IIMI Pakistan

INTERNATIONAL IRRIGATION MANAGEMENT INSTITUTE
PAKISTAN

IRRIGATION SYSTEM PERFORMANCE

HUNZA - GOJAL

International Irrigation Management Institute (Pakistan)

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

Report Submitted to Aga Khan Foundation

Lahore, August 25, 1989

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I INTRODUCTION

In collaboration with the Aga Khan Rural Support Programme, the International Irrigation Management Institute-Pakistan has undertaken field research in the Hunza-Gojal, Gilgit District of Pakistan, to analyze irrigation efficiencies in farmer-managed irrigation systems in the area. This report presents the main findings of the research programme, which was carried out in the area during a period of about 6 months from March 1989. A large body of data was collected in the field by a team consisting of two junior research associates (an agricultural and civil engineer), one irrigation engineer and one irrigation hydrologist, to which two AKRSP engineers were attached. Because of the short period between the final collection of data and the drafting of this report, some of its conclusions may be of a tentative nature. The conclusions presented herein, however, address the main issues as were stated in the objectives of the research project.

Having developed a successful intervention strategy for developing farmer-managed irrigation systems (e.g. see Maliha H. Hussein et al., 1989) [1], AKRSP had been urged by a 1986 World Bank interim evaluation report to address several interrelated downstream operation and maintenance issues. The Bank report recommended that attention be given to distributing the available water efficiently throughout the new irrigation systems and to minimizing water losses and system maintenance. With these comments in mind, research was carried out to determine current system performance in several AKRSP-assisted as well as older, established irrigation systems in Hunza-Gojal. The methods of assessing irrigation system performance included information gathering through questionnaires, in a procedure adapted from Pradhan et al. (1987), and measurements of physical parameters which permitted calculation of conveyance, distribution and application efficiency values. Considerable time in data collection was given to the determination of the efficiency values. This is reflected in the attention that efficiency concepts receive in this report as well, which is in response to the concern expressed in the World Bank report that irrigation water may not be used very efficiently in irrigation systems in Hunza-Gojal. However, it should be realized from the onset that farmer-managed irrigation systems often have multiple objectives and that their logic may or may not emphasize the efficient use of water as defined in strict engineering terms. Forcing a standard efficiency logic of operations on these farmer-managed systems may well be undesirable and incorrect (see also Coward and Levine, 1989).

[1] see list of references in annex 1

One of the objectives of the research programme was to identify possible improvements that could be made in the design, development and management of the irrigation systems currently followed by farmers. Specifically, a comparative assessment of irrigation system goals and efficiencies was carried out in new, AKRSP-assisted and previously existing Gojal farmer-managed irrigation systems. The major factors, both physical and operational, that govern irrigation efficiencies in the area were identified. And finally, some recommendations were made with respect to possible improvements in irrigation efficiencies in the irrigation systems in Hunza-Gojal that the authors feel are justified, desirable and feasible.

II ENVIRONMENTAL SETTING

II.a Physical environment

The Karakoram region of Northern Pakistan falls in a partial rain shadow and does not receive the monsoon rains. Some summer storms may occasionally visit the area, but in general the area is arid (annual rainfall of about 125 mm) and cultivation depends on irrigation. The Hunza river, as the other rivers in the Gilgit district, can only be channelled for cultivation at few locations (e.g. the channel irrigating the new Khaiber area, one of the sample channels studied in the report). Irrigation channels, fed by glacial sources and snow melt provide in most cases the only source of water to the small subsistence agricultural communities in the area.

Irrigation systems here are small-scale, traditionally farmer-designed, constructed and managed using indigenous technology and techniques. Government interventions in the 1970s to enlarge the agricultural resource base in the northern Pakistan through the construction of new irrigation systems generally did not come up to initial expectations. Since 1982 in the Northern Areas, AKRSP has been mobilizing rural people to undertake development work on a permanent, locally-sustainable basis through village organizations.

Glacial melt is tapped and carried up to 10 km through indigenous channels (kuhl) or recently constructed ones, across precarious slopes to alluvial fans and river terraces which constitute most of the arable land. These channels often have to cross almost vertical rock faces and a passage is then carved out or blasted along the rock wall. In landslide-prone areas as Hunza-Gojal, kuhls may take the form of tunnels. In Hunza, this is more often the case when the kuhl is traversing across scree. The kuhl is constructed on the scree slope and covered with slabs of rock. The scree soon covers the slabs forming a sort of tunnel. Actual tunnels and aquaducts are also found but are relatively rare. One example is the tunnel through which the irrigation channel feeding the new Soust area (one of the sample channels) traverses a mountain ridge.

The local climate in Hunza-Gojal varies considerably with altitude, with aspect and slope and/or with shading caused by surrounding mountains. These same effects govern the rate of snow 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 humidities and intense solar radiation are augmented by strong winds in causing a desiccating environment for crop production. Evidence of wind-caused erosion and blowing away of seeds has been reported in the area.

II.b Soils

The soils in the Hunza-Gojal are immature soils. The parent material in the valley floor is present in the form of river terraces, alluvial fans, glacial morains or mud flows. If used for irrigated agriculture, the processes of irrigation and cultivation have modified the soil profiles to a shallow depth. 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, whereas the subsoil remains unchanged.

Some screes have well graded young soils which are cultivated if the slope permits, for growing alfalfa and forage trees. An example of this type of cultivation can be seen in the old Khaiber village, one of the sample areas.

In a number of locations in the Gojal valley, the materials eroded from the upper slopes of the mountains have been deposited on the lower slopes, so called deluvial soils. Some portions of the areas commanded by the newly constructed canals of Soust and Khaiber consist of these materials.

In general, the agricultural soils are characterized by shallow profiles, low water holding capacity, which often is reduced even more because of the presence of rocks and boulders buried in the profile, low inherent fertility and by alkalinity (pH in excess of 7.8). Most characteristic, however, is the large degree of spatial variability. This is obviously so for the depth of profile enhanced by the formation of horizontal terraces on a naturally sloping terrain. But the spatial variability in fertility status and water holding capacity also far exceed the variability one would expect in most agricultural soils in other areas.

Compaction and crust formation are common, caused by free wandering of livestock after the harvest and - during early irrigations - when the farmer walks through his field 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 those steep and terraced fields which are inaccessible for tractors. There plowing is carried out by the traditional plow, pulled by a bullock. These plows don't work the soil deeper than 6 inches and the soil is not turned, and therefore applied farm-yard manure is not buried properly. In one of the sample areas, the new Khaiber area, cultivation has to be done by hand tools, because the suspension bridge cannot be crossed by bullocks or tractors.

II.c Agriculture

Hunza-Gojal is a single cropping area where all crops are spring sown. The upper part of the region offers a short growing season and the ripening of crops depends largely on the temperatures and cloudiness at the end of the season. In the lower portions of the Hunza-Gojal the growing period is sufficiently long and sowing and harvesting dates are more flexible. Before the onset of frosts some fodder crops may be grown there after harvesting the main crops. The agricultural crops produced in the Hunza-Gojal are wheat, barley, potatoes and pulses. Seeding rates of grains are high, which leads to lodging. The farmer generally broadcasts nitrophos (contains 23% N) at a rate of 10-12 kg/kanal (80-100 kg/acre) to grains and of 25-30 kg/kanal (200-240 kg/acre) to seed potatoes, in addition to the application of farm-yard manure.

Other crops produced in the area are fodder, vegetables and fruit, mainly for the home market.

Each village has also a sizeable area as irrigated 'waste' land, which is usually divided between the farmers, for the production of firewood (e.g. Hippophae sp. and later salix and poplar) and as grazing lands for livestock.

II.d Availability of labour

Shortage of farm labour is one of the major factors effecting crop husbandry in both old and newly developed areas of Gojal. In the villages, one sees mainly old men and women and children below the age of 14. The majority of the young men are working outside the area. The growing season coincides with the tourist season and in the most 'touristic' villages (e.g. Passu) young farmers work as porters or guides and some run their own inns and hotels.[2] It is also the season for building houses and repairing

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[2] To relate labour shortage with the tourist industry may not be valid for the whole of Hunza-Gojal.

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 families. Moreover, the growing of vegetables and the collection of firewood are also duties of the women. No wonder that irrigation 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. There irrigation cannot so easily be interrupted by other activities. Of course, the time spent by going to and fro these remote fields is considered a burden. The need for a fixed rotational delivery system is dictated in some areas not by a perceived water scarcity but results from the need to ensure that water for irrigation is available once the trip to the remote fields has been made.

III <u>SAMPLE IRRIGATION SYSTEMS</u>

Six irrigation channels were selected in Hunza-Gojal for a detailed study of irrigation system performance. Three of these were old channels and three newly constructed with AKRSP support.

The selected systems were located in the villages of Passu, Khaiber and Soust. Each of these villages have a new and an old irrigation system.

III.a <u>System in Old Passu</u>

The <u>source</u> of water is the nullah which comes from the Passu glacier. There is plenty of water available and although the supply varies throughout the season, there is no shortage of water for domestic or irrigation use.

The <u>command area</u> in the section of the system which was studied is 45 acres. Some 20 years ago, the command areas of the two channels off-taking from the Passu nullah, were reduced in size by about 60% because of floods of the Shimshal and Hunza rivers.

The water supply remaining the same for a much reduced area explains the absence of any water shortage.

The <u>channel</u> traverses a steep area through a rocky, irregular bed on a glacial morain. The intake of the channel consists of a simply constructed 'wall' which directs the water into the irrigation 'channel'. The channel leads to a bifurcation from which two irrigation channels, through culverts under the Karakoram Highway, serve the irrigated area of the Passu system.

The flow can be regulated just above the culvert where excess water can be drained back to the moraine. Below the culvert, the water is conveyed directly into a network of <u>distribution</u>

channels, consisting in the sample area of two main branches which in turn feed 6 minor branches. Their total length is about 15000 ft. The distribution channels are stable with grassy, well-compacted embankments. Eventually, the distribution channels drain into the Hunza river. At field level drainage could present a problem as the field drains serve as irrigation ditches for the lower fields.

The irrigation water is used for irrigation of properly laid out fields and for the running of mills. Farmers practice night irrigation but not because of water scarcity. They expect to further the development of tubers (potatoes) and spikes (wheat) by this practice.

The distribution channels are not maintained as maintenance is not needed. At some spots they are completely overgrown by grasses, which the animals graze at the end of the season. The annual collective maintenance of the approach channel is no longer carried out. The drainage channels consisting in fact of continuations of distribution channels, are well maintained.

III.b System in New Passu

The source of water of the New Passu channel is the Batura glacier. The nullah carries a large flow, ranging - to give the orders of magnitude - from 50 cfs in January to 6000 cfs in July, which presents a problem for the intake of the channel which is located on the high side of the nullah bed. The discharge in the nullah depends on the weather as has been observed with all nullahs fed by glacial melt. The diurnal variation in nullah flow results in variations in discharge in the channel, which is illustrated for the months of May and June in Figure 1. At present the command area of the New Passu channel consists of approximately 52.5 acres, which have been allocated to the 60 members of the village organization, of which 45% is cultivated, and of two small nurseries and some forested areas. The total cultivated area is now nearly 35 acres. The total area that could be cultivated is estimated by AKRSP to be 680 acres. However, at present the farmers find the capacity of the channel already too small.

The channel length is 9750 ft up to the bifurcation from where the channel on the right hand side goes to the nurseries and the other one to the cultivated fields (see Figure 2). The intake of the channel consists of two parts: a diverting wall, some 1500 ft upstream of the actual intake, which forces the main stream of the nullah to the right side, and 2 diverting walls at the intake, one for low discharges and the other for high ones. Each year the upstream diverting wall needs to be rebuilt; some years farther upstream than in other years, depending on the discharge in the nullah in spring. Flow regulation takes place by moving rocks in the walls near the intake, but when the higher supply channel transports enough water, the lower one is partially or even completely closed by a wooden plank which diverts the water back to the nullah. Four chowkidars carry out these regulating activities. A staff gauge has been installed by the research team and a rating curve provided (see Figure 3) to facilitate the flow regulation. The effect of regulation can be seen in graphs that show the variation in discharge at the head of the New Passu channel on sunny days, which are included in the annexes.

The chowkidars also monitor the flow at the difurcation and irrigate the areas with trees.

The main channel has some escapes and some direct outlets which irrigate shrubs and trees by wild flooding. The escapes are used for regulation and for diverting the flow in case of a breach in the channel. Breaches have occurred where the left bank of the channel is steep and where no silt had been deposited to prevent seepage. Small amounts of seepage can weaken the bank and cause breaches. Instability in parts of the mountain slope on the right hand side of the channel result in damage from boulders.

After the bifurcation the left side channel has a length of 2900 ft, traversing an unregulated drop, a lined section and a culvert for crossing the KKH before reaching the distribution channels.

The distribution system consists of two channels of 4200 and 4300 ft length with stable banks and no danger of overtopping. The offtakes to the plots are usually gaps in the channel bank protected by rocks. Closure of the field inlets when not in use is often not complete which leads to seepage losses. On the right distribution channel at some inlets the construction of small drop structures has been necessary because this channel is higher than the fields. Nevertheless erosion has occurred. Drainage is inadequate as a very large area is nearly always ponded.

No rotation is practiced and the system runs on a first comes first served basis, which has the disadvantage that farmers may find that they have to wait for their turn after they have travelled all the way from Passu to the area. Night irrigation is sometimes practiced for the same reasons as given above for Old Passu.

Maintenance of the supply channel at New Passu is carried out collectively by the farmers at the beginning of the year and continuously during the growing season by the appointed chowkidars. Each farmer is responsible for the maintenance of that part of the distribution channel in front of his own plot.

III.c System in Old Khaiber

The source of water is a spring, whose flow is apparently sufficient to run the hydro-electric plant throughout the year. Water scarcity is not a problem, as the flow diverted for running the plant flows back into the nullah and is available for the channel. Snow melt is available as an additional source of water, which causes the usual seasonal and daily fluctuations in discharge and in silt level.

The command area consists of 21 acres agricultural crops and 35 acres with grasses, shrubs and forage trees. The system is expanding gradually as more 'waste' land is converted into agricultural production.

The approach channel, i.e. the conveyance channel up to the last regulator or escape structure, is 160 ft long with a well-defined and stable bed. The water then enters a desiltation tank, followed by the second part of the approach channel, which is 800 ft long. This portion of the channel traverses two unstable scree slopes through tunnels. The intake structure consists of a loose wall of boulders and rocks.

A possible escape is provided by a low spot at the end of the second part of the approach channel where the flow can be drained back to the nullah. The supply channel is 800 ft long and has a rocky bed. Ample freeboard is provided. Shrubs and trees grow on the lower, right bank of the channel.

The first portion of the distribution channel, 1500 ft long, is poorly defined, shallow and with highly variable width. There are many off-takes, accidental or intentional, that water 'waste' land. The second part is 2300 ft long with rectangular profile and stable banks. The offtakes are well-defined, although many are leaking.

Free drainage occurs to a 'swampy' area before the water is drained through a culvert to the Hunza river. At field level drainage ditches serve as supply ditches for lower fields which may therefore be irrigated unintentionally.

Water shortage has been claimed to occur during early spring when a peak demand for land preparation coincides with a limited supply of spring water only. During that period a four-day rotation of supply is practiced. In general thereafter water distribution is characterized by a high degree of flexibility, facilitated by the proximity of the fields to their houses, ample water supply and close relations within the small community. Irrigation rights play no role, as is to be expected considering the adequacy of the water supply.

A chowkidar is appointed by the sub-village Imamabad, who 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.

Actual field irrigation is labour intensive as the fields are poorly levelled. The farmers appear to be aware of this but incapable of improving it. Like in other old systems, the disadvantage of a heavy silt load in the water outweighs the advantages in terms of soil building and some farmers have dug desiltation pits at the field inlets.

Maintenance in addition to that carried out by the chowkidar, consists of removal of pebbles and silt every 5-7 days or - when the water is clear - every 15-30 days. Maintenance of the field ditches is rather poor.

III.d System in New Khaiber

The source of the water is the Hunza River, a nearly in limited supply but from May onwards with a large silt load. Near the tail end of the area, a nullah provides a possible source of additional water, which at present is not needed.

The command area is estimated to be 30 acres out of a possible 80 acres under cultivation. The area is not levelled and undulating, planted with alfalfa, fruit trees and trees for forage and firewood, as well as agricultural crops, e.g. grains and beans, in regular fields. Land development is still continuing and the current year (1989) was the first growing season after sub-division of the land in plots had taken place. The area is characterized by striking differences in land quality and stand of the crops/trees. Large parts of the area are covered by boulders, gravel and sand. Soil building by silt deposition offers potential for land quality improvement, provided the land is levelled first and boulders and gravel are removed.

The conveyance channel (approach section till the last escape) has a length of 2700 ft with gentle slope and therefore large silt deposits. No desiltation takes place as the silt is still needed for soil formation. The intake is marked by big boulders, but there is no proper diversion wall. During the season, the intake is washed away and the actual intake of water moves farther downstream. As the river bed of the Hunza is lowered by scouring, it will be necessary to extend the conveyance channel gradually farther upstream. Flow regulation takes place through control structures and irregular escapes in the approach channel. The supply channel is 7000 ft long with a gentle slope. The channel is well sealed. During heavy rain the channel is threatened by mountain streams, that drain to or cross the channel, and by land slides. At the end of the supply channel, the water drops over some 10 ft in an uncontrolled way and is collected again in a number of smaller channels.

There are two distribution channels, one of 250 ft with a steep slope, ending in smaller ditches, and one of 3600 ft, with little slope and hardly any embankments, which leads to frequent overtopping. The offtakes are ill-defined and nearly all are leaking. The water leaking from this channel and from the off-taking field ditches benefits areas where alfalfa has been sown, or leads to soil formation. Irrigation of these areas and of some ill-defined fields with trees is by wild flooding. There is no drainage network. Drain water is collected in low spots and cannot flow back to the river. Regulation of the water supply then amounts to draining excess water; only during May and September water may be in short supply which would necessitate the prevention of losses or moving the intake.

During May a five-day rotation was practiced but no longer adhered to when the water supply became abundant. Regulation of flow in the channel takes place by farmers as they desire. The last farmer to leave the area is expected to close the channel to prevent damage during the night from sudden floods.

Irrigation water is used for trees (and some grains), but also deliberately for silt deposition and soil formation. Trees are over irrigated as they can stand 'wet feet' better than water deficiency in these shallow soils. However, in ponded areas the trees have died.

The rate of siltation is about 1 ft in 5 years. Farmers expect that it will be possible to grow wheat and barley in about 5 to 10 years, provided a bridge has been built so that manure can be brought to the area.

The supply channel had been maintained before the start of the season. The VO arranges for this routine maintenance and all farmers are expected to participate. Desiltation of the supply channel takes place once a year, before the start of the season.

The maintenance of the longest distribution channel was poor.

III.e System in Old Soust

The source of the water is the Soust Nullah, fed by glacial and snow melt. This same nullah is the source for New Soust (Husseinabad) and Nazimabad on the left bank of the nullah.

The command area (Aminabad) consists of about 29 acres irrigated fields (wheat, barley, seed potatoes and black peas) and 10.5 acres grasses and bushes in addition to area occupied by houses and barren land.

The approach channel is 400 ft long from intake to desiltation tank (under construction). The intake consists of a wall of rocks of ca. 1.5 ft high which is located nearly in the middle of the nullah and diverts the water to the right where the approach channel starts. The wall is not water-tight, so it is not possible to divert the entire flow of the nullah. The supply channel is 300 ft long. It runs through stable terrain and has tree- and shrub-lined banks. At its end it bifurcates into the main distribution channel and a small distribution channel, which runs along the mountain side feeding a strip of land with grasses, shrubs and trees and supplying water to the night reservoir. A wooden gate can be used to influence the amount of water that is diverted to each.

The distribution channels form a network of smaller channels and branches to cover the entire area. These channels are mostly stable, but in a few places little freeboard is provided and overtopping has occurred. Usually, the soil adjacent to the channels is wet for some considerable distance indicating lateral seepage. Offtakes to field channels are sometimes well defined with rocks on both sides or just gaps in the earthen banks.
The night reservoir has a roughly circular shape with a diameter of 55 ft. A water depth of 5 ft is possible, which gives it a capacity of about 12000 cubic feet. It is filled from a small ditch that lets its water flow down along the inner wall of the reservoir. The outlet is a 3" hole that can be plugged with a wooden pole. Irrigation water is used also to run three mills, when the water supply is abundant.

Rotation of supply between Nazimabad and Aminabad is organized by the farmers of both villages themselves. This rotation implies an irrigation frequency of once every four days. When there is no rotation of supply between these two systems, the frequency of irrigation is every two days.

There are no chowkidars and regulation of the flow at the bifurcations and at the intake is carried out by individual farmers. Frequent regulation is required because of gravel deposits in the approach channel. Flushing of the gravel might take place more than once a day, especially when tailenders find their supply too small. Most farmers have desiltation pits near their field inlets.

The night reservoir is mainly used during April - May. It is usually filled by a farmer, whose turn it is the next day. Up to six farmers can be supplied from the night reservoir.
Night irrigation is sometimes practiced for the same reasons as were mentioned before.

The areas with grasses and bushes are irrigated by the farmers who own the areas and the irrigation is subject to the same rotation.

Once a year collective maintenance is carried out of the approach and supply channels, and less frequently, of the night reservoir. Collective maintenance of the distribution channels does not take place, even though the tailenders may suffer from water shortage or rather have to irrigate with inconveniently small flows..

III.f System in New Soust

The source of water is the Soust Nullah as was mentioned above.

The command area can be divided into two sections:

- A steep terraced part with mainly trees and some alfalfa, where each farmer owns a plot of about 0.4 acres (3 kanal)

- A flat part on a river terrace which is cultivated for some 70%, and where each farmer has a plot of 0.5 acres (3.85 kanal). For 60 farmers the total cultivated area then becomes 42.5 acres. The length of the supply channel is 3100ft of which the first 1800 ft are along a scree and rocky slope. It then traverses a mountain ridge through a tunnel. The intake is located the farthest up the nullah of the three Soust schemes. It consists of a wall of rocks and boulders, which spans nearly the complete width of the nullah. It does not divert the complete flow, though, because of substantial leakage through the 'wall' which is necessary otherwise no water would reach the other two intakes. The flow is regulated primarily by moving rocks and stones around at the intake and along the first part of the outer bank of the approach channel.

The distribution part of the system starts straight after the tunnel, where the channel bifurcates. The right branch feeds roughly half the terraced part of the area. The length of this channel is greater than needed for irrigation of the terraced part for future irrigation of presently barren land. It is, however, unlikely that supplies are adequate for further expansions of the irrigated area.

The left channel at first feeds its part of the terraced terrain and then drops steeply to the river terrace where it branches into two smaller distribution channels. The length of the left part, before the bifurcation, is 2100 ft and the smaller distribution channels have lengths of 1700 ft (top one) and 2000 ft (bottom one). Where the channel drops from the top portion to the bottom part of the command area the channel is poorly defined and badly eroded and as it is close to a steep drop down to the old system, that portion requires stabilizing.

Most field ditches from the top small distribution channel start with a substantial drop (1-2ft) and/or the field ditch is in fill. In most cases several border strips share one inlet from the ditch. These inlets are simple cuts in the bunds that form the bank of the ditch.

Due to a greater scarcity of water in Soust than in the other two villages studied, it has been observed that the farmers here are more conscious of water saving. Often the farmer tries to reuse the drainage water for other fields. Both field distribution channels run into depressions where water is left ponding. Silt deposits in these depressions of course are used for soil formation.

Husseinabad (New Soust) gets water later in the season than the other two systems, because the farmers prefer to start with the fields near their homes. Once New Soust has started, however, it gets water continuously. Within New Soust itself, a rotation is practiced, which implies that each day 15 out of 60 farmers irrigate, half of them during the morning and half in the afternoon, each group along the same field distribution channel. No chowkidars are employed and the farmers regulate the flow at the intake according to a roster. This means that each farmer has to 'open' the intake at 5 am and 'close' it at 7.30 pm once every 60 days.

At the beginning of the season, all farmers participate in the annual maintenance of the main channel. Emergency maintenance is here as in the other new schemes organized by the VO whenever necessary. Each farmer maintains the section of the distribution channel (both in terraced part and in the river terrace part) in front of his plot. Many a farmer inspects the distribution channel he depends on before irrigation and repairs it where and when necessary.

III.g Conclusions

From the information presented above on the comparative system performance of the six irrigation systems studied, a number of conclusions can be drawn :

- water scarcity is not an important factor throughout the growing season affecting system performance; at most during the first few weeks of the season, it may necessitate certain strict rotational rules. In the new irrigation systems, however, water scarcity may well occur with further land development.

- management of the system takes place in one way or another in all of the systems studied. It may be done through chowkidars, employed specifically for that purpose, or through mutual agreements between the farmers of the area themselves.

- in the older and well established systems, informal relations suffice to make the system perform well; this is facilitated also by the proximity of the fields to the houses of the farmers.

In the new schemes, more formal arrangements and rotations are required, partly or perhaps mainly to ensure effective use of scarce labour.

- in the newer systems it may appear that water is wasted but in terms of soil formation through silt deposition little if any water is 'wasted'. In addition, water used for the irrigation of grasses, bushes and trees on so called waste lands is well spent because it helps to provide fodder for animals and firewood for the households.

- in both systems, new and old, inputs other than irrigation may well be the limiting factors in agricultural production, e.g. the degree of mechanization and/or skills required for land preparation and precision levelling appear to be lacking.

IV CONVEYANCE EFFICIENCIES

IV.a Objective

As mentioned in the Introduction, the World Bank report expressed concern about the efficiency of conveyance and use of irrigation water, especially in the new systems. For that reason conveyance efficiencies were measured in sections of conveyance and distribution channels of all six sample systems. The results are reported in this chapter.

IV.b Methodology

Discharge measurements were carried out at two locations in sections of conveyance and distribution channels of the six systems. The locations where the discharges were measured were chosen such that a representative portion of the channel was enclosed between the measuring sites. Current metering for the determination of the flow velocity, combined with measurements of the cross-sectional area of flow, was the method used most often.

In some channels it was possible to measure the flow with a RBC-flume or a V-notch weir. The methods of measurement are described in most textbooks of surface irrigation and need not be expanded on here.

IV.c Results

The values of the conveyance efficiency are listed in Table 1.

IV.d Conclusion

The values of the conveyance efficiency in sections of the conveyance and distribution channels are all in the range of 80-100%, with the exception of a couple of values of the distribution efficiencies in Old and New Soust which are slightly lower. The efficiency values expressed per unit length to allow comparison between values obtained over sections of different lengths, indicate that the losses incurred over 100 m are at most 5% of the flow entering a section of canal of that length. Because of probable inaccuracies, (the methods used were not particularly suitable for fast flowing channels) the uncertainty in the values is at most plus or minus 10%. Nevertheless, it is clear from the data that the new channels perform as well as the older, well established ones.

In view of the sediment deposition in these channels, a smooth well sealed channel bed was expected. It is encouraging to note that the new channels became well sealed within a few years and that losses of water during conveyance are small.
When looking at these favorable efficiency values, it should be remembered that in the discussion of the irrigation systems mention was made of a few weak spots in the channels where the sustainability of the channel and hence of the system might be treatened. These are spots where even small amounts of seepage water may cause severe damage to the channel embankments.

V APPLICATION EFFICIENCIES

V.a Objectives

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 root zone for uptake by plant roots. Application efficiency is expressed as the ratio of the amount of water stored in the root zone and amount applied to the field. In view of perceived uncertainty of the efficiency with which water is used in new irrigation schemes in the Hunza-Gojal, application efficiencies were determined in the fields of sample farmers located at the head, middle and tail reaches of distribution channels in the irrigation schemes studied. The objective of the study was to assess the efficiency and to determine which factors influence, and to what extent, the observed application efficiencies. This with the view of evaluating how efficiencies could be improved.

As part of this study, the degree of uniformity of application was also determined. It is conceivable that water appears to be applied efficiently at field level, i.e. the amount applied to the field accords with the amount that could be stored in the root zone, but that the uniformity of the application is poor, which would result in over-irrigation in one part of the field and under-irrigation in another. In case of the uniformity of application it was also attempted to identify the governing factors with a view to improve - if possible - the uniformity of application attained in the fields of the sample farmers.

V.b Methodology

Application efficiency and uniformity of application were determined at field level. It was therefore necessary to determine the size and dimensions of the fields. Dimensions of border strips and furrows, if present, were also noted, as were their overall slopes. In case of furrow irrigation (potatoes), both wetted perimeter and width of the evaporating, i.e. wet, area were determined to obtain, by multiplication with the furrow length, the wetted and evaporating areas, resp. Slopes of zig-zag furrows are meaningless since thresholds and other obstacles obstruct flow.

The discharge in field channels was usually measured with an RBC-flume and in some instances determined by the float method or merely estimated. Frequent determinations were required when the flow in the distribution channels varied. The distribution of the field channel flow over a number of furrows or border strips, irrigated at the same time, could usually not be determined exactly but had to be estimated.

Infiltration measurements were carried out with ring infiltrometers shortly after land preparation and wherever possible, again shortly before the end of the growing season. The latter observations were difficult and often impossible to do in mature grain fields and where danger of damage to potato tubers existed the late season readings in the furrows had to be omitted as well.

Moisture contents in the soil profile were assessed by a version of the USDA method, in which the intervals of 25% available moisture were divided into two sub-intervals of 12.5% each. (Soil moisture values could not be determined in any other way as an oven and balance were not available in the area.) Moisture contents were evaluated in this way for 1" depth intervals down to usually 4" in the profile. These determinations were repeated at a number of sites in the field.

Depth of root zone was determined by removing a few wheat and barley plants or by opening up a ridge in case of potatoes. A reasonable estimate of effective root depth could thus be made. These estimates were checked against values reported in the literature (FAO Handbooks 24 and 33).

The depth of the soil profile was determined by auguring. Soil samples were analyzed in laboratories of the Soil Fertility Survey and Soil Testing Institute and of the Centre of Excellence of Research in Water Resources, both at Lahore, for the assessment of water holding capacity, textural analysis and fertility status.

Evaporation pans were locally made and installed at New Passu and Old Soust. Pan evaporation values were converted by means of a suitable pan factor to net reference evaporation. Crop evapotranspiration could then be estimated. For potatoes the crop cover and the evaporating area in the furrows needed to be calculated.

Infiltration opportunity times, i.e. time elapsed between initial wetting and the disappearance of water from the surface, were measured at sites marked with stakes in the field. In mature grain fields it became impossible to place the stakes and infiltration opportunity times were recorded for patches which could be identified otherwise.

The degree of levelling of the field was recorded. Presence of the farmer in the field during irrigation was indicated on a scale from 1 - 5, each unit representing 20% of the time. Likewise, farmer's intervention during irrigation was scaled, depending on the irrigator's activities with the pai or spade in regulating flow within the field and at strip or field inlets.

V.c Results

Values of the application efficiency and the degree of non-uniformity (ratio of the standard deviation of the infiltration opportunity times over the mean value of these time periods) are presented in Table 2 for wheat and barley fields. In the same table values are given for a number of factors which affect application efficiency and non-uniformity or which were expected to do so. The statistical dependence of application efficiencies and non-uniformities on all factors, which were determined or measured in the field, was evaluated and its significance calculated. The statistical data for the two most striking factors, percent available water at the time of irrigation (PAW) versus efficiency and the average slope of the strip versus non-uniformity, are listed in Table 3. Negative values of the correlation coefficients indicate that the application efficiency decreases with an increase in available moisture and non-uniformity decreases with an increase in slope. The lower the value of the probability, the more clearly the dependence has been established of the application efficiency and non-uniformity on the factor PAW and slope, resp.

Likewise, the application efficiencies and non-uniformities for potatoes are listed in Table 4, together with the values of a number of factors affecting them. The statistical analysis is presented in Table 5. When all data are taken together, the most significant factors are the average flow at field inlet, the degree of farmer intervention and the available water at the time of irrigation (PAW), but none of these shows a high correlation coefficient (or really low value of probability) with application efficiency. For the new systems considered separately, especially the degree of farmer intervention and an indication of the infiltration rate (listed in the tables as s, log t-log Icum) are significant.

The degree of non-uniformity for the irrigation of potatoes is presented in Table 6. Here for all data taken together, the average application time and the average flow per furrow, divided by its length, are most significantly related with the measured non-uniformity.

Total irrigation application during the season for the grain fields and for potatoes is listed in Table 7 for five irrigation systems. No data are given for New Khaiber, since that area is still being developed and no regular fields have been made. The mean values of the seasonal irrigation application are 35" and 18" for cereals and potatoes, respectively, with considerable variation per scheme around these mean values.

The dependence of application efficiency on irrigation depth for grain fields and potatoes is given in Table 8. When all data for the wheat and barley fields are grouped together the dependence is strong as evidenced by the low value of the corresponding probability. For potatoes in the new systems, dependence of application efficiency on irrigation depth is also indicated. These relations show that application efficiency decreases with average irrigation depth applied per turn.

Some of the results of the soil analyses as carried out by the soils laboratories in Lahore, are presented in Table 9. From these data and from observations in the field it appears that the soils in the older systems are deeper than in the new systems, undoubtedly because of the much longer period of soil formation through silt deposition. In some low-lying areas of New Khaiber, the process of soil formation has been remarkably fast, due to the high silt load of the Hunza river. The percentage clay in all soils is low and remains more or less constant with depth, whereas the percentage silt increases somewhat with depth in the older soils. In the new areas, the finer materials are found in the upper inches only. The soil profile is not yet mixed as it is in the older systems.

In accordance with the observation that the older soils have higher contents of fine materials and organic matter, higher saturation percentages which increase with depth, were reported for the older soils.

Infiltration rates in wheat fields in the new systems are generally somewhat higher than in the older systems. Phosphates are higher in soil samples from the older systems, especially in the upper part of the profile. This probably reflects the effect of application of farm yard manure and nitrophos for a large number of years. All soil samples were slightly alkaline (pH values of around 8).

V.d Discussion and Conclusions

The application efficiencies are low, which means that the farmers do not attempt to economize on water at field level. Whether the actual efficiencies are as low as those reported in the tables can be disputed, considering the number of assumptions made in the calculations and the inherent uncertainty of some of the basic data. The values reported in the tables are based on the estimated water contents in the root zone according to the USDA method, on estimated values of the water holding capacity of the soil profiles and on assumed average depths of the root zone.

All of these values exhibit considerable spatial variability under the best of circumstances while it is known that the soils in Hunza-Gojal show large variations in their physical characteristics over short distances as related with various parent materials.

Application efficiencies were also calculated from the crop evapotranspiration data, derived from pan evaporation data as explained in chapter Vb. These data were consistently somewhat higher, but they are not presented here because it was felt that the uncertainty with those data exceeded the one associated with the efficiency data, calculated from the moisture deficiency in the profile, reported in this chapter. Furthermore, these data are not included because one of the pans was not installed until June so only part of the season is covered. Moreover, statistical analysis of the dependence of both types of efficiency values on factors measured in the field is not expected to lead to different results.

Application efficiencies of grain fields

The factor which most markedly affects application efficiency in case of grains is the available water at the time of irrigation (PAW). In about one-third of all irrigation turns analyzed, farmers were irrigating fields that still contained 80% or more of the water that could be stored in the root zone. As a rule of thumb, one could say that irrigation is not needed until about half of the available water in the root zone has been taken up by plant roots. Irrigation frequency is often dictated by the rotation system imposed, but even then it may well be possible to postpone irrigation until the next turn comes.

If the soils are still wet when they are irrigated, it becomes very difficult or even impossible to apply the small amounts of water that are needed in a uniform way. The required infiltration opportunity time becomes small in relation with the time required for the stream of water to reach the end of the border strip or furrow. The farmer always waits at least until the water reaches the tail end of the field and this leads to over-irrigation of most of the rest of the field and, consequently, to low application efficiencies.

A small discharge at the field inlet also has a negative effect on application efficiencies when it is split up between too many strips to be irrigated at the same time. This may be illustrated by the following example : it was observed at a field in Old Soust, with relatively long strips (114 ft) and a fairly poor degree of levelling. The farmer irrigated the soils (loamy sand) with a flow of only 0.07 cfs (2.1 l/sec) at the field inlet. He found it difficult to get the water to the tail end of the field. Only after prolonged irrigation of the head and middle portions of the field did the infiltration rate decrease sufficiently for the advancing water front to reach the tail end of the strips. The farmer did not intervene (she was absent during most of the time), which led to an application efficiency of 4%.

Generally, the degree of intervention is higher in the new systems than in the old, which is due to fewer distractions in the newly developed areas as they are farther from the villages. After lengthening of the strips (about one month after sowing date), farmer intervention decreases to merely regulating the flow at the field and strip inlets. The farmers justify the use of longer strips by increased soil compaction and lower infiltration rates. This was not supported by the results of the application efficiency and uniformity data.

It was observed that in nearly all fields infiltration opportunity times decreased going down the field; the last part of the field, however, was often ponded. Farmers appear to accept the ponding although many are aware of its adverse effects on crop growth.

Application efficiencies of potatoes

It has been observed that during the irrigation season, farmers decrease the flow per zig-zag furrow, irrigating longer in anticipation of lower infiltration rates due to sealing of the furrows. Smaller flows lead to greater uniformities in application.

The number of days since planting of the potatoes does not appear to have a direct effect on uniformity, apart from the effect just mentioned through a change in irrigation practice through the season.

Farmer's intervention in the irrigation of potatoes is limited to adjustments in the flow per furrow and some guiding of the flow in the furrow. Bearing in mind that not all interventions are explicitly aimed at improving uniformity, one should not be surprised by the inconsistent statistical correlations of this parameter.

Non-uniformity in the old fields remains about constant at 40%, while in the new fields the non-uniformity of application tends to decrease down the furrows. Tail ends of the furrows have by far the longest infiltration opportunity times.

Zig-zag and straight furrows differ in infiltration behavior. The straight furrows drain freely, whereas in the zig-zag furrows water is ponded at the tail end. It has been observed that part of the farm yard manure (and presumably also of the fertilizer) that was applied drained from the straight furrows by runoff. One would expect that these nutrients accumulate at the tail end of the zig-zag furrows. Applying the fertilizer by 'injection', i.e. by placing the fertilizer in the ridges which were opened up next to the tubers, would prevent the ready loss of nutrients from the zig-zag furrows.

The correlation between application efficiency values and furrow length is not statistically significant (apparently other factors obscure this one), but the sign of the correlation coefficient indicates that the trend exists for longer furrows to result in lower efficiencies.

For the new areas, the average flow per furrow is positively and significantly correlated with the application efficiency. This is not true for the furrows in the old systems. The reason for the difference is not apparent, but may be due to differences in infiltration rate.

From some of the other relations, it may be concluded that on average, the more water is taken at the field inlet, the less efficient it is applied.

Although not significant in statistical terms, the trend is for the efficiency to decrease with available water at the time of irrigation.

It can be concluded for the irrigation of potato fields, that no single factor or combination of factors governs the application efficiencies. Apparently, these values result from a combination of events and circumstances. However, from the four factors which exert more influence on application efficiencies than the others, i.e. average flow per furrow length, average discharge at field inlet, degree of farmer intervention and available water at time of irrigation (see Table 10 for values of the multiple regression coefficients), it is obvious that farmers could play an active role in applying water in a more efficient manner. This is illustrated also by the consistent significant relation between application time and average flow per furrow length, which are both manageable parameters.

An interesting example is provided by the single farmer who grew his potatoes on straight furrows. He chose to irrigate with small flows during long application times. This led to a number of advantages in comparison with the usual practice of irrigating potatoes in zig-zag furrows, some were measured in the field, others are based on the assessment by the farmer :

- more gradual lateral infiltration into the ridges
- more even distribution of silt deposition
- better control of pests
- higher value of the uniformity of application
- less need for intervention by the farmer
- less erosion
- more homogeneous stand of the crop
- relative larger area cropped,
  and most interesting in this context,
- a much higher value for the application efficiency (42%).

VI GENERAL DISCUSSION

The new and the old systems each have a number of characteristics which are peculiar for that group of systems.
The conveyance channels of the new systems are designed with less slope than the conveyance channels of the old systems. Characteristic longitudinal profiles are presented in Figures 4 and 5. Undoubtedly, this has led to the rapid sealing of these channels of the new systems and in consequence, to values of the conveyance efficiency which are comparable to that of the old systems. As has been pointed out before, channel losses are not merely important from the point of view of preserving a presumably scarce resource, water, but should also be considered in terms of channel stability and hence sustainability of the systems.

The conveyance channels of the new systems have been constructed after a general survey of its alignment. During the construction the final slope is chosen depending on the circumstances and based on experience. This combination of technology (surveying) and skills has led to generally stable channels for conveying the much needed water to arable lands.

Application efficiencies, as was discussed in the previous chapter, are low in both old and new systems. Factors which affect the efficiency with which water is applied to the field are expected to be found in the design and construction of the systems, in inherent variability of the physical environment in which the water is transmitted from source to sink (the plant roots), and in the operation of the system. The effect of some construction-related factors was analyzed, e.g. the effects of the dimensions of the field, and slope of border strips, amount of water applied, application times, etc.

It was found that some factors exert a greater influence on the application efficiencies than others, but that in general no single factor could be identified which governs the application efficiency. To the contrary, it was concluded that application efficiencies depend on a number of, sometimes interrelated, circumstances and conditions.

The operational effects - the management aspects related with the application efficiency - have been described in terms of rate and duration of flow, state of maintenance of the distribution system, and degree of levelness of the fields and farmer intervention, among others.

The reported low values of the application efficiency, in our opinion, result from the lack of need to economize on water use, combined with a substitution of water for labour, in the sense that labour is more scarce than water.

Till and Bos (1985) reported that low field application efficiencies may be the only practical option when the soils are quite variable in texture, water holding capacity and infiltration rate.

Moreover, water that is not stored in the root zone and for the calculation of the application efficiency is considered 'inefficient', is not all lost or wasted. Some of the drainage flow is used for irrigation of lower fields, some is used for the irrigation of shrubs, grasses and trees, often bracketed together as 'non-beneficial use by phreatophytes'. It has already been pointed out earlier that this use is 'beneficial' as the products are used for fodder by livestock and for timber and firewood for households. In addition, it has been reported that 'inefficient' water is of importance in soil formation and perhaps also in nematode control and temperature regulation of potato fields.

Leaching of Nutrients

One aspect of low application efficiencies needs to be considered separately, and that is the likelihood of leaching of nutrients from the soil profiles. It has been reported widely (see e.g. Viets et al., 1967) that the nutrient anions, nitrate, chloride and sulphate, are completely mobile in soil water, because of the absence of strong adsorptive forces in alkaline soils, as are present in Hunza-Gojal. The form in which ammonium-N is present depends on the pH, and these ions are generally held rather tightly by the exchange complex of soil clays and organic matter.

In case of the Hunza-Gojal soils with low clay and organic matter contents some mobility of ammonium-N is also to be expected, and perhaps even of the phosphate ions which are usually strongly adsorbed by the absorption complex. The order of ease of leaching of the nutrients in the Hunza-Gojal soils would then be nitrogen, sulfur and phosphorous. The leaching of sulphate ions may not present much of a problem considering the presence of calcium and magnesium suphates in the soils and irrigation water.

Leaching of nitrogen in the form of nitrates and ammonium needs to be considered. No physical measurements on leaching could be carried out in the field and hydraulic properties of the unsaturated zone in and below the root zone are not known[3]. Comparison with soils of similar texture and water holding capacity,although somewhat speculative, indicate that the unsaturated permeability at field capacity would be of the order of 0.1 - 0.5 cm/day.

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[3] Knowledge of the hydraulic properties of the soil profile, combined with further analysis of the data of this study, would throw some light on the various components of the water balance, and could check the magnitude of the application efficiency values.

In furrow irrigation of potatoes this may not have much of an effect on the availability of nitrogen to the plant roots in the ridges, because of lateral movement of irrigation water, and the dissolved nutrients, from the furrows into the ridges. Based on the hydraulic properties as mentioned above, in grain fields cumulative leaching during the growing season could amount to some 12 - 50 cm, the latter value being of the same order of magnitude as the seasonal crop water requirement.

The situation is confounded by the fact that below the shallow root zone, the soil becomes impermeable or nearly so. Soil auguring has indicated (near) saturated conditions below the root zone. Downward movement of water and solutes would only occur directly after irrigation and change into upward movement from the shallow water table thereafter resulting in much lower seasonal leaching of nutrients than indicated above.

Without knowledge of the physical and chemical parameters which govern the process of nutrient leaching in these soils, it can only be noted that - especially in the grain fields - leaching could account for substantial losses of nutrients from the root zone, perhaps under unfavorable circumstances amounting to some one-third of the fertilizer applied.

It has been observed that, in general, farmers are unaware of the fact that over-irrigation leads to loss of nutrients. Those who acknowledge the leaching effect assume that the nitrophos will only be washed out after a few irrigation turns and that therefore leaching would not be a serious problem.

Representativeness of Sample Irrigation Systems

The selection of irrigation systems for this study was done jointly by the management of AKRSP and the IIMI scientists responsible for the study. In our opinion the results presented in this report are representative for the systems in Hunza-Gojal. Well established systems can be found in other villages in the area which are likely to have many things in common with the old systems of Passu, Khaiber and Soust. Likewise, new systems that have been started in Hunza-Gojal or could be initiated in that area will have many of the characteristics of the new systems described in this report. Some differences are bound to occur. One will be that labour shortage as a result of employment in tourist activities could vary depending on the touristic attractiveness of the village and the surrounding area.

The irrigation systems cannot be considered representative for other areas of Gilgit district as farming systems are greatly affected by the extent of the growing season which would allow double or single cropping.

VII RECOMMENDATIONS

It is possible to suggest a number of feasible improvements in the conveyance part of the new systems, ranging from a few drop structures to some more sophisticated regulators. The question is, however, whether these improvements would be justifiable in terms of improvements in conveyance for the costs in terms of labour and finances. That question, in our opinion, should be answered in the negative. It would be more a matter of improvements in terms of engineering aesthetics than engineering necessity.

Stabilization of the left bank of the New Passu channel, providing aquaducts at few locations for water crossing the New Khaiber channel, and stabilization of the flow channel between the terraced part and the river terrace of the New Soust command area, are not in the above category. These suggested improvements are recommended to make the sustainability of these systems more ensured. Because of the general fragility of the environment, no human effort can fully ensure the sustainability of any of the systems. Large investments, however, have been made during the construction of the system and since on the development of the command areas. It would be highly regrettable not to make the necessary additional investments now to make it more likely that the system can be fruitfully operated for years to come.

Improvements in the efficiency with which water is applied in all systems, new and old, can be made as should be obvious from earlier chapters. Here the question is whether farmers would be motivated to make the necessary changes in the operation and maintenance of the systems. There could be three reasons for the irrigators to do so: first, more efficient use of water at field level may well correspond with a saving in the amount of labour needed for irrigation; second, more efficient use of water probably leads to less leaching of nutrients with corresponding higher yields or lower expenses for fertilizers; and third, more efficient use of water would lead to (more) water being available for further expansion of the cultivated areas of the new systems.

These additional benefits are unlikely to materialize straight away when a programme for improved levelling of the fields is introduced, or when the growing of potatoes in straight furrows is propagated, or rotations are agreed upon which allow greater flexibility in timing of irrigations to make them agree better with the need of the crops. All of these (and several others) could be components of a programme to induce farmers to use irrigation water more sparingly. Without irrigation-oriented agricultural extension, supported by field trials in farmers' fields, it is hard to see how the necessary changes in irrigation behavior could be brought about.

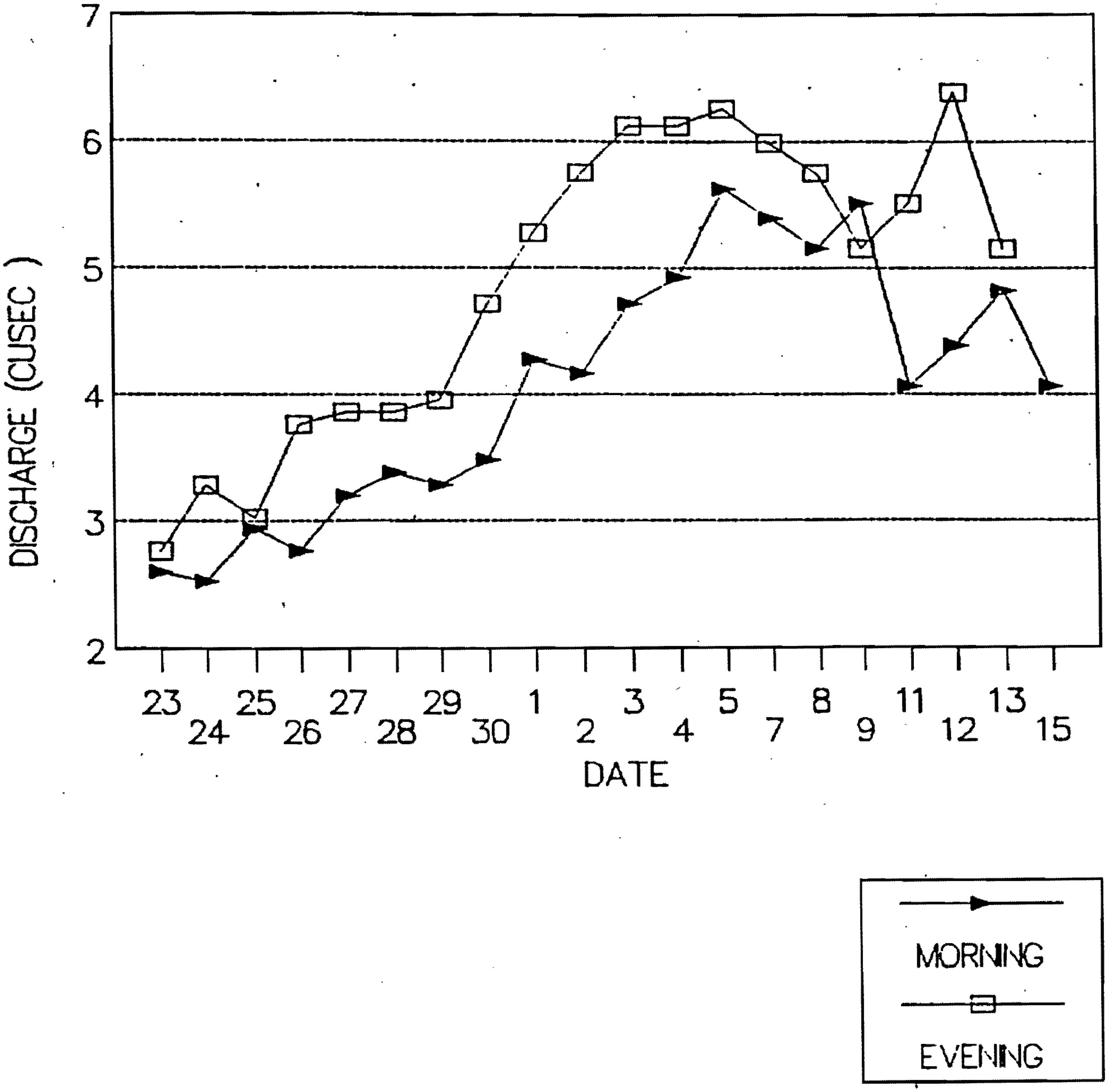

Figure 1: New Passu (head) May-June 1989
Morning and Evening Flows

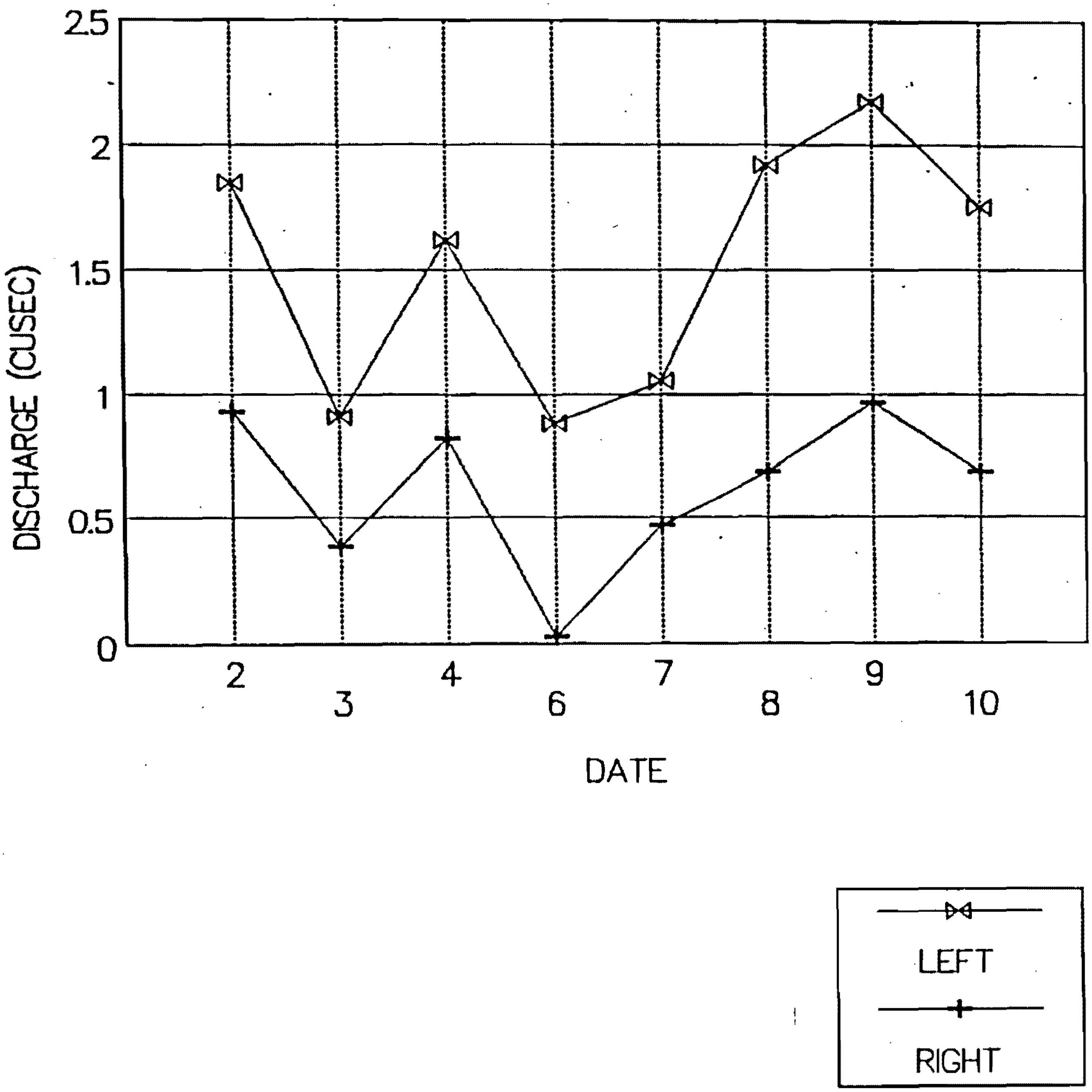

Figure 2: Distribution of Flow by Farmers in Left & Right Branch of New Passu

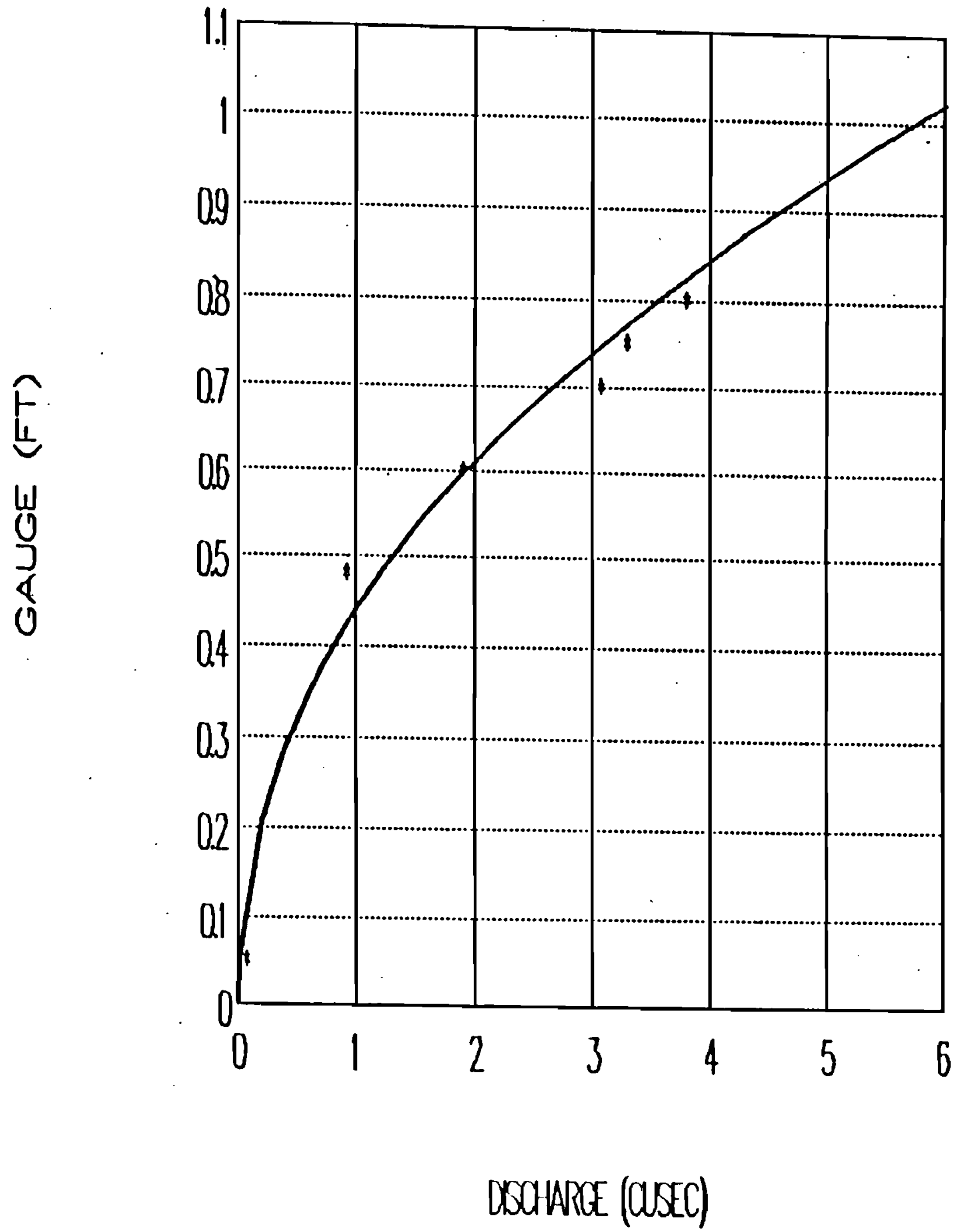

Figure 3: Stage Discharge Relationship at New Passu Head

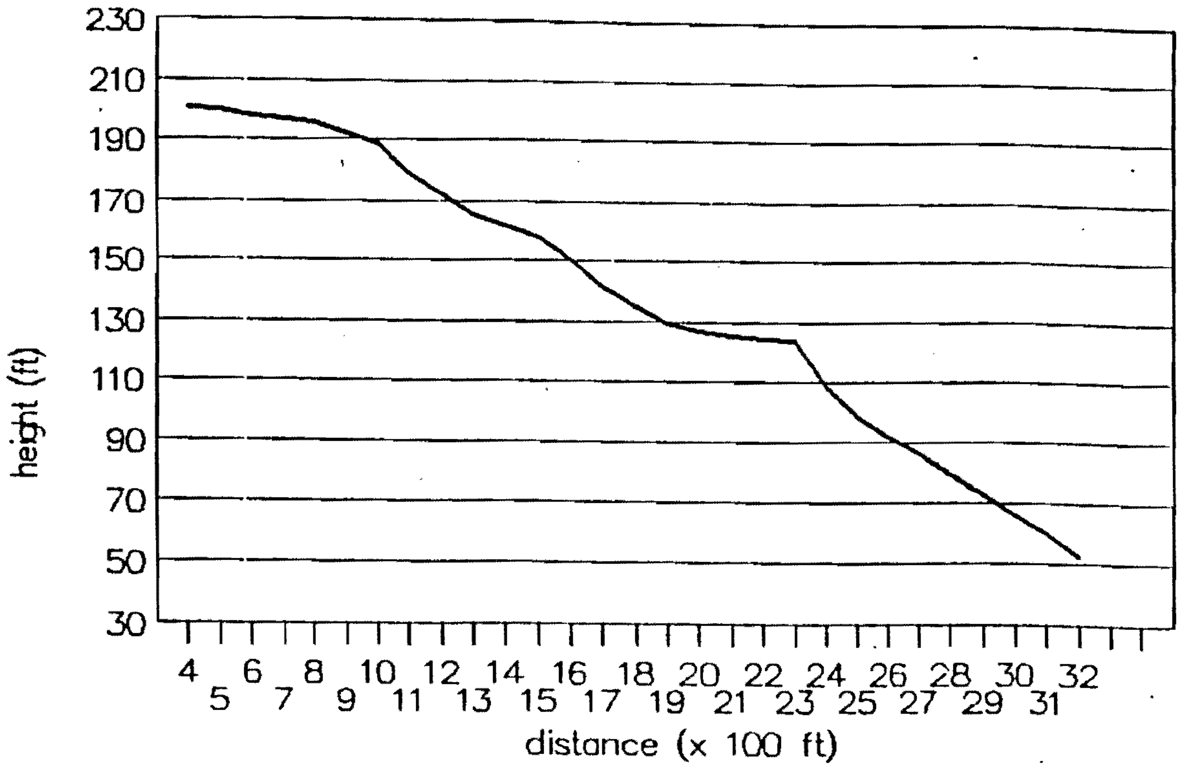

Figure 4: Longitudinal profile of Supply and Distribution Channel Old Soust

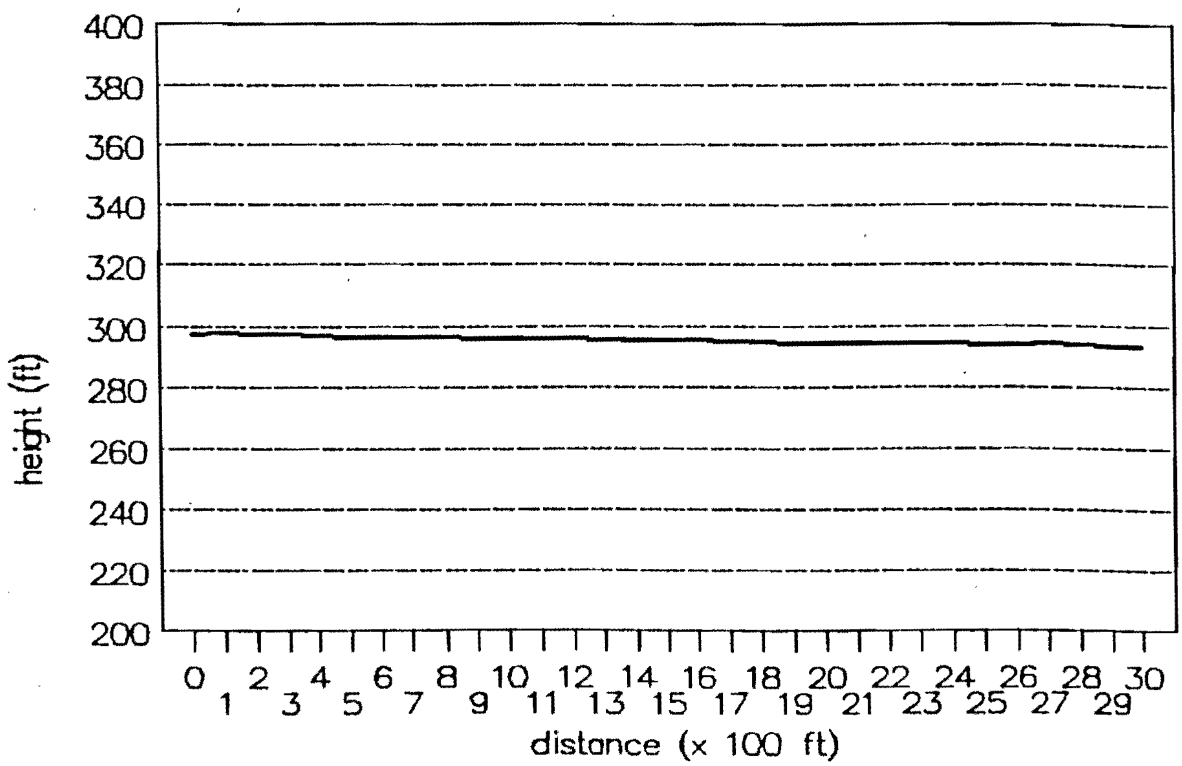

Figure 5: Longitudinal profile of Supply Channel New Passu

Table 1: Conveyance and distribution efficiencies

systems	conveyance or distribution (c or d)	number of measurements	average length of canal section (m)	average efficiency (%)	average efficiency per 100 m (%)
Old Passu	d	2	500	80	96
Old Khaiber	c	5	240	94	97
Old Soust	d	3	500	75	95
New Passu	c	4	2940	87	100
	d	5	330	96	99
New Khaiber	c	5	1140	90	99
New Soust	c	1	980	96	100
	d	10	670	72	96

Table 2: Application efficiencies, non-uniformities and some other parameters for wheat and barley fields

systems	number of cases	average efficiency (%)	average non-uniformity (%)	average degree of farmer intervention (1-5)	average PAW before irrigation (%)	average flow at field inlet (cusec)
Old Passu	5	9	33	1.8	83	0.35
Old Khaiber	6	5	51	3.2	75	0.27
Old Soust	6	8	45	2.5	72	0.19
New Passu	6	8	49	3.2	41	0.20
New Khaiber	1	25	49	5	15	0.14
New Soust	10	14	41	3.8	39	0.12

Table 3: Statistical analysis of application efficiency and non-uniformity as dependent on PAW and slope respectively for wheat and barley fields

systems	application efficiency vs.: number of cases	application efficiency vs.: average PAW before irrigation	non-uniformity vs.: number of cases	non-uniformity vs.: average slope
Old Passu	5		3	
corr.coeff.		-0.64		-0.91
probability		0.24		0.28
Old Khaiber	6		6	
corr.coeff.		-0.91		-0.84
probability		0.01		-0.04
Old Soust	6		5	
corr.coeff.		-0.47		-0.35
probability		0.34		1.0
New Passu	6		4	
corr.coeff.		-0.23		not defined
probability		1.0		
New Khaiber	1		1	
corr.coeff.		not defined		not defined
probability				
New Soust	10		8	
corr.coeff.		-0.32		-0.43
probability		1.0		0.29
NEW	17		12	
corr.coeff.		-0.31		-0.37
probability		0.21		0.23
OLD	17		14	
corr.coeff.		-0.75		-0.62
probability		0.00		0.02
ALL	34		26	
corr.coeff.		-0.57		-0.44
probability		0.00		0.03

Table 4: Application efficiencies, non-uniformities and some other parameters for potato fields

fields	number of cases	average efficiency (%)	average non-uniformity (%)	average length of furrow (ft)	average application time per furrow (min)	average flow per furrow / length (10^-4 cusec /ft)	average flow at field inlet (cusec)	average s (log t-log 1cum)	average degree of farmer intervention (1-5)	average PAW before irrigation (%)
ALL OLD	9	12	43	112	55	2.6	0.087	0.87	3.6	51
OLD ZIGZAG	7	9	52	125	19	3.2	0.074	0.68	3.1	54
ALL NEW	5	6	46	200	52	3.5	0.116	0.73	2.4	47
ALL	14	10	44	143	54	2.9	0.097	0.83	3.1	50
ALL ZIGZAG	12	8	50	156	33	3.3	0.091	0.70	2.8	51

Table 5: Statistical analysis of application efficiency as dependent on length of furrow, flow at field inlet, slope (log t - log Icum), farmer intervention and PAW for potato fields

		application efficiency vs.:				
fields	number of cases	average length of furrow	average flow at field inlet	average s (log t- log Icum)	average degree of farmer intervention	average PAW before irrigation
ALL OLD	9					
corr.coeff.		-0.293	-0.404	0.050	0.155	-0.353
probability		1.0	0.280	1.0	1.0	1.0
OLD ZIGZAG	7					
corr.coeff.		-0.199	-0.435	0.657	-0.629	-0.574
probability		1.0	0.329	0.109	0.129	0.177
ALL NEW	5					
corr.coeff.		-0.486	-0.882	-0.887	0.921	-0.508
probability		1.0	0.048	0.044	0.026	0.384
ALL	14					
corr.coeff.		-0.320	-0.503	-0.221	0.354	-0.340
probability		0.284	0.068	1.0	0.213	0.234
ALL ZIGZAG	12					
corr.coeff.		-0.374	-0.625	-0.090	0.214	-0.496
probability		0.230	0.029	1.0	1.0	0.101

Table 6: Statistical analysis of application non-uniformity as dependent on application time, flow per furrow-length and farmer intervention for potato fields

fields	number of cases	application non-uniformity vs.: average application time per furrow	average flow per furrow / length	average degree of farmer intervention
ALL OLD	9			
corr.coeff.		-0.841	0.730	-0.894
probability		0.004	0.025	0.001
OLD ZIGZAG	7			
corr.coeff.		-0.536	0.484	-0.761
probability		0.215	0.271	0.046
ALL NEW	5			
corr.coeff.		-0.910	0.952	0.817
probability		0.031	0.012	0.091
ALL	14			
corr.coeff.		-0.842	0.825	-0.195
probability		0.000	0.000	1.0
ALL ZIGZAG	12			
corr.coeff.		-0.776	0.798	0.266
probability		0.003	0.001	1.0

Table 7: Irrigation frequencies, depths and water use (per season)

systems	WHEAT and BARLEY average number of irrigation turns	WHEAT and BARLEY average irrigation depth (inch)	WHEAT and BARLEY total water use per season (inch)	POTATOES average number of irrigation turns	POTATOES average irrigation depth (inch)	POTATOES total water use per season (inch)
Old Passu	14	2.3	35	13	1.0	13
Old Khaiber	16	2.4	38	12	1.3	16
Old Soust	14	2.8	39	14	0.9	13
OLD average	15	2.5	37	13	1.1	14
New Passu	19	1.8	34	24	0.7	19
New Soust	16	1.7	27	15	2.0	30
NEW average	18	1.8	31	20	1.1	24
average	16	2.2	35	16	1.1	18

Table 8: Statistical analysis of application efficiency as dependent on irrigation depth

systems	application efficiency vs.: irrigation depth at wheat and barley fields	irrigation depth at potato fields
Old Passu		
corr.coeff.	-0.808	
probability	0.098	
Old Khaiber		
corr.coeff.	-0.512	
probability	0.299	
Old Soust		
corr.coeff.	-0.795	
probability	0.058	
New Passu		
corr.coeff.	-0.560	
probability	0.247	
New Soust		
corr.coeff.	-0.432	
probability	0.212	
OLD		
corr.coeff.	-0.626	-0.222
probability	0.007	1.0
NEW		
corr.coeff.	-0.427	-0.868
probability	0.087	0.056
ALL		
corr.coeff.	-0.558	-0.288
probability	0.000	0.318

Ta[illegible] e 9: Soil properties (as averages of the different fields per system)

systems	average soildepth (inch)	sample depth (inch)	average clay (%)	average silt (%)	average sand (%)	USDA class	saturation (%)	K (ppm)	P (ppm)	Ca + Mg (ppm)	EC (x10^-3)	organic matter (%)	pH
Ol Passu	19												
		0-6	7	11	82	LS/S	34	230	23	2.0	2.3	1.9	7.8
		6-12	8	14	78	LS	36	175	16	1.8	2.1	1.4	8.0
		12-18	9	8	85	S	44	118	14	1.5	1.7	0.8	8.0
Ol[illegible] Khaiber	10												
		0-6	13	18	69	LS/SL	40	103	14	2.1	2.3	1.0	8.2
		6-12	13	18	69	LS/SL	40	118	9	2.0	2.2	1.0	8.2
Ol[illegible] Soust	24												
		0-6	8	8	83	LS	32	118	25	3.5	3.7	1.8	8.1
		6-12	7	11	81	LS	34	192	25	3.3	3.8	1.5	8.1
Ne[illegible] Soust	4												
		0-6	5	4	91	S	30	274	22	1.4	2.1	0.4	8.3
		6-12	3	3	94	S	35	365	23	1.5	2.8	0.8	8.2
N[illegible] Khaiber	9												
		0-6	11	13	76	LS	33	79	5	1.0	1.3	0.4	8.3
		6-12	5	6	89	S	38	95	5	1.2	1.5	0.5	8.3
		12-18					28	51	3	1.0	1.2	0.2	8.4
New Soust	7												
		0-6	7	7	87	S	34	297	11	1.3	1.9	0.2	8.4
		6-12	7	8	85	S	30	175	10	5.4	5.8	0.2	8.3
		12-18	8	6	87	S							
O[illegible]	1.5 ft												
		0-6	9	12	78	LS	35	171	21	2.5	2.8	1.5	8.0
		6-12	9	15	78	LS	37	162	17	2.4	2.7	1.3	8.1
		12-18	9	6	85	S/LS	44	118	14	1.5	1.7	0.8	8.0
N[illegible]	0.5 ft												
		0-6	7	8	85	S	32	217	13	1.2	1.8	0.3	8.3
		6-12	5	8	90	S	34	212	13	2.7	3.3	0.4	8.3
		12-18	8	6	87	S	28	51	3	1.0	1.2	0.2	8.4

Table 10: Statistical analysis of application efficiency as multiple dependent on two sets of parameters for potato fields

fields	number of cases	application efficiency vs.: average flow at field inlet	application efficiency vs.: average PAW before irrigation	application efficiency vs.: average flow per furrow / length	application efficiency vs.: average flow at field inlet	application efficiency vs.: average degree of farmer intervention	application efficiency vs.: average PAW before irrigation
ALL OLD	9						
multiple R		0.517		0.917			
probability		0.31	0.38	0.01	0.00	0.28	0.37
OLD ZIGZAG	7						
multiple R		0.620					
probability		0.57	0.30				
ALL NEW	5						
multiple R							
probability							
ALL	14						
multiple R		0.580		0.781			
probability		0.07	0.25	0.05	0.00	0.19	0.18
ALL ZIGZAG	12						
multiple R		0.728		0.728			
probability		0.03	0.13	0.98	0.15	0.98	0.20

VIII SUMMARY

Current system performance was evaluated in six irrigation systems in Hunza-Gojal: three traditional, well established ones and three new systems, which were constructed and developed with support from the Aga Khan Rural Support Programme. The sample irrigation systems are located in three villages, Passu, Khaiber and Soust with in each of these an old and a newly established irrigation system.

Special attention was given to the assessment of conveyance losses in new channels as compared with those occurring in the older channels, and to the determination of application efficiencies at field level. The methods of assessing the system performance included the use of questionnaires and the measurement of physical parameters which permitted the calculation of conveyance, distribution and application efficiencies.

The environmental setting of the irrigation systems in Hunza-Gojal is described in terms of the physical environment, the predominant features of the soils in the cultivated areas and the agricultural practices. Availability of labour in the area is studied as it is expected that farm labour may be scarce, especially in those villages where alternative employment may be found through tourist-oriented activities.

The six irrigation systems are described in detail. The source of the water is in most cases melt water from snow and/or a glacier and for the channel at New Khaiber the source is the Hunza River itself. The sizes of the command areas and specifics of the approach channel, the conveyance channel and the distribution systems are given. Moreover, the operation and maintenance of the systems is described. In some systems chowkidars are employed for (parts of) the flow regulation and maintenance chores, in other the farmers attend to these activities themselves on a roster basis.

It was found that water scarcity did not affect system performance. At most, scarcity occurred during the first few weeks of the growing season. Usually water was not wasted either; what may appear to be lost often benefitted the production of grasses, shrubs and trees, which are used for fodder, timber and firewood, or contributed to soil formation through silt deposition.

The conveyance efficiencies attained in the new channels did not differ from those in the old channels. Sealing of channel beds in new systems was helped by the fact that the design slope of the new channels is less than the slope in the older channels.

The calculated values of the application efficiencies in grain fields and potatoes in both old and new schemes were low. The factor which most markedly affected application efficiency in the case of grains is the available water in the root zone at the time of irrigation. In case of potatoes, no single factor could be identified that influenced the application efficiencies most. Here it is a combination of four factors, average flow per furrow length, average discharge at field inlet, degree of farmer intervention and available water in the profile at the time of irrigation. It was observed that one farmer who planted his potatoes on straight furrows rather than the generally practiced zig-zag furrows, attained a higher application efficiency.

From a comparison with soils for which the hydraulic characteristics are known and which are assumed to be similar in behavior to the soils of Hunza-Gojal, it was tentatively concluded that leaching of nutrients under the current irrigation practice for potatoes in ridges is probably not excessive. For grains much depends on the presence of a (nearly) impermeable layer just below the root zone, but it is estimated that under the most unfavorable circumstances leaching of nutrients in grain fields could be substantial.

Based on the results reported, it is recommended that some parts of the new channels are stabilized in order to ensure the sustainability of the systems. It concerns here the left bank of the New Passu channel, parts of New Khaiber channel, where small mountain streams cross the channel, and the ill-defined flow channel between the upper terraces and the lower river terrace of the New Soust scheme.

It is felt that improvements in application efficiency could be attained, provided farmers are motivated to change the irrigation practices. Savings in water are likely to reduce labour requirements, as less frequent irrigation would suffice, decrease nutrient leaching and provide water for possible future expansion of the command areas. Agricultural extension and demonstration plots at farmers fields may be required to implement changes in irrigation practices.

IX ACKNOWLEDGEMENTS

The financial support provided for this study by Aga Khan Foundation, Canada and the Canadian International Development Agency (CIDA) is gratefully acknowledged.
Gratitude is expressed to the management and supporting staff of the AKRSP office in Gilgit for the logistic and moral support so generously provided to the members of the field team and to the visiting IIMI staff members.

Profound thanks are expressed to the members of the 'Hunza field team', R. Afaq, M. Anees, E.J. Huyskes and P. Klop for their persistent efforts in data collection in the sample irrigation systems and for their untiring support during the hectic days of data analysis and report writing.

ANNEX 1

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Annex 2: Sample questionnaires

<u>- Questionnaire for sample farmers</u>

Interviewer:
Date & place:

Farmer's name:
His position in the village:
Total holding: in old system:
in new system:
elsewhere:
Cultivated area:
Present cropping pattern: old:
new:

How does he determine when he may irrigate?
Is night irrigation practiced?
in old system: yes / no / sometimes
when:
why:
in new system: yes / no / sometimes
when:
why:
Experience of water shortage?
in old system: yes / no / sometimes
when:
why:
in new system: yes / no / sometimes
when:
why:
Is water distribution controlled in the old system? And in the new system?
if yes, who controls it?
what is the method of control?
is distribution controlled throughout the season?
if no, why not?
Can farmers exchange irrigation turns?
if yes, how:
Does the farmer inspect the channel before or during irrigating?
if yes, which part of the channel?

How frequent is the channel maintained collectively in the old system? And in the new system?
who controls it?
who arranges emergency maintenance?

Is irrigation discussed at meetings of the village organizations?
Which are the problems and how these are resolved?

Is the farmer satisfied with channel performance?
if not, why?
Farmer's suggestions for improving (main and distribution) channel performance for old and new systems:

- Questionnaire for chowkidars

Interviewer:
Date & place:

Chowkidar's name:
His position in the village:

Total period of duty:
Daily timings of duty:
Which are his specific tasks on the main channel?
How many times a day he regulates the flow at head?
When he increases discharge?
When he decreases discharge?
For what reasons?
How does he regulate the flow at head?
Does he daily check the whole length of the channel for leakage or damage?
  if yes: how many times a day?
  if no: which part of the channel is checked?
Can he point out which parts of the channel are more liable to damage or leakage?
Does he have any role in water distribution?
  if yes: which?

Total number of chowkidars:
Is there any rotation among the chowkidars?

Who is responsible for his/their appointment?
What is his remuneration?

Is the chowkidar staisfied with channel performance?
  if not: why?
Chowkidar's suggestions for improving channel performance:

Annex 3: System characteristics

	OLD SYSTEMS			NEW SYSTEMS		
	OP	OK	OS	NP	NK	NS
watersource	Passu glacier	spring snow	snow	Batura glacier	Hunza river	snow
usual silt load	fair	low	high	high	high	fair
variability [1]						
year to year	no	no	yes	yes	yes	yes
seasonal	no	no	yes	yes	yes	yes
day to day	no	no	yes	yes	no	yes
diurnal	no	no	yes	yes	no	yes
net command area (acres) [2]	36	45	40	35	30	43
type intake	diverting wall					
approach channel				n.a.		n.a.
length (ft)	2000	1000	400		2700	
slope	steep	0.014 [3]	0.025		0.004 [3]	
bed material	rocky	rocky	stony		silty	
stability	+	+	<>		+	
leakages	much	none	much		much	
overtopping	much	none	little		none	
supply channel	n.a.					
length (ft)		800	300	12700	7000	3100
slope		0.014	0.010	0.002	0.004	0.001 [3]
bed material		rocky	gravelly	silty	silty	silty
stability		<>	+	-	-	<>
leakages		none	little	little	little	little
overtopping		none	none	little	none	none
seepage		little	little	little	little	little
distribution channel(s)						
length (ft)	15000	4000	2200	8500	4000	5800
slope	0.004	0.053	0.060	0.011	0.001 [3]	>0.01 [4]
bed material	stony	stony	stony	gravelly	silty	gravelly
stability	+	+	+	<>	<>	-
leakages	little	little	little	little	little	little
overtopping	none	much	little	none	fair	little
seepage	little	little	little	little	little	little
water shortages	no	no	yes	some	yes	yes
when	n.a.	n.a.	early spring+ weather	early spring	A,S	early spring+ weather

	OLD SYSTEMS			NEW SYSTEMS		
	OP	OK	OS	NP	NK	NS
rotation with other channel	no	no	yes	no	no	no
when	n.a.	n.a.	early spring+ weather	n.a.	n.a.	n.a.
how	n.a.	n.a.	1/2	n.a.	n.a.	n.a.
among fields	no	yes	yes	no	no	yes
when		early spring	<always>	n.a.	n.a.	always
how	n.a.	5/20	12/24	n.a.	n.a.	7+8/60
max. discharge	3	5	6	6	4	3
means of flow regulation at head	rocks	rocks	gate	gates plank rocks	gates	rocks
usual frequency of regulation (p. day)	0	2	>2	3-4	2	2
efficiency of regulation	<>	+	+	<>	<>	<>
# of chowkidars	0	1	0	4	0	0
role in water distribution	n.a.	no	n.a.	yes [5]	n.a.	n.a.
silt problem	no	little	big	no	no	fair
desiltation tank	no	yes	yes [6]	no	no	no
field-basins	no	yes	yes	no	no	no
night storage	no	no	yes	no	no	no
night irrigation	some	some	some	some	no	no
drainage	+	+	+	<>	-	<>
coll maintenance frequency	0	0	1	1	1	1
patrolling of appr + supply	no	no	yes	yes	yes	yes
distribution	no	no	yes	some	yes	some
other uses water						
domestic	yes	yes	yes	no	no	no
mills	yes	no	yes	no	no	no
soil building	no	yes	no	no	yes	yes

1) variability of irrigation water availability requiring operational interventions
2) this refers to the actually irrigated area
3) reasonably estimated (not surveyed)
4) this average figure gives a wrong idea as it is composed of stretches of 0.009, 0.030 and the very steep drop (see text)
5) water distribution to trees along channel and at bifurcation
6) a desiltation tank is being constructed and will probably be completed by the end of the year (1989) at the latest

high, fair, low	rating 1
much, fair, little, none	rating 2
+, <>, -	rating 3 for good, mediocre, poor
n.a.	not applicable