CHAPTER 4

A Comparative Study of Farmer-Managed Systems in Northern Pakistan

Jacob W. Kijne

INTRODUCTION

IN 1986, A World Bank evaluation mission recommended that the Aga Khan Rural Support Programme (AKRSP) should study the potential for distributing available water more efficiently throughout the new small-scale irrigation systems that have been developed with AKRSP assistance throughout the Northern Areas of Pakistan. The mission also urged that Northern Area farmers be assisted in adopting methods to minimize water losses and system maintenance requirements. Subsequently, IIMI Pakistan was asked by AKRSP to carry out research on these issues, with the overall objective of determining the actual performance parameters of such newly established farmer-managed irrigation systems (FMIS). In collaboration with AKRSP, and supported by funding from the Aga Khan Foundation (AKF), IIMI Pakistan implemented a six-month comparative study of a small number of farmer-managed irrigation systems in the Gojal region of Hunza, Gilgit District, Northern Areas. This paper reviews the principal findings of the study, a preliminary report of which was submitted to AKF, Pakistan, on 1 September, 1989.

OBJECTIVES AND DESIGN

The primary objective of this research project was to determine a range of irrigation efficiencies of small-scale mountain irrigation systems in northern Pakistan. Reliable data on actual physical performance parameters of such systems were virtually absent, and this research sought to provide significant knowledge about an irrigation system commanding some 400,000 ha of the national irrigation environment.

IIMI was also interested in initiating studies of FMIS in Pakistan to expand the geographical scope of its management research activities focusing on the special problems of delivering support services to the farmer-managed sector. Data and information on the performance of small-scale irrigation systems in northern Pakistan would facilitate comparative analyses of similar systems elsewhere in the trans-Himalaya region including Nepal, where IIMI research on FMIS has already resulted in significant changes in national irrigation policy and programs.

A secondary objective of the project was to determine the suitability of well-established, practical field research techniques and methodologies for measuring the actual physical performance of small-scale irrigation systems in mountain environments, where conditions of climate, soils, slope and aspect are highly variable and often extreme. No new technologies were developed or tested.

While developing the research design, it was recognized that there were two broad categories of small-scale irrigation systems in the Karakorum Mountains of northern Pakistan: (1) long-established systems which could be assumed to be essentially stable or mature, and (2) systems newly constructed or expanded in the past 5 years, with AKRSP assistance, which were in the process of stabilizing. It was initially thought that it would be necessary to carry out comparative analyses of a sample of paired systems from each category if the key issues of concern to AKRSP — opportunities for enhancing water distribution efficiency, water loss minimization, and improved system maintenance processes — were to be effectively examined in newly established or improved FMIS.

Limited resources and time, however, restricted the research to a single, relatively accessible area of Gilgit District. Following a rapid field reconnaissance in Hunza-Gojal, six small-scale irrigation systems were selected for study. In each of the three Gojal villages, one AKRSP-assisted system was paired with an older, well-established FMIS.[20] Following initial field surveying and mapping, the irrigation operations (water conveyance, distribution and field application) and maintenance activities were systematically observed and measured in each of the six systems. The data obtained form the primary basis for the research results are reported here.

Finally, it should be noted that although the narrow focus of this research was on efficiency irrigation issues, it is understood and acknowledged that FMIS frequently have multiple objectives. Their logic, therefore, may or may not emphasize the efficient use of water in strict engineering terms, and an evaluation of their operational performance solely by such strict criteria may well be both inappropriate and undesirable. Nevertheless, as Coward and Levine (1989) have pointed out, much recent research on FMIS has been so heavily social science-oriented that the equally important engineering dimensions of FMIS have been under-emphasized. This research makes a modest effort to redress that imbalance. It also represents only an initial component in a larger effort to compare FMIS performance over both physical and social parameters for a wider area of northern Pakistan.

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[20] Field observations and measurements for each system were done over a 5-month period by a team comprising two IIMI Pakistan field professionals (an irrigation engineer and a hydrologist), two IIMI Pakistan junior research associates (both engineers) and two AKRSP engineers, under the general guidance and supervision of two IIMI Pakistan international staff. In the course of the study, advice was obtained from the Soil Survey Institute of Pakistan. Soil samples were analyzed by the Soil Fertility Survey and Soil Testing Institute, Punjab, and the soils laboratory of the Center of Excellence in Water Resources Engineering, Lahore.

PROJECT AREA

Physical Environment

The Karakoram region of northern Pakistan falls under a partial rain shadow and does not receive the monsoon rains. Summer storms occasionally visit the area, but in general it is arid (annual rainfall is about 125 mm) and agriculture depends on irrigation. (This is distinctly different from much of Nepal Himalaya where FMIS studied were in areas which receive heavy monsoon rains [up to 2,000 mm] and rice is grown.) In most cases, irrigation channels are fed by glacial sources and snow melt. The irrigation systems are small-scale, traditionally farmer-designed, constructed and managed using indigenous technology and techniques. Glacial melt is tapped and carried as far as 10 km through old channels or recently constructed ones, across precarious slopes to alluvial fans and river terraces which constitute most of the arable land. Where channels cross almost vertical rock faces, a passage is carved out or blasted along the rock wall. In Hunza, channels often take the temporary form of tunnels when they traverse scree slopes.

The local climate in Hunza-Gojal varies considerably with altitude, aspect and slope, and with shading caused by surrounding mountains. These same effects govern the rate of snow and glacial melt and therefore discharges of the mountain streams, which are highly variable and differ on cloudy and clear days during the growing season. Low humidity and intense solar radiation are augmented by strong winds, creating a desiccating environment for crop production. Reliable data on potential evapotranspiration are few (e.g., Butz and Hewitt 1985). Evidence of wind erosion is clearly visible and removal of seeds by the wind has been reported in the area.

Agriculture

The Gojal region comprises the upper portion of the Hunza River valley beginning about 2,500 m above sea level. It is predominantly a single crop area where all annual crops are spring sown and experience a relatively short growing season. The rate of ripening is strongly influenced by temperatures and cloudiness at the end of the season. Close to the border with Hunza proper, the growing period is slightly longer and both sowing and harvesting dates are somewhat more flexible. Crops grown for both market and household consumption include wheat, barley, potatoes and pulses; fodder, vegetables and fruit are primarily produced for local consumption. Each village also has a sizeable area of adjacent irrigated "waste" land which is usually divided among resident households and is used for the production of firewood (e.g., Hippophae sp., Salix and Poplar) as well as for grazing and fodder for livestock, especially during the winter months.

Soils

The soils in Hunza-Gojal are immature soils. The parent material in the valley floor is present as river terraces, alluvial fans, glacial moraines or mud flows. Soil formation is largely due to the deposition of silt carried by the irrigation water. The top soil is enriched gradually with these fine materials, and the water holding capacity of the top few inches of the profile improves, whilst leaving the subsoil unchanged. Some scree have well graded young soils which are cultivated, if the slope permits, with alfalfa and forage trees.

The agricultural soils are characterized by shallow profiles (maximum of 0.6 m), by low water holding capacity (at most, 12 percent volume, which is often reduced further by the presence of rocks and boulders buried in the soil), by low inherent fertility and by alkalinity (pH in excess of 7.8). Again, this is different from Nepal, where the soils of the study areas contain mainly clay and silt, and are found on well-drained, deep river terraces. Soils here, however, show a large degree of spatial variability, due in part to differences in parent material over short distances. Inherent variability in soil depth has been enhanced by the formation of horizontal terraces on a naturally sloping terrain.

Compaction and crust formation are common, caused by free wandering of livestock after harvest and — during early irrigations — by the farmers walking through fields, or directly by the flow of water, weeding and thinning.

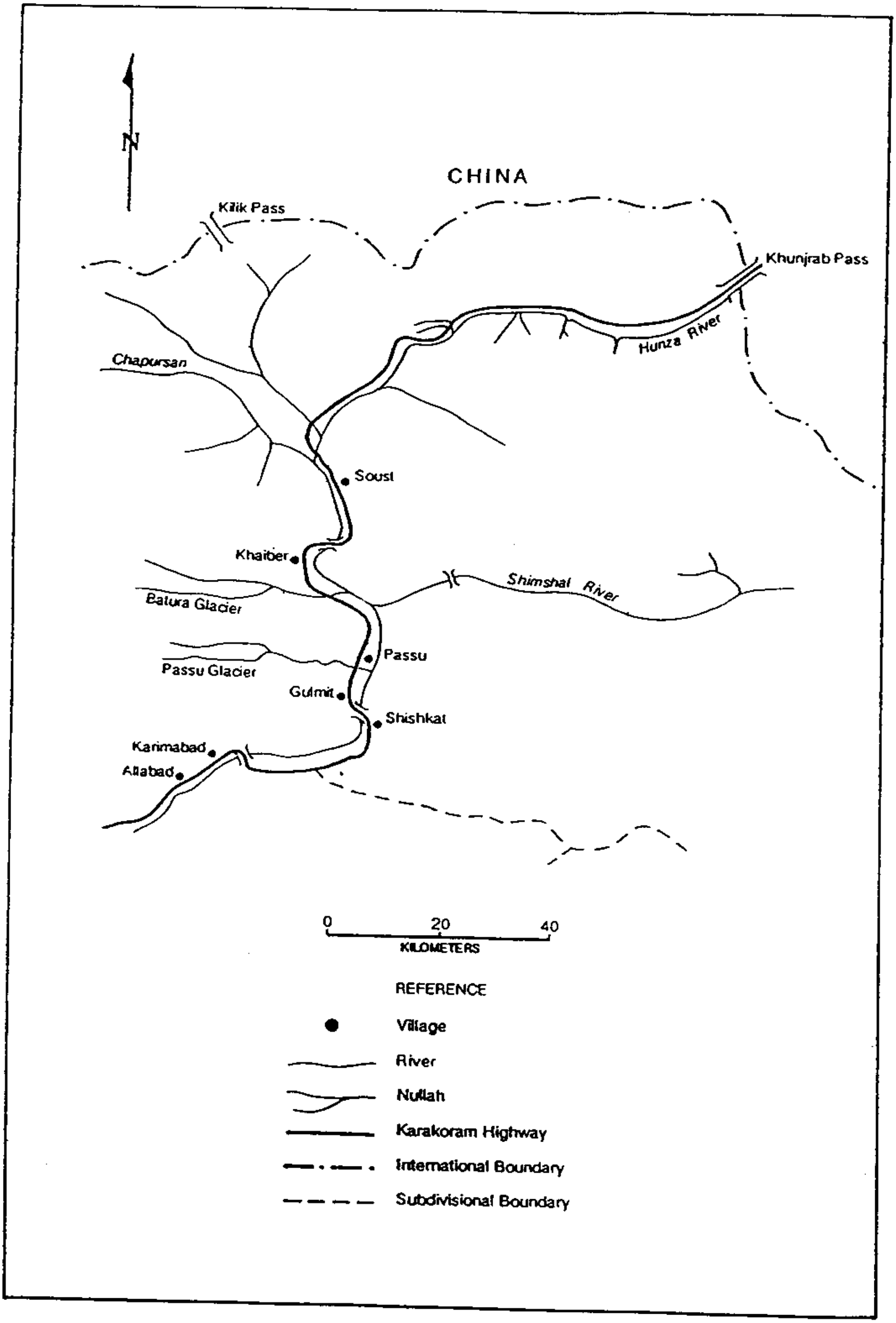
In most of the villages of Gojal, plowing is done by tractors, except on inaccessible steep and terraced fields where it is done by the traditional plow, pulled by a bullock. These plows penetrate no deeper than 15 cm and do not turn the soil over, and therefore, farm-yard manure applied is not buried properly. In one of the sample areas, the new Khaiber area (Figure 4.1), cultivation is done by hand tools, since the suspension bridge cannot be crossed by bullocks or tractors.

Availability of Labor

Shortage of farm labor is one of the major factors affecting crop husbandry in both old and newly developed areas of Gojal. The majority of the young men are working outside the area. The growing season coincides with the tourist season, and in the more "touristic" villages (e.g., Passu) young farmers work as porters or guides and some run their own inns and hotels. To relate the labor shortage to the tourist industry may not be valid for the whole of Hunza-Gojal, but summer is also the season for building houses and repairing animal sheds and houses. Some people accompany livestock to the summer pastures.

Often, women irrigate the fields but they have to do so between household chores and while attending to the needs of their children. Moreover, the tasks of growing vegetables and collecting firewood also fall to the women. It is hardly surprising, therefore, that irrigation in the older areas near the villages is often done with a minimum of physical attendance in the fields. This is not the case in the newly developed areas, which are far away from the villages and where irrigation is not so easily interrupted by other activities.

Figure 4.1. Map of Hunza-Gojal, Gilgit District.



Sample Irrigation Systems

Six irrigation channels were selected in Hunza-Gojal for a detailed study of operation and maintenance. Three of these are old channels and three are newly constructed with AKRSP support. The selected systems are located in the villages of Passu, Khaiber, and Soust (Figure 4.1). Each of these villages has an old and a new irrigation system.

In general, three types of channels can be distinguished in each system: the approach channel, supply channel, and the distribution channels. The first two, approach and supply channels, constitute the conveyance part of the irrigation system but not all systems have both types of channels. The approach channel is defined as that part of the channel which lies between the intake and the last regulator or escape structure through which water can be made to escape back to the mountain stream *(nullah)* from which the water has been diverted. The supply channel has no escapes and conveys the water from the approach channel to the network of distribution channels. Data on lengths and slopes of the different sections of the systems are listed in Table 4.1.

Table 4.1. Systems characteristics.

	Old systems			New systems		
	Passu	Khaiber	Soust	Passu	Haiber	Soust
Irrigated area (ha)	14.5	18	16	14	12	17.5
Maximum Q, (1/sec)	85	145	170	170	115	85
Approach channel:						
length (m)	600	300	120		800	
Slope	0.014	0.025			0.004	
Supply channel:						
length (m)		250	90	3900	2100	950
slope		0.014	0.01	0.002	0.004	0.001
Distribution channel:						
length (m)	4600	1200	650	2600	650	1800
slope	0.004	0.053	0.06	0.011	0.001	0.009-0.030

In all sample systems, the intake structure consists of some type of diverting wall built in the nullah from readily available stone and rock (or in the case of the new system in Khaiber, built in the Hunza River itself). Sometimes there are two diverting walls and two intakes, one each for low and high discharges in the mountain stream. It is usually necessary to rebuild the structure each spring, as it is washed away during high floods each year. Flow regulation takes place by moving rocks in the nullah near the intake and/or by regulation of the escapes along the approach channel.

The bed material of the approach and supply channels consists of rock and stones in the old systems, and of silt in the new systems. The silt has been deposited in a relatively short time due to the much smaller slopes of the channels in the new systems (Table 4.1).

Water shortages exist in both systems in Soust during early spring, and also later in the season depending on the weather. The channels in Soust take water from a nullah that is fed by snow melt. The rate of snow melt is highly affected by temperature and cloud cover. This has necessitated the introduction of a rotation between two channels that obtain their water from the same nullah, one feeding the old system in Soust and the other the old system in Nazimabad, on the left bank of the nullah. The new system in Soust is initially excluded from the rotation because farmers prefer to start with their fields near the village (Old Soust); farming begins later in New Soust. However, once fields have been prepared there, the new channel receives water continuously. Rotations between fields take place throughout the season in both New and Old Soust and also during early spring in Old Khaiber.

A night reservoir is operated in the old system in Soust, but only during April and May. Up to six farmers can be supplied with water stored during the previous night; it has a capacity of about 340 cu.m.

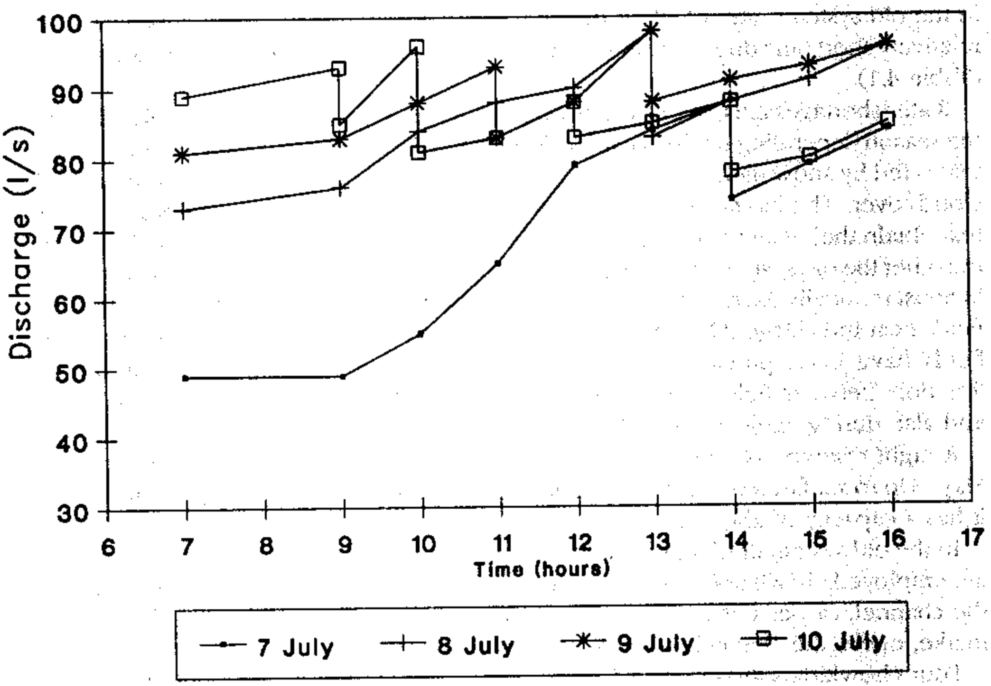
In the old system in Khaiber and the new system in Passu, *chowkidars* (watchmen) are employed. In Khaiber the chowkidar is appointed by a sub-village and he patrols the channel, carries out repairs, cleans the desiltation tank, regulates the flow at the intake, opens the channel at 4 a.m. and closes it at 5 p.m.

Four chowkidars are employed in the New Passu system. They regulate the flow at the intake and patrol the channel four or five times a day. The effect of regulation can be seen in Figure 4.2, where the discharge at the intake of the channel of New Passu during the day has been plotted for a number of sunny days in July. Only by regulation can the flow be maintained at a near steady and safe level throughout the day, paying due consideration to the stability of the channel embankments. Other tasks of the chowkidars include the irrigation of forested areas, usually at night, and some maintenance.

In addition to irrigation, the water in the old systems is also used for domestic purposes and sometimes for the running of flour mills. Another important use of irrigation water in the new systems at Khaiber and Soust is in soil formation by ponding the water and depositing the silt load in shallow recessions.

The old channels are quite stable, in spite of their steep slopes, and require little maintenance. Numerous rocks and boulders act as natural drop structures. Maintenance of the distribution system is left to the individual farmer.

Figure 4.2. Flow regulation at the intake of the new channel at Passu.



Collective maintenance usually takes place in the new systems once a year, at the start of the season. It includes desiltation of the channels and is arranged by the village organization, set up by AKRSP, which also organizes emergency maintenance when required. All farmers are expected to participate or compensate in kind or pay a fine.

METHODOLOGY

Conveyance Losses

Conveyance efficiency has been defined as the flow delivered at a point downstream as a percentage of the flow at an upstream location. Operational losses should not occur between the two measuring points and the observed decrease in discharge between the two points can then be ascribed to percolation and seepage losses.

In the systems studied, it was not always possible to decide whether or not losses due to overtopping and leakage were intentional (sanctioned or tolerated), as the water would often serve some purpose in the irrigation of trees or grasses. The terminology as proposed by Bos and Nugteren (1974) for the determination of efficiencies in different sections of irrigation systems therefore cannot strictly be applied to the systems in Hunza.

To account for small outflows occurring in the section over which the conveyance losses are to be determined, conveyance efficiency has been calculated according to:

$$E_c = \frac{Q_2 + \left[\frac{d_1}{d_1 + d_2}\right] Q_{out}}{Q_1 - \left[\frac{d_2}{d_1 + d_2}\right] Q_{out}} .100 \qquad (1)$$

where Ec is the efficiency in percent, Q_1 the measured discharge at the upstream location, Q_2 the measured discharge at the downstream location, Q_{out} the measured or estimated (small) outflow between the measuring points, d_1 and d_2 the distances to point 1 and point 2, respectively. A similar approach could be followed for a small accidental inflow within the measuring reach.

The distance between the measuring points was made as long as possible to improve the reliability of the observed difference between the two measured discharges and to obtain a representative figure.

No conveyance losses were determined in the approach channels, as losses occurring in these sections are part of flow regulation. For Old Passu, no conveyance efficiency could be calculated, as there is no supply channel (Table 4.1).

Distribution efficiency was calculated using an equation similar to (1), taking measuring points in the distribution channels. All flow measurements were carried out by the velocity-area method, in which the velocity was determined with a small current meter. It can be assumed that seepage losses[21] from conveyance channels are linearly related to discharge, according to the following relationship:

$$q = k.Q \qquad (2)$$

where Q is equal to the discharge in the channel, q the rate of change of Q with distance along the channel (-dQ/dx) and k is a seepage factor. This assumption is at best an approximation, as has been shown by Wachyan and Rushton (1987), but it permits easy comparison of losses between different channels through comparison of their k-values.

The coefficient k can be calculated by integrating (2) between the limits of Q1 and Q2, which are measured at the two ends of the reach, a distance X apart, as follows:

$$k = - (1/X).(\ln Q2/Q1) \qquad (3)$$

Conveyance losses per unit length of channel per unit cross section are found by dividing the product of k and Q by a characteristic value of the wetted perimeter. Changing the time units from seconds, as in the values of Q, to days gives the losses

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[21] This, of course, is not true for "intentional" losses such as overtopping.

in units of m per day as is commonly done (e.g., see Lauritzen and Terrell,1967), thereby inferring that the losses are a function of the wetted perimeter of the canal.

Application Losses

Application efficiency is a sensitive measure of the degree to which water that has been applied to the field becomes beneficial to crop growth by being stored in the rootzone for uptake by plant roots. Application efficiency can be expressed as the ratio of the amount of water stored in the rootzone and the amount applied to the field:

$$Ea = 100 \frac{D.(FC - PWP).(1 - PAW/100)}{V/A} \tag{4}$$

where Ea is the application efficiency in percent, D the depth of rootzone, FC is field capacity (moisture content reached presumably a few days after irrigation), PWP is permanent wilting point (moisture content in the soil when plants wilt permanently, presumably the lower limit of the storage capacity of soil for water), PAW is the percentage of actually available water in the soil, and V is the volume of water applied to a field of size A.

This concept of efficiency is based on the assumption that free drainage occurs and that whatever water is applied to the soil that cannot be stored in the rootzone, drains out of the profile. The amount of water in the rootzone cannot therefore be more than what is in agreement with field capacity for any length of time, and whatever is stored is available for evapotranspiration. This concept has been severely criticized in recent years (e.g., Hanks and Ashcroft 1980) but is still useful as a basis for efficiency determinations at field level.

An alternative definition of application efficiency relates the depth of water applied to the field with the amount of water used by evapotranspiration during the irrigation interval, as follows:

$$Ea = 100 \frac{Epot.Fc.Fgc.Fae.I}{V/A} \tag{5}$$

where Epot is the potential evapotranspiration, Fc is a crop coefficient depending on type of crop and period within the growing season, Fgc is a coefficient that depends on ground cover (especially important with crops that do not provide a complete ground cover, e.g., potatoes and tree crops) Fae is a coefficient which expresses the effect of advective energy not accounted for in the Epot term, I is the irrigation interval, and V and A are volume and area as defined before.

In this study, both approaches (equations 4 and 5) have been followed. Sample fields with wheat, barley and potatoes were selected, as far as possible, in the head, middle and tail reaches of distribution channels in the irrigation systems studied. In New Khaiber, agricultural production has hardly started yet, so sample fields with these three crops could not be found for all systems.

Depth of soil profile was determined by augering. Soil samples were analyzed in the laboratories of the Soil Fertility Survey and Soil Testing Institute and the Centre of Excellence of Research in Water Resources, both at Lahore. From these analyses an (incomplete) characterization of the soils was obtained, which allowed an estimate of the values of FC and PWP to be made. Moisture contents in the soil profile were assessed by the USDA field method, in which the interval of 25 percent available moisture were divided into two intervals of 12.5 percent.

The depth of the rootzone was determined by removing a few wheat or barley plants, or by opening up a ridge in case of potatoes. A reasonable estimate of the effective root depth could thus be made, and the values obtained were checked against values reported in the literature (FAO Irrigation and Drainage Papers 24, 33 and 36).

The discharge in field channels was usually measured with a RBC-flume (with a capacity of 8.8 l/s) and in some cases by floats. Frequent measurements were required when the discharge in the distribution channel varied during the course of an irrigation that was being monitored.

Infiltration opportunity times, i.e., the time lapse between initial wetting and the disappearance of water from the surface, were measured at sites marked with stakes in the field or in segments of zig-zag furrows in the case of potatoes. In mature grain fields, where it was impossible to place the stakes, infiltration opportunity times were recorded for patches in the field which could be identified by different means.

The degree of leveling of the field was recorded on a scale from 1 to 5. The irrigator's presence was similarly recorded, as was his or her intervention in the process of irrigation. Irrigation intervals were ascertained from farmer interviews and field observations.

Potential evapotranspiration rates were derived from (limited) values in the literature (Butz and Hewitt, 1985), combined with values from evaporation pans placed at New Passu and Old Soust to which a conversion factor was applied. Values of the crop coefficient, the ground cover coefficient and the advective energy factor were estimated from literature sources (FAO Handbooks referred to above) and through "common sense."

The method of propagation of errors has been used to try to determine which of the two approaches for calculating the application efficiency is likely to be more reliable under the circumstances of the field work in Hunza-Gojal. However, the available data are insufficient for a rigorous statistical analysis that would have provided a sound basis for choice.

It was concluded that both methods have their merits, depending on the circumstances. For example, early in the season the efficiencies obtained from equation (4) may be more reliable than those from (5).

FINDINGS

The number of irrigations and the total amount of irrigation water applied during the measuring period are listed in Table 4.2 for wheat, barley and potatoes. The average soil depth is presented in the same table. Soils are shallow, and many small irrigations are given. The average number of irrigations is the same for grains and potatoes, but the average amount applied per irrigation turn is significantly less for the potato fields. There are no significant differences, in number of irrigations and amounts applied, between old and new schemes.

Values of the seepage factor k and of conveyance efficiencies for supply and distribution channels are listed in Table 4.3. Variability amongst the measurements is high, probably resulting from the difficulty of measuring flow velocities in fast flowing channels with a current meter. Statistically, therefore, only the low value of k for conveyance losses in the New Passu channel differs significantly from the other values. Losses in distribution channels exceed those in supply channels.

Table 4.2. Average values of irrigation parameters.

		Wheat and Barley			Potatoes		
	Soil depth (cm)	Number of turns	Depth applied (cm)	Total application (cm)	Number of turns	Depth applied (cm)	Total application (cm)
Old							
Passu	48	14	5.8	81	13	2.5	33
Khaiber	25	16	6.1	98	12	3.3	40
Soust	61	14	7.1	99	14	2.3	32
Average	45	15	6.3	95	13	2.7	35
New							
Passu	10	19	4.6	87	24	1.8	43
Khaiber	23						
Soust	18	16	4.3	69	15	5.1	77
Average	17	18	4.5	81	20	3.1	62
Average of all	31	16	5.5	88	16	2.9	46

In Table 4.4, the average values of application efficiencies and other parameters are listed for wheat and barley fields. The Epaw values refer to efficiency values calculated from the amounts of water stored in the rootzone (equation 4) and Ecu values were calculated from evapotranspiration data (equation 5). These two sets of data differ by an order of magnitude. The nonuniformity values are equal to the relative standard deviations of the infiltration opportunity times (i.e., their standard deviation divided by the mean value).

Differences between the mean values for old and new systems are significant for the length of the fields, flow at field inlets, degree of farmer intervention and available water in the rootzone at the time of irrigation.

A similar set of data is also included in Table 4.4 for potato fields. Here, the mean values for old and new systems do not differ significantly.

Table 4.3. Seepage factor, k of conveyance and distribution channels (mean values per system).

	Conveyance units (x 0.0001 m^{-1})	Distribution units (x 0.0001 $^{-1}$)
Old		
Passu		5.8
Khaiber	2.8	
Soust		5.8
New		
Passu	0.4	1.7
Khaiber	0.9	
Soust	5.3	5.5
Mean Value	2.6	4.5

Table 4.4. Average values of application efficiencies and other parameters.

	Wheat and Barley			Potatoes		
	Old	New	All	Old	New	All
Epaw (%)	7	15	11	12	8	10
Ecu (%)	54	71	63	54	45	50
Non-uniformity	44	44	44	43	46	44
Length (m)	25	14	20	34	61	44
Flow (1/sec)	7.5	4.2	5.7	2.5	3.3	2.8
Farmer intervention	2.5	3.6	3.1	3.6	2.4	3.1
PAW at irrigation (%)	70	38	54	51	47	50

Notes: Ecu is application efficiency from (5)
Length is length of field or furrow
Flow is flow at field inlet
PAW is percent available water in rootzone at time of irrigation

DISCUSSION

The amount of water applied to potato fields (average value of 46 cm during the measuring period, Table 4.2) seems low compared with an expected seasonal crop water requirement of some 50 cm. Potatoes were planted around the middle of May and harvest was expected to take place around 15 September. At the end of the measuring period, 1 August, some five more weeks of irrigation were to follow, which means an additional 30 cm of irrigation, given an average irrigation interval of 4 days (the most common value) and an average application of 2.9 cm. Nevertheless, 76 cm seasonal application and average application efficiency for potato fields of 54 percent (Ecu value in Table 4.4), give a consumptive use of only 41 cm.

No such discrepancy exists with the wheat and barley data. The grains were sown earlier and were closer to harvest at the end of the measuring period. Moreover, an average of 88 cm of water had already been applied. With an expected seasonal irrigation requirement of about 55 cm, and application efficiency of 63 percent (Ecu value in Table 4.4), the seasonal requirement had been already applied.

From these comments it is also apparent that the Ecu values are more likely to be of the correct order of magnitude than are the Epaw values in Table 4.4. It has been observed in the field that the soil profiles are shallow (Table 4.2) and the rootzone is often underlain by an impermeable layer of rocks and pebbles. Under these circumstances, the assumptions inherent in the derivation of equation 4 do not apply: free drainage from the rootzone is obstructed, and water applied to the soil in excess of field capacity remains available for uptake by roots during the irrigation interval. Application efficiencies that have been calculated assuming that water is only available between field capacity and permanent wilting point clearly underestimate the real uptake of water by plant roots.

Differences in irrigation practice between old and new systems are significant in wheat and barley fields, but not in potato fields. The lengths of the fields, the flow at field inlets and the amount of water present in the soil profile at time of irrigation were all lower for grain fields in the new systems than in the old systems. One would expect that these factors combined with a higher degree of farmer intervention, would lead to higher values of application efficiencies in the new systems. The average values of both efficiency parameters clearly show this difference, but because of the high standard deviations of the efficiency values, these differences are not statistically significant.

The dependence of application efficiency (Ecu) on the other parameters listed in Table 4.4, has been investigated.

Figure 4.3 shows the relation between efficiency and the flow at field inlet for potato fields. Efficiency clearly decreases with an increase in discharge available to the farmer at his field inlet. It should be noted that the largest flow is only 5.6 l/s. The correlation between the two parameters of Figure 4.3 is significant at a 0.01 probability level. A similar decrease in efficiency with flow at the field inlet is apparent in grain fields.

In Figure 4.4, efficiency is plotted against degree of farmer intervention for all wheat and barley fields. It is interesting to observe that high efficiencies are possible regardless of the degree of farmer intervention. There appears to be an indication that farmer's intervention in irrigation has an optimum. The same tendency exists when efficiency data are plotted against farmer intervention for potato fields. For smaller sets of data, a clear improvement in efficiency may be found with an increase in farmer intervention (Figure 4.5, for potatoes in the new areas).

An increase in nonuniformity, i.e., the variability in infiltration opportunity times in the field, is expected to lead to a decrease in application efficiency. This has been observed, and it is particularly apparent when the PAW-efficiency is plotted as dependent variable, as in Figure 4.6. Low efficiencies may occur at low values of nonuniformity — obviously resulting from other effects — but high efficiency does not occur when the nonuniformity is high. This points to the importance of the leveling of fields to attain more uniform application of water.

Figure 4.3. Application efficiency (%) as function of flow at field inlet for potato fields.

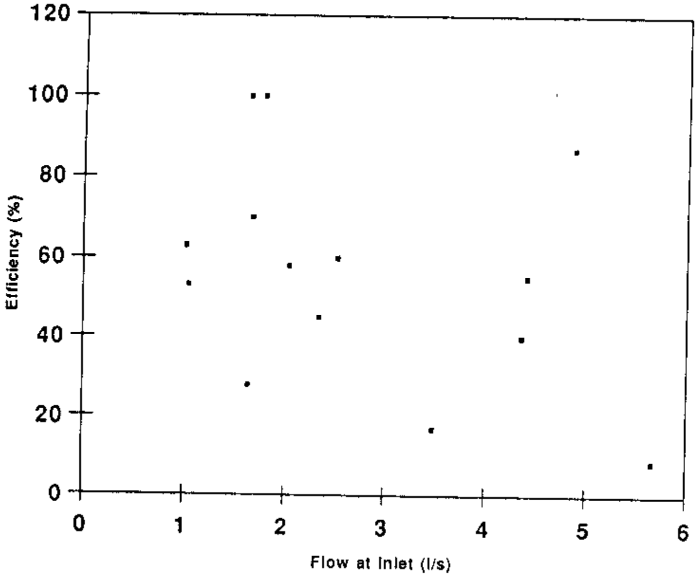


Figure 4.4. Application efficiency (%) as a function of degree of farmer intervention for all wheat and barley fields.

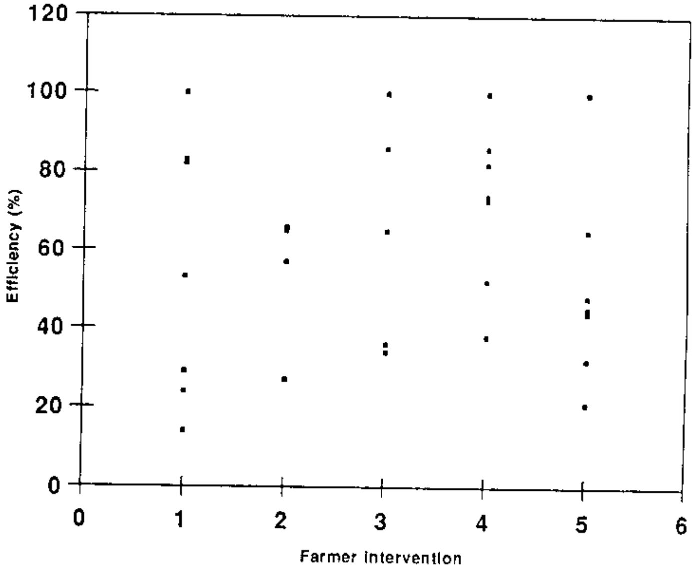


Figure 4.5. Application efficiency (%) as a function of farmer intervention for potato fields in the new systems.

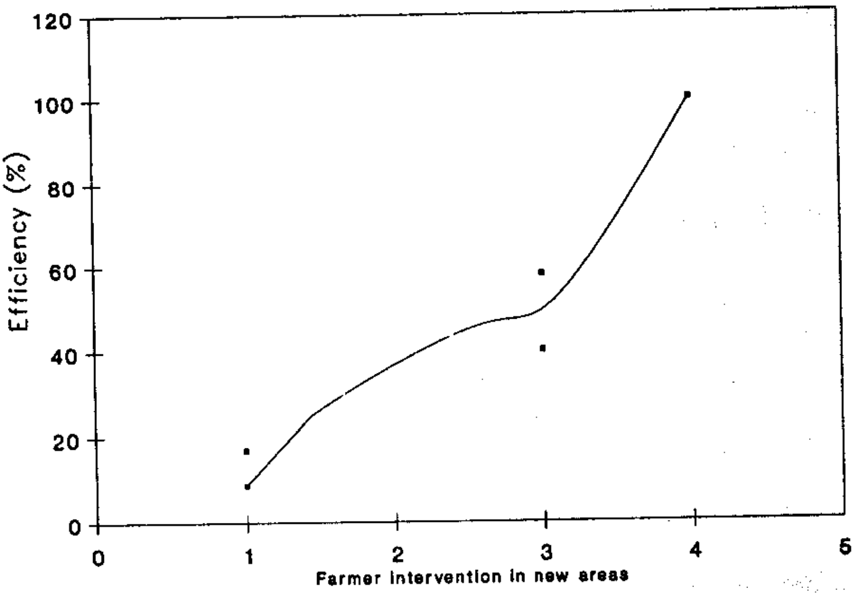
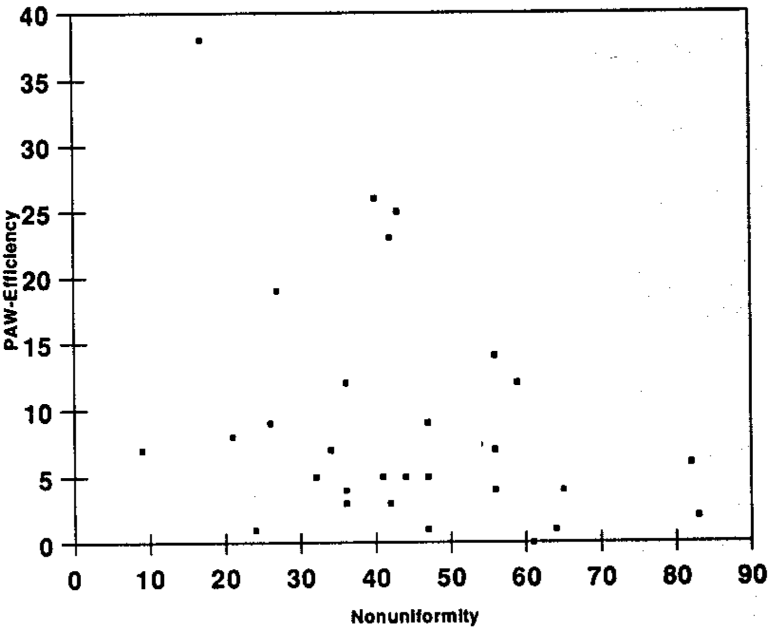


Figure 4.6. Application efficiency (%) as a function of nonuniformity for all wheat and barley fields.



Conveyance efficiencies are listed in Table 4.3. It is not meaningful to calculate distribution efficiencies for the network of distribution channels unless the total length of distribution channels flowing at any time is taken into consideration. When conveyance losses are expressed as seepage loss per unit area, a value of about 0.2 m/day is obtained for the supply channel in New Passu; the other channels have a loss of about 1 m/day. These values are in reasonable agreement with data reported in the literature. For example, Wachyan and Rushton, 1987, gave values for unlined large distributaries in southern India of about 0.2 m/day. Values of 0.45-0.6 m/day for pervious soils and of 0.75-1 m/day for gravel have been reported (Worstell 1976). Most of the conveyance channels in the sample systems traverse gravel, whereas the supply channel of New Passu is well-sealed because of silt deposits.

CONCLUSIONS AND RECOMMENDATIONS

The large variations in present application efficiencies indicate that improvements could be made. One expects that a more precise control of water at the field inlet, better leveling of the fields, and appropriate intervention by the irrigator during the process of irrigation would lead to improved efficiencies at field level. The data indicate that field losses are less in the new areas than in the old ones, pointing to the importance of the farmer's presence during irrigation and his or her intervention in it.

It is tempting to suggest that less frequent irrigation with larger applications would improve field application efficiency *and* reduce the labor requirement. However, before making that suggestion, one needs to be sure that it can be implemented on the shallow soils of Hunza-Gojal.

Water scarcity does not affect system operation in Gojal to a large extent. Only during the first few weeks of the season are strict rotational rules implemented in some of the systems. In the new irrigation systems, however, water scarcity could occur, at some point, with further land development.

Operation and maintenance of the systems is done either by the farmers themselves on an informal basis, as in the old systems, or by chowkidars, employed specifically for that purpose. Whether chowkidars are employed depends on circumstances. In New Khaiber, where the farmers walk along the conveyance channel to get to their fields, chowkidars were no longer needed once land was subdivided into individual holdings. But in New Passu, where the supply channel is on one side of the road and the fields are on the other, chowkidars are employed to adjust flows, to patrol and inspect the supply and approach channels, and to do minor maintenance. Old systems have a lower demand for maintenance; in the new systems, maintenance of approach and supply channels is done once a year, organized by the chairman of the village organization who also arranges for emergency maintenance to be carried out when necessary.

In both new and old systems it often appears that water is being wasted, but when it is actually irrigating grasses, bushes and trees on so-called waste land it is well-spent, because it helps to provide fodder for animals and firewood for the households.

Drainage water ponded in low depressions leads to soil improvement by silt deposition.

Conveyance losses in supply and distribution channels are much as expected, given the types of soil they traverse. These losses are no larger in the new channels than in the older ones, undoubtedly because of the sealing of channel beds by silt deposition, facilitated by the relatively flat slopes of the new channels. In the New Passu channel the losses are even less than in the older channels.

It was found that it took more time than was anticipated to supervise an activity of this nature in such a remote area as the Northern Areas of Pakistan. First, because of frequent cancellations of flights between Islamabad and Gilgit on account of adverse weather conditions, all but one of the trips to Hunza-Gojal had to be made by road. The trip between Islamabad and Gulmit, where the field staff had its quarters, took between 16 and 25 hours each way, depending on the road conditions. Second, the field team required considerable supervision because team members were unfamiliar with the environmental conditions of Hunza-Gojal in general, and of the irrigation systems in particular.

The obvious lesson in this is that travel time and supervisory time should be budgeted realistically for projects carried out far from IIMI-Pakistan's headquarters in Lahore.

RELEVANCE FOR IIMI AND NEXT STEPS

Among the several research themes emphasized in IIMI's current strategy is the management of irrigation support services to farmers focusing on the special problems of improving agency effectiveness in delivering assistance to farmer-managed irrigation systems, in order to enhance both the productivity and sustainability of these systems.

Most immediately, it is possible to communicate some of the foregoing recommendations (e.g., improved field leveling to increase irrigation application efficiency, optimal length of furrows for irrigating potatoes) to existing agricultural extension services in Gilgit District. Less certain is the degree to which these recommendations would be further disseminated to farmers in ways that would lead to their adoption.

Clearly, the research on FMIS in Hunza-Gojal has yet to determine all the causative factors that influence the overall performance of small-scale irrigation systems in northern Pakistan. However, significant progress has been made in defining a range of physical performance parameters. A deeper analysis of the data presented here, in conjunction with research findings on FMIS in analogous environments elsewhere and including the social dimension, may permit the synthesis of a general conception of irrigation management in harsh mountain regions which could yield "first approximation" answers to that important issue.

The results of such an integrated effort should be disseminated to AKRSP, which has developed a successful intervention strategy for assisting FMIS development and improvement (e.g., Maliha Hussein, et al. 1989), as part of a larger institutional development program seeking to achieve a more self-sustaining and productive rural economy in northern Pakistan. The capacity of AKRSP and constituent village organizations to apply those results could be enhanced by further training of local engineers and social organizers to conduct comparative, diagnostic and monitoring studies of FMIS performance. The participation of two AKRSP engineers throughout the field phase of this project was a modest first step in that direction.

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