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Water conservation through water-course improvement

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ABSTRACT

On-Farm Water Management Program was initiated in the country in 1976. One of the components of the programme was to reduce losses in the watercourses thereby increasing water availability at the farm gate. Quite a few thousands of watercourses have since been improved. Based on the analysis of monitoring data available a procedure has been developed to predict the operational losses for unimproved watercourses. In addition, this paper reviews the watercourse improvement and the resultant magnitude of water conservation. It is observed that the watercourse improvement is being attended partially and the water conservation estimate per watercourse are on the higher side.

INTRODUCTION

Purpose and Scope

In the past the investments in the Water Sector mainly focussed on development of additional water to increase crop production. It was assumed that the water already made available to the farmers through a network of unlined distribution system is being delivered efficiently and also used effectively at the farm level. Post project Scarp monitoring, however, indicated that the anticipated increase in cropping intensity is not being achieved and the need to investigate the causes is imminent. The Water Management Studies, therefore, were initiated in 1973 by WAPDA at its Mona Reclamation Experimental Project (MREP) with the assistance of Colorado State University (CSU). Conveyance losses in over 250 sections of 9 watercourse systems were measured through inflow outflow method and it was found that the losses were much more significant than earlier assumed figure of 10% used for design purposes. In view of these findings the Government of Pakistan with assistance from the international community initiated pilot On-Farm Water Management (OFWM) program which included watercourse improvement. Monitoring and Evaluation of this program is being carried out by various agencies and wide variety of benefits are being claimed.

The purpose of this paper is to make a dispassionate critical review of the information available and determine magnitude of water conservation being achieved through watercourse improvement.

Delivery System Below Mogha

The command of a distributary/minor for purposes of further distribution of irrigation supplies is divided into sub-commands, measuring 300 to 900 acres depending upon topography. These sub-commands, termed as 'outlet chaks', are supplied water from the canal through a canal outlet also called 'Mogha'. Canal commands in which lands originally belonged to the state, the outlets chaks were divided in squares or rectangles and an earthen channel from outlet point known as "Watercourse", "Sanctioned Watercourse" or "Sarkari Khal" was laid in such a fashion that it passes by each square. Position of a water offtake point in this earthen channel is identified for each square of land or holding and is called 'Nakka' or 'Sanctioned Nakka' for that square of land or holding. The position of 'watercourse' and 'Nakka' cannot be altered by the cultivators and its maintenance is the joint responsibility of the share holders. Water from 'Nakkah' is diverted by each

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farmer to his field through another channel, called 'farmer's channel or 'field channel' the maintenance of which is his individual responsibility.

The water delivery system below outlet is thus basically divided into two parts i.e. 'watercourse' or government laid out channel; and the "farmer's channel" which lead from the watercourse nakka to the individual fields. The original intent of the Watercourse/Sarkari Khal was to deliver water to a side or corner of each farmer's land. Each farmer was given a 'Nakka' from Sarkari Khal from which he would built his own channel to carry water to his fields. Over time, with land ownership changes and subdivision, the strict differentiation between Sarkari Khal and farmer's channel. However, there is still an understanding among the farmers between which portion of the watercourse system belongs to the community or government and which are their own channels.

The water from the watercourse (Sarkari Khal) is taken according to a schedule known as 'Warabundi", which prescribes turn and the time for each share holder. Normally, one complete cycle of Warabundi has 7 days duration. Warabundi is either sanctioned or non-sanctioned. Sanctioned Warabundi is prescribed by the canal officer at the request of the cultivators and becomes a binding on all share holders and cannot be altered. The non-sanctioned Warabundi is mutually laid by all the share holders and the canal officer does not interfere into it unless a complaint is lodged.

The total length of a Sarkari Khal varies according to size of the outlet chak. The watercourse (Sarkari Khal) may have one or more branches depending upon the layout controlled by topographic features. The general design yard stick is that the Sarkari Khal or any of its branch should not be more than 10,000 feet long. The total length of water channels comprising Sarkari Khal and farmer's channel running on one or two sides of each acre of land and on the average it requires about 150 to 200 feet of water channel per acre of land irrigated, of which, 15% is the Sarkari Khal and remaining is the farmer's channel. Nearly 80% of the channle utilized to reach any one field is Sarkari Khal. During each Warabundi period whole of Sarkari Khal and some percent of farmer's ditches (40 to 60%) are used to irrigate about 20 percent of the commanded land.

During each Warabundi period entire Sarkari Khal comes under use but for different lengths of time as shown in Fig. 1. Utilization of Sarkari Khal and farmer's channel of five sample outlets based on an operational loss study data extending over 3 Warabundi cycles is given in Table 1. The weighted average length of Sarkari Khal and farmer's branch utilized was 1090 (33%) and 310 (3.5%) meter respectively.

During planning of lower Rechna Remaining (SCARP V) and pilot 'Command Water Management' projects data of 108 sampled outlets was collected alongwith their Warabundi schedule and the relevant statistics is summarized in Table. 2.

The effective length has been calculated by the equation (1) and can be defined as the length which if remain in use for entire Warabandi period would result in water loss equal to that occuring from the Sarkari Khal during the same period. The effective length as percent of total length for sampled outlets vary from 18 to 35 percent with a weighted average of 21 percent.

$$\bar{L} = \frac{\Sigma L_1 t_1}{L} \qquad (1)$$

where; $\bar{L}$ = effective length;

L_1 = length of Sarkari remained in use for period t_1

t_1 = time for which Sarkari Khal length L_1 remained in use;

L = Total length of Sarkari Khal

On-Farm Water Management Programme

The On-Farm Water Management Program (OFWM) components in general include earthen-cum-lining improvement of the Sarkari Khal and providing cement concrete nakkas; precision land levelling, demonstration plots and On-Farm Water Management training. The broad objective of this programme is to minimise the water losses both in the conveyance system and at the field and that its impact would indirectly emerge in control of waterlogging, increased agricultural production and prosperity of the farming community.

In 1977 Government of Pakistan initiated a USAID financed OFWM programme for implementation through the Provincial Agriculture departments under the overall control of the Federal Ministry of Food and Agriculture & Co-operatives. The other institutional arrangements to implement the programme included creation of Federal Water Management Cell in the Ministry and establishment of On-Farm Water Management Directorates in the Provincial Agriculture Departments.

The watercourse improvement programmes pursued included two types of improvements:

a) *'Regular Technology:* It includes demolition and complete rebuilding of the Sarkari Khal after removal of trees and bushes, construction of culverts at major crossings and buffalow-wallows, lining of some percent (10 to 30%) of the Sarkari Khl and installation of prefabricated nakkas at junctions and authorised water off-take points (Sanctioned Nakkas).

b) *Accelerated Technology:* It includes heavy cleaning of the Sarkari Khal and installation of limited number of pre-fabricated nakkas at the authorised water off-take points. This earthen improvement includes removal of trees and bushes; desilting of channels, strengthening, straightening and raising the banks at required places, restoring a relatively uniform cross-section and improvement of deteriorated junction points.

The USAID financed OFWM programme was followed by other similar programmes through World Bank (IDA/IFAD), Asian Development Bank (ADB) etc. In addition to own contribution by the Government of Pakistan and farmer's input in the form of free labour and cooperation in the project. As the programme continued, watercourse improvement was also made an essential component in sone of the on-going and new drainage projects. A brief statistical review of the various On-Farm Water Management Programmes projects specifically related to watercourse improvement is given in Table (3)

CONVEYANCE LOSSES BELOW MOGHA

Loss Measurement Units

Factors effecting losses from the watercourses are numerous and have been thoroughly discussed by Thomas J. Trout (6) which can be referred for further understanding. Of the several

different units to describe water losses the most prominent are:

- Loss per unit of wetted perimeter;
- Percent of inflow lost in the system;
- Loss per unit length of the system.

All the above units have their inherent weaknesses. The seepage into the wetted perimeters assumes that infilteration rate into all portions of the wetted perimeter is uniform, a condition usually applicable to large canals and not necessarily true in case of watercourses. Similarly, the percent of inflow loss unit is system specific and is not generalizable to other conveyance systems. It is most useful for describing the efficiency of a conveyance system and least useful for understanding water losses. Water loss on per unit length basis is a more representative unit though it also suffers from the disadvantage of its inability to compare losses from channels of different sizes and capacities. However, this unit has the added advantage of being the actual measured parameter in most cases and can be generalized to total water losses from a given conveyance system by knowing the system length and the time utilized.

Losses in Sarkari Khal

Losses from the water courses were earlier used to be considered as the steady state seepage loss from the wetted perimeter and estimated about 10%, though some of the Investigators did estimate as high as 28% including farmers' ditches (9). To determine these losses generally ponding studies were carried i.e. uniform well defined straight reach of the watercourse selected and bunded from both sides and water ponded into, and the loss rate estimated. Two such recent studies, one carried by the Hunting Technical Services on 11 watercourses, during Lower Indus Project studies (1) and the other by the Punjab Irrigation Research Institute on 12 watercourses (4) are available. The loss rate estimated vary from 1.6 to 8.3 with an average of about 5 cubic feet per second per million square feet (cfs/msf) of the wetted perimeter. If an average wetted perimeter of about 5 feet is assumed then the loss rate per thousand feet would be of the order of 0.025 cubic feet per second.

The losses in a watercourse comprise many components such as steady state and transient seepage into the wetted perimeter, leakage through rat holes, spillage due to over topping and water retained as dead storage after portion of the water channel is drained etc. The watercourse losses in the recent past, therefore, have been studied from a different angle that is to measure the losses, as it is, in the running watercourse through inflow-outflow method and without preventing leakages through spongy banks or spillage due to over topping by poorely maintained watercourses. The argument is that in addition to genuine seepage losses avoidable losses occur due to poor watercourse maintenance by the farmers and does reduce the amount of water reaching nakkas.

Many agencies have made sporadic measurements some of which are poorly recorded and all sorts of losses magnitude are now available. However, certain special surveys specifically designed for the purpose have now generated a data base which can be relied upon for losses information and are:

1. Losses measurement on 29 sample watercourses during planning of Lower Rechna Remaining (LRR) Project (1977-78);
2. 61 watercourse survey carried for Revised Action Planning (1978);
3. Pre-project bench mark data of 45 Nos. sample watercourses selected for post project

monitoring of USAID Pilot Project; (1980)

4. Pre-project bench mark data of 45 watercourses (20 for regular technology and 25 for accelerated technology), selected for post project monitoring of IDA/IFAD On-Farm Water Management Programme, Phase–1.

In study 2 to 4 the water loss estimation is based on delivery efficiency of the sample farms selected at head, middle and tail of the watercourses, while the study I was primarily aimed at measuring the water loss over a length of the Sarkari Khal to estimate the loss per unit length. The loss data of the studies '3' and '4' has been reanalysed to determine the loss per unit length. The Variation in loss per 1000 feet with discharge and distance for the two studies are given in Table 5 and 6. The perusal of these tables would indicate that there is wide variation in loss rate and rightly so as there are innumerable physical and human factors which can affect the rate. Regression analysis of several stepwise multiple regression models were used to ascertain the most important factors explaining variation in loss rate per 1000 feet. (7) The factors in order of importance are the length over which the loss is measured and the mogha discharge. Regression analysis of the conveyance efficiency data both linearly and exponentially with distance was earlier carried out. The two models described the data equally well, however, it was found that the relationship between loss rate and normal inflow rate is best described by the following equation:

$$Q_x = Q_e - Rx \qquad (2)$$

where;

Q_x = discharge at any section distance 'x' from the source.
Q_o = discharge at inflow point;
'R' = loss exponent considered constant over the section 'X'
'X' = length of section over which loss measured in 1000 feet.

The equation (2) can be rearranged to determine the loss exponent (R) and the loss rate (q_L) per 1000 feet:

$$R = \frac{\ln Q_o/Q_x}{X} \qquad (3)$$

$$q_L = Q_o(1-e^{-R}) \qquad (4)$$

Loss exponent determined from the data of various studies is given in Table 7. It is observed that the value of 'R' is higher for smaller distances. One apparent cause for higher values is the difficulty in accurately measuring small changes in discharge with the cut throat flume under field conditions. In IDA/IFAD project (regular) more than 50% measurements are for distances less than 3000 feet and thus do not represent average condition. Neglecting odd measurements the average value of loss exponent for Sarkari Khal (R_s) from these studies can be taken as 064. Inserting this value in equation (4) the average loss rate in Sarkari Khal (qLs) per 1000 feet is given by the following equation:

$$q_{Ls} = .062\ Q_o \qquad (5)$$

The average loss per 1000 feet from equation (5) comes to 6.2% of the inflow discharge which compares favourably with 6% determined in loss Study in Sahiwal district (3).

The data analysed and given here is based on the steady-state measurements made at one point of time and therefore does not record.

* transient seepage into wetted perimeter;

* dead storage;

Total loss (operational losses) measurement is only possible if these are measrued over 2–3 warabandi cycles continuously following the water where it goes.

As this is a time consuming process, therefore, it had been carried out under a separate study on 5 sample watercourses detailed in Table 1. The summary of result of this study is as under and the flow diagram given in Fig 2(7)

The weighted average (i.e. effective length) length of Sarkari Khal used in the above study was 1090 meter (3574 feet). Reference equation (5) the percent water lost-in this effective length can also be calculated as:

$$\% \text{ Water lost} = 6.2 \times 3.574$$
$$= 22.2\% \text{ of } Q_o$$

This represents the steady state seepage loss, leakages/breaches and compares favourably with 21.2% determined through actual study. It is, therefore, concluded that the steady state seepage loss for any unimproved Sarkari Khal can be estimated if its average loss exponent and effective length is available. For total operational loss another 4% may be added to account for other losses as detailed above (Table 8).

Losses in Farmer's Channel

On the basis of similar analysis as done for Sarkari Khal the average loss exponent (R_f) for the farmer's channel is given in Table (9) as below:

The average value of 'R_f' for farmer's channels is 0.213. Equation for farmer's channel can be arranged as:

$$q_{Lf} = Q_f\ (1 - e^{-.213})$$
$$= 0.192\ Q_f$$

where;

q_{Lf} = average loss per 1000 feet in farmer's channel

Q_f = discharge delivered to farmer's channel

From the above it is estimated that the steady state loss per 1000 feet in the farmer's channel is 19.2 percent of water delivered to farmer's channel. The effective length of farmer's channel is only 310 m (1016 ft) and the percent loss is as under:

$$\%\text{water lost} = 19.2 \times 1.016$$
$$= 19.5\% \text{ of } Q_f$$

Converting this to Mogha discharge ($Q_f = 0.75\ Q_o$) it comes to 14.6% as compared to 15.84% determined in the operational loss study. To determine total loss in farmer's channels nearly 3% other losses may be added.

Total losses

The steady state seepage loss estimated for the Sarkari Khal and farmer's channel is as under:

Sarkari Khal	=	22.20 percent
Farmer's channel	=	15.6 percent
(Total)	=	36.80 percent

Nearly 7% other losses covering evaporation, dead storage, transient seepage etc. are to be added to the steady state seepage losses bringing the total loss to 44 percent which is quite comparable to the operation loss study.

The delivery efficiency determined in the operational loss study for Sarkari Khal, farmer's channel and overall would be as under:–

	Delivery Efficiency
Sarkari Khal	75%
Farmer channel	73%
Overall	55%

It is, therefore, concluded that through determining average loss exponent (R) for Sarkari Khal and farmer's channel and knowing effective length of Sarkari Khal and authorized discharge, it is possible to predict the operational losses.

WATERCOURSE MONITORING RESULTS

Background

In order to monitor the benefits of the OFWM program Monitoring and Evaluation was considered necessary both to satisfy the donor agencies and also for continued improvement of the programme. Two OFWM projects one funded by USAID and the other by IDA/IFAD were picked up for the purpose. Three stage random sampling was made to select distributaries, watercourses and farms. In all 45 watercourses under USAID project (including 9 control) and 45 under IDA/IFAD project (20 for regular and 25 for accelerated) were selected. Pre and post project monitoring and evaluation has been carried out and reports published. The monitoring in addition to agro-socio-economic impact also observed the improvement in delivery efficiencies and the resultant water saving. Main observations with respect to improvement and water conservation are briefed here.

Watercourse Improvement

Watercourse improvement included part lining, earthen improvement, installation of precast nakkas and culverts. The percent of a watercourse (Sarkari Khal) improved varies but the average of the sample in both projects is briefed as under:

From the information given in monitoring reports of 29 Sarkari Khals under USAID project, 20 had branches covering 36 percent of total length.

Delivery Efficiency

To determine the pre and post improvement data on water losses instead of measuring the losses over a complete warabandi cycle only spot measurements were made with respect to the farms selected at head, middle and tail. Three flumes were used one at the head to determine inflow, one at farm nakka to determine water going to farmer's channel and the third at the point where water enters the field. It further appears that in case of branched watercourses only main branch of the watercourse was observed as the data only reports the efficiency of "main watercourse". The results of the two studies is briefed in Table 11.

Delivery efficiency calculated from flume at source and at farm nakka has been termed as delivery efficiency of "main watercourse". The efficiency calculated from flume at source and at field nakka has been termed as "overall".

Water Saving

On the basis of pre and post improvement delivery efficiency determined, following increases in supply through saving in losses in main watercourse and farmer's channel has been envisaged (12,13):

During preparation of Seventh Plan the Committee estimated the annual saving of water loses per watercourse as given in Table–13.

It is, therefore, obvious that estimation of losses saved on volumetric basis is being calculated from the delivery efficiencies determined on the basis of the monitoring results derived as this is the only properly organized monitoring study available in the country.

Optimization of Watercourse Improvements

In resource scarce environments it is necessary that envisaged improvements be optimized to obtain the desirable return economically. Watercourse improvements being carried out presently is using two technologies i.e. pucca lining a part of the watercourse and earthen improvement of the remaining portion. The question arises as to which part of the watercourse should be lined and at what point the lining technology should give way to earthen improvement technology. The answer to this question can be found in the conventional economic theory i.e. one would only wish to apply these to reaches on which the net return is positive. Optimization of watercourse improvement has been studied at length by Reuss which can be referred for details. Based on the linear loss model the time for which a part of the channel should remain in use during a warabundi to justify lining is given by the following equation:

$$t = \frac{168\,(c' - c'')}{VKQ_o\,(F' - F'')} \qquad (6)$$

where;

Q_o = Mogha discharge (cfs);

t = time in hours the channel should remain in continuous use during a warabandi period;

c' = Annual cost of lining (Rs/foot);

c" = Annual cost of earthen improvement (Rs/foot);

f' = percent of losses saved by lining;

f" = percent of losses saved by earthen improvement;

k = percent loss rate per 1000 feet;

v = marginal value of water (Rs/acre foot).

The percent of length qualifying for lining decreases with decrease in Mogha discharge and increase in number of branch watercourses. A situation may arise where even earthen improvement strictly from economic stand point may not remain justified. The hours of continuous operation to justify earthen improvement can be calculated from the following equation:

$$t = 168\ c''/Vf''K\ Q_o \qquad (7)$$

REVIEW OF IMPROVEMENT AND WATER CONSERVATION

Watercourse Improvement

The perusal of the monitoring data (Table 10) indicates that watercourses (Sarkari Khal) have been improved partially leaving their substantial parts unimproved. In the USAID-OFWM project on the average lining was done of 9% and earthen improvement of 69% leaving nearly 22% of the watercourse unimproved. Lining was mainly concentrated on the main branch. Though branch watercourse covered 36% of the total length, yet on the average only 2% was lined. It also appears that the precast nakkas were not installed in the entire watercourse as only 25 per watercourse provided under USAID-OFWM project as compared to 34 under IDA/IFAD–Phase 1 project.

In the IDA/IFAD Phase–1 Project, under regular technology lining on the average was provided for 13% length and earthen improvement for 33%, leaving 54% Sarkari Khal lengths as unimproved. In accelerate technology only 22% length was provided with earthen improvement leaving 78% unimproved and nakka provided were only 8 per watercourse.

It is, therefore, obvious that watercourse improvement programme is proceeding under invisible stresses and strains and is not being implemented in a manner to cover the entire Sarkari Khal including branches.

Monitoring

Monitoring and evaluation of OFWM projects carried out by WAPDA is the only well organized effort to estimate the post-project improvements. Four major monitoring components involved were:

a. Improvement of Watercourses,
b. Precision land levelling,

c. Sociological aspects,
d. Evaluation of training as well as overall program.

The data collected for the purpose of item (a) i.e. watercourse improvement evaluation consists of the following:–

* General feature maps showing watercourse layout, nakka cuts, roads, village sites, "Deras", tubewells, land ownership, farm operators, and division of watercourse into reaches.

* Topographic maps of a grid interval of 100 feet (30.5 meters) for the entire command and 50 feet (15.0 meters) for each of the 6 sample farms.

* Watercourse profile maps showing profile at 100 feet intervals for the main and branch watercourses.

* Crop survey maps showing crops grown during Rabi and Kharif seasons.

* Delivery efficiencies measured by the inflow-outflow method using the cut-throat flume.

* Irrigation requirements measuring soil moisture deficiency by the "touch and feel" method.

* Flow velocity in the watercourse measured by the float method.

* Watertable depth as recorded from open wells.

* Precipitation as monitored at the meteorological station nearest to the sample watercourse.

* Soil samples to a depth of 12 inches from the center of every 13th "Killa" (1.1 acre) for square-bundi watercourses and at 1100 feet, grid on watercourses not having square-bundi.

* Objective yield measurements for wheat from crop cuttings from a 300 square feet plot on each sample farm.

* Source record information such as mogha discharge, canal commanded area, warabandi, etc.

* Land use by season including non-crop uses such as pasture, forest, built-up and water-logged and saline lands (through interview);

* Production by crop, landlord tenant shares, quantity of produce sold and consumed in the home (through interview).

Basic objective of watercourse improvement program was to reduce losses and improve water availability. As delivery efficiency is function of distance, for proper evaluation of improvement and water conservation two options were available:

1. To measure losses following the water covering the entire warabandi period before and after improvement;

2. To determine the average percent water loss per 1000 feet and then estimate the total loss by using the effective equivalent length as calculated from equation (1)

In view of concentrating on collection of a large volume of data not directly connected with this evaluation, important information regarding identification of Sarkari Khal, farmer's channel, number and location of sanctioned nakkas, sanctioned warabandi etc. has been poorly attended. Average delivery efficiency of sampled farms before and after improvement has been used to estimate water saving. The average delivery efficiency is reported of the "main watercourse" not defining what the main watercourse means and why its results be taken as the representative of the entire watercourse. No evaluation of the lining and earthen improvement carried out to see if this was the optimum arrangement as discussed in equations (6) and (7), or more benefits could be derived with same expenditure by adopting different improvement pattern. Saving of losses by lining and earthen improvement has not been identified separately which could provide data for subsequent economic evaluation. For optimization or suggesting change in technology the values of percent of losses saved by lining (f'), percent of losses saved by earthen improvement (f"), useful life of improvement, marginal value of water (V) etc. has not been attempted for the obvious reason of too much attention to other aspects.

The overall deliery efficiency is given by the equation:

$$E_{do} = E_{ds} \quad E_{df} \qquad (8)$$

Where;

E_{do} = overall delivery efficiency
E_{ds} = delivery efficiency of main watercourse
E_{df} = delivery efficiency of farmer's channel

From equation (8) the $E_{df} = E_{do}/E_{ds}$, and using information given in Table (11) it varies from 87–90% before improvement to 90 to 93% after improvement. This indirect value of 'E_{df}' derived is on the higher side and also that no credit for any increase in efficiency of farmer's channel could be attributed to watercourse improvement without extending it beyond farm nakka. It can be aruged that as more water was delivered to the farmers channel therefore this improvement has occured. This reasoning is also not correct as the loss rate tends to increase with increase in discharge (Table 6) and therefore, should result in further decrease in the efficiency.

Estimation of Water Saving

In table (13) an estimate of water saved per watercourse under Regular and Accelerated technology is given. Here again the water saving is estimated at field nakka instead of Farm nakka upto which only the improvement appeares to have been make. The saving at the farm nakka is shown in table 14.

It is, therefore, obvious that water conservation through watercourse improvement is being over estimated even in the most careful monitoring study. Water saving on a country level is even more exaggerated and bears no relationship with the improvement. According to the information available the target and achievement of watercourse improvement of various programs since 1976 is detailed in Table - 3 and summarized below:

Target

Regular	12586
Accelerated	20718

Achievement (30.6.87)

Regular	9016
Accelerated	19971

It may also be noted that many watercourses improved under accelerated program are subsequently taken for regular improvement. If all the target is presumed to have been achieved by end of 6th Plan (June 1988) even then the maximum anticipated saving neglecting the post improvement deteriation would be as detailed below:

Regular	12586 x 82	= 1.03 maf.
Accelerated	20718 x 34	= 0.70 maf.
	Total:–	1.73 maf.

The additional water available at farm gate by end of 5th plan was estimated 3.57 maf increasing to 5.57 maf by end of 6th plan whereas the actual maximum can be hardly more than 1.73 maf by end of 6th plan and that too after neglecting deterioration.

Case Study

Watercourse code number (15) has been picked up at random to explain the process of measurement adopted. The discharge at source (Q_s), at farm nakka (Qf_m) and at field nakka (Qfd) was measured for each of the selected sample farm. The distance from source to farm nakka (L_{fm}) and farm nakka to field nakka (Lfd) during pre and post measurements and the discharges is summarized in Table 15. The loss exponent (R) and delivery efficiencies for each section has been determined for pre and post improvement period and also given in Table 15.

Choice of Indicator

Pre and post improvement comparison can be made through many indicators as:

- Loss exponent 'R'
- Delivery efficiency
- Loss per 1000 feet before and after.

Reference table 15, the loss exponent of main water course remains unchanged indicating no improvement. On the contrary the delivery efficiency concept shows that it has improved from 78 to 92%. If the simple loss per 1000 feet concept is used then the losses were 0.068 cfs (.18/2640) before improvement and remains 0.068 cfs (.16/2328) after improvement thus indicating no effect.

The above analysis therefore brings out that some thinking is required to see which indicator should be adopted. Delivery efficiency gives the total percent water loss and is function of discharge an the length measured. Unless the measurement before and after is made for nearly same discharge and length it cannot be sued as an indicator of water saving. Also as the effective length of the

watercourse may or may not compare with the length over which the delivery efficiency has been measured, therefore again it may not represent the true condition.

Loss exponent 'R' can be used to determine percent of inflow lost per 1000 feet from equation (4). The percent of inflow lost per 1000 feet for this case using R = 0.057 is 5.5% both before and after improvement. In absolute term using the inflow of 1.21 and 1.96 cfs before and after respectively the loss per 1000 feet would be .066 and .108 cfs respectively. This indicates that the loss rate has increased. Therefore, again here the necessity to have more or less same order of inflow before and after is very vital. This method, however, has the advantage of applying this rate of loss to the effective length of the Sarkari Khal to determine total saving.

Modified Technology

Watercourse improvement presently include lining of 10-15% length of main watercourse and earthen improvement of the remaining length. The project being capital intensive therefore, in 10 year period only 10-12 thousand watercourses could be attended. In order to expedite the pace of improvement, the need is felt to reducing the cost of improvement so that within same resources benefit can be extended to greater number of watercourses. Review of existing improvement technology led to the development of the modified technology hypothesis which proposes that if instead of 10-15 percent lining the earthen improvement which is currently limited to the main watercourse/Sarkari Khal is extended to include the farmer's channels, a greater water conservation can be achieved at a lesser cost. To facilitate maintenance of earthen improvement by the farmers it is proposed to construct 4 feet long brick lined guide profiles at suitable intervals both in the Sarkari Khal and farmer's channels. Pucca nakkas are assumed to be provided in Sarkari Khal only.

In order to examine the validity of this hypothesis data on effect of earthen improvement on water conservation is available from the monitoring of 25 accelerated improved watercourses under IDA/IFAD (OFWM) project. In order to estimate the water loss before and after earthen improvement the effective length procedure explained earlier is adopted.

The average loss exponent (R) of Sarkari Khal before and after improvement and that of farmer's channels before improvement is briefed in Table 16.

The percent water loss per 1000 feet due to steady state seepage, leakages/breaches before and after improvement as worked out by equation (4) are as under:

The average length of Sarkari Khal and farmer's channel on the basis of various surveys has been assumed as 5000 and 7250 meters respectively. The effective length of Sarkari Khal is 21% of its total lengyh i.e. 1050 m. and represent 75% of channel used to carry water to any farm. The approximate effective length of farmers channel is 25% i.e. 350 m (1050/3). Assuming an average discharge of 1.7 cfs at Mogha the water loss before and after improvement is shown in table 17.

The perusal of the table (17) indicates that saving of the order of 82 acre feet can be anticipated under modified technology as against 82 under regular and 34 under accelerated technologies provided the improvement pattern of the Sarkari Khal is extended to all the farmers' channels. However, how long this saving would remain effective needs to be looked into as the maintenance of such long channels especially when these remain unutilized for a considerable portion of time appeares very difficult.

CONCLUSIONS AND RECOMMENDATIONS:

On the basis of analysis presented in the paper, following conclusions can be drawn:-

1. Watercourse improvement under USAID project provided 9% lining and 69% earthen improvement leaving 22% length of watercourses unimproved. Under IDA/IFAD Phase-I project 13% lining and 33% earthen improvement was provided leaving 54% length of watercourses unimproved. The watercourse improvement is not being planned in a manner to optimise the benefits.

2. The water conservation through watercourse improvement reflected upto end of sixth 5 year plans is over optimistic and not commensurate with the watercourse improvement program or the savings anticipated.

3. Too much attention in monitoring is being paid to collection of information not directly related thus diluting the effort of accurate determination of the water conservation. Many parameters such as saving from lined and unlined portions, marginal value of water etc. required for optimization have not been determined. Distinction between Sarkari Khal and farmer's channel is not being maintained with the result that whatever data is collected cannot be effectively utilized for improvement of the programme.

4. The delviery efficiency concept to estimate the total losses and water conservation is not an accurate procedure. Total water losses and savings can be fairly accurately determined by using the effective length concept and percent loss rate.

5. The effective length of a Sarkari Khal varies from 18 to 35% of its total length with an average of about 21% and represents 75% of the total effective length including Sarkari Khal and farmer's channels. If the effective length of the Sarkari Khal is known, the effective length of the farmer's channels can be estimated as 1/3rd of the effective length of the Sarkari Khal.

6. To estimate steady state conveyance losses in unimproved watercourses the loss exponent for the Sarkari Khal and farmer's channel with fair accuracy can be assumed as 0.06 and 0.21 respectively.

RECOMMENDATIONS:

i) In order to fully understand the magnitude of water conservation from watercourse improvement a few improved watercourses need to be monitored for water loss through a complete warabandi cycle:

ii) In order to optimise improvement, the monitoring should concentrate in determining the saving in losses through lining and earthen improvement separately.

iii) Before undertaking any monitoring measurements, watercourse map clearly indicating Sarkari Khal and farmer's channel should be prepared through strict identification of these two types of channels separately.

iv) Modified technology for watercourse improvement is not very promising as the farmer's channels which are 6 to 7 times the length of the Sarkari Khal remain in use for a very small time. The maintenance of the improvement of channels which remained unuti-

lized for a considerable part of the warabandi period would be very difficult if not impossible.

v) Water availability at farm level is estimated on basis of many assumptions which may not be entirely valid. In the 5 year plans, therefore, the water availability should be limited upto head of the watercourse. Any saving in the watercourse losses beyond outlet may be considered as a bonus instead of accounting it in the planning objectives.

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Table - 1

Utilization of watercourse channels on the five operationally studied watercourses(7)

Watercourse Section	Length of Channels Utilized (m)	Percent of Total Channels Utilized (%)	Weighted Average Channel Length Utilized (m)	Distribution of Usage (%)	Percent time of Channel Usage (%)
TW 81-R					
Sarkari Khal	3400	100	1310	80	39
Farmers' Branchs	7900	41	330	20	2
Total	11300	49	1640		7
TIK // 1					
Sarkari Khal	4900	100	1155	80	24
Farmers' Branches	16900	67	290	20	1
Total	21600	72	1450		5
MP // 6*					
Sarkari Khal	3260	100	1340	87	41
Farmers' Branches	8390	55	196	13	1
Total	11650	64	1535		8
MP // 35*					
Sarkari Khal	980	100	436	50	44
Farmers' Branches	3350	27	300	20	2
Total	7010	43	1520		9
MP // 52*					
Sarkari Khal	3660	92	1220	80	31
Farmers' Branches	3350	27	300	20	2
Total	7010	43	1520		9
Average					
Sarkari Khal	3240	98	1090	75	36
Farmers' Branches	8980	52	310	25	2
Total	12200	60	1400		7

* Average of three weeks (3 warabundi cycles) of data.

Table 2

Summary of Sampled Sarkari Khal Data

Canal	No of W.C	Q (Cfs) (Avg)	CCA ac) (Avg)	Average Length (ft) Total	Longest Br	Effective	Length per acre (ft)
6 – R	10	1.62	418	11899	7952	4214	29
Pakpattan	15	1.62	452	17885	9744	5085	39
Shahkot	9	1.95	728	19964	9307	4781	27
Naulakhi	15	1.5	480	24439	10527	5402	51
Sehra	20	1.36	494	32480	11348	5967	66
Warsak	10	1.17	294	20278	7773	4015	69
14 distys (LRR)	29	–	443	19980	–	5165	45

Table 3.

On – Farm Water Management Programs/Projects

Program/Project	Target (Nos).	Achievement (No. of Watercourses Improvved)												TOTAL
		5th Plan					6th Plan							
		76-77	77-78	78-79	79-80	80-81	81-82	82-83	83-84	84-85	85-86	86-87	87-88	
USAID Pilot Project	1211	5	48	174	427	676	–	–	–	–	–	–		1330
IDA/IFAD Phase - I														
Regular	3350	–	–	–	–	–	513	791	1032	904	396	–		3636
Accelerated	20718	–	–	–	–	–	2830	5124	8030	3924	63	–		19971
ADB Program for Lieah and D.I. Khan	1934	–	–	–	–	–	128	330	426	355	336	88		1663
Sheikhupura District (U.K. grant)	56													59
IDA/IFAD-Phase II.	2425	–	–	–	–	–	–	–	–	–	627	1290		1917
ADB Program for Gujranwali Distt:	330													68 (Dec. 86)
Command Water Management Project	1050										157	313		470
SCARP Projects														
IV Drainage	190													171 (Dec. 86)
Scarp VI.	256													249 (June 85)
Ghotki	125													58 (July 86)
South Rohri	680													310 (Nov. 86)
LBOD	612													–
Mardan	270													270 (June 86)
East Khairpur	97													98 (July 86)
Total:														
Regular	12586													10297
Accelerated	20718													19971

Table 5

Variation in loss rate with distance
(without improvement)

Distance over which loss observed (ft)	Loss Rate (Cfs/1000 feet)			
	LRP. Project		USAID (OFWM)	
< 500		–		
500 – 1000		–	(4)	.297
1001 – 2000	(1)	0.13	(8)	.204
2001 – 3000	(10)	0.11	(12)	.132
3001 – 4000	(13)	0.12	(15)	.104
4001 – 5000	(5)	0.06	(12)	.141
5001 – 6000	(15)	0.08	(10)	.149
6001 – 7000	(7)	0.07	(7)	.105
7001 – 8000	(4)	0.065	(5)	.106
8001 – 9000	(3)	0.10	(6)	.162
9001 – 10,000	(2)	0.087	(3)	.142
> 10,000	(5)	0.036	(5)	.181
Weighted (Avg:)		.09		.147

( ) No. of measurements.

Table 6

Variation in Loss rate with inflow discharge
(without improvement)

Discharge range	Loss rate (cfs/1000 ft) LRR–Project		USAID (OFWM)	
(cfs)				
< 1.0	(9)	.048	(9)	.054
1.1 to 1.5	(19)	.057	(17)	.081
1.6 to 2.0	(18)	.10	(20)	.102
2.1 to 2.5	(10)	.108	(5)	.118
2.6 to 3.0	(2)	.05	(8)	.210
3.1 to 4.0	(5)	.19	(5)	.152
4.1 to 5.0		–	(10)	.243
> 5		–	(8)	.348

( ) No. of measurements.

Table 7

Variation of Loss Exponent (Rs)
With distance in Sarkari Khal
(Without improvement)

Distance from Head (ft)	Loss Exponent 'R'			
	LRR Project	USAID (OFWM)	IDA/IFAD (OFWM)	
			Regular	Accelerated
< 1000		(4) .09	(14)* .168	(11) .20*
1000 – 2000	(1) 0.065	(9) .134	(17)* .121	(8) .092
2000 – 3000	(10) 0.053	(12) .056	(22) .109	(12) .088
3000 – 4000	(13) 0.091	(15) .070	(14) .089	(14) .078
4000 – 5000	(5) 0.047	(12) .062	(5) .074	(13) .075
5000 – 6000	(15) 0.049	(10) .056	(8) .065	(10) .078
6000 – 7000	(7) 0.062	(7) .039	(2) .042	(9) .095
7000 – 8000	(4) 0.051	(5) .041	(4) .049	(5) .076
8000 – 9000	(3) 0.057	(5) .055	(1) .05	(4) .06
9000 – 10000	(2) 0.033	(3) .058	(4) .04	(1) .045
10000 – 11000 & above	(5) 0.026	(5) .072	–	(2) .042
	.053	.067	.064	.073

* neglected ( ) No. of measurements.

Table - 8

Operational Losses

Type of Losses	Sarkari Khal (%)	Farmer's channel (%)
Steady state seepage	20.16	15.84
Surface evaporation	0.21	0.09
Visible leakage	0.63	0.57
Dead storage	2.20	1.50
Breaches etc.	0.40	0.30
Transient seepage Wetting dry banks	1.40	0.90
	25.00	19.00

Table - 9

Variation of Losses Exponent 'R_f' with distance in Farmer's Channel (without improvement)

DISTANCE (ft)	USAID (OFWM)		IFAD/IDA (OFWM) : 1 Regular		ACC.	
	No.	Rf	No.	Rf	No.	Rf.
< 500	(11)	0.36	(8)	0.694	(16)	.453
501 – 1000	(25)	0.239	(24)	0.291	(24)	.388
1001 – 1500	(16)	0.187	(9)	0.303	(7)	.166
1501 – 2000	(10)	0.166	(6)	0.180	(7)	.179
2001 – 2500	(5)	0.117	(3)	0.164	(2)	.13
2501 – 3000	(3)	0.131	(1)	0.108	–	–
3001 – 4000	(3)	0.097	(3)	0.119	(1)	.058
> 4000	(3)	0.038	(1)	0.09	–	–
	Avg:	0.167		0.243		.229

Table - 10

Watercourse Data and Improvements (12, 13)

Project	Watercourses Data			Improvements					
	No.	Total Length (m)	Average Length (m)	Lining (m)		Earthen Improved (m)		Nakka Installed	
1	2	3	4	5		6		7	
				L	(%)	L	(%)	No.	(Avg/Wc)
1. USAID									
NWFP	4	17,400	4,350	1868	(11)	12434	(71)	174	44
Punjab	18	89,179	4,954	5414[1]	(8)	69453	(78)	338	19
Sind	7	28,823	3,403	2953	(12)	8206[2]	(34)	226	32
	29	130,402	4,497	10253	(9)	90093	(69)	738	25
2. IFAD/IDA-I									
– Regular									
NWFP	2	9,912	4,960	698	(7)	–		81	41
Punjab	14	60,954	4,350	8826	(15)	23843	(39)	422	30
Sind	4	14,477	3,620	1474	(10)	3959	(27)	180	45
	20	85,343	4,267	10998	(13)	27802	(33)	683	34
– Accelerated									
NWFP	3	10,491	3,500	–		–		–	–
Punjab	19	74,353	3,910	–		20470	(28)	207	11
Sind	3	11,127	3,710	–		337	(3)	–	–
	25	95,943	3,840	–		20807	(22)	207	8

1/ Data of 4 watercourses not available.
2/ Data of 2 watercourses not available.

Table - 11

Delviery Efficiency

Project	Sarkari Khal (Main)				Overal			
	H	M	T	(Avg)	H	M	T	(Avg)
I. USAID								
Pre-Improved	76	71	63	70	66	63	54	61
Post-Improved	82	81	74	80	79	73	64	72
II. IFAD/IDA – 1								
Regular								
Pre-Improved	83	72	66	73	79	61	55	64
Post-Improved	90	81	70	80	87	71	63	74
Accelerated								
Pre-Improved	86	76	62	74	80	67	56	67
Post-Improved	87	79	68	77	85	72	60	72

H. . . . head M. . . . .middle T. . . . . tail

Table - 12

Water Supply Improvement

Items	USAID Project	IFAD/IDA	
		Regular	Accelerated
1. Average Mogha discharge	2.68	1.72	1.65
2. Pre-Improvement Efficiency			
Main W.C	70%	73	74
Overall	61%	64	67
Average Supply available:			
Farm Nakka	1.88	1.26	1.22
Field Nakka	1.63	1.10	1.10
3. Post Improvement Efficiency			
Main W.C	80%	80	77
Overall	72%	74	72
Average Supply available			
Farm Nakka	2.14	1.38	1.27
Field Nakka	1.93	1.27	1.19
4. Change in Water Supply (%)			
Farm Nakka	14%	10%	4%
Field Nakka	18%	15%	8%

Table - 13

IDA/IFAD OFWM – I Programme – Saving Losses.
(at Farm gate)

Period	Mogha Discharge (cfs)	Farm gate Discharge (cfs)	Efficiency Ed(%)	Losses %	Saving of Losses %	Losses in Acre feet	Saving of Losses in Acre feet
			Regular Technology				
Pre-Improvement (Rabi 1982–83)	1.72	1.08	64	36	–	232	–
Post Improvement (Kharif 1984)	1.70	1.24	74	26	28	167	65
(Rabi 1984–85)	1.66	1.22	73	27	25	133	61
						Seasonal	63
						Annual	126
			Accelerated Technology				
Pre Improvement (Rabi 1982–83)	1.65	1.10	67	33	–	199	–
Post Improvement Kharif 1984	1.71	1.21	72	28	15	181	18
Rabi 1984–85	1.59	1.15	72	28	15	133	34
						Seasonal	26
						Annual	52

Table - 14

Water Saving per Water course (acre feet) at Farm Nakka

Item	Mogha discharge	Delivery Efficiency	Losses	Saving of Losses	Losses	Water Saving
	(cfs)	(%)	(%)	(%)	(a.f)	(a.f)
1. Regular Technology						
Pre-Improvement	1.72	73	27	–	316	–
Post-Imp.	–	80	20	26	234	82
Accelerated Technology.						
Pre-Imp.	1.65	74	26	–	292	–
Post Imp.	–	77	23	12	258	34

/ 340 days of working per year assumed.

Table - 15

Summary of Field Data and Analysis

Farm No.	Qs	Q_{fm}	Q_{fd}	L_{fm}	L_{fd}	Loss exponent			Delivery efficiency		
						Main	Tarmer channel	Overall	Main	Farmer Br.	Overall
						(R_s)	(R_f)	(R_o)			
A.	Before Improvement										
1.	1.02	1.02	0.84	–	671	–	.092	.092	82	–	82
2.	0.99	0.99	0.58		806	–	.175	.175	63	–	63
3.	2.39	1.70	1.50	960	120	.096	.268	.121	74	90	67
4.	1.05	0.80	0.56	1061	335	.078	.318	.137	76	70	54
5.	1.00	1.86	0.74	1397	135	.029	.370	. 06	86	85	74
6.	0.9	0.80	0.75	1412	235	.025	.084	.034	89	76	66
7.	0.9	0.80	0.65	1412	430	.025	.046	.054			
Avg)	1.21	1.03	0.82	805	400	.057	0.215	.105	78	78	68
B.	After Improvement (III)										
1.	1.97	1.79	1.46	274	243	.11	.38	177	91	81	74
2.	1.97	1.79	1.40	274	317	.11	.196	176	91	72	66
3.	1.80	1.60	1.30	685	707	.052	.089	.071	89	78	70
4.	1.80	1.70	1.38	685	707	.025	.09	.058	94	75	70
5.	1.90	1.70	1.62	990	350	.034	.042	.036	89	69	61
6.	2.3	2.2	1.88	1348	181	.01	.265	.040	97	88	84
	2.3	2.2	2.05	1348	810	.01	.059	.016			
	2.3	2.2	2.10	1357	600	.01	.024	.014			
(Avg)	1.96	1.80	1.53	710	476	.057	.152	.09	92	77	71

The perusal of basic of data and the analysis given above indicate:

1. No distinction between Sarkari Khal and farmer's channel has been maintained during measurement. Term main watercourse is hypothetical and neither signify Sarkari Khal or its portion nor the farmer branch but include both at times.

2. Delivery efficiency is function of distance but the measurements before and after do not represent the same lengths. The average length measured before and after for main watercourse and farmer branch are:

	Main W.C.	Farmer branch	Total
Before	805 meter	400 meter	1205 meter
After	710 meter	476 meter	1186 meter

3. Cut throat flume under submerged condition has been used because of very flat slopes. The flume working under such condition is very insensitive specifically for low discharges. For example:

Range of 'ha'	Range of (ha – hb)	Discharge
(ft)	(ft)	(cf)
.02 to .14	.02 to 0.4	0
0.3 to 0.38	.08 to 0.4	0.2
.60 to 0.64	.16 to 0.4	0.6

'ha' . . . head upstream ha–hb. . . . head difference

Table - 16

Variation of Loss exponent with distance.
IDA/IFAD Project (Accelerated)

Distance (ft)	Loss exponent (R)			
	Main watercourse		Farmer's Channel	
	Before	After	Before	Alfter
1000	.20*	.201*	.414	.191
1000–2000	.092	.091	.205	.091
2000–3000	.088	.095	.130	.133
3000–4000	.078	.070	.058	.044
4000–5000	.075	.071	–	–
5000–6000	.078	.086	–	–
6000–7000	.095	.080	–	–
7000–8000	.076	.065	–	–
8000–9000	.06	.037	–	–
9000–10,000	.045	.44	–	–
10,000	.042	.042	–	–
Avg.	.073	.08	.202	.115

* neglected

Table - 16

Water Loss (% of inflow) per 1000 feet

Channel	Loss Rate (%)	
	Before	After
Main Watercourse	7	7.69
Farmer's chnannel	18.29	(not improved)

Table - 17

Anticipated Water Conservation Under Modified Technology

Item	Before	After	Saving[1/] (af)
Mogha Inflow	1.70	1.70	–
Loss in Sarkari Khal	0.41 (24.1%)	0.45 (26.48%)	–27
Inflow to Farmer's Channel	1.29	1.25	–
Loss in Farmer's channel	0.27 (21%)	0.110 (8.83%)2/	+109 +109
Inflow to field	1.02	1.14	82

1/340 working days. 2/ Assuming same loss rate as per Sarkari Khal

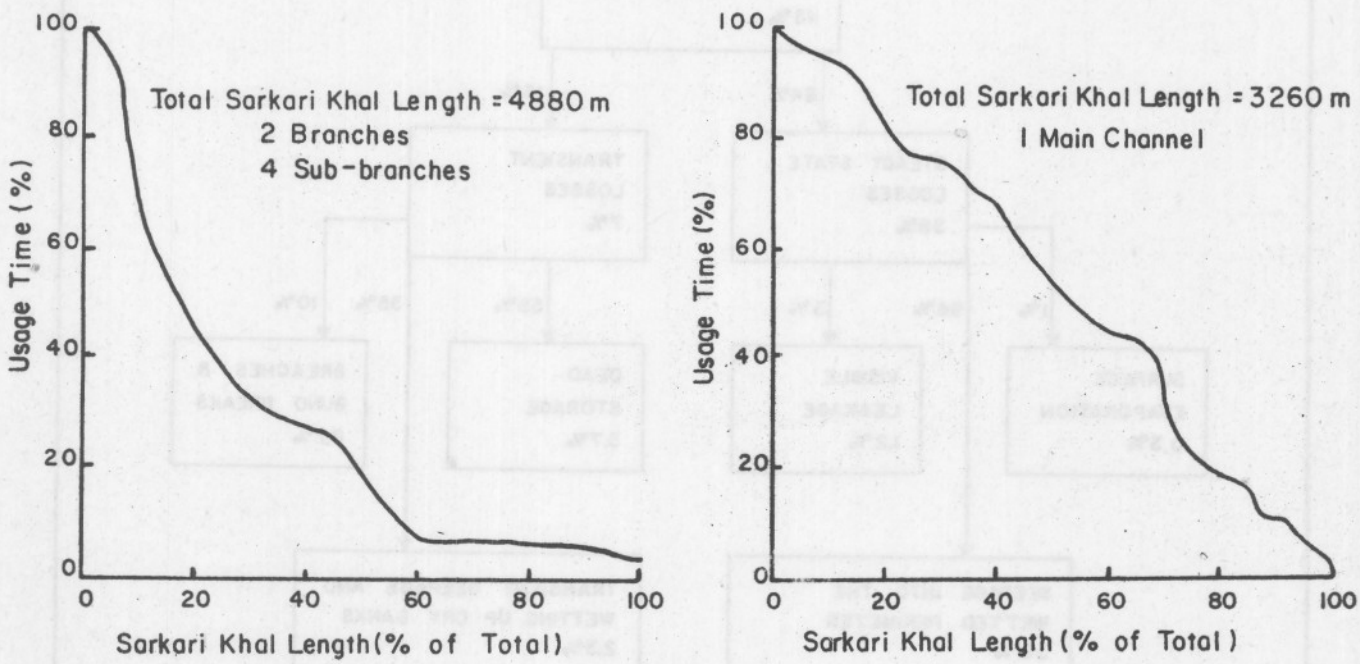
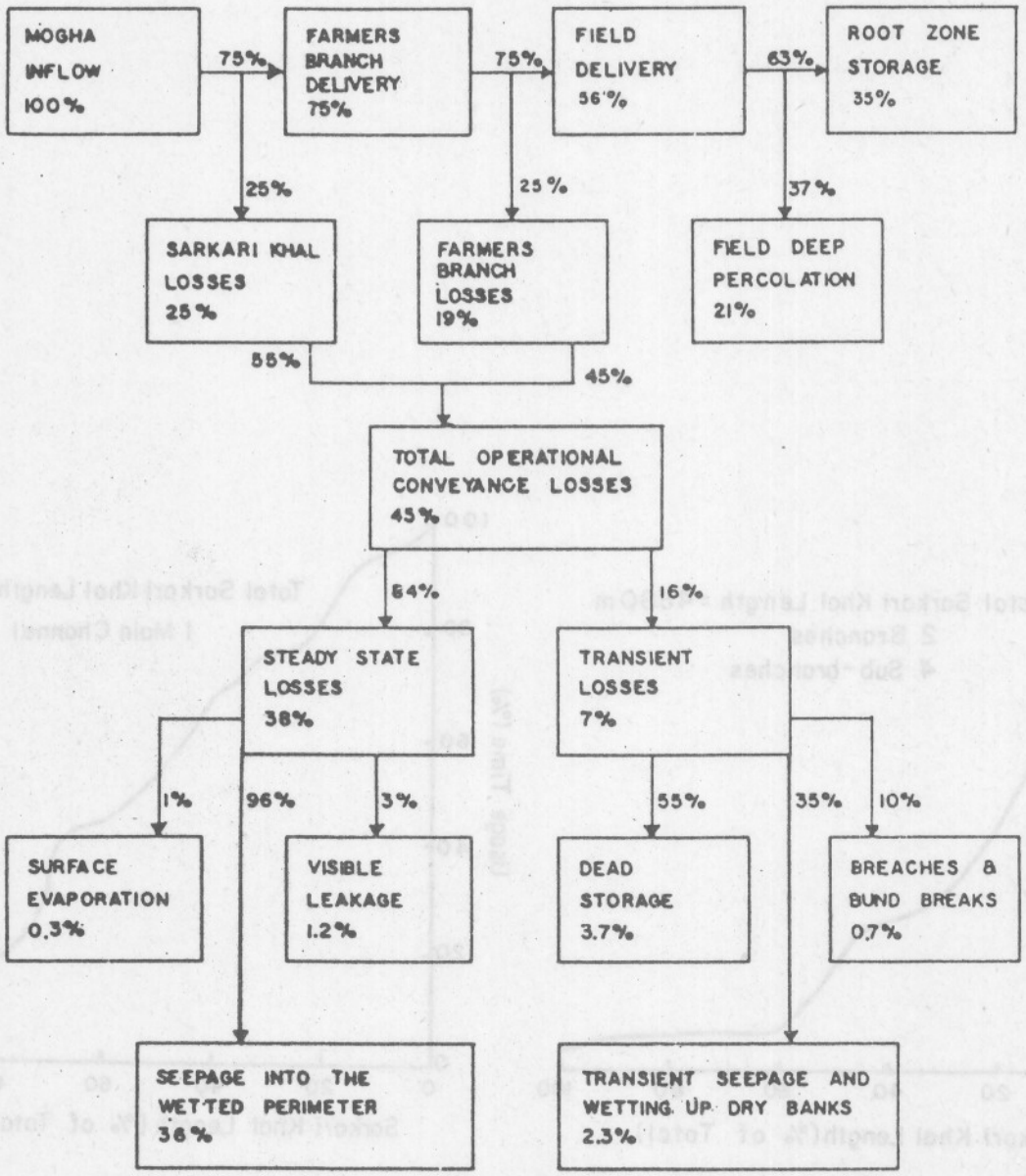


FIGURE: 1 NORMALIZED USAGE TIME Vs. SARKARI KHAL LENGTH

Paper No. 505



FLOW DIAGRAM

OPERATIONAL LOSSES

PAKISTAN ENGINEERING CONGRESS

List of papers in Annual Proceedings

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