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ESTIMATING SEEPAGE LOSSES IN DIFFERENT SIZE OF EARTHEN WATERCOURSES AT FARM LEVEL

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ABSTRACT

The research work evaluates the effect of different size of field channels on seepage losses and its comparison with empirical equations developed for seepage estimation. Inflow-Outflow method was used as bench mark method for seepage losses which estimated seepage losses as 0.0342 and 0.024 cusec per 30ft reach which equals to 4.86% and 3.3% under bed-width greater than and equal to flow depth, respectively. The significant differences were observed between Inflow-Outflow and empirical methods. Formula used under Indian conditions under estimated seepage losses for two cases i.e. bed-width greater than and equal to flow depth. However, values of soil factor (C) could be adjusted for tangible estimates. The values of C = 1.71 and C = 3.33 might provide better estimates that will match the measured data. Lower soil factor limits could be used for watercourses with bed width equal to flow depth while, upper soil factor limits could be useful in water courses with bed-width greater than flow depth. Formula used under Pakistan conditions over estimated seepage losses under both cases. Formula does not consider any other hydraulic or soil parameters except discharge for seepage computations that is not enough to estimate actual seepage losses. The hydraulic parameters and soil characteristics for a range of soils need to be considered. Otherwise, this equation cannot be used to estimate seepage losses for clay loam soil. The results of this study can be referred by the engineer and decision makers who are actively involved in seepage estimation.

Keyword: Bed width, empirical equations, flow depth, inflow-outflow method, seepage losses, soil factor.

INTRODUCTION

Water is the most valuable resource for entire bio life living on the planet earth. According to statistics, approximately 2.05% of total water is frozen in glaciers, 0.68% as groundwater, and 0.011% as surface water in lakes and rivers (Pidwirny, 2006). This water is available for human consumption, agricultural production, industrial use and sanitation. People living in the under developed countries are suffering due to water crisis, which is becoming a key global issue (Starkey, 2012). Pakistan is no exception, where water is dwindling at an

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alarming rate. Recent assessments suggest that per capita availability of water has declined by 5 times from 5,260 m^3 in 1951 to 1,038 m^3 in 2010 (PWAPDA, 2012; ORSAM, 2013). If this trend continues, then by 2026, water availability would further drop to about 800 m^3 per annum (GoP-PC, 2007), while it will further decrease to an extremely low level of 575 m^3 in 2050 (ORSAM, 2013). At present, Pakistan is classified as water stress country and by the year 2025, it will turn into a water scared country. Therefore, the country will have to face a major challenge in water sector in the years to come. The problem of water shortage will aggravate further if the available water resources were not managed properly and used efficiently. The water security of the country is therefore a very critical issue. No doubt Pakistan possesses one of the world's largest contiguous irrigation systems; which is ranked 5^{th} in the world and 3^{rd} in Asia and is known as Indus Basin Irrigation System (IBIS). The irrigation system, consists of 3 large dams/ reservoirs (Tarbela, Mangla and Chashma), 19 barrages/ head works, 12 interlink canals, 2 major siphons, 45 main canals about 64,489 kms canals and distributaries carry water to 140,000 watercourses (Anonymous, 2010). Despite having this well-established irrigation system huge amount of water is lost in conveyance system creating waterlogging and salinity problems. Out of 142 MAF of annual river flows, about 92 MAF is diverted to the canal system, whereas about 31 MAF is lost in conveyance systems due to seepage (Anonymous, 2010).

Seepage is the most dominant factor by which water is lost in the conveyance systems. The accurate assessment of water losses from an irrigation conveyance system is vital for the proper management of the system. Thus, quantitative information of seepage losses is indispensable. For better operational planning and management of an irrigation system, an effective dependable forecasting of the seepage is thus important. Seepage from canals, watercourses and small farm channels is attributed to their earthen design, soil texture, silt deposition, groundwater table with respect to water surface in the channels, depth of water in canal, and hydraulic conductivity of the soil. Estimation of seepage losses is essential to make decisions while designing an irrigation channel or allocating water supplies at the head of canal. Inflow-Outflow method has been used as bench mark method (Sarki *et al*., 2008). In this method actual discharges are measured between two selected points on a channel. Seepage from canals occurs due to a combined effect of gravitational force and water tension gradients (Hansen *et al.,* 1980). According to Ali (2011) the conveyance efficiency in irrigation projects is poor due to seepage, percolation, cracking and damaging of the earth channel. Seepage losses in irrigation water conveyance system are very significant, as it forms the major portion of the water loss in the irrigation system. The geometric factors involved in the estimation of the seepage are the shape and dimensions of the irrigation channel and the depth of the water table and the depth to an impervious layer etc. Sarki *et al.* (2008) measured water losses in watercourse by ponding test method and inflow–outflow methods and found that losses were higher by 23% in ponded method. Bahramloo (2011) observed that the water seepage losses in canal were between 5.41% and 22.4% per 1 km (1.12 to 2.95 m per day).

Seepage rates are attainable either by direct measurement or indirectly by estimation. Various methods are used to estimate the canal seepage rate such as empirical formulae, analytical or analogue studies and the direct seepage measurement techniques, i.e. seepage meters, ponding tests and inflow–outflow tests. These methods have their merits, demerits and limitations which are well understood. Direct measurements are based on obtaining discharge measurements at different location along the earthen channel while in indirect methods, prediction can be made by empirical formulas. Mowafy (2001) computed seepage losses by applying empirical formulas that were based on measured values of seepage obtained through different field methods. Seepage is not only wastage of water, but also may lead to other problems such as waterlogging and salinization of agricultural land by rising water table. Canal seepage varies with: the nature of the canal lining; hydraulic conductivity; the hydraulic gradient between the canal and the surrounding land; resistance layer at the canal perimeter; water depth; flow velocity; and sediment load. Seepage rates are obtainable either by direct measurement or by estimation. The quantification of seepage rate in relation with its driving forces is necessary to estimate e.g. the effect of different sizes in terms of channel geometry on seepage. Keeping in view the above facts, this research has been conducted to estimate seepage losses using empirical equations and compare with those measured through direct field method (i.e. Inflow-Out flow method).

MATERIALS AND METHODS

Study was carried out at the field experimental station of Faculty of Agricultural Engineering, Sindh Agriculture University Tandojam. The experimental site is located at latitude: 25^0 25’ 28” N; longitude: 68^0 32’ 25” E; altitude: 26 m. Two different sizes of field watercourses were selected which already prepared in the experimental field. In one selected watercourse, the bed-width was greater than the flow depth and in other watercourse the bed-width kept equal to flow depth. The flow rate at the head of field watercourse was kept constant. The hydraulic parameters such as: cross-sectional area, wetted perimeter, flow depth, width of both the selected watercourses were measured using steel tape, while the bed slope was measured using a dumpy level and staff rod. Soil samples were collected at different bed locations and sides along the watercourse section using a core sampler and soil texture was determined.

Measurement of seepage losses by direct field method

The inflow-outflow method is considered one of the practical and reasonably accurate methods under dynamic flow conditions suited to actual field conditions. In present study, this method was used to measure seepage losses in two field watercourses and used as bench mark method due to its performance over time and advantage of applying in flowing condition in the water channel. The method involves measurement of discharge at two points. The initial point was considered as inflow and the other point at a downstream side as outflow. The discharge at both points was determined by using cut throat flume having 8” x 1.5’ dimensions. Two cut throat flumes were simultaneously installed at both points and inflow and outflow rates were measured. The selected portion of each watercourse was divided into five equal sections with an interval measuring 30ft apart. In this way, if an inflow point was located at zero distance (inlet) the outflow point was located at 30ft distance, next inflow point located at 30ft, the outflow at 60ft; subsequent inflow point at 60ft the outflow at 90ft; successive inflow point at 90ft, the outflow at 120ft; the final inflow point at 120ft, the outflow at 150ft. This yielded five inflow and five outflow measurement points which were then averaged.

The seepage losses were determined using following equation:

$$S = \frac{\text{Inflow - Outflow}}{\text{Reach length}} \qquad (1)$$

Empirical formulas used for seepage losses estimation

Two empirical equations were used in this study. The one equation developed by Mowafy (2001) using data from Northern Indus Plains India and reproduced as under:

$$S = \text{C A D} \qquad (2)$$

Where,

S = Total loss, cusec
A = Area of wetted perimeter, ft^2
D = Water depth in the channel, ft
C = Constant value

The value of C for the Northern Indus plain ranged from 1.1 to 1.8.

Mowafy (2001) also developed another equation and analyzed seepage losses from unlined canal in the Northern Indus Basin in Pakistan. In this equation, relationship between seepage losses per canal mile and channel discharge is given as follows:

$$S = 0.04\,(\text{Q})^{0.68} \qquad (3)$$

Where,

S = Seepage loss in cusec per channel mile
Q = Channel discharge in cusec

RESULTS AND DISCUSSION

Soil texture of selected watercourses under study

The results of soil texture of selected watercourse reveal that soil contained 31.2% clay, 28.4% silt and 40.4% sand particles. This particle size distribution reveals that the soil is clay loam.

Measurement of hydraulic parameters of selected watercourses

Hydraulic parameters of selected watercourses were measured and are presented in Table 1. The results on these parameters suggest that, in one watercourse the bed-width is three times greater than the flow depth. The average bed-width of this watercourse is 2.52 ft against average flow depth of 0.74 ft. This has resulted in greater wetted perimeter and cross-sectional area of watercourse. The average wetted perimeter of this watercourse was 4.63 ft with area of cross-section as 2.43 ft^2. The hydraulic radius of the section was 0.53 ft. while, the average flow velocity yielded to be 0.32 ft/sec. In other watercourse, the bed-with is almost equal to the flow depth. The bed width ranged between 0.92 and 1.3 ft and the flow depth ranged between 1.0 and 1.12 ft. This resulted in reduced wetted perimeter and cross-sectional area of water course. The average wetted perimeter of this watercourse was 4.13 ft while the area of cross-section was 2.32 ft^2. As expected, the hydraulic radius is greater and flow velocity is higher in this case.

The hydraulic radius of the section was 0.56 ft. while, the average flow velocity yielded to be 0.34 ft/sec. More seepage could be anticipated from watercourse having greater bed widths where water velocities decrease significantly and provide more seepage time through the channel bed. In contrast, water velocities are higher under the watercourse with smaller bed widths; this in turn provides lesser time for seepage to occur.

Table 1. Hydraulic parameters of selected watercourses.

Water-course reach (ft)	Bed-width (ft)	Flow depth (ft)	Flow velocity (ft/sec)	Cross-sectional Area (ft)	Wetted perimeter (ft)	Hydraulic radius (ft)	Bed Slope (S)
Hydraulic parameters of bed-width greater than flow depth of selected watercourse							
0-30	2.50	0.75	0.32	2.44	4.62	0.53	0.0003
30-60	2.54	0.74	0.32	2.43	4.63	0.52	
60-90	2.50	0.76	0.33	2.48	4.65	0.53	
90-120	2.52	0.75	0.32	2.45	4.64	0.53	
120-150	2.56	0.72	0.32	2.36	4.60	0.51	
Mean	2.52±0.015	0.74±0.07	0.32±0.00	2.43±0.02	4.63±0.005	0.53±0.005	
Hydraulic parameters of bed-width equal to flow depth of selected watercourse							
0-30	1.30	1.00	0.34	2.30	4.13	0.56	0.0003
30-60	1.10	1.10	0.34	2.42	4.21	0.57	
60-90	0.99	1.10	0.34	2.30	4.10	0.56	
90-120	1.30	1.00	0.34	2.30	4.13	0.56	
120-150	0.92	1.12	0.34	2.28	4.09	0.56	
Mean	1.12±0.095	1.06±0.03	0.34±0.00	2.32±0.005	4.13±0.01	0.56±0.00	

Seepage losses by inflow-outflow method

The results obtained by inflow-outflow method are presented in Table 2. It can be seen from the results that 4.9 % seepage losses occurred when the bed-width is greater than flow depth and 3.3% seepage losses yielded when bed-width is equal to flow depth for selected watercourses. The results reveal that bed-width and flow depth ratio had significant effect on seepage. If bed-width was greater than flow depth, the seepage losses were higher as compared to bed-width equal to flow depth. This is anticipated, because wider channel beds provide more space for water to infiltrate from the bottom of the channel. Also, wider channels have slower water velocities as compared to narrower beds, hence infiltration opportunity time increases that results in greater seepage losses.

Table 2. Seepage losses determined by direct field method (Inflow-Outflow), Indian and Pakistani formula at selected watercourses.

Watercourse Reach (ft)	Discharge (Cusec)		Seepage losses (cusec) per 30 ft of watercourse				
	Inflow	Outflow	Inflow-Outflow method		Indian Formula when C = 1.1	Indian Formula when C = 1.8	Pakistan Formula
			Cusec	%			
Seepage losses under width greater than flow depth watercourse							
0-30	0.776	0.74	0.041	5.28	0.0114	0.0187	0.0337
30-60	0.735	0.70	0.036	4.90	0.0112	0.0184	0.0324
60-90	0.699	0.67	0.031	4.43	0.0118	0.0193	0.0314
90-120	0.668	0.64	0.033	4.94	0.0115	0.0188	0.0304
120-150	0.635	0.61	0.030	4.72	0.0106	0.0174	0.0294
Mean	0.7026± 0.0353	0.67± 0.0325	0.034± 0.0028	4.86± 0.14	0.01131± 0.0002	0.0185± 0.003	0.0315± 0.0011
Seepage losses under width equal to flow depth watercourse							
0-30	0.777	0.75	0.026	3.35	0.0144	0.0235	0.0337
30-60	0.751	0.73	0.025	3.33	0.0166	0.0272	0.0329
60-90	0.726	0.70	0.025	3.44	0.0158	0.0259	0.0322
90-120	0.701	0.68	0.022	3.14	0.0144	0.0235	0.0314
120-150	0.679	0.66	0.022	3.24	0.0160	0.0262	0.0307
Mean	0.7268± 0.0245	0.70± 0.0225	0.024± 0.001	3.30± 0.0275	0.0154± 0.0001	0.0253± 0.0068	0.0322± 0.0075

Seepage losses using Indian formula

Data of various hydraulic parameters measured in the field and seepage losses estimated using Indian formula are summarized in Table 2. Seepage losses were estimated using soil factor values, i.e. C = 1.1 and C = 1.8, recommended for Northern Indus plains. Seepage losses estimated using C = 1.1 with the Indian formula are significantly less than those measured by direct field method for both condition i.e. bed-width greater than flow depth and bed-width equal to flow depth. Indian method underestimates seepage losses as compared to Inflow-Outflow method which seem to be affected by the soil factor values used in this equation. Comparison between cumulative seepage losses obtained with Indian formula, direct field method and calculated using measured data are depicted in Figure 1 and 2. Significant differences could be seen for the watercourses with width greater than flow depth (Figure 1). While, Indian method compares well with direct field method when C = 1.8 is used for watercourse having equal bed-width and flow depth (Figure 2). It appears that soil factor values suggested for northern Indus plains do not provide reasonable seepage estimates for our conditions. The soil factor (C) values for two watercourses were calculated using the measured data. The C values ranged between 2.9 and 3.95 and averaged to

3.33 for the watercourse with greater bed-width than flow depth. These results suggest that average C value i.e. 3.33 could provide better estimates on seepage losses that will match our conditions for width greater than flow depth. While C values ranged between 1.51 and 1.99 and averaged to 1.71 for the watercourse with equal bed-width and flow depth. These results further suggest that 1.71 provide better estimates on seepage losses that will match our conditions for bed-width equal to flow depth. Lower soil factor limits could be used for watercourses with width equal to flow depth while, upper soil factor limits could be applied in watercourses with greater bed-width than flow depth.

Seepage losses estimated by formula developed under Pakistan conditions

Seepage loss estimated using Pakistani formula is summarized in Table 2. Comparison between cumulative seepage losses obtained with this formula and Inflow-Outflow method has been demonstrated in Figure 3 and 4. Results reveal that formula mostly over estimates seepage losses for channels having bed-width greater than flow depth as well as when bed-width is equal to flow depth. Formula does not consider any other hydraulic or soil parameters except discharge for seepage computations. It appears that only discharge is not enough to estimate seepage losses. Formula generally returns identical seepage values which seem unrealistic.The ANOVA was applied for seepage losses estimated using empirical equations and the results are presented in Table 3.

The ANOVA results confirm that the seepage losses are non-significant at P = 0.01. Similarly, seepage losses calculated by empirical formulae, either underestimated or overestimated when flow width equal to flow depth was considered and losses were significantly different at P=0.05. The comparison between methods reveals that they were statistically significant with F-test value 180 (P< 0.05) in case of bed-width greater than flow depth. While, they were non-significant at P=0.05 in case of bed-width equal to flow depth. Furthermore, Tukey test was used to compare pair wise mean between methods at P= 0.05. The results on seepage losses measured using inflow-outflow method estimated by Indian formula at silt factor C = 1.1 and C =1.8 and Pakistani formula are summarized in Table 4. The Tukey test divided these means in four groups (A, B, C and D) and means of the groups are significant at P=0.05. The Tukey test revealed that seepage losses estimated by different methods were significantly different at P= 0.05 level. The present research reveals that there is considerable difference in seepage losses when the channel geometry is different. The seepage losses increase by increasing the bed width of field channels. These results are supported by Chahar (2006) in which he observed that there was linear combination of channel geometry and seepage function in relation with silt and cross-section. Moreover, the quantity of seepage losses from channel is always greater than a feasible of the same top width to depth ratio. Further the study suggests that Pakistani formula for estimating seepage rate overestimates the seepage rate estimated Indian conditions. The study demonstrates the possible change in value of soil factor C on weighted mean basis. The overall seepage losses by all methods employed for the study are in quite agreement with Khan (1997), IWASRI (2004), Sarki, *et al.* (2008) and Bahramloo (2011).

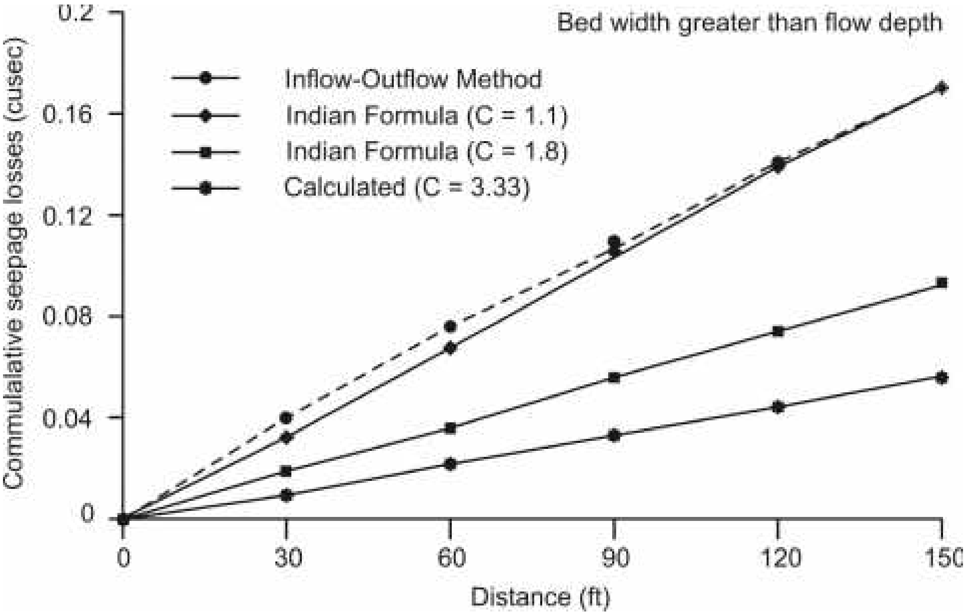

Figure 1. Comparison between Indian Formula and Inflow-Outflow method when bed-width is greater than flow depth.

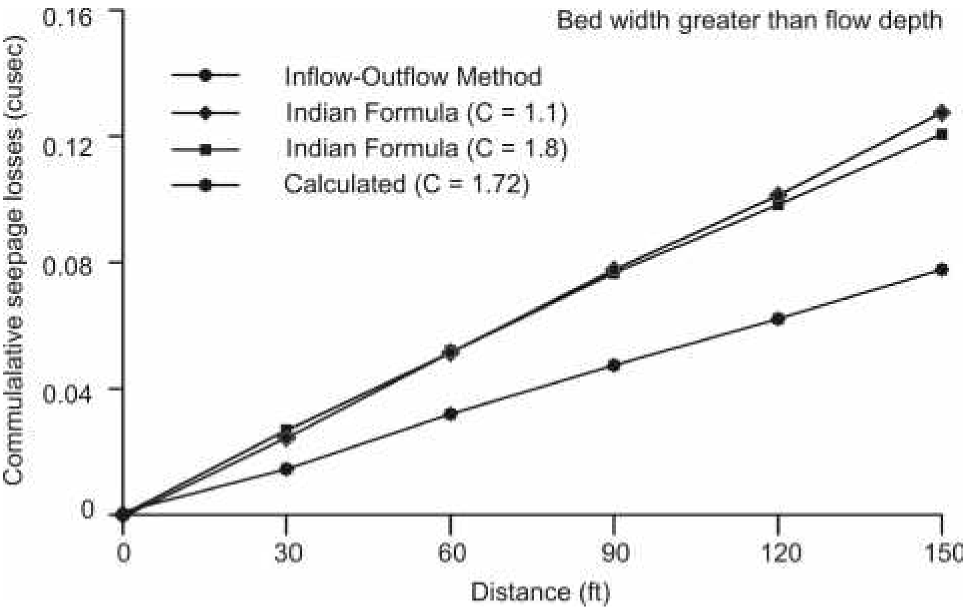

Figure 2. Comparison between Indian Formula and Inflow-Outflow method when bed width is equal to flow depth.

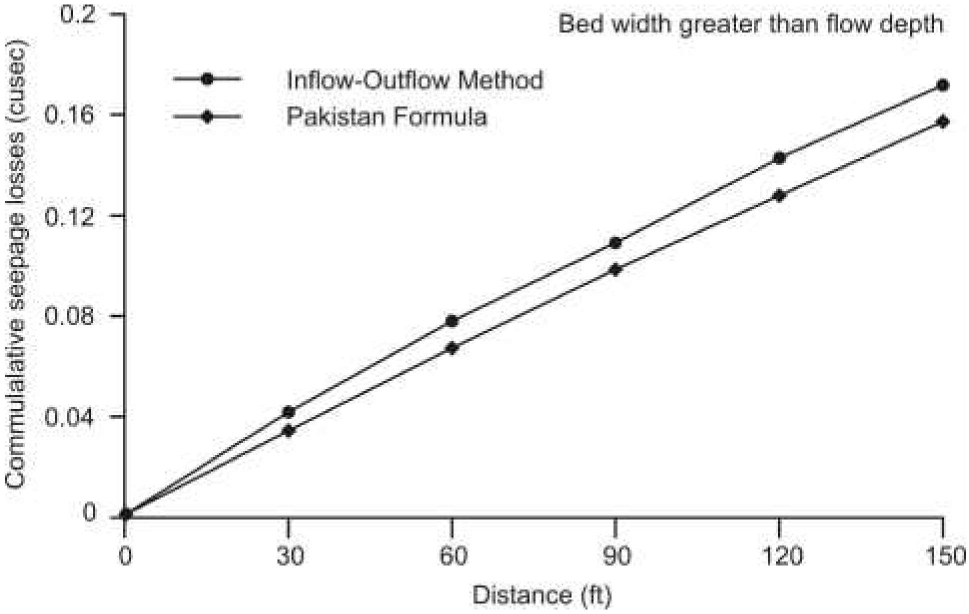

Figure 3. Comparison between seepage measured by Inflow-Outflow method and estimated using formula develoded for unlined canals in Pakistan for b > d.

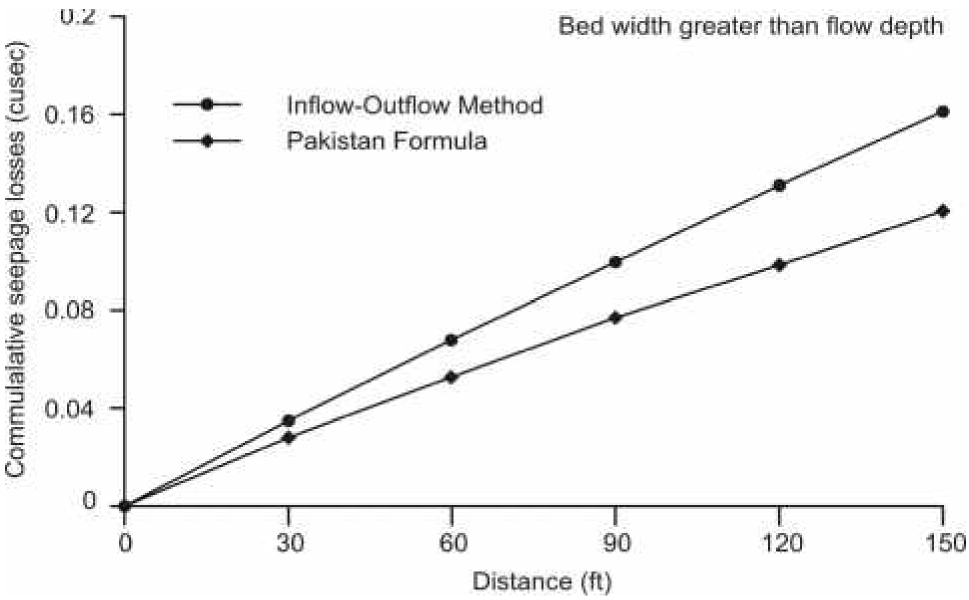

Figure 4. Comparison between seepage measured by Inflow-Outflow Method and estimated using formula develoded for unlined canals in Pakistan for b = d.

Table 3. ANOVA results on seepage losses estimated using empirical equation.

Seepage losses determined when width is greater than flow depth					
Source	DF	SS	MS	F	P
Replication	4	0.00004	1.038E-05	2.43	0.1047
Methods	3	0.00175	5.845E-04	136.82	0.0000
Error	12	0.00005	4.272E-06	-	-
Total	19	0.00185	-	-	-
Grand Mean = 0.0258			CV = 8.41		
Seepage losses determined when width is equal to flow depth					
Replication	4	1.582E-05	3.956E-06	2.51	0.0971
Methods	3	7.089E-04	2.363E-04	149.99	0.0000
Error	12	1.890E-05	1.575E-06	-	-
Total	19	7.436E-04	-	-	-
Grand Mean = 0.0260			CV = 4.66		

Note: DF is Degree of Freedom; SS is Sum of Square; MS is Mean Square; F is F-test values; CV compares the variability and P is Probability

Table 4. Tukey Test HSD all- Pair wise comparisons among different seepage methods.

Seepage losses Method	Inflow-Outflow	Indian Formula (when c = 1.1)	Indian Formula (when c = 1.8)	Pakistani Formula
Mean	0.0342	0.0113	0.0185	0.0314
Homogeneous Group	A	C	B	A

Standard Error for Comparison 1.370E-03 Critical Q Value 4.199
Critical Value for Comparison 3.882E-03
Means are significantly different from each other @ $P<0.05$

CONCLUSION

Empirical equation used under Indian formula condition, generally under estimated seepage losses while equation used under Pakistan condition, overestimated the seepage losses when bed-width is greater than flow depth. The soil factor used under Indian formula have been optimized that range between 1.71 and 3.33 to provide better estimates that will match the measured data. Lower soil factor limits could be used for watercourses with width equal to flow depth while, upper soil factor limits could be useful in water courses with greater bed-width than flow depth. The Pakistan formula does not consider any other hydraulic or soil parameters except discharge for seepage computations. It appears that only discharge is not enough to estimate seepage losses. Hence, this equation cannot be used for seepage losses estimation for clay loam soil. The results of this study may be supposed to be referred by the scientist and decision makers for further research.

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