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Determining economically feasible watercourse lining length in the irrigated area of Punjab, Pakistan

Pirzada M. Moshabbir[1], Hafiz Qaiser Yasin[2], Malik M. Akram[3], Arsam Ahmad Awan*[4]

[1]*High Efficiency Irrigation Systems Specialist (M&E, PIPIP), MM Pakistan (Pvt.) Ltd., Lahore, Pakistan.*

[2]*Deputy Director (Water Management), Deptt. of Agriculture, Govt. of the Punjab, Lahore, Pakistan.*

[3]*Director General (Water Management), Deptt. of Agriculture, Govt. of the Punjab, Lahore, Pakistan.*

[4]*Field Engineer (M&E, PIPIP), MM Pakistan (Pvt.) Ltd., Lahore, Pakistan*

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Abstract

A watercourse is the last leg of canal irrigation network of Pakistan from where the farmer diverts water to irrigate his crops. High irrigation water losses are impending during the conveyance through unimproved watercourses. Losses in watercourses varies with the length and flow time. A broad study has been carried out to determine the losses by using the inflow-outflow methodology for the determination of extent of lining which is economical. Annual savings 308 to 786 acre-ft. of water per watercourse were determined, which can be used to irrigate an additional area of 92 and 62 acres of crops in Rabi and Kharif respectively. Economic Internal Rate of Return (EIRR) for investments made against different incremental lining length percentages was calculated. Each watercourse will yield different values of EIRR depending upon the actual discharge of the watercourse, command area, and type of crops. It was found that lining length beyond 55% is not economically feasible as EIRR falls below 12%. It has been found that lining up to 50% length of the watercourse can reduce about 80% of conveyance losses with the EIRR 23%. Nonetheless, based on an economic analysis, the 50% lining length, which yielded EIRR of 23%, was found economically viable. It is therefore, recommended that watercourse lining length may be enhanced from the presently practiced 30% to 50% in order to conserve precious water to the maximum extent and to ensure food security.

***Corresponding Author:** Arsam Ahmad Awan ✉ arsamawan@gmail.com

Introduction

Water is very precious commodity now a day. Water has very pivotal role in our daily life practices. Irrigation water is one of the main driving forces for agricultural productivity. It is very important for the developing countries like Pakistan because their economy is majorly based upon agriculture. Irrigation system of Pakistan is known as Indus Basin irrigation System (IBIS). IBIS is a hoary, large and complex system. It consist network of Dams, Barrages, canals, distributaries, minor sand watercourses. As it is hoary, complex and large so it is difficult to maintain the whole system, irrigation water losses are very high during its travelling from dams to farmer fields. The irrigation water losses must be curtailed to improve the system efficiency. Due to improved system efficiency, more water is available for cultivation of additional land, that lead towards the better economy and livelihood of the people.

It will also help in eradicating the food security issues. With the increased demand of food for increasing population, food security of the province may get destabilized in the absence of enhancement in food production. The most fundamental deterrent in the enhanced food production is the water scarcity. There exist meagre chance of development of new water. Therefore it is high time to ensure much demanded additional water through salvation of water being lost in watercourses. Some developmental project may be initiated to save significant volume of water though enhanced length of lining of watercourses as indicated in preceding paragraph.

Watercourse is the last component of irrigation network which deliver water from outlet to field. Main causes of conveyance losses are, seepage, spillage, leakage, rodents, asymmetrical shape, dead ponding and vegetation. The Colorado State University, USA and the Water and Power Development Authorities (WAPDA) (1978) executed research for the determination of conveyance losses in watercourses. The results of these research studies were alarming which indicated that on an average about 46% of irrigation water was being lost before reaching the farmers' fields.

WPADA (1984) performed the pre improvement studies on watercourses on various locations of NWFP, Sindh and Punjab. Almost 45% conveyance losses were found. As a remedial measure, to minimize the conveyance losses in the watercourses lining was recommended. Siyal *et al.* (2007) did their studies in Sindh province of Pakistan. They mentioned that a majority of the farmers 86.5% perceived that there was great improvement in water delivery efficiency through watercourse renovation and improvement through lining. Sultan *et al.* (2014) described that the selection of lining for tertiary channels may be based on factors like the ability of the lining to manage and conserve water and soil in addition to cost/benefit ratios and delivery efficiencies. Therefore, it is recommended that watercourses must be lined for better efficiencies and sustainable water management. Proper improvement with bricks, concrete lining, with Naccas and checks may be done so as to save significant amount of water lost through seepage, rodent holes and other losses. Chatha *et al.* (2014) did their research on design and cost analysis of watercourse lining. They produced the watercourse lining cost per annum but there was no economic analysis done for the lining length feasibility determination. Chatha *et al.* (2014) did their work for determining the optimum lining length but this research did not address the economically feasible length and analysis. Awan *et al.* (2017) did their research work on the losses in the districts of Punjab province. They found that significant losses occur in watercourses which ultimately suffer the agriculture production and enhances the ground water pumpage.

Javed *et al.* (2012) found that cropping intensity of selected sites increased by 17 to 19 percent after lining. They further observed that on an average per hectare crop yield increased 530kg for wheat, 9600kg for sugarcane, 230kg for cotton and 190kg for maize after lining of watercourses. The authors are silent about the extent of lining against which the benefits were achieved. Javed *et al* expressed their findings that the average losses per 100 meter length in lined portion of watercourse ranged from 0.3 to 0.6 lps and 1 to 2 lps in unlined portion.

The average reduction in losses per 100m length of watercourse was 66.9%. Tareen *et al.* (2016) expressed that the improvement in conveyance efficiency of watercourses obtained was 8% by 30% lining of total length which helps to save 14.13 ha-m of water to cultivate 7 hectares more land as cultivated before lining. The cropping intensity has increased by about 29% in Rabi and 12% in Kharif seasons. The cropping pattern assessed before and after watercourse improvement has remained almost same as no other proper marketing facilities were available for the land owners for growing other crops like vegetables and fruits. Crop yield increased by 16% for wheat crop, 27% for cotton crop, 11% for sugar cane, 27% for chilies, and 19% for onion after lining the watercourses. On an average the water table in the command area of the watercourses under study has gone down by 1m after lining. Thus water logging problem has been minimized to some extent.

The benefit cost ratio of the project is worked out as 2.06 which is much more than unity which clearly indicates that the project is economically feasible and viable. The study did not correlate the results with length of lining. Michael, A.M. (2009) holds that the costs of lining of a watercourse and the construction of allied structures include the expenditure on earth work, masonry materials, laying the lining, plastering, provision of engineering and supervision, usually expressed on unit length basis. Malhotra (1982) recommended beneficial lining length of watercourses as 50% based on saved percentage of loss of water in unimproved watercourses. OFWM (2005) impact evaluation study of NPIW shows 3.4% increase in cropping intensity, 12.2% increase in yield of cotton followed by 9.2% increase in yield of wheat, 7.8% in rice and 3.5% increase in yield of sugarcane. Increase in cropped area has been claimed to be 8.3%.

All these impacts are realized at watercourses lined at 22.5% on an average but the authors are silent on the extent maximum beneficial lining length. The EIRR was estimated at 18% while planning and appraising of 3rd OFWM Project (2005), whereas it was re-estimated at completion of the project ranging from 22% to 28% under different scenarios.

In this project the lining was proposed 15% in fresh water zones and 30% in saline water areas. Similarly, in the project entitled NPIW, most of the watercourses were lined up to 30% with estimated EIRR ranging from 22% to 37%. The P&D Department of the Government of the Punjab has set the lowest acceptable EIRR at 12% for agricultural projects. Keeping in view of the new EIRR rate as prescribed by the Punjab Government, it is essentially required to find out the percentage of watercourse lining lengths that would keep the prescribed EIRR against the investment.

Although many researcher has attempted to assess the quantum of losses occurred in watercourses but none of them consider the entire length of watercourse and flow timings in different reaches of the watercourse. The above mentioned studies and facts described the benefits of watercourse lining in positive terms but none of them tells the economical feasible lining length.

Therefore, there is a need of an extensive research in area which determine the losses and their economic values to determine the economical feasible lining length of watercourses in the area. Therefore, it was high time to explore the threshold lining length from where the benefits starts diminishing for each unit of investment and pass on the same information to the planners and developmental agencies in order to undertake measures to bring more benefits to the farmers from every penny of investment and bringing back every drop of salvaged water in agricultural production.

Materials and methods

Selection of Sample Watercourses

Twelve (12) sample watercourses (8 unimproved and 4 improved) were selected in the administrative divisions of Bahawalpur, D.G. Khan, Multan, Sahiwal, Faisalabad, Lahore, Gujranwala and Sargodha of the Punjab province except Rawalpindi division, where there is no canal irrigation system. Detailed locations of these sample unimproved and improved watercourses has been shown in Table 1 and Table 2 respectively.

Table 1. Selected unimproved watercourse.

District	Tehsil	Watercourse No.	Chak	Main Canal	Disty. /Minor	Command Area (acres)
Bahawalnagar	Chishtian	6-R	54-F	Sadiqia Canal	B Khan Minor	369
D. G. Khan	D. G. Khan	16594-R	Jhok Utra	DGK Canal	Noor Wahi	550
Bhakkar	Darya Khan	31250-R	50-ML	Thal Canal	Mahota	708
Kasur	Radha Kishan	72432-R	Kot Nathu	BRBC	Handal	275
Vehari	Burewala	49173-L	136-EB	PPK	2-BR	453
Sahiwal	Sahiwal	21780-R	99-9L	LBDC	9-L	400
Chiniot	Bhoana	35480-L	210-JB	Jhang Branch	Gilotran	430
Hafizabad	Pindi Bhatian	15461-L	Nawan Manika	LCC	Fatehki	707

Table 2. Selected Improved watercourses.

District	Tehsil	Watercourse No.	Chak	Main Canal	Disty. /Minor	Command Area (acres)
Bahawalnagar	Bahawalnagar	3-AL	Ghanga Singh	Sadiqia Canal	Madrassha	291
D. G. Khan	D. G. Khan	32000-R	Basti Khosha	D. G. Khan	Qasim Wala	224
Bhakkar	Darya Khan	56610-R	Khansar	Thal Canal	Khansar	546
Kasur	Radha Kishan	14260-L	Baigpur	BRBC	Handal	275

Division of each Watercourse into Major Three Sections

Detailed layout (command area map) of each sample watercourse was obtained from the Irrigation Department. The warabandi list, which describes the weekly farm wise distribution/allocation schedule of water in the command area, was also obtained. The departmental layout and the warabandi was verified against the actual practice in vogue and necessary amendments were made in the layout and water distribution patterns accordingly. The longest length of the main watercourse (Sarkari Khal) was measured and divided into three equal sections L1, L2 and L3. The L1, L2 and L3 segments were termed as Head, Middle and Tail segments/sections respectively. Main branches of the selected watercourse were also measured and divided into head, middle & tail sections according to the distance starting from the Mogha for this study.

The distance of the part of branch that did not exceed L1 was considered as Head, the part of the branch that fell beyond L1 but remained within L2 was considered as Middle and any part of the branch that exceeded L2 was considered to be as Tail. No independent measurement was made for branches. It was assumed that the branches will behave similar to that of the longest main watercourse where flumes were installed.

Measurement of Losses in various Watercourse Sections

Cut-throat flumes were used for discharge measurement of the sample watercourses and losses were calculated by using the inflow and outflow techniques. The main watercourse was divided into three sections i.e. head, middle & tail sections by installing four cut throat flumes. The seepage loss data collected for head, middle & tail section of the main water course, was applied to the entire watercourse system following the warabandi list of each watercourse under study for the sake of estimating the total loss in the watercourse system. Distances between flumes were measured and loss per 100m was also calculated for each section of the watercourse. The loss rates so obtained for three sections were used to calculate the volumes of water lost from each segment of different flow time applying the relevant loss rate where it falls in accordance with the distance from mogha.

The annual cumulative water loss of the watercourse was also worked out by summing up the losses those occurred in all the watercourse segments. For this purpose the weekly loss was multiplied by 48 to determine the annual loss volume. On an average a watercourse remains flowing for 48 weeks in a year. However, this study did not take into consideration the farmers' ditches.

The annual loss for each segment was divided by its length and per 100m loss volume was determined. These segments were arranged in descending order in terms of per 100m loss volume. This arrangement enables the planners and implementers to decide priority as to which part/length/segment of the watercourse should be lined within a limited budget.

Curve for each watercourse has been plotted with all segments of watercourse with length of segment on the X- axis against the cumulative loss volume on Y-axis. The length on X-axis and the volume on Y-axis were also expressed as percent of total watercourse length and total loss volume respectively. This curve expresses different lining length and the corresponding percent volume of water that could be saved by lining.

Determining the Economically Feasible Length of Watercourse

This is an established fact that water loss continues to occur in a watercourse even after its lining with brick masonry or with PCPS. It was determined by measuring the losses from the sample lined watercourses. Therefore, the salvage of water by restricting losses, determined by using the above mentioned techniques was further reduced by the loss value found in the lined watercourses. This loss volume was calculated for each length of independent flow-time segment. Results obtained were termed as the saved water. It has been further assumed that the service life of improved watercourses will be 15 years. As such values of 15 years' saved water from the improved watercourse were summed up to compare the cost of construction against the achievable benefits from the salvaged water. The calculation was made against different percentage of main watercourse lengths. The percent length of watercourse for which the cost remained lower than the benefits was declared as feasible for lining. The results vary from watercourse to watercourse under different sets of site specific conditions, ecology, cropping pattern etc. However, under this study average value was used to work out the economically feasible lining length.

In this paper the benefits have been expressed in terms of additional acreage of Rabi and Kharif crops that could be brought under cultivation by dividing the annually saved water into two halves. It was further assumed that the saved water would be utilized at 62% irrigation efficiency.

Results and discussions

Lengths of sample improved watercourses were physically measured. In this respect both main watercourse and main branches were considered. The lengths for eight unimproved sample watercourses varied from 3420 to 9989m with an average of 6060m. Detail of lengths of eight unimproved has been shown in the Table 8. The mogha discharges and annual intakes of the selected unimproved and improved watercourses were measured which are depicted in Tables 3 and 4 respectively.

The measured mogha discharges of the selected unimproved watercourses varied from 31.66 to 80.65 litres per second (lps) as shown in Table 3. Mogha discharges of improved watercourses varied from 33.2 to 62.2 lps as shown in Table 4. Highest average loss rate was observed in watercourse No.15461-L and Lowest in watercourse No.354480-L. Per 100m length loss rate was also calculated for different reaches (H,M, and T) of the selected watercourses as shown in Table 5 for unimproved watercourses, water losses varies 1.02 to 1.84 lps per 100m.

Table 6 shows Conveyance losses in Lined section and earthen section of improved watercourses. In lined section losses varied from 0.2 to 0.38 lps per 100m while in earthen improved section it fluctuate from 0.7 to 1.1 lps per 100m. Annual loss volume for each segment was calculated as shown in Table 7.

Maximum annual loss was 980 acre-ft and minimum was 366.4 acre-ft. On an average 48% loss on volumetric basis was observed, with 59% as the highest for watercourse No.15461-L and 34% as lowest for the watercourse No. 31250-R.

The graphical representation of the annual intake of selected watercourses and annual volume of losses of the respective watercourse has been shown in Fig. 2.

By deducting this amount of water from the present level of losses, the possible saved water for each segment was determined. In order of priority the length of all segments were plotted on X axis with incremental cumulative lengths and the loss reduction as percentage for the whole watercourse on Y axis to find the relationship of water saved and percentage of watercourse lining length.

Based on the data worked out and mentioned above, the relationships was developed between the %age length of lining and corresponding percentage loss reduction. The % increase in total length of unimproved watercourse was taken as "x" and it was independent variable while "y" was % increase of water saving. It was dependent variable.

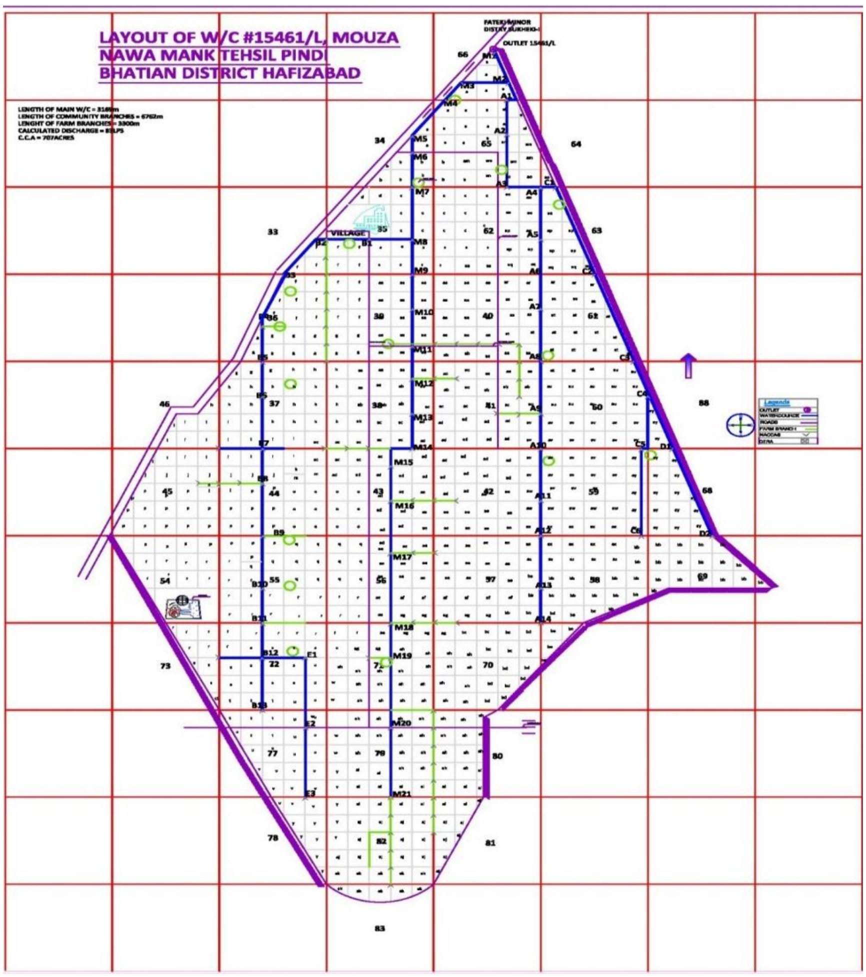

Fig. 1. Layout of a sample watercourse showing Head, Middle, Tail and flume locations.

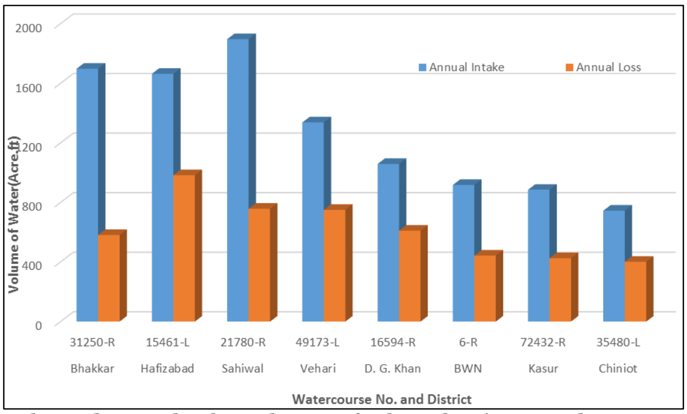

Fig. 2. Annual volume intake and annual volume losses of selected unimproved watercourses.

Table 3. Mogha discharge and annual intake of unimproved watercourses.

District	Tehsil	Watercourse	Chak	Main Canal	Disty./Minor	Annual Discharge (lps)	Intake Acre-ft
Bahawalnagar	Chishtian	6-R	54-F	Sadiqia Canal	B Khan Minor	39	917.28
D. G. Khan	D. G. Khan	16594-R	Jhok Utra	D.G Khan	Noor Wahi	46	1081.92
Bhakkar	Darya Khan	31250-R	50-ML	Thal Canal	Mahota	72.2	1698.14
Kasur	K.R.K	72432-R	Kot Nathu	BRBC	Handal	37.63	885.26
Vehari	Burewala	49173-L	136-EB	PPK	2-BR	56	1317.12
Sahiwal	Sahiwal	21780-R	99-9L	LBDC	9-L	80.65	1896.2
Chiniot	Bhoana	35480-L	210-JB	Jhang Branch	Gilotran	31.66	744.64
Hafiz Abad	Pindi Bhatian	15461-L	Nawan Manika	LCC	Fatehki	70.75	1664.04

Table 4. Mogha discharge and annual intake of improved watercourses.

District	Tehsil	Watercourse	Chak	Main Canal	Disty./Minor	Annual Discharge (lps)	Intake Acre-ft
Bahawalnagar	Chishtian	3-AL	Ghanga Singh	Sadiqia Canal	Madrassha	40.35	949.032
D. G. Khan	D. G. Khan	32000-R	Basti Khosha	DGK Canal	Qasim Wala	33.2	780.864
Bhakkar	Darya Khan	56610-R	Khansar	Thal Canal	Khansar	62.2	1462.944
Kasur	K.R.K	14260-L	Baigpur	BRBC	Handal	41.1	966.672

Table 5. Conveyance losses in the Head, Middle and Tail reaches of the unimproved watercourses loss in lps/100m.

District	Hafizabad	Chiniot	Bhakkar	Bahawal nagar	D.G Khan	Kasur	Sahiwal	Vehari	Average
W/C No.	15461-L	354480-L	31250-R	6-R	16594-R	72432-R	21780-R	49173-L	
Head	2.57	1.25	1.37	1.20	1.45	1.85	1.34	1.30	1.54
Middle	1.85	1.34	1.72	0.94	1.17	1.20	2.26	1.20	1.46
Tail	1.09	0.48	0.90	0.94	1.37	1.10	1.59	0.90	1.05
Average	1.84	1.02	1.33	1.03	1.33	1.38	1.73	1.13	1.35

Table 6. Conveyance losses in the improved section (Brick Lining) and earthen improved section of watercourses Water loss (lps/100m).

District	Bhakkar	Bahawal nagar	D.G Khan	Kasur	Average
W/C No.	56610-R	3-AL	32000-R	14260-L	
Lined	0.38	0.2	0.28	0.25	0.2775
Earthen	1.1	0.7	0.8	0.9	0.875

Table 7. Annual intake and volumetric losses of unimproved watercourses.

District Name	Watercourse No.	Annual Intake Acre. Ft.	Annual Loss Acre. Ft.	Annual Loss %
Bhakkar	31250-R	1698.1	467.8	27.55
Hafizabad	15461-L	1664.0	980.0	58.89
D. G. Khan	16594-R	1081.9	723.00	66.83
Vehari	49173-L	1317.1	433.0	32.87
Chiniot	35480-L	744.6	401.4	53.91
Sahiwal	21780-R	1896.9	757.7	39.94
BWN	6-R	917.3	446.0	48.62
Kasur	72432-R	885.1	386.4	43.66
Average		1275.6	574.4	45.03

For working out optimum length of lining, an average relationship between the percent lining length and corresponding loss reduction was developed and has been shown in the Fig. 3. At the same time equation was also developed to work out the extent of loss reduction against different percentages of lining lengths.

Two sets of relationship trends were observed i.e. beyond 50% and below 50% of lining lengths.

These two trends of relationships can be expressed with the following equations as shown in Fig. 4.

$y= -0.097x^2+3.094x+0.4606$ if $x=0-50$

$y= -0.0038x^2+0.7322x+54.825$ if $x=51-100$

It is clear in Fig. 4. that firstly there is a quick rise but the slope becomes near to flat beyond 55% lining length i.e. the rate of incremental saving of water becomes very low. The incremental benefits of the extent of lining beyond 55% of its total length are not significant.

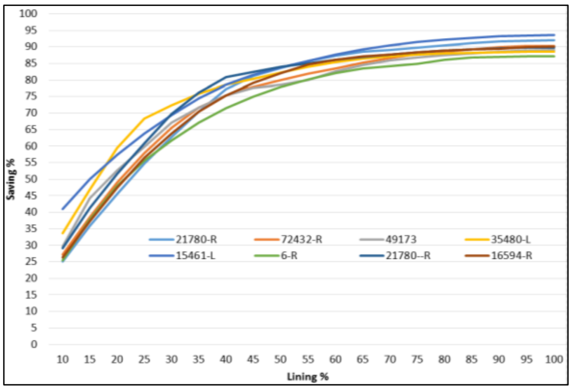

Fig. 3. Relationship between percent lining length & corresponding loss reduction (%).

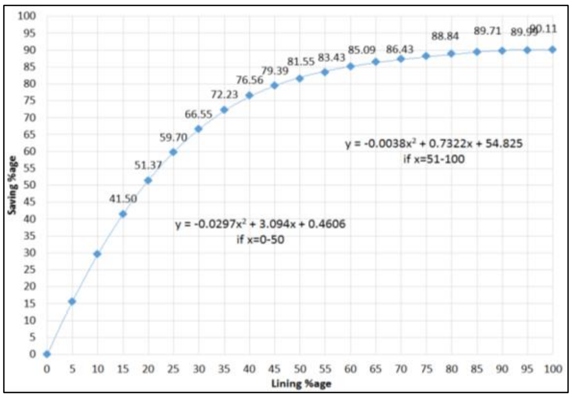

Fig. 4. Represents the best fit curve for relationship between percent length of lining and reduction of water-loss/salvation of lost water.

For working out the economic length of lining, benefits derived from the saved water through lining were expressed in terms of additional Rabi and Kharif crops acreage which could be grown with saved water was shown in Table in 8. Table 9 shows that saved water was divided into two halves to be used for Rabi and Kharif crops. Additional water available for crops were 282.7 acre-ft. Additional crop acreage due to saving of irrigation water for the Rabi and Kharif crops were 92 and 62 acres respectively. Table 10 shows the lining and EIRR percentage. Break even value of EIRR 12.1 was achieve for the 50-55% lining and at 55-60% lining length segment EIRR dips down to -1.0% which is not viable. After this point EIRR value becomes negative and below then the value recommended by P&D department for this purpose.

Table 8. Length of Community watercourse.

District	W/Course No.	Main length (Meter)	Branches (Meter)	Total (Meter)
Bhawalnagar	6-R	3290	1355	4645
D. G. Khan	16594-R	3165	3612	6777
Bhakkar	31250-R	3180	1728	4908
Kasur	72432-R	1980	1440	3420
Vehari	49173-L	3687	3030	6717
Sahiwal	21780-R	3066	2244	5310
Chiniot	35480-L	2154	4562	6716
Hafizabad	15461-L	3168	6721	9989
Average		2961	3087	6060

Table 9. Additional crop acreage which could be grown with saved water through 50% length lining of watercourses.

Crop	Avg. CWR	Avg. CWR	Annual Saved water in watercourses	Avg. Annual saved water at Nacca	Water Available to crop	Winter	Summer
Name	mm	Acre. ft	Acre. ft	Acre. ft	Acre. ft	Crop Acreage	Crop Acreage
Wheat	457.5	1.57	459	353.4	282.7		
Maize	573	1.91	459	353.4	282.7	92	74
Cotton	692	2.31	459	353.4	282.7		62
Sugar Cane	1338	4.46	459	353.4	282.7		32

Table 10. Segment wise EIRR and cumulative benefit of lined watercourse.

Lining by Segment %	EIRR by Segment %	EIRR for Cumulative Benefits %
5	45.9	45.9
5 to 10	65.0	52.5
10 to 15	96.7	63.8
15 to 20	96.1	70.4
20 to 25	58.0	68.3
25 to 30	39.0	64.1
30 to 35	47.3	62.0
35 to 40	43.4	59.9
40 to 45	42.1	58.1
45 to 50	28.3	55.5
50 to 55	12.1	52.0
55 to 60	(1.0)	48.5

Conclusions

The study aim at determining the economically feasible lining length of watercourses by finding the threshold value of investment, ultimately reduce the conveyance losses and improve the system efficiency. Thus making the system more reliable, viable and economical. The technical analysis reveals that lining of any watercourse is viable up to 55% which may save the water losses up to 81% but beyond this point saving is very marginal 19% against the remaining 45% of lining.

It is therefore, concluded that the lining of watercourse may be done to the maximum level of about 55%. For this purpose economic analysis was made to determine the economic viability. Potential cropped area in acres, for different crops, were estimated by considering the amount of additional water made available after lining of watercourse and the crop water requirements. Additional crop acreage can be grown with saved water are 92 acres and 62 acres for Rabi and Kharif seasons respectively. The EIRR of 50% lining length is 23%. Thus it is concluded that maximum 50% lining of watercourses can be done. For further research it is recommended to use advance non-linear techniques and high delta crops.

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