IIMI Pakistan

Final Report

IRRIGATION SYSTEM PERFORMANCE

HUNZA - GOJAL

INTERNATIONAL IRRIGATION MANAGEMENT INSTITUTE
PAKISTAN

International Irrigation Management Institute (Pakistan)

Irrigation System Performance in
Farmer - Managed Irrigation Systems
in Hunza - Gojal

Final Report Submitted to Aga Khan Foundation

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EXECUTIVE SUMMARY

At the request of the Aga Khan Rural Support Programme, IIMI-Pakistan carried out a six month comparative study of six farmer-managed irrigation systems in the Gojal region of Hunza, Gilgit District, Northern Areas. The overall objective of the study was to determine actual performance Parameters of' newly established irrigation systems, which had been developed with AKRSP assistance. In each of three Oojal villages, one AKRSP-assisted system was paired with an older, well established farmer-managed system. Field observations and measurements for each system were done over a five month period from April 1989. This report reviews the principal findings of the study.

The report describes the physical environment of Hunza-Gojal, and its dominant agriculture, i.e. production of spring-sown annual crops, including wheat, barley, potatoes and pulses and the production of firewood and fodder for livestock, mainly on irrigated waste lands. The agricultural soils in the area have shallow profiles and soil formation is due in large part to the deposition of silt carried hy the irrigation water. The inherent variability in soil depth has been enhanced by the formation of horizontal terraces on naturally sloping terrain. Shortage of farm labour is .one of the major factors affecting crop husbandry in both old and newly developed areas of Gojal.

Three types of irrigation channels are distinguished in each of the sample systems: the approach and the supply channels, constituting the conveyance part of the irrigation system, and the distribution channels. One of the systems contains a night reservoir, and in two systems chowkidars are employed for flow regulation and small repairs. The characteristic features of system operation and collective maintenance are analyzed. Conveyance losses in typical channel sections and application losses in sample grain and potato fields have been determined; the data were analyzed in terms of efficiencies. Large variations in application efficiencies were observed, which would indicate that improvements could be made. A more precise control of water at the field inlet, better levelling of the fields and appropriate intervention by the irrigator during the process of irrigation would lead to improved efficiencies at field level. Field data reveal the importance of farmer's presence during irrigation and his or her intervention in it. Less frequent irrigation with larger applications could improve field application efficiency and reduce labour requirement. However, it is realized that on shallow soils implementation of this suggestion would not be possible.

Water scarcity does not affect system operation in Gojal to a large extent. In the new irrigation systems, however, water scarcity could occur at some point with further development.

Conveyance losses occurring in supply and distribution channels are about what could be expected in these channels considering the type of soils they traverse. The losses are no larger in the new channels than in the older ones, which results from sealing of channels beds by silt deposition.

A COMPARATIVE STUDY OF FARMER-MANAGED IRRIGATION SYSTEMS IN NORTHERN PAKISTAN.

1 INTRODUCTION

In 1988. 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 adapting methods to minimize water losses and system maintenance requirements. Subsequently, IIMI Pakistan was asked by AKRSP to carry out research on these issues, the overall objective of which was to determine 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 report reviews the principal findings of the study, a preliminary report of which was submitted to AKF, Pakistan on 1 September, 1989.

2 OBJECTIVES AND DESIGN

The primary objective of the study 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 **heretofore** were virtually absent in the country. Thus this research sought to begin closing a significant knowledge gap on irrigation system performance that collectively commands as much as 400,000 hectares of the national irrigation environment.

Not incidently, **IIMI** was also interested in initiating studies of FMIS in Pakistan to expand the geographical domain of its management research activities that focus 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 a comparative analysis of similar systems elsewhere in the trans-Himalaya region, and could result 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 methodologiss to measure **the** actual physical performance of small-scale irrigation systems in mountain environment [illegible]

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) those systems long established which, therefore, could be assumed to be essentially stable or mature, and (2) those systems newly constructed or expanded in the past 5 years or so with AKRSP assistance which were in the process of stabilizing. Only through a comparative analysis of a sample of paired systems from each category was it likely to be possible to effectively examine the key issues of AKRSP's concern--opportunities to enhance water distribution efficiencies, water loss minimization, improved system maintenance processes--in newly established or improved FMIS.

Limited resources and time. however, restricted the research locale to a single, relatively accessible area of Gilgit District. Thus, following a rapid field reconnaissance in Hunza-Gojal, six small-scale irrigation systems were selected for study. In each of three Gojal villages, one AK SP-assisted system was paired with an older, well-established FMIS? After field surveying and sketch mapping, from headworks through the layout of the commanded area, systematic observation and measurement of irrigation operations--water conveyance, distribution and field application--and maintenance activities were conducted in each of the six systems. Data thereby obtained is the primary basis for the research results reported in this discussion.

Finally, it should be noted that although the focus of this research was narrowly on efficiency irrigation issues. it is both understood and acknowledged that FMIS frequently have multiple objectives. Hence their logic may or may not emphasize the efficient use of water as defined in more strict engineering terms. Thus, an evaluation of their operational performance solely by such strict criteria well may 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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[1]. Field observations end measurements for each system were done over a 5 month period by a team comprised of 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.

3 PROJECT AREA

A Physical Environment

The Karakoram region of northern Pakistan falls in a partial rain shadow and does not receive the monsoon rains. Summer storms may occasionally visit the area, but in general the area is arid (annual rainfall of about 125 mm) and agriculture depends on irrigation. This is distinctly different from much of Nepal Himalaya where FMIS have been studied in areas which receive heavy monsoon rains (UP to 2000 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 up to 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. with 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 also highly variable and differ on cloudy and clear days during the growing season. Low humidity and intense solar radiation are augmented by strong winds, causing a desiccating environment for crop production. Reliable data on potential evapotranspiration are few (e.g. see Butz and Hewitt, 1985). Evidence of wind erosion is readily seen and removal of seeds by wind has been reported in the area.

B Agriculture

The Gojal region comprises the upper portion of the Hunza River valley, beginning from about 2500 m above sea level. It is dominantly a single crop area where all annual crops are spring sown, experience a relatively short growing season and 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 used for production of firewood (e.g. Hippophae sp., Salix, and Poplar) as well as grazing and fodder for livestock, especially during the winter months.

C 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 due in large part to the deposition of silt carried by the irrigation water. Gradually the top soil is enriched with these fine materials and the water holding capacity of the top few inches of the profile improves, while leaving the subsoil unchanged. Some scree have well graded young soils which are cultivated if the slope permits, for growing alfalfa and forage trees.

The agricultural soils are characterized by shallow profiles (maximum of 0.6 m), low water holding capacity (at most 12 %vol.), which often is reduced even more because of the presence of rocks and boulders buried in the soil, low inherent fertility and by alkalinity (pH in excess of 7.8). Again a difference with Nepal can be noticed where the soils of the study areas contained mainly clay and silt and were found on well drained, deep river terraces.

Most characteristic of the soils, however, is the large degree of spatial variability, among others due 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 - due to the farmer walking through his fields with the 'pai' (farming tool used to direct the flow of water over the field) and during weeding and thinning.

Plowing is done in most of the villages of Gojal by tractors, except on steep and terraced fields which are inaccessible to tractors. There plowing is done by the traditional plow, pulled by a bullock. These plows don't penetrate deeper than 15 cm and do not turn the soil over and therefore applied farm-yard manure is not buried properly. In one of the sample areas, the new Khaiber area (see the map in Figure 1), cultivation is done by hand tools, because the suspension bridge cannot be crossed by bullocks or tractors.

D Availability of Labour

Shortage of farm labour 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 labour shortage with 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 the animals to the summer pastures.

Women often irrigate the fields, but they have to do it between the household chores and while attending to the needs of their children. Moreover, the growing of vegetables and the collection of firewood are also duties of the women. No wonder 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.

E 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 newly constructed with AKRSP support. The selected systems are located in the villages of Passu, Khaiber, and Soust (see Figure 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, the supply channel and the distribution channels. The first two, approach and supply channel, constitute the conveyance part of the irrigation system, but not in all systems both types of channels are present. 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 escaped back to the mountain stream (nullah) from which the water is 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 1.

In all sample systems the intake structure consists of some type of diverting wall built in tho nullah from readily available stone and rock (or in the case of the new system in Khaiber, in the Hunza River itself). Sometimes there are two diverting walls and two intakes, one for low and one for high discharges in the mountain stream. Usually it is necessary to rebuild the structure again each spring as it is washed away during high floods of the previous 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 of the old systems consists of rocks and stones, and of those channels in the new systems of silt. The silt has been deposited in a relatively short time due to the much smaller slopes of the channels in the new systems than in the old systems (see Table 1).

Water shortages exist in both systems in Soust during early spring of snow melt is highly affected by temperature and cloudiness. This has necessitated the introduction of a rotation between two channels that obtain their waiter 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 in New Soust later. 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 during early spring also in Old Khaiber.

A night reservoir is operated in the old system in Soust and then 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 cubic meter.

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 and opens the channel at 4 am and closes it at, 5 pm. Four chowkidars are employed in the New Passu system. They regulate the flow at the intake and patrol the channel four to five times a day. The effect of regulation can be seen in Figure 2, where for a number of sunny days in July the discharge at the intake of the channel of New Passu is plotted during the day. Only by regulation can the flow be maintained throughout the day at a near steady and safe level, considering the stability of the channel embankments. Other tasks of the chowkidars include the irrigation of forested areas, usually at night, and some maintenance.

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

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

Collective maintenance takes place in the new systems usually once a year at the start of the season. It includes desiltntion 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 by paying a fine.

4 METHODOLOGY

A Conveyance losses

Conveyance efficiency has been defined as the flow delivered at a point downstream as 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 losses due to overtopping and leakage were intentional (sanctioned or tolerated) or not 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 be applied, strictly speaking, 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 :

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

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 taken 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 1).

Distribution efficiency was calculated from a similar equation as (1) with the measuring points in the distribution channels. All can be assumed that seepage losses[1] 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 sec. as in the values of Q, to days gives the losses 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.

B Application losses

Application efficiency is a sensitive measure of the degree in 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 :

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

where Ea is the application efficiency in percent, D the depth of rootzone, FC is field capacity (moisture content presumably reached 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 actually available water in the soil, V is the volume of water applied to a field of size A.

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[1] This, of course, is not true for 'intentional' losses, e.g. overtopping.

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 can therefore not be more than is in agreement with field capacity for any length of time and whatever is stored is available for evapotranspiration. This concept has severely been criticized in recent years (e.g. see Hanks and Ashcroft, 1980) but is still useful as 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:

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

where Epot is the potential evapotranspiration, Fc is a crop coefficient depending on type of crop and period within the growing season, Fgc a coefficient which depends on ground cover, especially of importance with crops that do not provide a complete ground cover like potatoes and tree crops, Fae 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 as given by equations 4 and 5 have been followed. Sample fields with wheat, barley and potatoes were selected in as far as possible, the head, middle and tail reaches of distribution channels in the irrigation systems studied. In New Khaiber agricultural production has hardly started yet, so not for all systems sample fields with these three crops could be found.

Depth of soil profile was determined by augering. Soil samples were analyzed in the laboratory of the Soil Fertility Survey and Soil Testing Institute and of 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.

Moisture contents in the soil profile were assessed by the USDA field method, in which the intervals of 25% available moisture were divided in two of 12.5% each.

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/sec) and in some cases by floats. Frequent measurements were required when the discharge in the distribution channel varied during the course of an irrigation which was being monitored.

Infiltration opportunity times, i.e. the time elapsed 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 case of potatoes. In mature grain fields it became impossible to place the stakes and infiltration opportunity times were recorded for patches in the field which could be identified otherwise.

The degree of levelling 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 found 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 which were placed at New Passu and Old Soust to which a conversion factor had been 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 from 'common sense'.

Through the method of propagation of errors it has been attempted to decide 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, insufficient data are available for a rigorous statistical analysis of the propagation of errors which would have provided a sound basis for the choice between the two methods of calculating application efficiencies (equations 4 and 5).

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

5 FINDINGS

The number of irrigations arid the total amount of irrigation water applied during the measuring period are listed in Table 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 are listed in Table 3, for supply and distribution channels. Variability amongst the measurements is high, which probably results 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.

In Table 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 non-uniformity 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 fields inlets, degree of farmer intervention and available water in the rootzone at the time of irrigation.

A similar set of data is included in Table 4 also for potato fields. Here the mean values for old and new systems do not differ significantly.

6 DISCUSSION

The amount of water applied to potato fields (average value of 46 cm during the measuring period, Table 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 is 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 for an average irrigation interval of 4 days (the most common value) and average application of 2.9 cm, an additional 30 cm of irrigation. Nevertheless, 76 cm seasonal application and average application efficiency for potato fields of 54 % (Ecu value in Table 4), gives 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, on average 88 cm of water had been applied already. With an expected seasonal irrigation requirement of about 55 cm and application efficiency of 63 % (Ecu value in Table 4), the seasonal requirement had been applied already.

From these comments it is apparent also that the Ecu values are profiles are shallow (see data in Table 2) and often the rootzone is underlain by an impermeable layer consisting 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 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 that difference, but because of the high standard deviations of the efficiency values, these differences are statistically not significant.
The dependence of application efficiency (Ecu) on the other parameters listed in Table 4, has been investigated.

In Figure 3, the relation between efficiency and the flow at field inlet for potato fields is shown. 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/sec. The correlation between the two parameters of Figure 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.

Efficiency is plotted versus degree of farmer intervention in Figure 4 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 versus 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 5, for potatoes in the new areas).

An increase in non-uniformity, i.e. the variability in infiltration opportunity times in the field, is expected to load 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 was done in Figure 6. Low efficiencies may occur at low values of non-uniformity - obviously resulting from other effects - but high efficiency does not occur when the non-uniformity is high. This points to the importance of levelling of fields to attain more uniform application of water.

Conveyance efficiencies are listed in Table 3. It is not meaningful to calculate distribution efficiencies for the network of distribution channels, unless the total length of distribution channels that is 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 South India of about 0.2 m/day. For pervious soils values of 0.45-0.6 m/day and for gravel 0.75-1 m/day 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.

7 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 levelling of the fields, and appropriate intervention by the irrigator during the process of irrigation would lead to improved efficiencies at field level. The indication present in the data that field losses are less in the new areas than in the old ones, points to the importance of 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 labour 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 either done 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 the 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 on the other side, chowkidars are employed to adjust flows, patrol and inspect the supply and approach channels, and do minor maintenance.

Old systems have a lower demand for maintenance; in the new systems nals is done once a year, [illegible] 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 occurring in supply and distribution channels are about what could be expected in these channels considering the type of soils they traverse. These losses are no larger in the new channels than in the older ones, which undoubtedly results from sealing of channel beds by silt deposition, facilitated by relatively flat slopes of the new channels. In the New Passu channel the losses are even significantly less than in the older channels.

This study on FMIS in Hunza-Gojal does not pretend to have fully determined 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 their physical performance parameters, and some of the foregoing recommendations (e.g. improved field leveling to increase irrigation application efficiency, optimal length of furrows for irrigating potatoes) could be communicated 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.

AKRSP has developed a successful intervention strategy for assisting FMIS development and improvement (e.g. Maliha Hussein, et al., 1989) as a component In a larger institutional development program which seeks to achieve a more self-sustaining and productive rural economy in northern Pakistan. The capacity of AKRSP and constituent village organizations to apply these results also 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.

8 ACKNOWLEDGEMENT

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This final report was written by Dr. Jacob W. Kijne who wishes to thank Mr. F.E.Schulze and Dr. E.J. Vander Velde for valuable comments on earlier drafts of the report.

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TABLE 1

Systems Characteristics

	OLD SYSTEMS			NEW SYSTEMS		
	Passu	Khaiber	Soust	Passu	Khaiber	Soust
Irrigated area, ha	14.5	18	16	14	12	17.5
Maximum Q, l/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 channels						
length, m	4600	1200	650	2600	650	1800
slope	0.004	0.053	0.06	0.011	0.001	0.009-0.030

TABLE 2

Average Values of Irrigation Parameters

		Wheat and Barley			Potatoes		
	soil depth (cm)	number turns	depth applied (cm)	total appln. (cm)	number turns	depth applied (cm)	total appln. (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

TABLE 3

Seepage Factor,k, of Conveyance and Distribution Channels

	Conveyance	Distribution.
	(mean values per system;	units: x 0.0001 m^{-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

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-unif .	44	44	44	43	46	44
length,m	25	14	20	34	61	44
flow,l/sec	7.5	4.2	5.7	2.5	3.3	2.8
farmer interv.	2.5	3.6	3.1	3.6	2.4	3.1
PAW at irr.%	70	38	54	51	47	50

Epaw is application efficiency from (4)
ECU is application efficiency from (5)
Non-unif. is non-uniformity
length is length of field or furrow
flow is flow at field inlet
PAW is percent available water in rootzone
at time of irrigation

FIGURE 1. Map of Hunza-Gojal, Gilgit District.

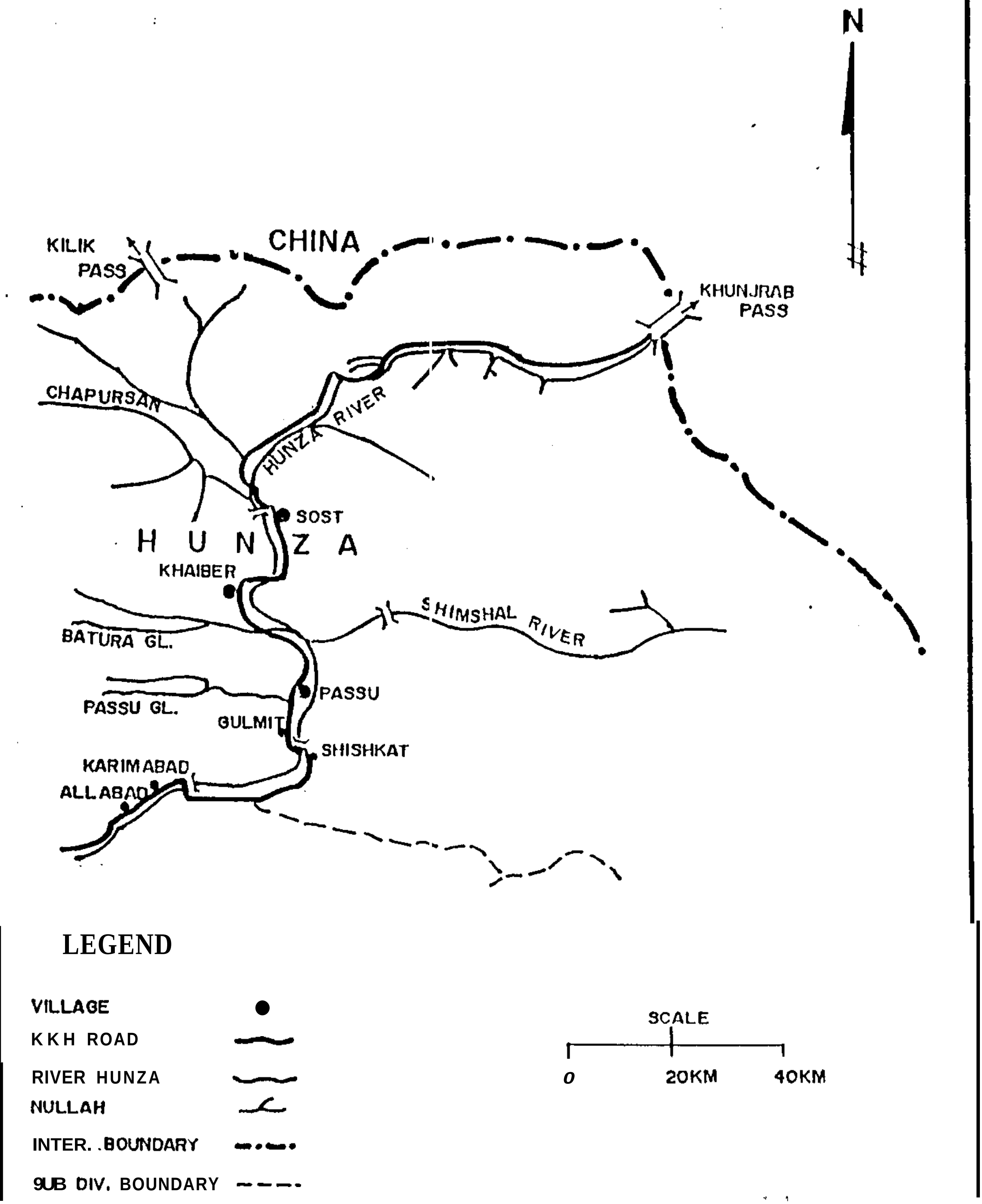

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FIG.2 FLOW REGULATION AT INTAKE OF
NEW CHANNEL **AT PASSU**

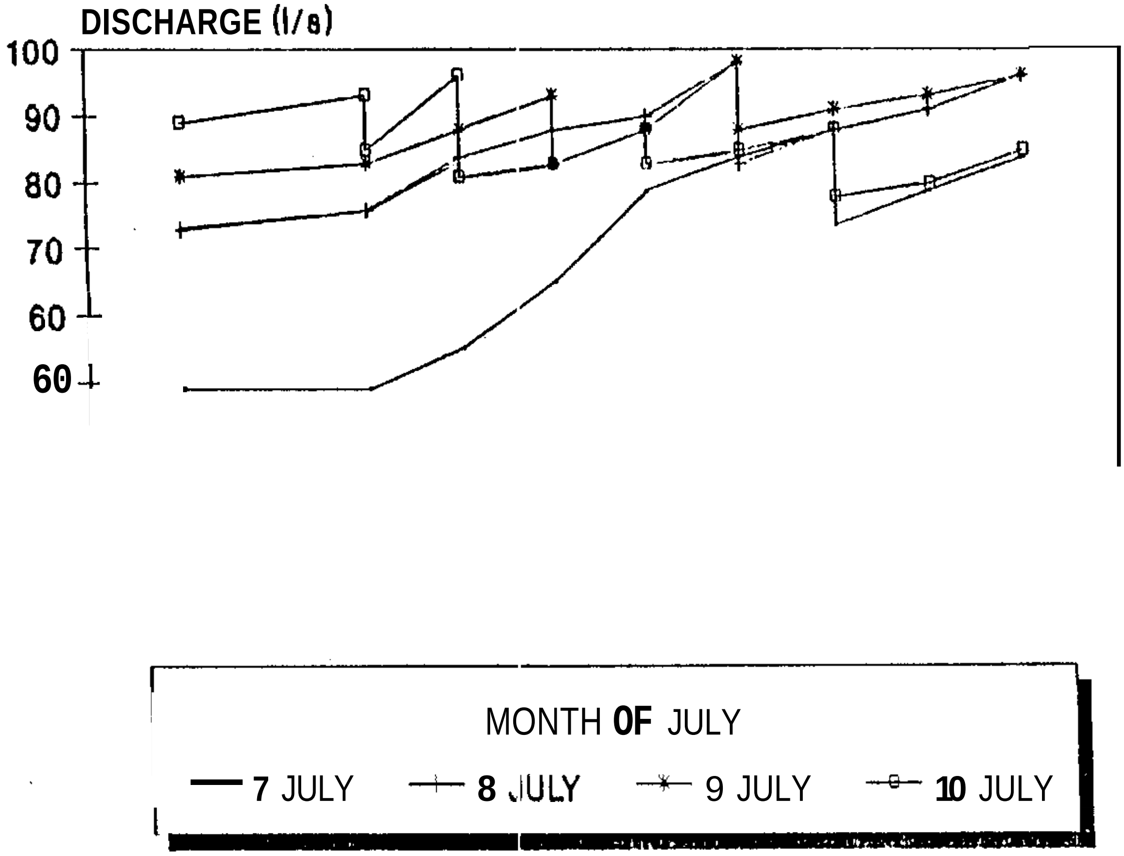


FIG.3 **APPLICATION** EFFICIENCY (%)
AS FUNCTION OF FLOW AT FIELD INLET
FOR POTATO FIELDS

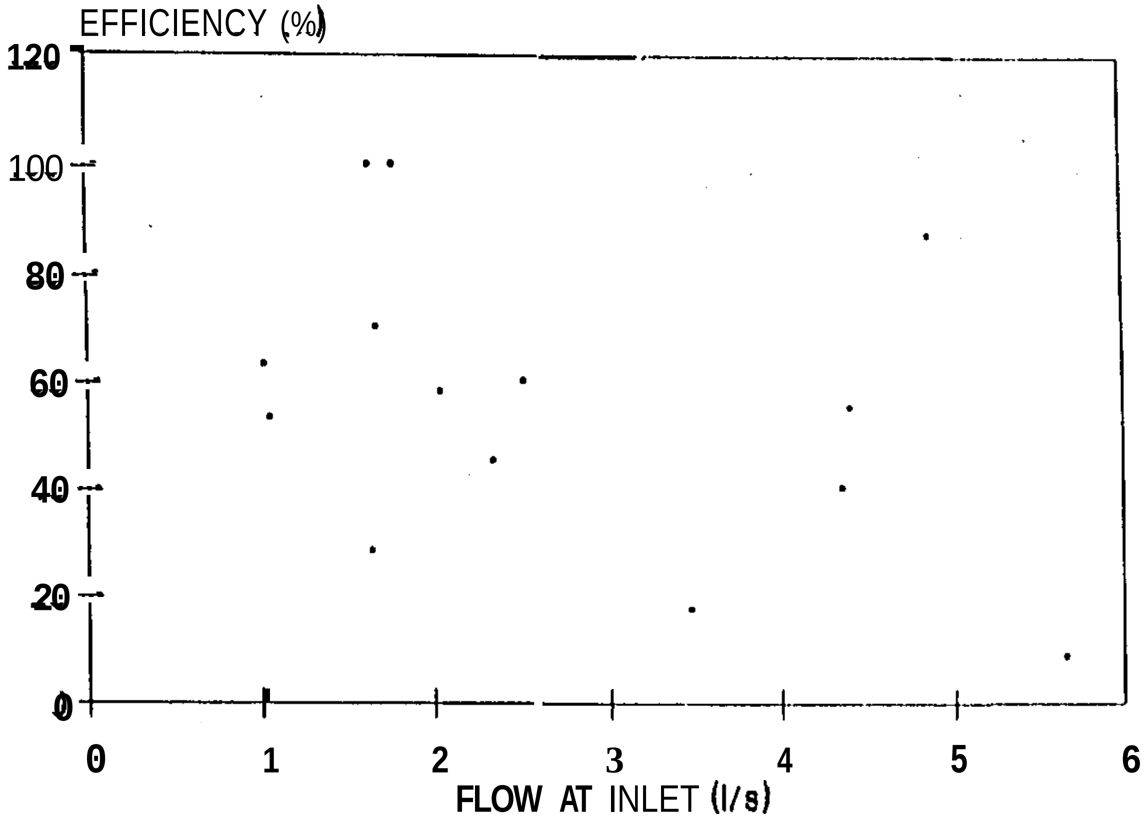
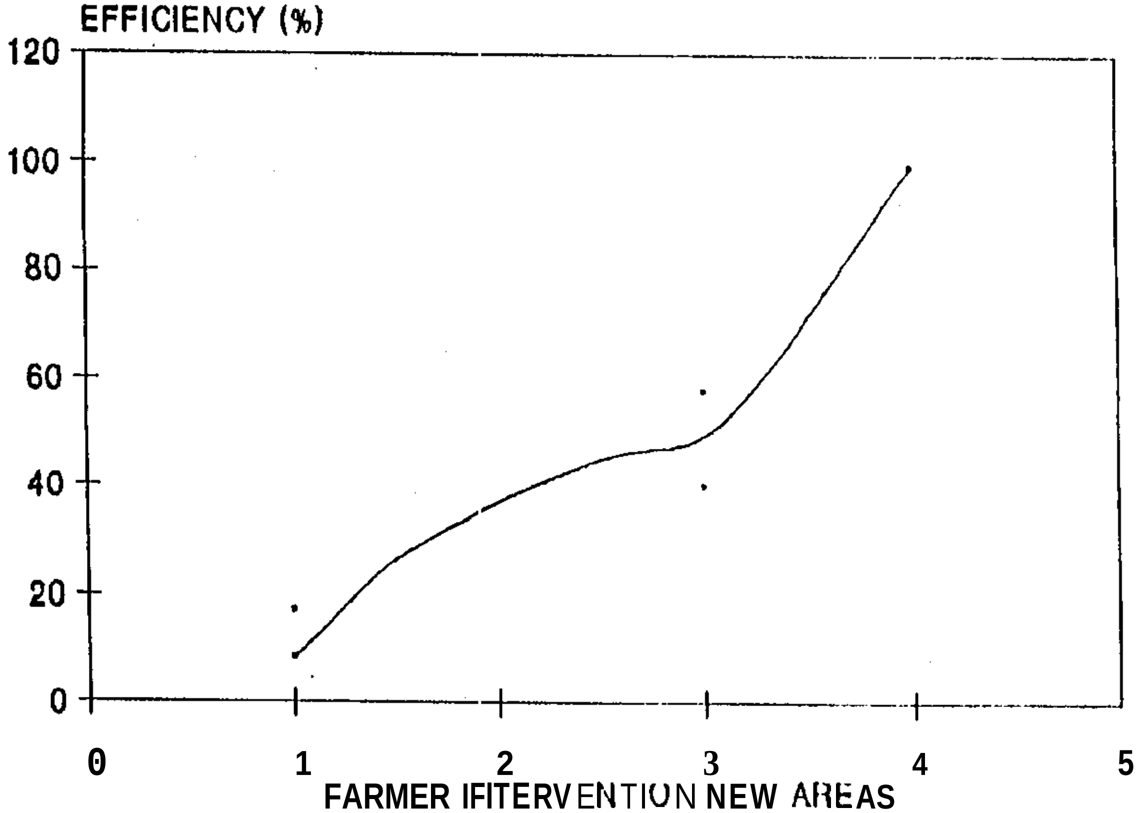
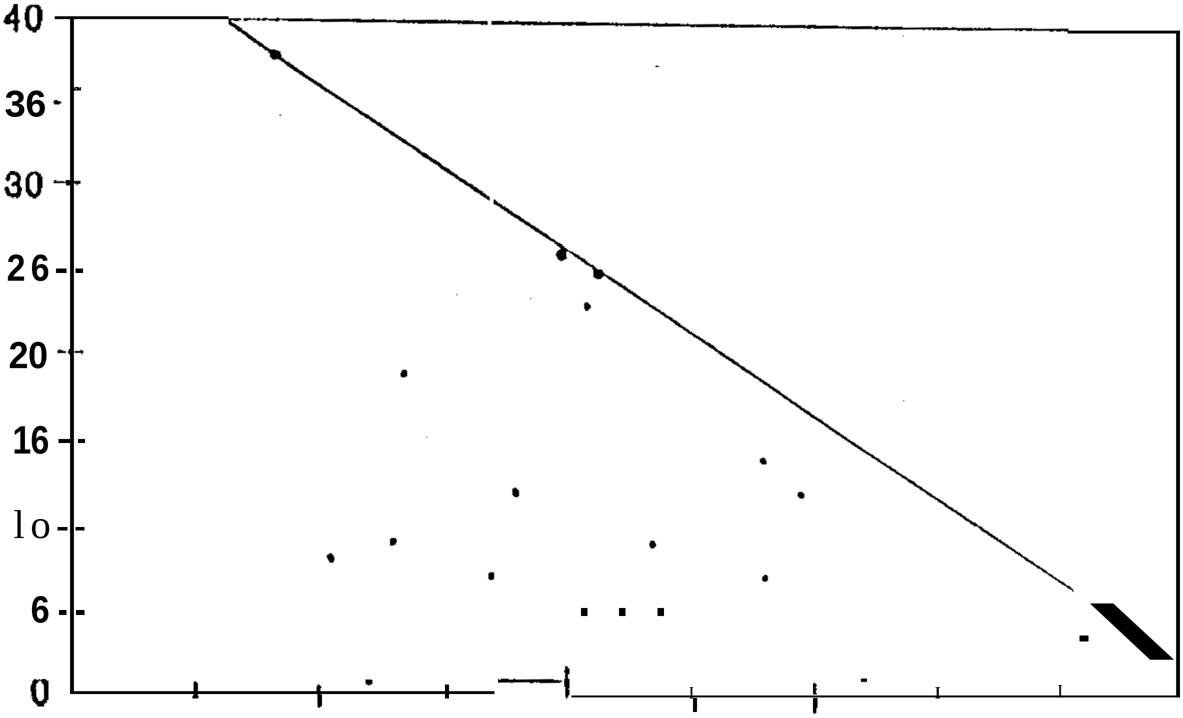


FIG.5 APPLICATION EFFICIENCY (%)
AS A FUNCTION OF FARMER INTERVENTION FOR
POTATO FIELDS IN THE NEW SYSTEMS

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INTERNATIONAL IRRIGATION MANAGEMENT INSTITUTE, PAKISTAN
AGHA KHAN FOUNDATION
RESEARCH ON IRRIGATION EFFICIENCIES IN FARMER- MANAGED IRRIGATION SYSTEMS IN HUNZA -GOJAL
FINANCIAL STATEMENT

		Pak Rs.	US $
A	**PERSONNEL**		
	IIMI Scientific Staff	--	18,95
	Junior Research Associates	--	6,00
	Field Research Assistants	115,342	
	Casual Labours	17,110	--
			--
		132,452	24,95
B	**TRAVEL & PERDIUM**		
	International Air Travel 2 Europe return	--	2,43
	IIMI Scientific Staff (DA)	46,999	--
	Domestic Air Fare/Road Travel	27,501	--
		74,500	2,4
C	**REPORT PREPARATION**	28,500	
	Sub-total in PKR/USD	235,452	27,3
D	IIMI LOGISTICAL t ADMIN SUPPORT (25%of above)	58,863	6,8
	Sub-total in PKR/USD	294,315	34,2
	EQUIPMENT		
E	Research Equipment handed over	11,181	4,7
	Grand-total in PKR/USD	305,496	38,[illegible]9

Lahore, December 9, 1989