaq (WC 20-L) could not be sowed. This field is located in a waterlogged area at the tail of Watercourse 20-L. The farmer prepared his field with a plough and ridger, but only the first foot of the top soil was dry and could be ploughed. The farmer explained that due to waterlogging in his field, only the topsoil could be dried. The topsoil was moist, but was prepared very well. However, at 1 foot depth, the soil was moist again and hard. The tractor (MF 240) could not pull the bed-and-furrow shaper, and was not able to operate the bed-and-furrow shaper to the required soil depth. After this failure, the farmer refused to try the bed-and-furrow shaper once more.

Ashgar Ali, also of Watercourse 20-L, was able to prepare a bed-and-furrow field. However, a couple of weeks after sowing, he abandoned his bed-and-furrow field because the germination percentage was too low (10-15%). He said, *"When sowing there was moisture in the field. The tractor used made the furrows deep. There were large soil lumps on the field and therefor,e seeds on the bed were not covered well with the soil."* Another farmer in the same area refused to sow beds-and-furrows after seeing the conditions in the fields of the two farmers. All farmers are now cultivating rice on these fields.

As a result, the land preparation in the waterlogged fields was inadequate to make bed-and-furrows.

One observation was that when the bed-and-furrow shaper was operated with a heavy tractor in these fields, it was difficult to maintain a constant depth of the furrows. When furrows are shallow, the shape of the beds is badly affected as well. Finally, due to the wetness of the top soil, the drilled seed was not covered with soil by the bed-and-furrow shaper. This seed does not germinate and is lost.

Soil conditions in waterlogged areas restrict the operation and efficiency of the bed-and-furrow shaper. Soil tillage cannot be maintained to the required level for the operation of the bed-and-furrow shaper. The weight of the bed-and-furrow shaper and the cohesiveness of the wet soil makes operation of the machine difficult. Seeds are not drilled properly under moist soil conditions. The bed-and-furrow method is applicable in waterlogged areas, but it is difficult to prepare the beds-and-furrows by the bed-and-furrow shaper. A better solution will be to prepare the beds-and-furrows manually in waterlogged areas, by means of a ridger. The sowing, however, will become quite labor intensive and might be constraining to the farmers.

Salinity. About 40 percent of the sample farmers (total sample of 37) in the research area mentioned the problem of soil salinity or *"kallar"*. According to several farmers (see for example Box 2), salinity has a negative effect on the germination of cotton seed. Of the 41 monitored bed-and-furrow fields, 16 fields (39 percent of the total) were sown earlier using the

traditional drill method. Germination failed, so farmers decided to use these fields to experiment with the bed-and-furrow technique. For the 37 monitored basin fields, 4 fields (10 % of total) were sown more then once.

Box 2. Effects of soil salinity.

> Rehmat Ali (WC 9-L) had a germination percentage on his bed-and-furrow fields of 25 percent. He tried to sow cotton two times with the basin method on this field; the third time he used the bed-and-furrow shaper. According to him, the main reason for the low germination rates is the soil salinity and sodicity. Though the germination rate was only 25 percent, he was happy with the result.

According to several farmers (see for example Box 3) the effect of soil salinity on germination in beds-and-furrows is less when compared with the basin method.

Box 3. Germination in bed-and-furrow and salinity.

> According to Mr. Sukhera (WC 29-L), the bed-and-furrow irrigation method is better than the basin method. On the bed-and-furrow field, which is monitored, germination failed three times this year with the basin method. He estimated the germination on the bed-and-furrow field at 75 percent, and at his basin field at 50 percent. On saline patches in his fields, seeds germinate with the bed-and-furrow method but not with the basin method.
>
> According to Zafar-Ullah (WC 40-L) the germination in the bed-and-furrow fields is better than in the basin fields. He observed a germination percentage of 70 percent for basins and a germination percentage of 95 percent in bed-and-furrow fields. He concluded that

Despite observed good germination results on bed-and-furrow fields in relation to soil salinity, there is still a need to verify to what extent cotton growth is affected or tolerant to soil salinity. It was observed in the field that, though germination was good in some fields, the plant growth in the salt affected fields were in a later growth stage retarded compared to fields without salinity problems.

Salt accumulation on beds. Through capillary rise, salts are accumulated on the beds of the cotton fields. For the wet furrows, salts are flushed downwards and are not visibly present. The salt accumulation is a side effect of the bed-and-furrow method, which draws the attention of a lot of farmers. They are concerned about the germination of the wheat crop in the coming *rabi* season. The salt accumulation on the beds is often mentioned as one of the major disadvantages of the bed-and-furrow technique (see Box 4).

Box 4. Salt accumulation.

> According to M. Sarwar s/o Shahab Din (WC 11-L):"In the bed-and-furrow field, salt accumulates on top of the bed. The method is good, but the only problems are the hoeing and salt accumulation."
>
> Mr. Ubaid Ullah (WC 40-L) acknowledged the same problem. But according to him, if he could apply sufficient water in the bed-and-furrow field, then he could control the problem.

All farmers using the bed-and-furrow method were asked to give their opinion about the salt accumulation on the beds in their fields (Table 7.11). According to 37.5 percent of the farmers, they did not have any problems of salt accumulation on the beds. About 60 percent of the interviewed farmers observed salt accumulation on their bed-and-furrow fields. However, about 25 percent of the sample group did not take action yet. According to a majority of these

farmers, the salt accumulation would affect the *rabi* crop, but with good soil preparation and irrigation these negative effects can be countered. About 37.5 percent of the farmers removed the beds-and-furrows by ploughing the field. A majority of these farmers irrigated the field after ploughing to leach the salts.

Table 7.11. Farmers Opinion in Relation to Salt accumulation on the Beds.

	No. of farmers	% of total
No problem of salt accumulation.	15	37.5
Yes, so I ploughed the field.	4	10.0
Yes, so I ploughed and irrigated the field.	9	22.5
Yes, because of salinity and weeds I ploughed the field.	2	5.0
Yes there is salt accumulation but I have not taken action to mitigate it.	10	25.0
TOTAL	40	100

Role of the farmer organization: example from Hakra 4-R Distributary. Delegating responsibilities to the Water Users Federation in the bed-and-furrow dissemination process proved to be very efficient for Hakra-4R Distributary. When the research plan for the bed-and-furrow irrigation method was explained to the farmers, they were very receptive towards the idea. The Federation put a lot of effort in awareness building activities for the farmers in the command areas, such as conducting village lectures and study tours. Further, the Federation organized five trainings (in collaboration with MREP) for farmers in the five selected watercourse command areas for this experiment. The selection of the sample watercourse was decided by IIMI's social organizers with the assistance of federation members. It was agreed that 5 to 10 acres per watercourse would be selected for the experiment. The main concern raised by the Federation was that most of the land is quite waterlogged and, therefore, farmers prefer to cultivate rice. In addition to the trainings, door-to-door visits were made by the WUA members, especially in Sub-system 4. In the Federation meeting held on April 29, 1998, decisions were made about the use of the bed-and-furrow shaper. A committee was established for this purpose (the decisions), comprised of two farmers per sub-system. The rent for the bed-and-furrow shaper was fixed at Rs. 50 per acre. The implement would stay five days in one sub-system. The committee was responsible for the booking and rent acquiring for the implements.

To observe that farmers have the ability to organize activities collectively, and foremost, the keen interest in experimenting with improved irrigation practices has been very encouraging. Of course, it is a learning process, and unexpected events can always occur, which disturbs the actual planning. Although everything was planned very well, yet one bed-and-furrow shaper came much too late (mid-June), which caused discrepancies in the rotation schedule of the bed-and-furrow shaper. Also, because of the delay, farmers did not want to wait any longer and decided to sow cotton in basins or allocated the land for other crops. Because of the delay, it was decided by IIMI to cover, also, an area beyond the selected five sample watercourse command areas, resulting in 50 farmers adopting the bed-and-furrow for selected fields (four farmers are from Hakra 3-R and 1L). Nevertheless, this experience shows that farmers are able to coordinate activities and are able to reach many more farmers in an effective manner. Once they are directly involved in an activity, a sense of care arises. It was very interesting to observe the efforts made by the President of the Federation in contacting the fabricator almost daily on the progress of the fabrication of the bed-and-furrow shaper. Further, it has been very encouraging to observe that in a WUF meeting, it had been decided that farmers collectively planned to purchase more bed-and-furrow shapers so that next years' demand can be satisfied. This indicates that farmers are interested in changing their farming practices into the direction of becoming more efficient in water use and are challenged by the fact that the crop production is much better. Farmers' have learned with this exercise that there is room for improvements and that by collective actions, relevant equipment can become directly available to farmers.

7.5.4.5. Farmers' Perceptions on the Bed-and-Furrow Irrigation Method

Kharif 1997. The main constraints, as perceived by farmers, pertained to the bed-and-furrow shaper set. The equipment is considered as impractical to handle, due to its weight and size. Problems occurred with the sowing mechanism. Farmers also noticed that the soil should dry sufficiently prior to using the implements, in order to avoid soil clogging and an unstable design of the beds-and-furrows. Due to the unavailability of the hoeing device, the weed development became severe for many fields; farmers perceived the weeding by hand to be labor intensive and time consuming.

Soon after preparing the bed-and-furrow fields, farmers started observing advantages. Farmers observed that the method facilitates the irrigation process, resulting in less time required for irrigating a bunded unit or acre. This time saving factor is for farmers an important fact, because it allows them to use the irrigation turn more effectively. Next, to the time-saving, an equally important, if not more important, aspect is that most of the farmers observed an increase in yield by using the bed-and-furrow irrigation method. Already during the germination, farmers observed a better germination rate, and over the season the crop developed much healthier. As mentioned by Farmer Mustafa: "*I experienced the new irrigation method as water saving, it improved the yield and the crop was not affected by the rainfall*"; and by Farmer Hussain: "*I have my land in WC Azim 111-L and I have to rely entirely on tubewell water. The tubewell use has become too costly. Since the bed-and-furrow irrigation method is considered to be water saving, I tried this method and discovered indeed that it required less tubewell operation. Further, my land is not of good quality, but due to this method, I have been able to obtain good cotton yield, and I can even keep cotton seeds for the next kharif season*" .

The farmers observed that during the monsoon rains that the crop was not affected by ponded water. Farmers, who have a saline-sodic soil, observed a better germination than ever before and the soil crust did not hamper the crop, since it is standing on the bed; so that the bed soil remains very soft. The softness of the bed soil is a result of the capillary rise of the water in the soil. Some farmers noticed that the crop was matured earlier and, thus, would benefit the next *rabi* season (i.e. wheat can be cultivated earlier), thus, late sowing is avoided. Farmers' experiences with late sowing of wheat is that yield reduction occurs due to the change in climate (lower temperatures). Most of the farmers observed a reduction in chemical spray use, since the crop is matured earlier. One farmer mentioned that, despite the late sowing of the cotton, he received a better yield after all for the bed-and-furrow bunded units, compared with the basin bunded units.

Six farmers clearly indicated that they prefer the bed-and-furrow irrigation method for the cotton crop above any other method, like basin or basin-with-corrugations. The main reasons are the water (time) saving factor and the expected or achieved yield increases. However, in this season, only a few farmers gave a firm statement that they would use the bed-and-furrow irrigation method in the next year as well.

Kharif 1998. In the land preparation phase, some hesitation was shown by the farmers from the Hakra-4R command area regarding their concern about salinity accumulation on the bed, and the difficulty for small farmers to have access to stronger tractors. Further, during the preparation of the beds-and-furrows, in some instances, difficulties occur in operating the bed-and-furrow shaper, often because of initial inexperience of the tractor driver (it is difficult to make straight furrows). Further, a number of farmers took the requirement of good land preparation lightly; afterwards, they realized the importance of good land preparation (the result will be more straight and stable beds-and-furrows).

During the germination stage, the farmers expressed their enthusiasm about the method. The method has given a higher germination rate as compared to flat sowing (in basins). Good

germination was even observed by farmers for *kala kallar* (black salinity) fields. After the heavy rainfall in the second week of June, 1998, a lot of fields, - with cotton sown in flat basins-, in the region were destroyed, whereas the seeds sown on the beds were saved. Time saving was observed by farmers for the first few irrigation events. Farmers started discussing the dual advantages of the beds-and-furrows; on the beds, vegetables and melons could be sown. All these news reached other farmers; suddenly, more farmers were demanding the bed-and-furrow shaper. For farmers in Sub-system 3, an unsatisfactory attitude was observed because, as farmers mentioned, the germination was poor and a few farmers ploughed the fields again. However, the dissatisfaction was not so much related to the irrigation method; moreover, farmers explained that some of the reasons were poor quality seeds, canal closure (no water availability), late sowing and high temperatures. Further, sowing occurred in wet fields.

During the season, the main positive comments mentioned by the sample farmers regarding the bed-and-furrow irrigation method were that: (1) the crop looks comparatively better; (2) it is easy to drain out the water; and (3) that despite the saline and waterlogged conditions, a better germination is achieved. Farmers, however, experience the increase in the number of irrigation applications as a constraint because of the unreliability of the canal water and taking into account that other fields also need water. The beds become hard, and this is considered to be problematic when the field has to be prepared for the *rabi* season. In some instances, the furrows collapsed due to rain and the plants lost their stability. In general, it is perceived that the weeds grow quickly on the beds. The late arrival of the hoeing machine made farmers wait too long, or made them to do the weeding manually. Some found this latter not a real problem, whereas others perceived this as labor intensive. Further, some farmers expressed their concern about irregular crop cover, due to the occasionally malfunctioning of the sowing device (becomes easy clogged with soil if the land is not properly dry).

With respect to the application of spays, a farmer in Sub-system 2 observed that the attack of harmful insects was less as compared with the basin fields, mostly (as he perceived) because of the proper space and aeration in the field. Other farmers discovered the easiness of applying chemical sprays; the tractor can easily follow the traces of the furrows, even after an irrigation in basin fields, it is difficult to maneuver through the fields; crop may get damaged too.

Farmers from the Fordwah Distributary command area indicate, more or less, the same advantages and disadvantages. With respect to water savings, it is expressed that water is saved per irrigation event, but not per season. Farmers observed a relatively quick growth and early maturity. Farmers indicated that more care is required during an irrigation event to prevent water overtopping the beds, and more dependence on tubewells is required due to the frequent irrigation applications, taking into consideration the unreliable canal water supply.

7.6. Constraints and Limitations

In order to reach conclusive results based on the development-oriented approach of this research, sufficient farmers (i.e. large sample size) must be reached. To formulate any conclusions about the feasibility of the technical interventions, successive years of field experiments are being conducted and the feasibility of the technical interventions scrutinized in relation to the farmers' socio-economic environment, physical setting and perceptions. The research pertaining to interventions in the basin irrigation system solely remained a one season experiment for a few farmers, which will provide insufficient evidence for assessing the feasibility of the technical interventions for a larger scale, nor can a clear relationship be established with the physical environment. With the research on the bed-and-furrow irrigation method - conducted in two successive years - to a certain extent, a larger farmer community has been reached, divided over three distributary command areas on the Fordwah-Eastern Saddiqia Irrigation System. In the Fordwah Distributary command area, a clear development occurred. There was an increased receptive attitude from farmers; in 1997, about 15 farmers

showed an interest in the bed-and-furrow irrigation method; while in 1998 this number increased towards 70 farmers, whereby even other canal command areas were reached.

One major reason for the limited ability to expand the research is partly related to IIMI working too much in isolation. A much earlier involvement of national agencies would have allowed a broader audience to be reached. Unfortunately, the involvement of national agencies was not explicitly formulated in the Project Document because there was a felt need for IIMI staff to first learn what to do, followed by generating interest among other national agencies. Because of limited time and limited research staff availability, one is confined to a smaller research area and a smaller number of sample farmers.

That collaboration with line agencies can be fruitful is reflected with IIMI's collaboration on the dissemination of the bed-and-furrow irrigation method in the command area of the Bahadarwah Minor. In this locality, IIMI works in close collaboration with OFWM (field office in Bahawalnagar). From both sides, field staff were involved in the data collection activities, which resulted in more farmers being included in the sample. This resulted from the Director General (Water Management) recognizing that IIMI's field results were ready for broader dissemination starting in 1997, as well as the success of the IIMI collaborative research with MREP in the FESS project area. Now, in future years, improved surface irrigation technologies can be more broadly disseminated by national agencies.

7.7. Future Research Challenges

There is quite a potential and a strong need to improve irrigation practices in Pakistan. Farmers' are quite receptive towards improving their field and farm irrigation management; however, in many areas, the exposure to improved irrigation practices is missing and means to change this situation is lacking. There is a necessity to develop a feasible strategy that can be integrated into the National Research Agenda for developing irrigated agriculture in the different provinces of Pakistan. It should be recognized that there is a tremendous potential for increasing water productivity and crop production, which is related to how the water is being managed at the field and farm levels.

Several interventions have been investigated under this Dutch-funded Project; however, the potential of low-cost pressurized irrigation systems have not been scrutinized. These methods have proved to be very productive and effective in desert areas and orchards; Israel is the greatest example of its potential. Though basic research is being done (e.g. PCRWR in Cholistan Desert, WRRI in Islamabad), yet research on how the results can be translated into feasible packages for farmers and how the technology can be transferred to larger areas has been insufficiently emphasized.

Though furrow irrigation is mostly used for potato crops and some vegetables in Pakistan, however, the furrow irrigation method is suitable for many crops, like maize, cotton and sugarcane. Having this method being practiced, rather than basins, will increase the productivity of water. Nowadays, Australian researchers and extension services are promoting the furrow irrigation methods for cane growers, because of the potential of higher water productivity.

In this research, the technical interventions were the basin with shallow and deep corrugations and the bed-and-furrow irrigation methods. Other alternative options to be investigated could be an alternate furrow irrigation method.

Another issue which requires an emphasis in research and development is how to make the laser-leveling technique widely available to the farmers. The problem currently faced is that the equipment is only used by large farmers, who never return the equipment or return very late (comments by OFWM staff). Laser leveling makes the basin irrigation method more efficient,

because the undulations and irregularities are diminished. The biggest example originates from the United States after the laser leveling technology was introduced, basin irrigation became quite popular among the farmers again. In addition, research could be undertaken on how the concept of surge flow irrigation could be integrated into the existing conditions encountered in Pakistan (i.e. used for basin and furrow irrigation methods, considering the fact that farmers open and close their field inlets manually).

8. SALINITY MANAGEMENT

8.1. SALINITY MANAGEMENT ALTERNATIVES

8.1.1. Waterlogging and Salinity Control

In arid and semi-arid irrigated areas around the world, shallow groundwater of less than 1.5-2 meters (m) below the ground surface will allow the capillary rise of groundwater into the root zone, where it will eventually be used for plant transpiration, soil evaporation or leached as deep percolation back to the groundwater because of rainfall or irrigation. The more saline the groundwater, the more salt will enter the root zone by capillarity. As the groundwater becomes more and more shallow, the more difficult it becomes to leach the salts form the root zone.

The worst situation is an abundance of sodium ions in comparison with the combination of calcium and magnesium salts, which is measured by the sodium absorption ratio (SAR = $Na^+/\sqrt{Ca^{2+} + Mg^{2+}}$ measured in milliequivalents per liter, meg/l). In particular, the sodium ion plays a role in the flocculation of soil particles, which reduces the pore space. This, in turn, reduces the hydraulic conductivity. Reclamation of sodic soils usually relies on replacing the sodium ions adsorbed on the soil particles in the root zone with calcium ions (e.g. application of gypsum on croplands). As the hydraulic conductivity is reduced, it become increasingly more difficult to infiltrate sufficient water for ion exchange to occur, as well as to leach salts from the root zone by deep percolation. Thus, the reclamation of sodic soils is much more difficult and expensive when compared with the reclamation of saline (mostly calcium) soils.

Another commonly used sodicity parameter is the soil exchangeable sodium percentage (ESP). The ESP is commonly calculated from the SAR, which is a linear relationship. For many decades, ESP was considered to have a threshold value of 15 (U. S. Salinity Laboratory, 1954). Values of ESP greater than 15 were expected to affect soil structure that would reduce hydraulic conductivity, which would become more and more affected as ESP increased above 15. This concept of an ESP threshold value was recently dispelled by three Italian Soil Scientists (Crescimanno, Lovino and Prevenzano, 1995) who clearly demonstrated that the relationship between ESP and saturated hydraulic conductivity is nearly linear and no threshold value exists. These research results are most profound in interpreting sodicity in the irrigated soils of Pakistan because even low values of SAR will affect soil hydraulic characteristics and crop yields.

More recent research (Kahlown et al, 1998) in the Fordwah Eastern Sadiqia (South) Irrigation and Drainage Project near the border with India in Southern Punjab, has separated the impact of waterlogging and salinity of the yields on wheat, cotton, rice and sugarcane, which are the major crops in Pakistan (Figure 8.1). In particular, the research results show the effect of sodicity on reducing the yield potential of these four major crops, which is the area between the U. S. Salinity Laboratory results reported by Hoffman and Maas (1977) and the relationship for the 2 - 3 m watertable depth shown for each major crop in Figure 8.1; the area between the watertable depths of <1 and 2 – 3 m results from the lack of sub-surface drainage. These results demonstrate the importance that must be given to waterlogging, salinity and sodicity to achieve sustainable crop yield increases.

The upper surface of the groundwater, termed the watertable, plays a tremendous role in crop production. The location of the watertable is usually measured from the ground surface as the depth to watertable (DTW). When DTW = 0.5m, which is the average for 0-1m, only rice can be grown to achieve reasonable yields. The preferable range of DIW is 1-2 m, where the depth is 1.5m, largely because of unreliable canal water supplies, because a portion of the crop water requirement can be met by capillary rise from the groundwater; this is satisfactory for low values of soil SAR, but becomes less desireable as the soil SAR increases. When sodicity becomes a significant problem, then a watertable depth in the range of 2-3m will be preferred, which will still require soil reclamation measures.

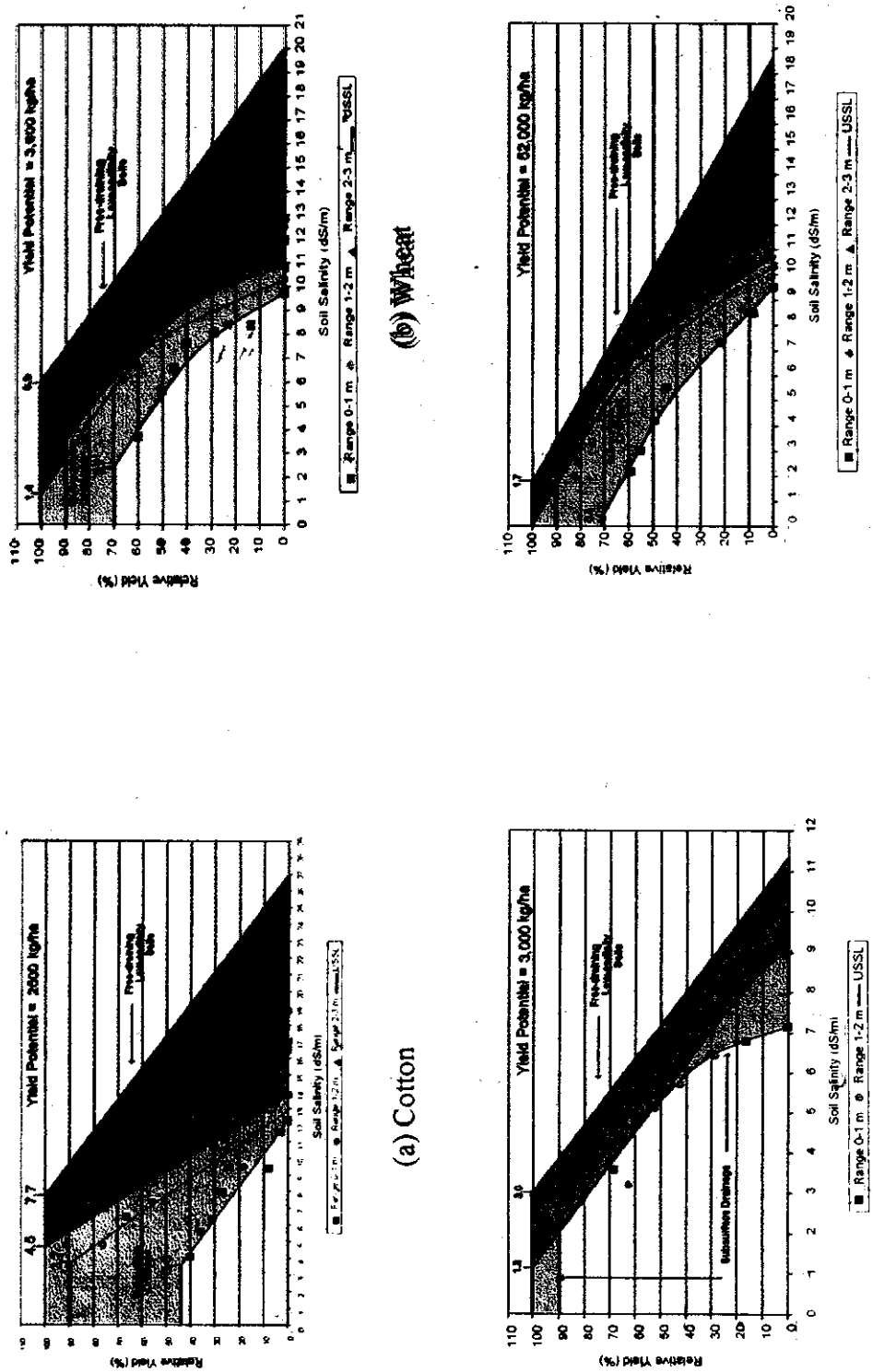


Figure 8.1. Relative Yields of Major Crops Related to Salinity at Various Watertable Depths.

For croplands underlain by good quality fresh groundwater (FGW), an effective means for lowering the watertable is to encourage the installation of private tubewells, where the water can be used for irrigation to supplement canal water supplies. This has occurred in the doabs of the Punjab Province. For example, in the late 1970s, much of the area surrounding the city of Faisalabad in lower Rechna Doab had become waterlogged with water on the ground surface; the explosion of private tubewell development in the 1980s resulted in significantly lowering the watertable that would easily accommodate crop production. Where this approach has been possible it has been done because of the tremendous benefits for farmers.

In the Sindh Province, a different approach is required because extensive tracts of croplands have high water tables (<1m) underlain by highly saline groundwater (SGW) where the salinity levels vary from 25-100 percent of ocean water, which are unfit for either domestic or irrigation purposes. For this situation, in order to reduce waterlogging, drainage facilities must be installed.

An excellent example in the Sindh Province is the Left Bank Outfall Drain (LBOD) providing drainage for an area of 500,000 ha in the districts of Nawabshah, Sangar and Mirpurkhas at a cost of U. S. $ 1 billion. The main feature of the LBOD is a Spinal Drain and Tidal Link that provides an outfall for saline effluent to the Arabian Sea, which is the only outfall to the sea in Pakistan other than the Indus River. The other features include: (1) saline tubewells for discharging saline groundwater to lower the watertable; (2) interceptor drains along canals and branch canals to collect canal seepage water for irrigation; (3) scavenger or compound wells that pump shallow fresh water for irrigation and deeper saline groundwater that is discharged into open drains; (4) sub-surface horizontal pipe drains in portions of Mirpurkhas District; and (5) surface drains for collecting saline effluents that are conveyed to the Spinal Drain for disposal into the sea.

8.1.2. Conjunctive Use of Groundwater and Surface Water

In the Indus Basin Irrigation System (IBIS), the principal locations, where fresh groundwater (FGW) is available, are the Peshawar Vale and the Punjab Province. By far, the greatest number of tubewells have been installed in the Punjab Province (Figure 8.2).

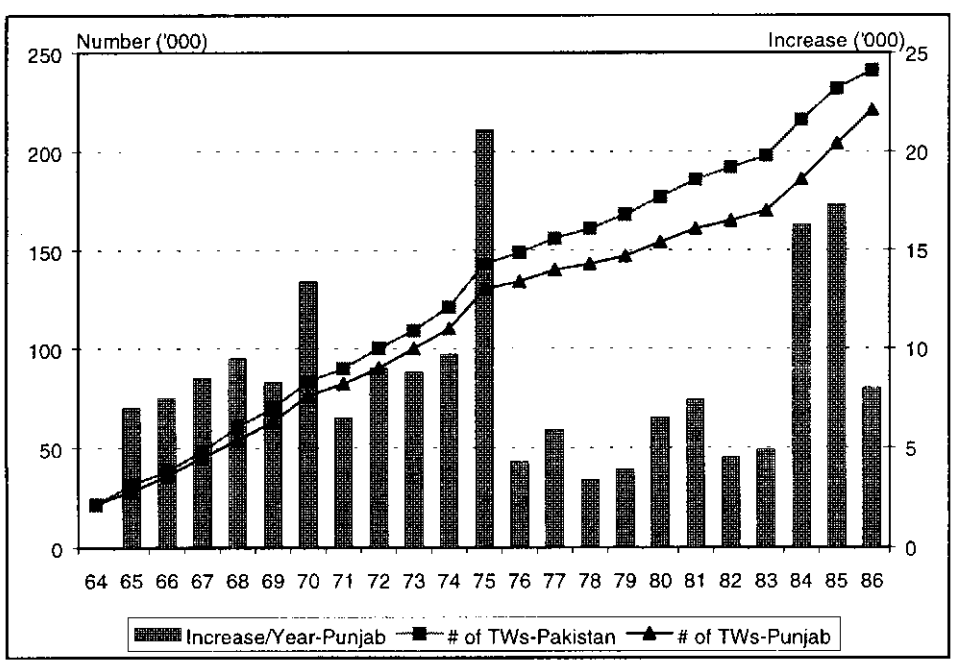


Figure 8.2. Private Tubewell Development in the Punjab Province and Pakistan.

Continued pumpage from higher salt bearing strata has accelerated the process of secondary salinization in the root zone that has adversely affected crop yields; however, this increase in pumpage has also repressed the rising watertable levels that had previously threatened the agricultural productivity from large tracts of land in the Punjab Province, particularly in the lower Rechna Doab during the late 1970s and early 1980s.

When public tubewells began being installed during the early 1960s, there was very limited groundwater data available, so only a simple one-dimensional pumping analysis could be done. But, a vertical salinity gradient in the groundwater reservoir requires a three-dimensional groundwater model as used by IIMI. This model was used to generate Figure 8.3, which illustrates the long-term value in managing or regulating tubewell discharge capacity commensurate with groundwater salinity conditions so as not to salinize the groundwater resource over time. Over a 40-year period of time, public SCARP tubewells in the lower Rechna Doab can be expected to have salinity increases of 170-380 percent (2.7-4.8 times the salinity originally pumped). Private tubewells would be expected to experience salinity increases of 70-200 percent, whereas fractional skimming wells having 6-12 lps (0.2-0.4 cusecs) capacity would have salinity increases of only 10-70 percent after 40 years, which is a much more sustainable pumping option. Similarly, but perhaps slightly less dramatic results would be expected in the lower portions of the other doabs.

Private tubewells usually have discharge rates of one-half, or less, compared with public tubewells. However, when groundwater salinity levels increase, the pumping discharge rates should be decreased to avoid salinizing the groundwater, which results from upconing of more saline groundwater in the lower portions of the reservoir. In some cases, fractional (less than one cusec) tubewells should be employed having discharge rates as low as 7 lps (one-fourth cusec).

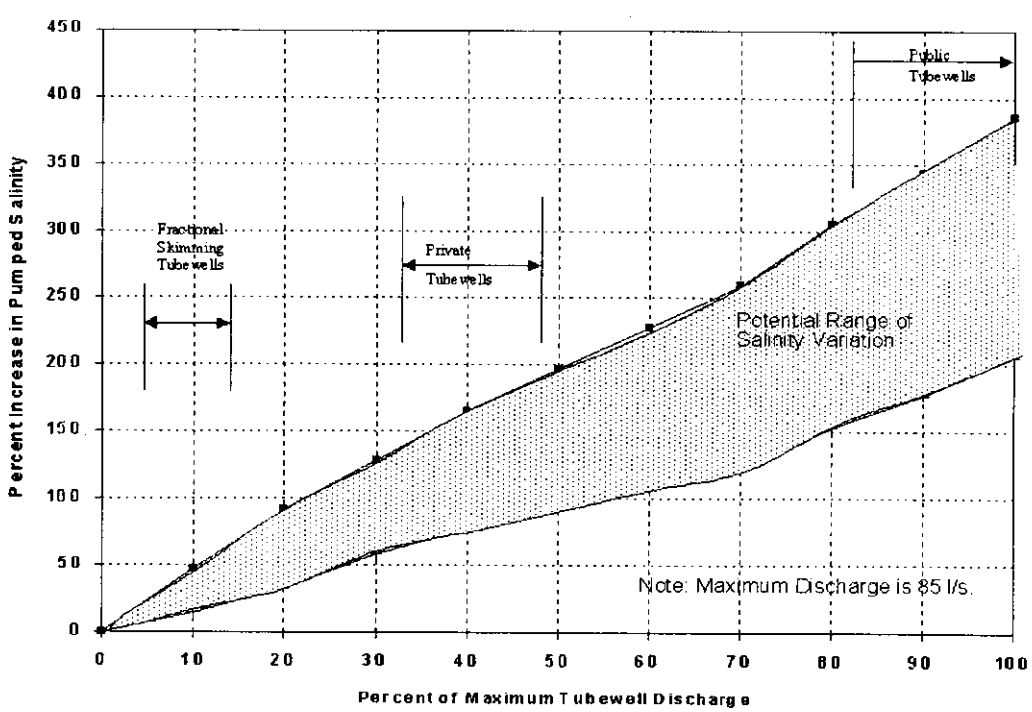


Figure 8.3. Impact of Tubewell Pumpage Rete on Relative Salinity Increase of Pump Discharges.

The combination of SCARP public tubewells and the rapid increase in the number of private tubewells has resulted in lowering groundwater levels, and subsequently, reduced waterlogging. Reducing the amount of land that was waterlogged had to allow the leaching of salts from the root zone. But, the tubewells were also used as additional irrigation water supplies, which resulted in secondary salinization because of using poor quality tubewell water (Kijne and Kuper, 1995).

The source of much of this tubewell salinity is the high salinity concentrations of the groundwater overlying the marine geologic formation at the base of the unconfined groundwater reservoir. These deep-lying salts move upwards (upconing) when tubewell discharges are too large. However, to salinize croplands takes a number of years depending on the tubewell discharge rate primarily, but is also dependent on the frequency and duration of tubewell pumping. Fortunately, there is a sustainable tubewell discharge rate for most groundwater situations.

The primary advantage of private tubewells is having discharge rates of only one-third to one-half that of public tubewells. This significantly reduces the hazard of secondary salinization. But, in a number of cases, the discharge rates for private tubewells are still too high for the existing groundwater situation.

When interviewing farmers, most of them know if their tubewell water is of good or poor quality, but, in general, they are not receiving any technical assistance that could be used to manage their salinity problems, particularly sodicity problems. A logical implication is that, in the future, there will be an increasing need to provide farmers not only meaningful technical assistance, but new technologies that they can use for pumping lower discharge rates to manage salinity, while increasing agricultural productivity.

Based on the findings resulting from the investigations under this project, along with their implications, the major conclusion is that more and more emphasis over time will be required on improving the management of land and water resources in the doabs of the Punjab Province. An integrated approach is required that focuses on the conjunctive management of surface water and groundwater supplies in combination with increasing agricultural productivity, taking into account the deleterious effects of salinity and sodicity, as well as potential groundwater pollution from industrial wastes and agricultural chemicals, so that increased crop yields are achieved in a manner that supports sustainable irrigated agriculture.

8.1.3. Improved Canal Operations

The most important reason for improving canal operations is to provide much more reliable water deliveries that would result in substantial crop production increases. This is a highly cost-effective technology because only a very modest amount of equipment is required, some maintenance of flow control structures, but mostly human resources development of existing field staff of the Provincial Irrigation Departments (PIDs).

From the standpoint of salinity management, improved canal operations in FGW areas would reduce the dependence of farmers on tubewells, which would result in less secondary salinization. For SGW areas, improved canal operations would result in reduced groundwater recharge because of reducing the excessive water supplies to some of the croplands, along with reducing irrigation water supplies early and late in each season when crop water requirements are low, as well as when there are excessive monsoon rains.

A branch canal command area would constitute the smallest unit for implementing a decision Support System (DSS) for improved canal operations. The ideal unit for DSS is a total canal command area.

The basic administrative management unit in a canal command area is a sub-division. Improved canal operations can be undertaken simultaneously on all sub-divisions in a branch canal command area or a canal command area, or it can be done sequentially for one sub-division, followed by another, until all of them have an established DSS.

All of the activities described above in Section 5.2 on Canal Operational Management would be undertaken for each sub-division. These activities would include: (1) field calibration of all essential flow control structures such as the canal and branch canal head regulators, all cross-regulators, head regulators for distributaries and minors, and each outlet serving a tertiary watercourse command area; (2) measuring the channel losses in each reach between cross-regulators, as well as distributary and minor canals, using the inflow-outflow method under steady state flow conditions; (3) develop the downstream gauge rating for the canal headworks, each cross-regulator, and each distributary and minor head regulator for the benefit of the gate operators; (4) use the unsteady flow hydrodynamic model, "Simulation of Irrigation Canals (SIC)", for describing hydraulic conditions in the canal network to support the Irrigation Management Information System (IMIS) and to resize the outlets along the distributaries and minors to support the farmers in achieving equitable water deliveries to watercourses; (5) develop water balances for the various reaches in the canal network that can be used as inputs to IMIS to support equitable water deliveries to distributary head regulators; and (6) install a communications network in the canal command area to support rapid transmissions of field data, as well as instructions from irrigation managers to gate operators.

8.1.4. Combined Management of Irrigation and Drainage Facilities

In irrigation command areas susceptible to waterlogging, it becomes highly important to manage both the irrigation and drainage facilities in order to control the watertable depths. In a canal command area, there will most likely be significant differences in the degree of waterlogging, as well as having some portions without a waterlogging problem. Consequently, a canal command area should not be managed uniformly; instead, various portions need to be managed in a manner befitting the local situation. For this purpose, secondary canal command areas (distributaries and minors) are more ideally suited for managing watertable depths, including the tertiary watercourse command areas. Even in a distributary command area, the degree of required management will most likely vary for different portions of the command area. In addition, the management requirements will be changing during the year and from year-to-year.

A good illustration is again the Left Bank Outfall Drain (LBOD) in Sindh Province. For example, the tubewells installed for pumping saline groundwater that discharge into the open drain network were designed to operate 16 hours per day. But, this is required only for a few months each year depending on the monsoon rains; during the remainder of the year, the pumping hours each day can be decreased in accordance with the depth to watertable, which varies from one location to another. In the case of three pilot distributaries where the farmers were organized (Bandaragoda et al, 1997), the Dhoro Naro Minor in Nawabshah District does not have to pump the saline tubewells during most of the year, while the Heran Distributary in Sanghar District needs to pump considerably more, and the Bareji Distributary in Mirpurkhas not only needs to do a lot of pumping, but a significant portion of the command area is underlain by subsurface drainage because of extreme waterlogged conditions.

8.1.5. Farm Resources Management

Farmers in Pakistan receive very little technical assistance for enhancing agricultural productivity. Although the infrastructure exists, the services are rather ineffective, with only influentials (rural elite) being benefited. Yet, as shown by Kielen (1996a, 1996b), farmers do have strategies for coping with salinity problems. However, farmers have difficulty in coping with sodicity because the recommended soil reclamation practices take a number of irrigation seasons and are expensive.

While waterlogging problems often require solutions covering large areas, salinity problems are more frequently "patchy" that require solutions suitable to individual farms, or sometimes only certain fields on a farm. Thus, an appropriate approach requires that individual farmers should be the target for any technical assistance program. The World Bank (1994) recommended the implementation of a program throughout Pakistan on Farm Resources Management (FaRM).

A FaRM program requires a capability for diagnosing the situation on a farm, understanding the causes and constraints inhibiting agricultural productivity, and making sound-economic recommendations that are implementable by farmers. These suggestions should include seed quality, cultivation practices, soil fertility, improved irrigation methods and practices, integrated pest management, as well as salinity and sodicity management practices, including chemical amendments.

8.2. SALINITY SITUATION

8.2.1. North West Frontier Province

The major irrigated area in the North West Frontier Province (NWFP) is the Upper Swat Canal (USC) and Lower Swat Canal (LSC), which are adjoining canal command areas that divert water from the Swat River. The Pehur High-Level Canal (PHLC) is presently under construction that will convey water from the Tarbela Reservoir on the Indus River that will be discharged into the Machai Branch Canal of USC. This area has benefited from the construction of two Salinity Control and Reclamation Projects (SCARPs); namely, Mardan SCARP and Swabi SCARP. What is needed in the future for sustainable irrigated agriculture are programs for improved canal operations and farm resources management, which constitutes a minimum strategy for achieving sustainability. This would also be largely the case for the irrigated lands surrounding the city of Peshawar.

The Chashma Right Bank Irrigation Project (CRBIP) is under construction, which will serve 230,680 ha of cultivated land, most of which is new irrigated land. Nearly 63 percent of the upper lands are located in the NWFP, while the remaining lower lands are located in the Punjab Province. Construction is about half completed, so many of the distributaries in the NWFP are operating; some of them for nearly ten years. Because there is presently excess water, many of these distributaries are applying 40 percent more water than the design water duty of 8.1 cusecs/1,000 acres, which is also quite high in comparison with canals in the Punjab Province, where the typical water duties are 3.5-4.5 cusecs/1,000 acres. Aggravating this situation is that the soils are high in natural salts. Undoubtedly, much of the agricultural lands will soon become waterlogged and saline, thereby significantly reducing crop yields. A program of combined management of irrigation and drainage facilities will soon be urgently needed, along with programs for improved canal operations and farm resources management.

In addition, there needs to be a strong emphasis on maintaining the drainage system so that it can effectively operate; at the same time, the canal system should be operated in a manner so as not to drown the drainage channels. Finally, a Farm Resources Management (FaRM) program that will provide technical assistance to individual farmers for improved water management and agronomic practices.

The recommendations described above are schematically presented in Figure 8.4. The major emphasis is on improved canal operations, which includes organizing the farmers in each distributary served by a canal, as well as establishing a decision support system for each canal command, including an effective communications network.

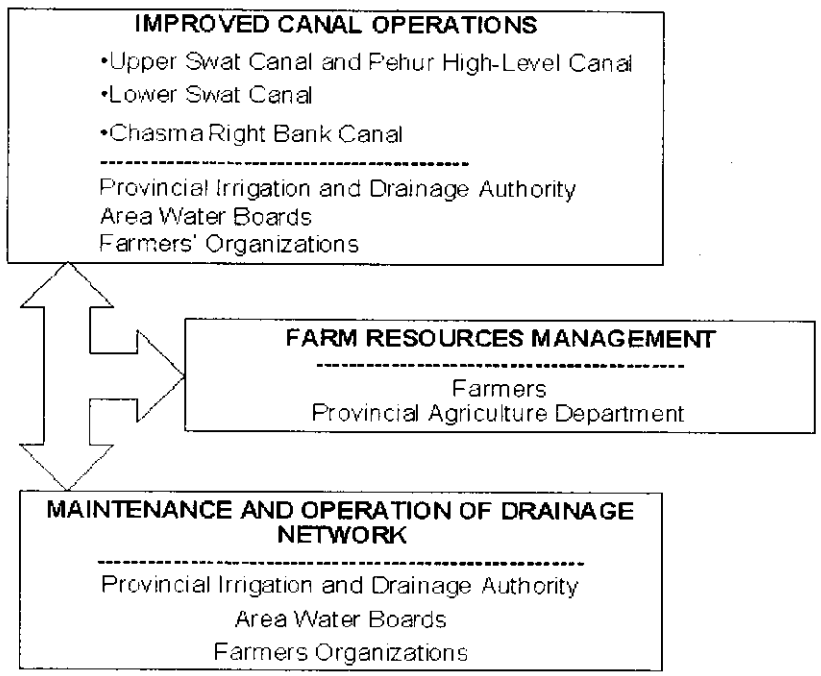


Figure 8.4. Schematic of Recommendations for Sustainable Irrigated Agriculture in the Major Canal Commands of North West Frontier Province.

8.2.2. Punjab Province

Based on the findings resulting from the investigations under this project, along with their implications, the major conclusion is that more and more emphasis over time will be required on improving the management of land and water resources in the doabs of the Punjab Province. An integrated approach is required that focuses on the conjunctive management of surface water and groundwater supplies in combination with increasing agricultural productivity, taking into account the deleterious effects of salinity and sodicity, as well as potential groundwater pollution from industrial wastes and agricultural chemicals, so that increased crop yields are achieved in a manner that supports sustainable irrigated agriculture.

The six major recommendations are diagramed in Figure 8.5. Each block contains the title, or function, of the recommendation in capital letters, with the likely actors listed underneath. In Pakistan, a temporary commission is sometimes used to address major topics of concern (e.g., National Commission on Agriculture, 1986-88). Since no government agency is presently responsible for groundwater, a Punjab Provincial Commission on Groundwater Management is proposed for addressing the groundwater situation and making recommendations to the Provincial Government of Punjab regarding the future management of this valuable resource for all of the province.

These recommendations are focused towards a proposed program on Farm Resource Management (FaRM) that will support an intensive agriculture development strategy that, in turn, can feed the nation, as well as increase farm income. However, the sustainability of irrigated agriculture in the lower portion of the doabs is under attack. Only by improving the management of both surface water supplies and the groundwater reservoir can this trend be reversed. Without sustainability, intensive agriculture cannot be achieved!

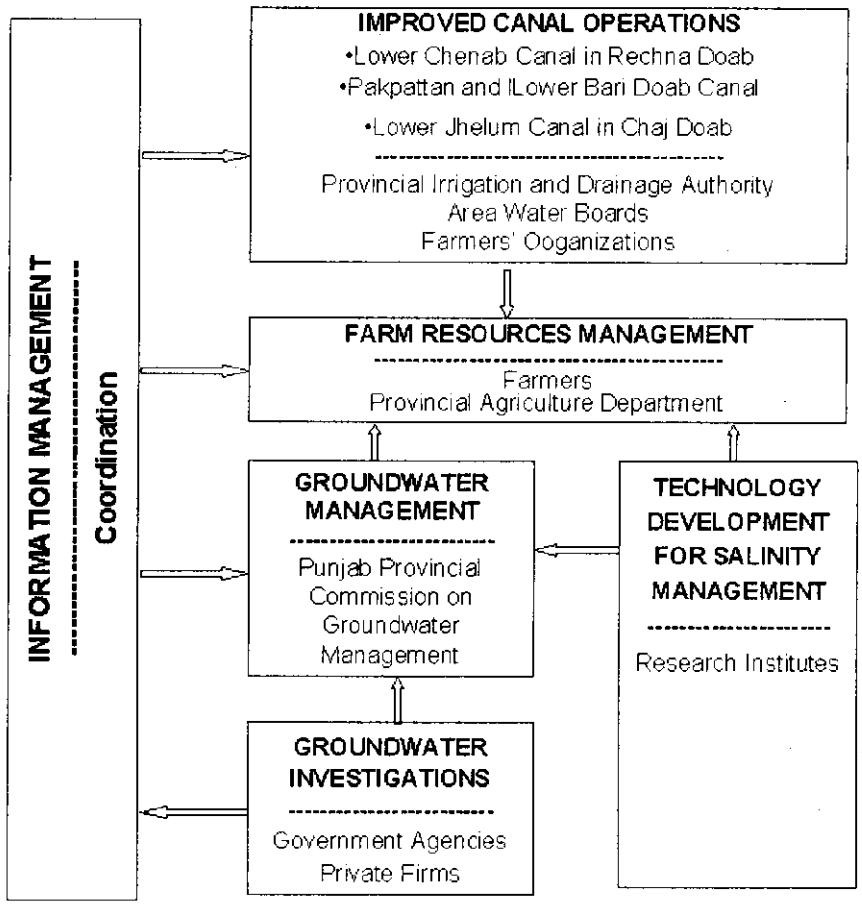


Figure 8.5. Schematic of Recommendations for Sustainable Irrigated Agriculture in the Doabs of the Punjab Province of Pakistan.

8.2.3. Balochistan Province

Only a small portion of Balochistan Province receives irrigation water from the Indus River. Pat Feeder Canal is the largest command area having a CCA of 712,000 acres. The other irrigated area (CCA = 75,269 acres) is served by Khirthar Branch of the North West Canal. The two irrigated areas are adjacent to one another. Both suffer enormously from waterlogging and salinity. The solutions for this situation are identical with Sindh Province, which will be described in the following section.

8.2.4. Sindh Province

The Sindh Province represents the most difficult waterlogging and salinity situation in the Indus Basin Irrigation System (IBIS). In general, the croplands are underlain by highly saline groundwater. With high watertable levels, the capillary rise of groundwater into the root zone will result in much higher soil salinity levels and sunsequent crop yield reductions. Tubewells are used adjacent to the Indus River, along with skimming wells adjacent to canals and branch canals; otherwise, the groundwater is much too brackish, except for some localized situations. The IIMI field surveys throughout Sindh Province during 1997-98 disclosed that 12 percent of the interviewed farmers used some canal water to supplement canal water supplies.

The IIMI studies under this project on "Waterlogging and Salinity Management in the Sindh Province" (see the list of IIMI publications at the back of this report listed under R-70) disclosed that some adjustments in the water allocations among the 14 canal commands, as well as modifications in cropping patterns, could reduce groundwater recharge, thereby lowering groundwater levels, which would enhance agricultural productivity. In addition, there are other opportunities for increasing crop production. The major conclusion from these studies, however, is that the major emphasis needs to be focused on management interventions.

A major physical constraint in Sindh Province is the very flat topography having an average slope of 1:14,000. This implies that superb canal management practices are required in order to avoid waterlogging. The data shows that groundwater levels continue to slowly rise in a number of locations.

To lower groundwater levels, surface drains have been constructed, which were never maintained, so they have limited utility. The Left Bank Outfall Drain (LBOD) Project has constructed a world-class drainage system consisting of a variety of facilities, unfortunately, these facilities are not being adequately maintained. Even more importantly, the LBOD drainage facilities are not being effectively managed.

Despite these shortcomings, in order to reduce waterlogging, drainage facilities need to be constructed or installed, but more importantly, they need to be properly maintained and effectively managed; otherwise the investment costs are wasted as well as adding to the national debt burden. Because drainage works are quite expensive, these costs can be minimized by the combined management of irrigation and drainage facilities, including improved canal operations (Figure 8.6). This should be followed by a program of Farm Resources Management (FaRM). Such a program combination is both expensive and time-consuming, requiring a number of decades for completion. A totally different management approach will be required in order to be successful.

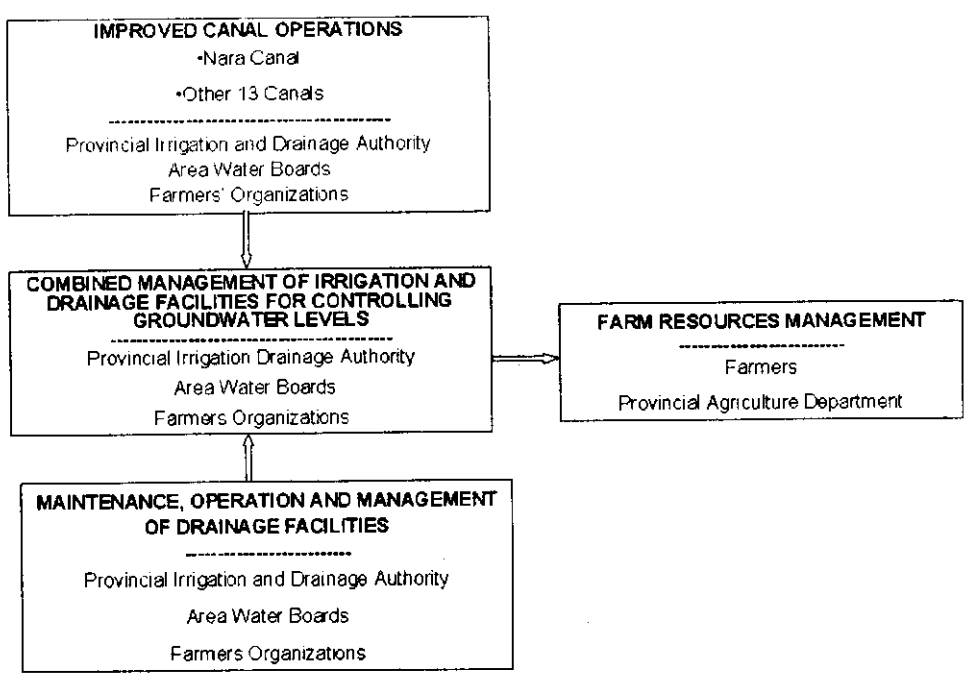


Figure 8.6. Schematic of Recommendations for Sustainable Irrigated Agriculture in Sindh Province.

PART C
EPILOGUE

9. SUSTAINABLE AGRICULTURE IN THE INDUS BASIN IRRIGATION SYSTEM

9.1. SALINITY MANAGEMENT STRATEGIES

Looking at the situation across the Indus Basin Irrigation System (IBIS), three possible strategies can be seen. The simplest, Strategy A, would consist of improved canal operations and farm resources management. An intermediate course of action, Strategy B, would consist of improved canal operations, groundwater management and farm resources management. The most rigorous, Strategy C, would implement programs on improved canal operations, combined management of irrigation and drainage facilities, followed by farm resources management. These strategies are listed in Table 9.1. The employment of these strategies in the IBIS is identified in Figure 9.1. For each pilot canal command, the appropriate salinity management strategy could also be roughly indicated in Figure 9.1.

The success of Strategy A would largely be dictated by the capability and strength of farmers organizations (FOs). A Decision Support System (DSS) for improving canal operations will only be fully effective if every distributary served by a branch canal or main canal is managed by a Water Users Federation (WUF). Likewise, a WUF can be highly effective in outreaching, organizing activities and facilitating the dissemination of improved agricultural practices in a program of farm resources management.

Pakistan will never have sufficient surface water storage. Present facilities (Tarbela and Mangla) are less than 20 percent of the mean annual flow in the Indus River. Groundwater storage in the Punjab, however, is many times greater than the annual volume of the Indus River. The lower half of the doabs are threatened by groundwater salinity. At this time, no organization is responsible for managing this huge groundwater reservoir. Many decades are required to salinize groundwater and once this occurs, even more decades will be required to reclaim this reservoir. There is an urgent need to embark upon a program of groundwater regulation and management.

The irrigated croplands in the Province of Sindh, as well as the lower portion of the doabs in Punjab, have to contend with serious problems of waterlogging and salinity. In most cases, the shallow groundwater is quite saline and unfit for either domestic purposes or irrigation. The combined management of irrigation and drainage facilities implies managing the water table so that it is located at a sufficient depth to minimize the groundwater capillary rise into the root zones of crops. Invariably, this task requires the heavy involvement of organized farmers in order to be successful.

Managing groundwater through the proper management of irrigation and drainage facilities in an extensive area essentially demands a high degree of coordination among the water users. Operation and maintenance of some of these facilities can best be accomplished by the users themselves. Logically, the management involvement of organized users groups, such as WUFs and WUAs, and their collective interactions with agencies managing larger components of irrigation and drainage systems, become a significant element of a changed institutional arrangement for sustainable irrigated agriculture in the IBIS.

9.2. FROM EXTENSIVE TO INTENSIVE AGRICULTURAL DEVELOPMENT

The vast majority of farmers in the IBIS have to practice extensive agriculture because of the inequity and unreliability of canal water deliveries. Thus, an Improved Canal Operations Program is absolutely essential for farmers to practice intensive agriculture. In fact, the only hope for feeding the growing population early in the next century is to be practicing intensive agriculture (Rehman et al 1997). A Farm Resources Management (FaRM) Program will be much more effective if the Improved Canal Operations Program is already underway for a canal command. Many, many decades will pass before this can be accomplished on all of the canal

commands in the IBIS. These programs need to proceed at a pace commensurate with a growing population and increasing food demands.

Table 9.1. Strategies for Salinity Management in the Indus Basin Irrigation System.

Strategy A	Strategy B	Strategy C
Improved Canal Operations (FOs & DSS)	Improved Canal Operations (FOs & DSS)	Improved Canal Operations (FOs & DSS)
	Groundwater Management	Combined Management of Irrigation & Drainage Facilities
Farm Resources Management (FaRM)	Farm Resources Management (FaRM)	Farm Resources Management (FaRM)

Note: The Improved Canal Operations Program and the Farm Resources Management (FaRM) Program are universal throughout the Indus Basin Irrigation System.

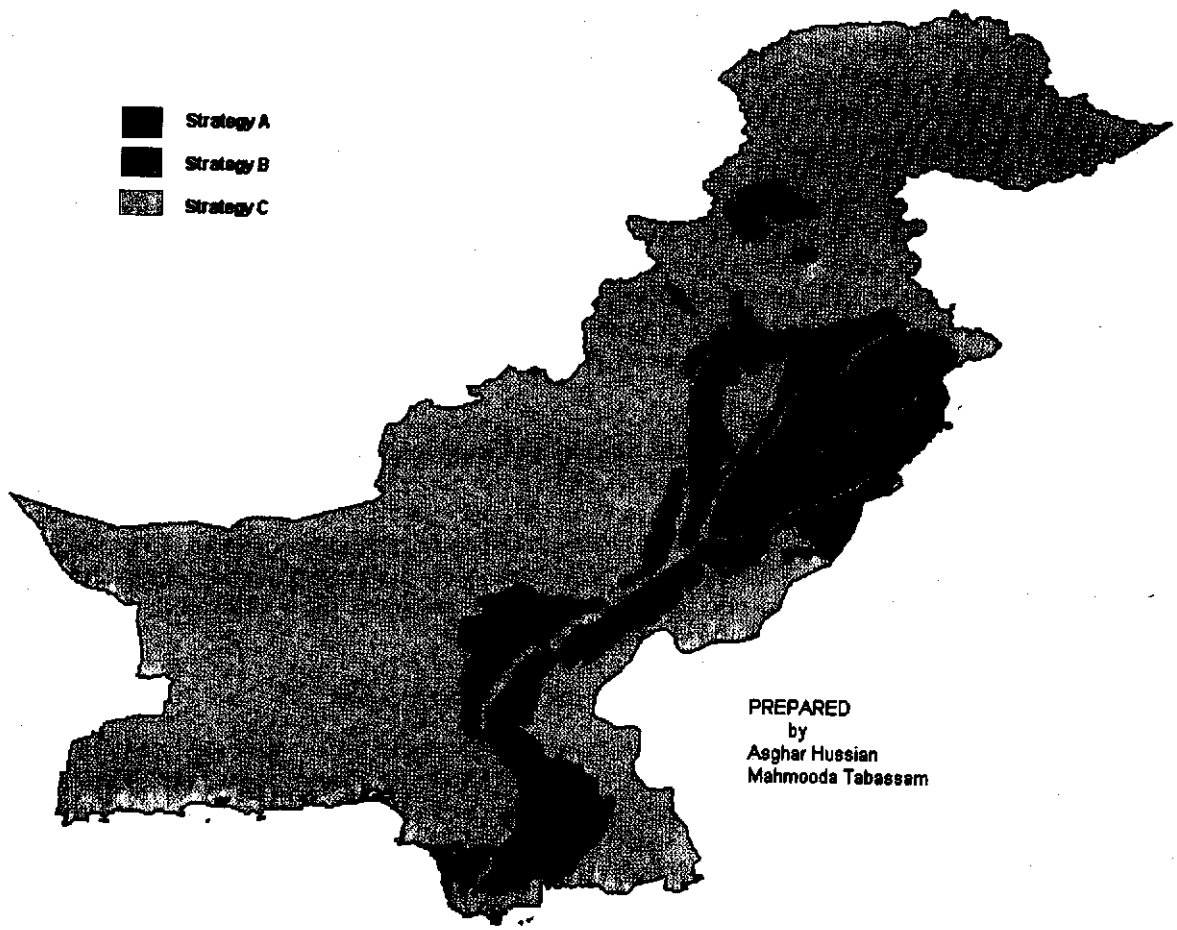


Figure 9.1. Salinity Management Strategies for the Indus Basin Irrigation System.

9.3 INSTITUTIONAL REFORMS FOR MANAGING IBIS

9.3.1 PIDA Acts

Suggested strategies for environmentally sustainable agriculture in the IBIS requires a user-friendly institutional framework. With the planned reforms being in place, the future opportunities for implementing these strategies are significant. During mid-1997, each of the Provincial Assemblies in Pakistan passed a Provincial Irrigation and Drainage Authority (PIDA) Act. These Acts envisage transforming each of the Provincial Irrigation Departments to a semi-autonomous PIDA. While initial steps have been taken in this direction, the provinces have also started action to provide for a pilot canal command area in each province, which would be governed by an Area Water Board (AWB) with membership from both the government and farmers in about equal proportions.

The research reported herein has always advocated that the farmer membership on the AWB should come from the WUF leaders, not the rural elite nominated by the government unless they are WUF leaders selected by the water users themselves. This would provide the ultimate continuity that began at the grass-root level WUAs to the WUF and onwards to the AWB. Each province is selecting a pilot canal command area for implementing the principles embodied in the PIDA acts. This is a sensible approach that acknowledges some concerns about the outcome of these reform plans, as well as the method of implementing them. The goal should be to establish a "visible success story" for each of the pilot canal commands. In many ways, a canal command is not a pilot, but rather a prototype experiment in social organization and agricultural development. Most of all, these four selected canal commands provide opportunities for learning how to significantly improve agricultural productivity. Much that has been learned from this Dutch-funded research project can be applied to these selected canal commands.

9.3.2 Institutional Reforms for Hakra Branch Canal

The Royal Netherlands Government has supported in recent months the development of a Project Formulation Document on "Institutional Reforms and Water Management Project for the Hakra Branch Canal". This project is based on the results reported herein regarding Farmers Organizations (FOs) and Decision Support Systems (DSS). All of the distributaries served by Hakra Branch Canal will be organized as WUFs by the On-Farm Water Management (OFWM) Directorate, Punjab Department of Agriculture. The Punjab Irrigation and Drainage Authority (PIDA) will implement a DSS from the Hakra Branch Canal Head Regulator to each of the distributary head regulators. Each WUF will implement a DSS from the distributary head regulator to each outlet serving a tertiary watercourse command area. Instead of an AWB, there will be a Joint Committee for Water Allocation for the Branch Canal. IIMI also has a significant role, along with a few research institutes. With Hakra Branch Canal being a smaller command area than the selected pilot canal command area of Lower Chenal Canal (East), along with work already accomplished to date, this project is expected to provide much quicker results and serve as a training ground for those working in the pilot canal command area.

10. FARMERS FIRST

10.1. FROM A FARMERS' PERSPECTIVE

Chapter 2 of this Report discussed how the historical influences can fashion the technological advances and the style of natural resources management in a developing context. As for water resources management in Pakistan, its current situation is determined by a number of historical influences. Ancient traditions, feudalistic social structures, colonial laws and administrative procedures, trauma of partition days, and post-independence political modernization efforts all have a combined effect on the socio-technical environment of Pakistan's irrigation water management.

Interestingly, some of the strongest elements from each influence factor seem to be so closely interwoven and mixed together that the resultant amalgam has formed a strong institutional "hardpan". Lack of regard for innovative ideas, lack of accountability, poor law and order situation, and lack of concern for equity and environmental considerations, can all be seen converging in an overall bureaucratic indifference, which cannot be easily permeated by ad-hoc or sporadic droplets of change. One possible solution to this apparent impasse is to make the end users' (farmers') needs the prime consideration, and accordingly develop an integrated package of change strategies to be introduced and internalized with their maximum possible participation.

The pilot efforts have proved that organizing farmers at the distributary level is socially feasible and an economically viable strategy for improving the equity and productivity of water resources management in irrigated agriculture (Bandaragoda et al, 1997). The success story of the social organization experiment conducted at the Hakra 4-R Distributary, though still limited by many external constraints, provides a strong signal that taking the farmers' perspective into account will have the greatest potential for solving several chronic problems confronted by them in the present context.

10.2. CHRONIC PROBLEMS

The agricultural situation in Pakistan can be characterized as stagnant. Although inadequate canal operations and delayed maintenance are the major culprits, there are a number of additional factors. For example, the "social disease triplets" of political interference, rent-seeking and farmer anarchy significantly hinder the employment of good water management practices, including canal operations and maintenance. In addition, farmers often have nightmares about difficulties in securing good quality water, and other agricultural inputs. Junk fertilizers and highly adulterated biocides are parasites sucking the lifeblood out of agriculture. Since the Government agencies are unable to regulate these practices, the only feasible approach is to organize farmers so that they can address their own destiny.

10.2.1. Social Disease Triplets

The social disease triplets affect primarily the management of secondary canals (distributaries and minors). That is why this research project undertook, as its main emphasis, "learning how to organize farmers on a secondary canal", wherein the pilot test was to establish a Water Users Federation (WUF) among the farmers served by Hakra 4-R Distrubutary. Certainly, in the case studies to date in Punjab and Sindh Provinces, organized farmers are demonstrating their potential to become an effective deterrent to political interference, rent-seeking and farmer anarchy in canal administration. Their present capacity to apply prompt curative measures to eradicate these social ills may still be limited, but they are developing a strong preventive capability to reduce the possible infliction by the three social diseases associated with canal operations and maintenance.

The organized farmers groups in these pilot sites have shown that their collective action to mobilize resources and undertake operation and maintenance themselves can effectively

neutralize the influences from the elitist minority among them. They have also effectively resisted the chronic rent seeking behavior by some officials, at least within their pilot distributary canal command areas. With their initial successes in establishing organizations in the pilot areas, they have been courageous enough to publicly discuss these social problems and been able to identify the main culprits. This initial effort augurs well in developing a very strong capability for effective collective action, not only to liberate individuals' actions, but also to sanction deviant behavior among individuals.

Improving canal operations is technically one of the simplest and least costly alternatives for achieving major increases in agricultural productivity in Pakistan. But, the present bureaucratic arrangements for canal operations and maintenance are major impediments to any improvement. Considering the chronically ailing agencies and the related social disease triplets mentioned above, farmers organizations are the only hope for the planned Provincial Irrigation and Drainage Authorities (PIDAs) to improve canal operations. In fact, a prerequisite to reliable and equitable canal water deliveries is that every distributary in a canal command be organized. Empowering the farmers groups on a broader basis would pave the way for a strong self-reliant farmer community, by which means the society and the economy at large would certainly be strengthened.

10.2.2. Four Farmer Nightmares

Numerous field interviews with farmers during the project revealed that they are constantly suffering from four main psychological stresses, which the farmers termed as their "four nightmares". After making substantial investment in starting a crop season, farmers are worried about obtaining the necessary inputs: water, seed material, fertilizer and pesticides. In their self-evaluation interaction sessions, the farmers have acknowledged that getting organized and collectively taking over management responsibility for water distribution would relieve first of the four farmer nightmares; namely, unreliable and inequitable canal water deliveries. Poor quality seed, lack of timely availability of fertilizers that are also low in nutrients, and highly adulterated chemicals (biocides), which cause the other three farmer nightmares, essentially need to be resolved with adequate support from appropriate government actions. An important role of Government is regulation, but field observations prove that enterprises dealing with seeds, fertilizers and biocides are largely unregulated. Again, the only hope for overcoming these constraints is for organized farmers to develop solutions for combating them. Certainly, individual farmers have been unable to do so. The effect of collective action is reflected in a recent successful attempt by the organized farmers of Hakra 4-R Distributary command area to secure arrangements for good fertilizer directly with the manufacturers, bypassing the middlemen.

10.3. So Near, Yet So Far

The main reason for the farmers' grievances is that even the good intentions of the government are often thwarted by the process in which they are implemented. The primary beneficiaries of rural development projects aimed at the poor have been almost exclusively Government staff and the rural elite (Tahir and Rinaudo, 1999). Although many of these projects were intended to primarily benefit the poor, only paltry amounts reach this level. The National Commission on Agriculture commented in 1988: "Input subsidies and price supports for cash crops worked more to the advantage of the large farmers. In fact, most of the increases in production resulted from the minority of large and medium farmers. The overall institutional support has not adequately benefited all crops, nor all categories of farmers". While this selectivity in benefit provision has remained largely unchanged, the number of small landowners has been steadily increasing due to fragmentation.

In Pakistan, the average per capita income in rural areas (where about 70% of the population live) is less than half that in urban areas, and value added per worker in agriculture (which

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employs about 50% of the work force) is less than one-third of the rest of the economy (Hamid and Tims, 1990). Absolute rural poverty dropped by only one-third in twenty years, a much lower rate compared to achievements in some States of India (John Mellor Associates and Asianics Agro-Dev, 1994).

A more recent evaluation pointed out that poverty considerations had not been a priority in Pakistan's irrigation development projects (World Bank, 1996). "While the projects helped alleviate poverty through their effects on farm production, they also provided large and unnecessary transfers of public resources to some of the rural elite". In effect, On-Farm Water Management Projects, the Irrigation System Rehabilitation Project and the Command Water Management Project have all tended to favor the more affluent farmer groups. There has not been much investment in human resources development for farmers except for the rural elite. For overall improved productivity, all farmers need to grow in their profession, not just the large farmers, to develop their new skills, so that they can better sustain their families and collectively enhance the Indus Food Machine to support a growing population.

10.4. Partnership with Public and Private Sector Agencies

Social dynamics at the farmer-agency interface reflect an institutional tendency to favor the elite. Special attention to promote effective participation by the organized farmer groups in this interface activities can be very productive in remedying the bias towards the rich that is inherent in the normal development process. This was evident from an experiment tried in the pilot project on social organization. For the Hakra 4-R Distributary, a Field Implementation Coordination Committee (FICC) was established with about 20 members representing the WUF, Agriculture and Irrigation Departments, other local government representatives and IIMI. There was considerable difficulty with attendance in the beginning, but once the WUF was established, the FICC became highly effective as a coordinating mechanism. Government representatives quickly learned that the WUF was able to effectively mobilize 4,600 member farmers for implementing a variety of programs. They were also able to interact with the farmers in a more efficient manner. For instance, in the area of agricultural extension, which is usually accomplished by interactions with groups in a village; the Hakra 4-R WUF having an organizational coverage over 41 villages can become a significant vehicle for very effective change in agricultural practices.

To cope with the nightmares regarding seeds, fertilizers and biocides, the WUF needs to develop linkages with the suppliers that bypasses the local distributors. They need to seek reliable suppliers. The WUF also needs to develop mechanisms for testing the quality of inputs being provided by suppliers so as to assure the WUF members that they are receiving good products for their money.

10.5. Sustainability Of Water Users Organizations

There are three major collective action capabilities that determine the sustainability of WUFs: (1) the ability mobilize sufficient resources to effectively undertake operation and maintenance of the distributary after paying for upstream canal O&M; (2) the ability to effect equitable water distribution; and (3) the capacity to apply sanctions against members who do not comply with collectively agreed decisions. The first two issues will likely determine whether or not a WUF can start off and continue as an organization. The third issue is the real measure of long-term sustainability.

Once a WUF has been established, many activities are undertaken to strengthen the new organization. An important activity is diagnosing the maintenance situation by doing a "walk-thru" with the farmer leaders. The maintenance needs are prioritized according to their impact on operating the canal network, as well as costs. When the farmers agree on a maintenance plan, then the priority maintenance needs are undertaken. The objective is to improve the

hydraulic operation of the irrigation channels. Then, the equity of water distribution is measured, with the results being reported to the WUF membership, who in turn will most likely heatedly discuss the results. After many discussion periods, hopefully, the farmers can agree on an operations plan for achieving equitable water distribution.

The pilot distributaries in Punjab and Sindh Provinces are all working towards equitable water distribution. One of the pilot distributaries in Sindh Province attempted to modify some of the outlet structures to improve equity, but they had so much interference from the agency staff that they could not continue. Now, the three pilot sites in Sindh Province are awaiting the signing of a Joint Management Agreement between the WUF and Sindh irrigation authorities before implementing equitable water distribution.

Once farmers feel free to report offenders and the WUF can apply and enforce appropriate sanctions, then the WUF can be considered as sustainable. The Hakra 4-R WUF has been making good progress on this issue.

10.6. Joint Management Agreements

The social organization process used for establishing the Hakra 4-R WUF, as well as the three pilot distributaries in Sindh Province, relies upon a formal Joint Management Agreement (JMA) between each WUF and the Provincial Irrigation and Drainage Authority (PIDA). In essence, the JMA serves two purposes. First, it would represent a legal recognition of the WUF, which will be useful in its relationships with its own members. Second, the JMA will provide legal authority to the WUF for operation and maintenance of the irrigation network in the distributary command area, and in this process, for its legitimate transactions with its membership, as well as with outside individuals and agencies.

The turnover point would be the distributary head regulator, with PIDA being responsible for operation and maintenance of the distributary head regulator and the upstream channels and structures, including the canal headworks. The other major issue is the assessment and collection of water charges or irrigation and drainage service fees by the WUF and establish what amount is to be retained by the WUF for the distributary command area O&M, and what amount is to be given to PIDA for O&M of the canal headworks, canal and branch canals, and distributary head regulators. There has been a tremendous reluctance by the newly established PIDAs, as demonstrated by their inordinate delay in action, in providing adequate legal authority to WUFs. Considerable effort was expended in attempts to sign various JMAs. However, none has been formally signed to date.

10.7. Reorientation of Roles

The stagnant agricultural situation in the Indus Basin Irrigation System is the result of many factors, but the major culprits are the social disease triplets. The main argument, as presented in the previous section, is that the most feasible option for overcoming these diseases is to organize farmers. In this scenario, the traditional roles of both farmers' groups, as well as the government agencies, have to be correspondingly changed.

Farmers are experienced in operating and maintaining their tertiary watercourse channels, but will need to adjust themselves to more organized economic activity in operating and maintaining the distributaries. This research project has clearly shown that farmers can be organized equally well at both the tertiary and secondary distributary levels. Many farmers, after becoming organized at the distributary level, stated that never in their lifetime had they thought of the possibility of becoming organized for higher responsibilities. They also acknowledged that, prior to this new experience, they had a strong dependence on government agencies to provide services, and never thought about what they could do for themselves. They had spent years requesting the Provincial Irrigation Department (PID) to undertake

maintenance on their secondary canal, and spent considerable time in visiting government authorities for this purpose.

The research project concluded that Farmers Organizations (FOs), when properly formed, establishes a much more independent state of mind among the individuals, where they begin to think about working together and undertaking activities themselves for improving the irrigation and drainage system in order to sustain their families. The normal prudent behavior, which farmers are accustomed to, makes them look for opportunities to avoid bureaucratic hassle, delays and inefficiencies, and to make the best use of their new status of independence. In fact, pilot project experience shows that, hitherto, farmers have been the most underutilized resource for improving the productivity and sustainability of irrigated agriculture in Pakistan.

But for FOs to develop, grow and flourish, there needs to be supporting mechanisms. First of all, they must have appropriate legal authority, rather than being placed in submissive secondary roles where they have practically no meaningful authority. Secondly, these organizations should be provided highly appropriate technical assistance services, whether public or private, which will emphasize farmers first; these services need to be provided with a mental attitude of supporting and strengthening FOs so that they can play an ever-increasing role in the quality of rural life. The implication is that government agencies should play more and more of a role in providing technical assistance services to rural areas, with an emphasis on "service" rather than "control".

An excellent example is the Provincial Irrigation and Drainage Authority (PIDA), which is responsible for operating and maintaining (O&M) the canals, branch canals, distributaries and minors. By establishing WUFs that will be responsible for O&M of the distributaries and minors, the O&M burden of PIDA is reduced, but they are still needed for providing technical assistance to the secondary canal command areas, but at the request of the WUF. Likewise, the establishment of an Area Water Board (AWB) for each canal command area, with representatives from WUFs and government agencies, provides excellent opportunities for undertaking "service activities" that will enhance the capabilities of farmers for managing the irrigation facilities.

10.8. Support Services

10.8.1. Decision Support Systems

The typical Decision Support System (DSS) for a canal command area would involve the PIDA, AWB and WUFs. This would be a technical assistance service activity implemented by PIDA, with strong communication linkages with the AWB and each WUF. The DSS would have a monitoring and evaluation (M&E) component, which provides feedback to all parties. In turn, the WUFs would provide feedback to the AWB, which would deliberate upon all feedback and then communicate with PIDA representatives regarding refinements of the DSS.

Each WUF would also have an internal DSS to monitor the distribution of available water supplies among all of the watercourses in the secondary canal command area. A monitoring and evaluation report would be issued periodically to each WUA for their information and feedback. These reports would most likely be issued shortly after the completion of a distributary rotation schedule (three weeks), but it could follow any schedule mutually agreeable to the WUAs and WUF. In their periodic meetings, the WUF would thoroughly discuss all feedback and make decisions on how to refine their DSS. In order for the WUF to effectively manage a DSS, they would need technical assistance support for field discharge calibration of the distributary and minor head regulators, as well as all of the moghas (one mogha at the head of each watercourse). A number of the farmers would require water

measurement training so they could frequently measure the discharge rate at each of these flow control structures.

10.8.2. Watercourse Management

In general, farmers are fairly good about periodically cleaning their watercourses so that water reaches the tails of the command areas. However, there are also numerous cases where water does not reach the tail of the watercourse during periods of water scarcity, while the same areas become flooded when the water demand upstream is quite low, which occurs during heavy monsoon rains and at times of harvesting. The value of a Water Users Association (WUA) for a watercourse command area is to develop communication among the farmers in order to improve watercourse management practices that will enhance agricultural productivity. Organized behavior is expected to result in more equitable water distribution among all of the farmers along a watercourse. An important activity is cleaning of the watercourse at appropriate times when sediment deposition and vegetative growth are not only limiting the flow of water, but also increasing upstream seepage losses.

A highly important technical assistance service would be to train farmers how to measure water. First of all, many farmers should know how to measure the water discharge rate passing through the mogha at the head of the watercourse. Secondly, Rectangular Channels could be locally fabricated and installed at some of the nakkas (serving about 25 acres each) along the watercourse so farmers would know how much water they are receiving in comparison with the mogha, along with knowing the water losses in each reach between two Rectangular Channels. In turn, when these water losses continue to increase over time, the WUA members could decide when it would be beneficial to reconstruct the earthen watercourse embankments in order to decrease the water losses.

10.8.3. Irrigation Methods and Practices

The focus on farm water management practices is to: (1) increase agricultural productivity; and (2) enhance the sustainability of the croplands, which is related to salinity and sodicity management.

Placing blocks on the underside of planks for establishing corrugations on a bunded field is readily adaptable by farmers. They only need to be informed about the low cost, improved water uniformity across a field, and increased crop production.

In contrast, the bed-and-furrow technology requires a significant investment for equipment to form the beds-and-furrows and for the hoeing of weeds in the furrows during the growing season. The majority of farmers would not have the financial resources for purchasing this equipment. Thus, for these farmers to participate, some form of collective enterprise is required. For example, the WUF could purchase this equipment and then provide to farmers on a rental basis per unit of land. Thus, the WUF could recover their equipment expenditures and then purchase additional equipment so more farmers can benefit.

The technical assistance services required for bed-and-furrow irrigation are: (1) monitoring the water application for each irrigation event throughout the season on selected fields; (2) measure the crop yield on each selected field; (3) evaluate the reasons for better hydraulic performance and yields; and (4) share this information throughout the farming communities, including the WUFs and WUAs.

10.8.4. Waterlogging and Salinity Management

Generally, the combination of waterlogging and salinity affects large tracts of land. Thus, the AWBs are an appropriate entity for being involved with overcoming such difficulties. For FOs, the necessity is to manage both the irrigation and drainage facilities. Technical assistance

services are required for evaluating the performance of the drainage infrastructure, then sharing this information with the AWB, WUFs and WUAs, as well as presenting recommendations regarding the combined management of irrigation and drainage. This is a large undertaking, but essential, recognizing that no drainage project in Pakistan has ever been properly maintained, nor managed. Instead, these drainage graveyards have mostly contributed to the national debt burden. Again, FOs are most likely the only possible solution for overcoming this situation.

Generally, for tracts of irrigated land without waterlogging, the salinity and sodicity problems are "patchy", which implies that these problems have to be addressed at the farm level. Farmers do have strategies for coping with salinity problems (Kielen, 1996a and 1996b), but have difficulties in coping with sodicity. Technical assistance services are sorely needed in much of the IBIS, which can be provided through WUFs and WUAs, but targeted at the farm level. The technical assistance would be provided by Provincial Agriculture Departments (PADs). The FOs can be instrumental in bringing members together to observe the results at various farms, as well as disseminating solutions to other farmer members.

10.9. Enabling Institutional Framework

The recommended "support service" approach described above contrasts with the traditionally used "control-oriented" administrative style. For the technological advances that are needed in the proper operation and maintenance of canals and in alleviating the problems of salinity, the institutional framework must be supportive and service-oriented. This project, therefore, has endeavored, through an analysis of its three inter-related components: operational management, institutional development and salinity management, to highlight the often neglected role of institutions. Even within the scope of institutional development, the emphasized focus is on users organizations, which, if adequately developed and supported, are most likely to be the leading partner in progress.

10.10. Changing Institutional Environment In Pakistan

Donors' initiatives (World Bank, 1994) and senior policy makers' interests, encouraged by earnest research inputs from many analysts, started off a change process in Pakistan. The first major land mark of this process was the passage of the four PIDA Acts in 1997. Since then, the path of institutional change took a rugged route in a jungle of different local opinions to proposed changes. There was mixed reactions to successes of social organization experiments in pilot sites. While the farmers were extending their unreserved support to change processes that promoted greater water users' involvement in water resources management, some of the agency staff would debate its appropriateness in Pakistan's large canal systems, and some would reluctantly acknowledge is potential benefits. In the midst of all these constraints, the second major land mark was reached in the formation of initial PIDA structures and the arrangements to try pilot canal commands in each of the four provinces.

In view of the developing policy interest in the country, and the support forthcoming from many donors, the change process is most likely to continue. The main reason for this continued interest is the demand for change arising from the farmers, who have been quick to become enlightened about the potential gains from institutional change at this stage of stagnant productivity in the irrigated agriculture sector. Obviously, they find solace in the blowing winds of change.

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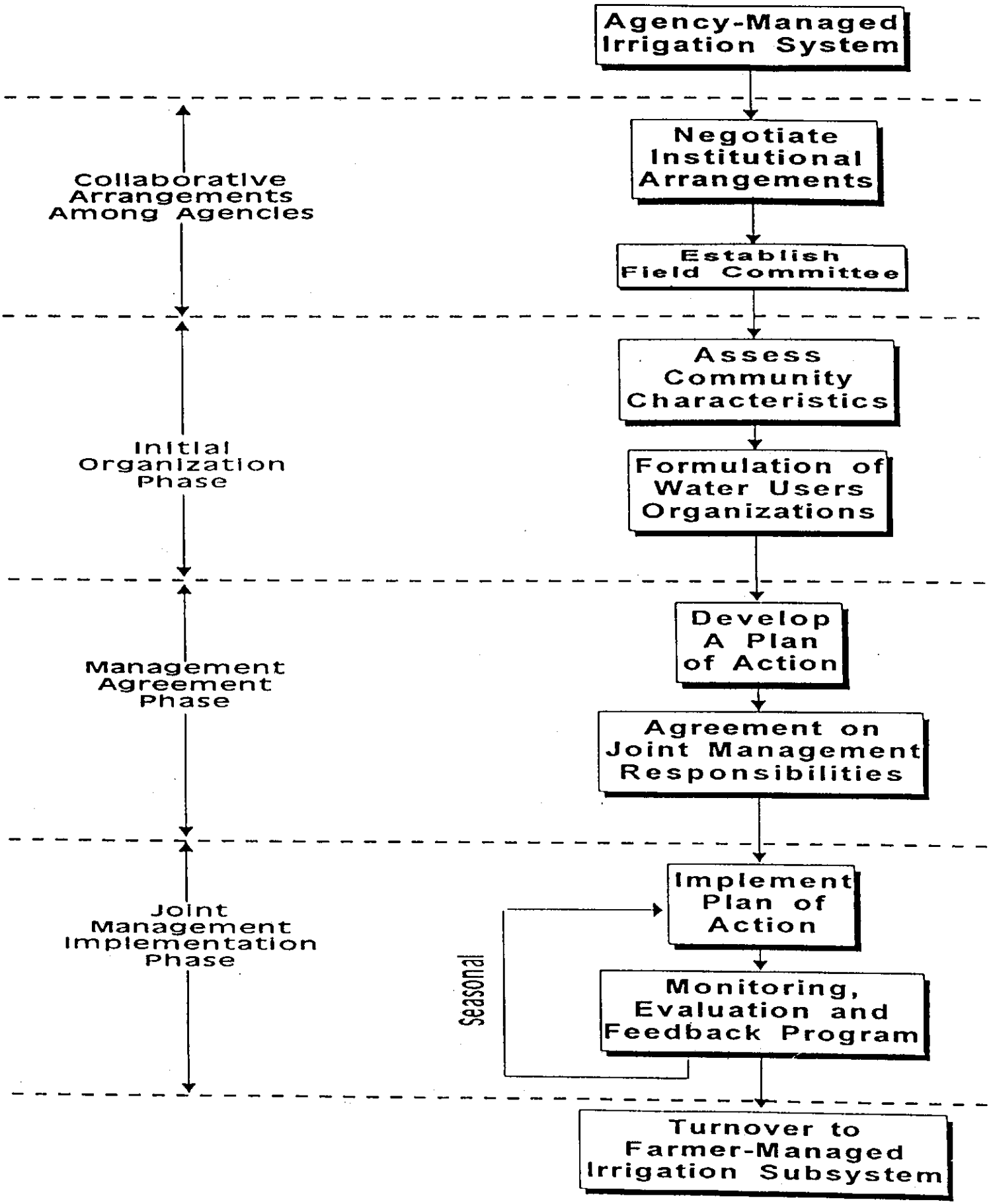
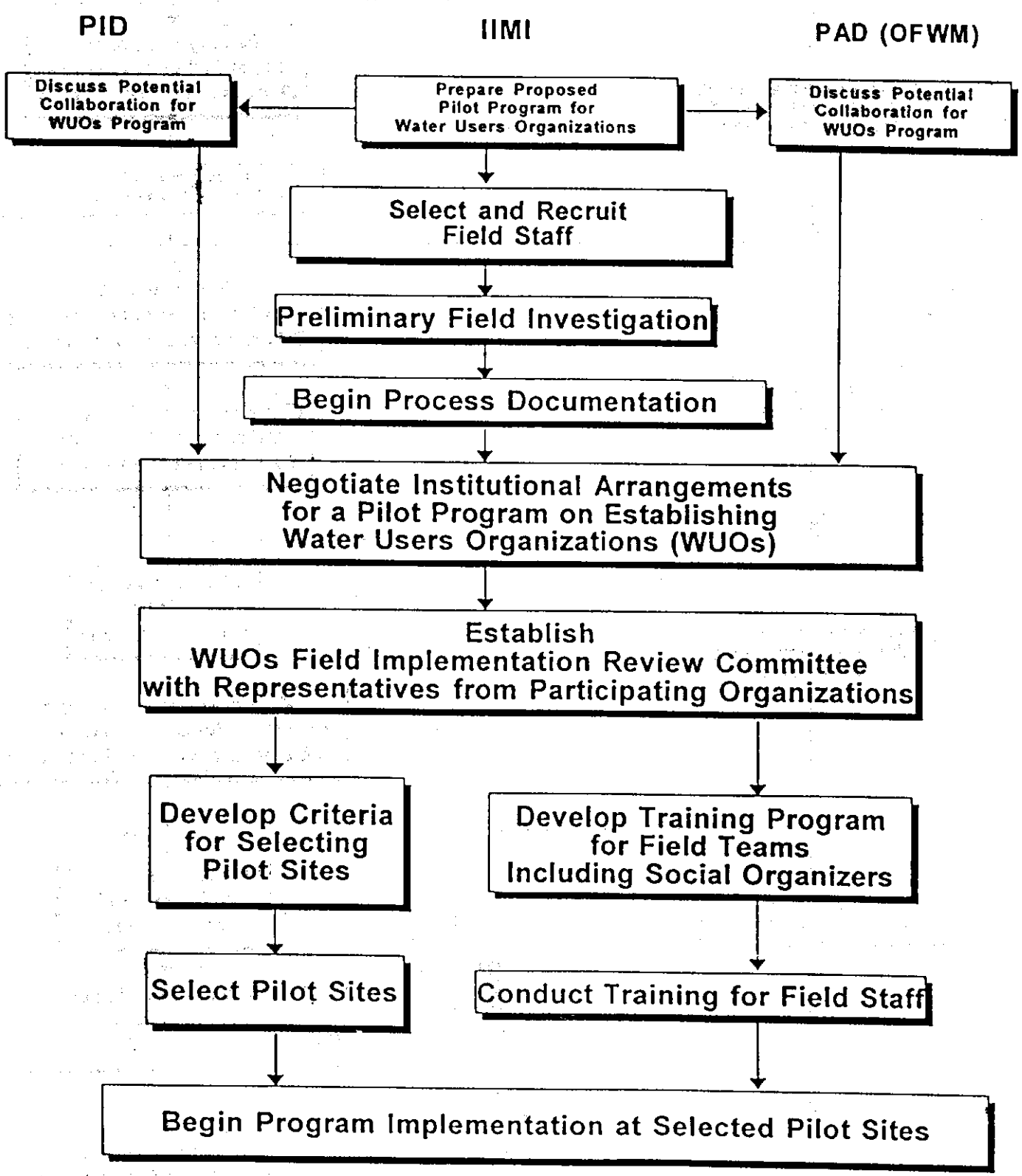
ANNEX

PROCESS FOR CREATING SUSTAINABLE WATER USERS ORGANIZATIONS IN PAKISTAN

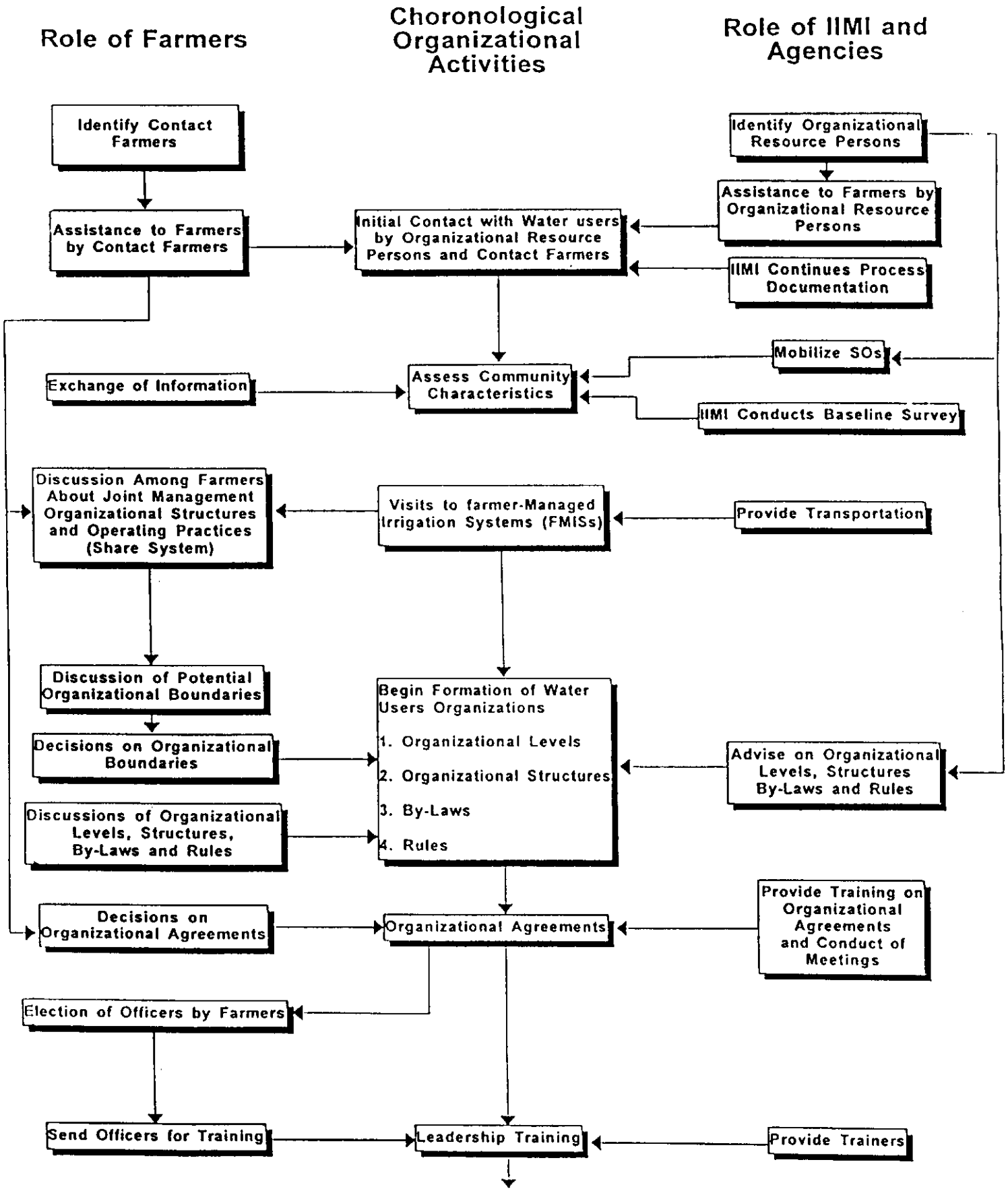
PROPOSED PROCESS FOR CREATING SUSTAINABLE WATER USERS ORGANIZATIONS IN PAKISTAN



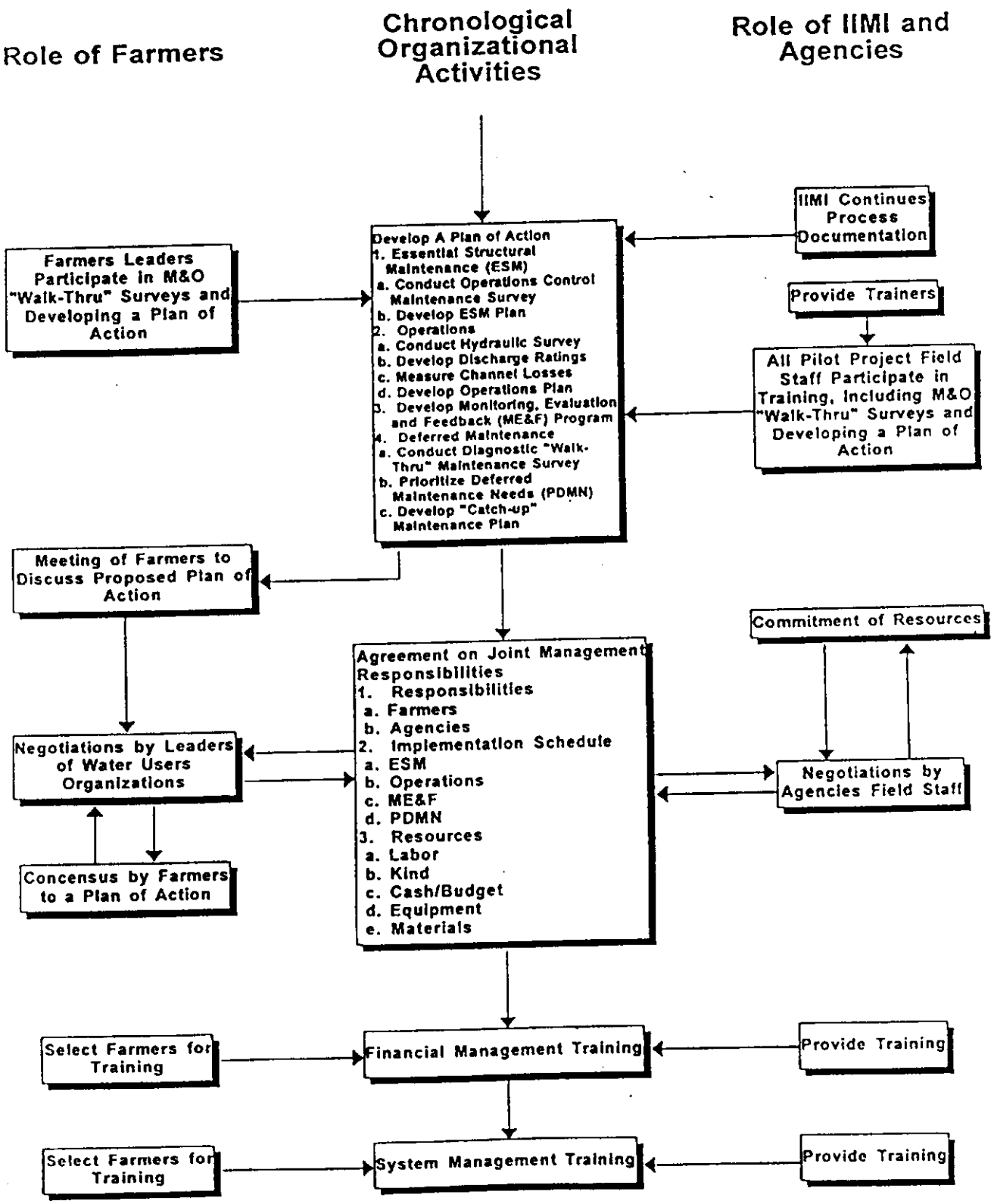
Phase I: COLLABORATIVE ARRANGEMENTS AMONG AGENCIES



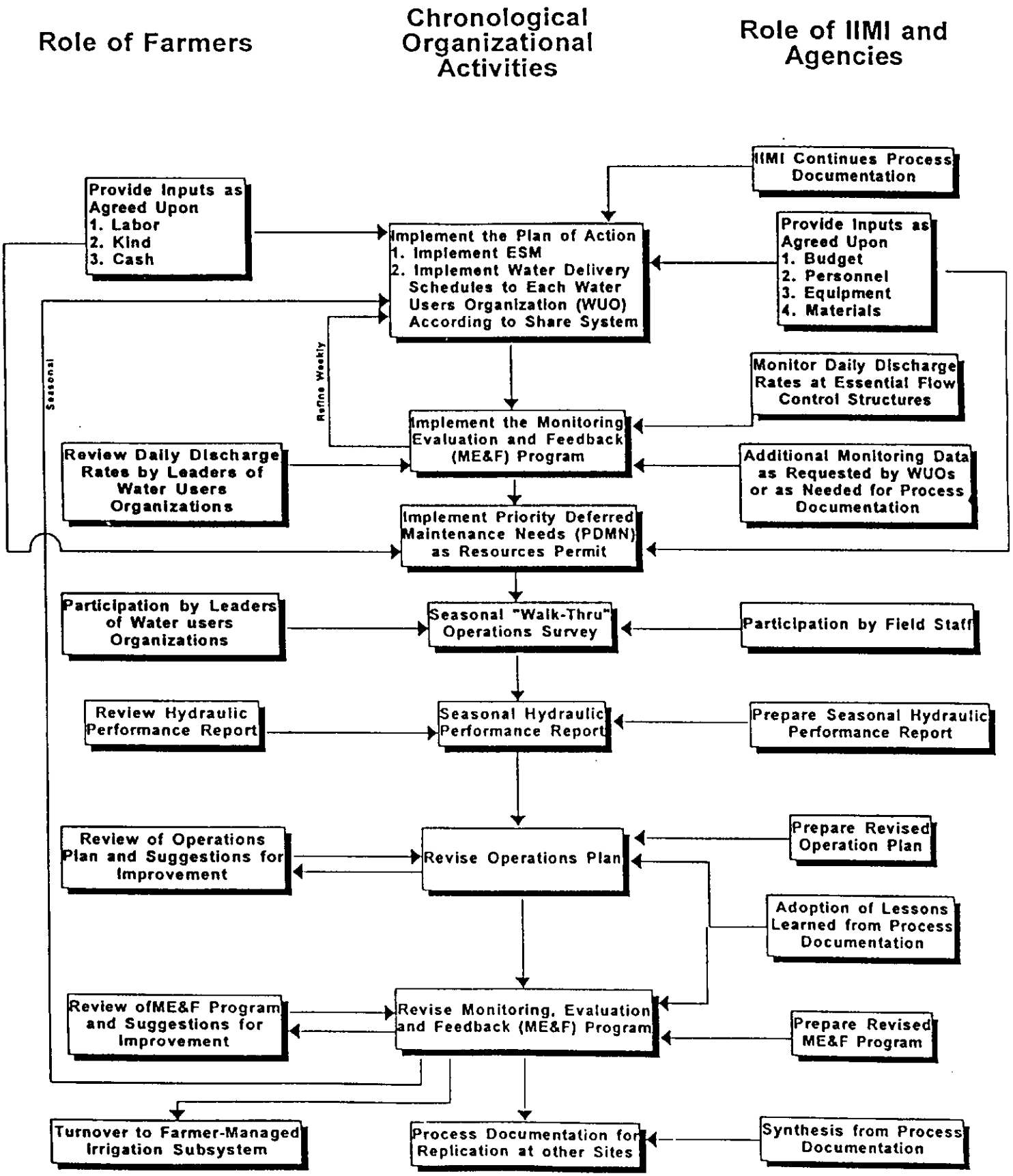
Phase II: INITIAL ORGANIZATION



Phase III: JOINT MANAGEMENT AGREEMENT



Phase IV: JOINT MANAGEMENT IMPLEMENTATION



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