Iranian Journal of Science & Technology, Transaction B, Vol. 28, No. B5
Printed in The Islamic Republic of Iran, 2004

"Technical Note"

AN EMPIRICAL MODEL FOR PREDICTION OF CONVEYANCE EFFICIENCY FOR SMALL EARTH CANALS*

A. R. SEPASKHAH[1**] AND H. R. SALEMI[2]

[1]Dept. of Irrigation, Shiraz University, Shiraz, I. R. of Iran
Email: sepas@shirazu.ac.ir
[2]Dept. of Agricultural Engineering, Isfahan Center of Agricultural Research, Isfahan, I. R. of Iran

Abstract– Most of the water loss in distribution and conveyance earth canals occurs through seepage. This loss should be considered in irrigation network design through conveyance efficiency (e_c). It is a common practice for the value of e_c to be measured in existing irrigation systems under different soil types, vegetation covers and canal sizes. However, it is a costly and time consuming practice, therefore, empirical models to indicate the relationship between e_c and soil texture, canal capacity and vegetation cover in earth canals may be effective in the estimation of e_c at different conditions. This research was conducted to measure the conveyance efficiency in earth canals that are well above groundwater level with different soil textures and water weed densities in the northern and north-western areas of Isfahan province, I.R. of Iran. Conveyance efficiency of a km reach in distributary earth canals with a sandy loam soil was 67.3%, and for a clay loam soil in tributary earth canals 95.8%. The vegetation cover in the earth canal did not affect the e_c value significantly. Therefore, it is concluded that traditional earth canals with medium to heavy soils in the study area have high e_c and the lining may not be economically justified. Furthermore, for earth canals well above the groundwater level a multiple regression model was presented to estimate the e_c value based on flow rates smaller than 404 $l\ s^{-1}$ in distributary and tributary canals and sand content in soil.

Keywords– Modelling, conveyance efficiency, small earth canal

1. INTRODUCTION

Water utilization efficiency is a major parameter in planning, designing and operation of an irrigation system. This parameter is usually the "guess" factor in the design of an irrigation system, therefore, engineers are facing the problem of uncertainty in their calculations. Thus, there is an urgent need for a more basic knowledge of irrigation efficiencies under different climatic, soil, and agricultural conditions.

The system of water distribution is split up into the following successive stages:

(i) Conveyance by main, lateral, and sublateral (tributary) canals to the farm inlet.

(ii) Conveyance by farm ditches (distributary) to the field.

The efficiency in the first stage is defined as the water conveyance efficiency, e_c, and can be expressed as [1]

$$e_c = V_f / V_t \quad (1)$$

where V_f is the volume of water delivered to all farms in the area and V_t is the total quantity of water supplied to the area. The efficiency in the second stage is defined as the farm ditch efficiency, e_b, and can be expressed as [1]

$$e_b = V_n / V_f \quad (2)$$

where V_n is the field application to the cropped area and V_f is the volume of water delivered to all farm inlets in the area.

The difference between the numerator and denominator in Eqs. (1) and (2) increases as the seepage loss in canals increases, which results in lower e_c and e_b values.

---

*Received by the editors February 10, 2002 and in final revised form January 23, 2004
**Corresponding author

Different factors influence the e_c values. These factors are the command area, the size of rotational units, canal lining material, soil texture, canal size and water weed management [1]. They reported that farms with lined ditches or farms situated on less permeable soils (silty clay and clay) have e_b values above the average value.

The low values of e_c or e_b are mainly due to the seepage loss in earth canals. Canals through sandy soils can have quite high seepage losses along the entire length of the canal [2]. The average value of e_c was reported to be about 70% [1]. Lengthy unlined canals, water weeds, and rodents are the main causes of water loss in traditional water distribution systems. It is clear that soil texture affects the water seepage loss is greater in light soils [3]. Furthermore, greater vegetation cover in earth canals, especially in medium to heavy soils, may result in greater seepage loss [4].

It is a common practice for the value of e_c to be measured in existing irrigation systems under different soil textures, vegetation covers and canal sizes. However, it is costly and time consuming, therefore, empirical models to indicate the relationship between e_c and soil textures, canal capacity and vegetation covers in earth canal may be effective in the estimation of e_c at different conditions. Furthermore, for comparison purposes, the e_c value should be measured in a similar length of canals.

This research was conducted to measure the conveyance efficiency in earth canals in fields that are well above groundwater level with different soil textures and water weed densities in northern and north-western areas of Isfahan province, I.R. of Iran.

2. METHODS AND MATERIALS

The amounts of seepage in 18 earth tertiary (discharge of 57.0 to 404.0 $l\ s^{-1}$) and distributary (discharge of 25.0 to 58.0 $l\ s^{-1}$) canals with different reaches of 98 to 270 m in length were measured in the irrigation network of the Barkhar area of Isfahan province. The canals are located in Ashegh-abad, and Mahmood-abad in the north and northwest province of Isfahan (Fig. 1). The soil texture of these canals varied between heavy and light textures. The details are shown in Table 1. The vegetation cover varied in canals for each soil texture group. We classified the vegetation cover in canals as low (10-35%), medium (35-55%) and high (55-95%).

Table 1. Soil physical characteristics and vegetation covers for different small earth canals with different length (m)

Canal reach	Canal length	Canal order	Vegetation cover %	Soil* texture	Silt %	Clay %	Sand %
1	127	4	Low	CL	49.4	28.0	22.6
2	150	4	Medium	CL	40.0	35.0	25.0
3	190	4	High	CL	31.0	39.5	29.5
4	270	3	Low	CL	48.0	31.0	21.0
5	250	3	Medium	CL	39.5	29.5	31.0
6	210	3	High	CL	38.0	26.4	35.6
7	170	4	Low	L	35.0	25.0	40.0
8	98	4	Medium	SiCL	51.0	30.0	19.0
9	140	4	High	L	42.0	28.0	30.0
10	198	3	Low	SiL	43.0	19.0	28.0
11	188	3	Medium	SiL	52.0	15.0	33.0
12	144	3	High	SiCL	51.0	31.0	18.0
13	138	4	Low	SL	5.0	20.0	75.0
14	152	4	Medium	SL	4.0	18.0	78.0
15	100	4	High	SL	4.0	20.0	76.0
16	144	3	Low	SL	4.0	16.0	80.0
17	166	3	Medium	S	5.0	5.0	90.0
18	190	3	High	SL	13.0	15.0	72.0

(*) CL=Clay loam, L=Loam, SiCL=Silty clay loam, SiL=Silt loam, SL=Sandy loam, S=Sand

Fig. 1. Schematic position of the study area

The canal water loss was measured by the inflow-outflow method as proposed by [3] in a manual for irrigation canal lining published by FAO. The accuracy obtainable in this method is high as stated in this manual (pp: 39). These measurements were made in May, June, and July with three replications in May. The average of these measurements was considered as the temporal average. For any of the 18 canals at any time, the outflow discharge was lower than the inflow discharge, therefore it may be assumed that the measured seepage rate is within the error bounds of the measurements. The canal water loss consisted of seepage and surface evaporation. Therefore, the amount of surface evaporation was subtracted from the total loss to determine the seepage loss. The water surface evaporation was estimated by multiplication of the pan coefficient (K_p) and pan evaporation. The pan evaporation for the study periods was obtained from the nearby meteorological station, i.e., the Murchekhurt station for Ashegh-abad and Mahmood-abad areas with K_p of 0.8 and the Isfahan Technical University station for the Asghar-abad area with a K_p of 0.7. For the portions of canal with vegetation covers, the evapotranspiration (ET_p) was used instead of evaporation. The ET_p was estimated by ET_o, multiplied by crop coefficient (K_c) of 1.2 [5].

These seepage losses are for canals that are well above groundwater levels, so that seepage is not influenced by groundwater. The conveyance efficiency (c_e) of canals was estimated by dividing the measured flow rates at the end of the canal reach to its value at the beginning of the reach. The accuracy of flow measurement was 2-5%. The length of the canal reach was different, therefore the values of e_c were linearly scaled for a length of one km for canal reach.

3. RESULTS AND DISCUSSION

The average ET_p for the months of May, June and July were 0.00703, 0.0105 and 0.0117 $m^3\ m^{-2}\ d^{-1}$, respectively, for all canals. The average value for all three months was 0.01 $m^3\ m^{-2}\ d^{-1}$. The average seepage in canals for the months of May, June and July were 0.947, 0.681 and 0.708 $m^3\ m^{-2}\ d^{-1}$, respectively. The value for the three months was 0.679 $m^3\ m^{-2}\ d^{-1}$. These data indicated that 98.6% of the water loss in canals occurred through seepage and only 1.4 % was due to ET_p. The average seasonal seepage rates (mean value of seepage rate for all three months) were used in further analyses.

The seasonal (temporal) average of conveyance efficiency, e_c (%) of a km reach for different earth canals with various soil textures and flow rates at three different times of year with various vegetation covers are shown in Table 2. In general, the temporal mean of e_c was lower for light soils (sand to loam soils), and its value was higher for medium soil (silt loam to clay loam soils). Furthermore, the value of e_c was lower for smaller flow rates in canals and higher for larger flow rates. The lowest mean e_c was 67.3 % for a sandy loam soil with a flow rate of 43.5 $l\ s^{-1}$ (distributary canal) and the highest value of e_c was 95.8 % for a clay loam soil with a flow rate of 356.8 $l\ s^{-1}$ (tributary canal). It is clearly shown that e_c for light soils decreased by 30 % in comparison with medium texture soils.

The data in Table 2 did not show a significant difference between e_c values for different vegetation covers in the earth canals. Similar results were stated by [2].

Table 2. The temporal averages of conveyance efficiencies (average for 5 measurements), flow rates and vegetation covers in different reaches of earth canals

Canal reach number	Conveyance efficiencies, %	Flow rates $l\ s^{-1}$	Vegetation covers, %
1	84.5	31.8	15.0
2	86.2	37.0	40.0
3	86.3	58.4	85.0
4	95.8	356.8	15.0
5	91.9	115.3	40.0
6	95.2	404.4	70.0
7	62.9	24.5	17.3
8	76.9	52.3	40.0
9	68.8	54.0	90.0
10	90.7	229.3	17.3
11	90.1	232.7	40.0
12	87.3	164.4	70.0
13	67.6	50.0	15.0
14	69.3	36.3	45.0
15	67.3	43.5	65.0
16	70.4	144.5	15.0
17	68.5	56.9	45.0
18	77.5	87.0	65.0

The relationship between e_c (%) and the incoming flow rate in the canal (Q, $l\ s^{-1}$) and sand content in soil (%) was obtained by multiple regression analysis using all data as follows:

$$e_c=83.2+0.054Q-0.22(\text{Sand\%}), \text{ for } R^2=0.73, \quad n=18, SE=6.10, \quad p<0.001 \tag{3}$$

where R^2 is the coefficient of determination, n is the number of data points, SE is standard error and p is the probability level.

The results indicated that the e_c value is higher for a tributary canal than that for a distributary canal. This is depicted by the positive value of the coefficient for Q in Eq. (3). Furthermore, e_c value is reduced in light soil. This is shown by the negative coefficient for sand content in soil. A power correlation between e_c, Q and sand content in soil was obtained as follows:

$$e_c=85.4Q^{0.092}(Sand)^{-0.132} \tag{4}$$

$R^2=0.74$, SE=1.08, n=18, $p<0.0002$

However, the value of R^2 was similar to that obtained for linear correlation Eq. (3). Therefore, Eq. (4) is not superior to Eq. (3). Equation (3) may be used to estimate the conveyance efficiency of earth canals with different soil textures and flow rates in the range of 24.5-404.4 $l\ s^{-1}$. A plot of conveyance efficiency versus flow rate and soil sand content is shown in Fig. 2. Another set of data for conveyance efficiencies were obtained from [6] for small earth canals with different soil textures and flow rates and used in Eq. (3). The relationship between measured and estimated values of e_c (e_{cm} and e_{ce}, respectively) is shown in Fig. 3. The linear relationship between these values is obtained by regression analysis as follows:

$$e_{cm} = -0.16 + 0.89\, e_{cm}, \quad R^2 = 0.74, \quad p < 0.001 \qquad (5)$$

The slope of this line is 0.89 which is close to 1.0 statistically and its intercept (-0.16) is negligible. Therefore, this linear equation is close to the 1:1 line, statistically.

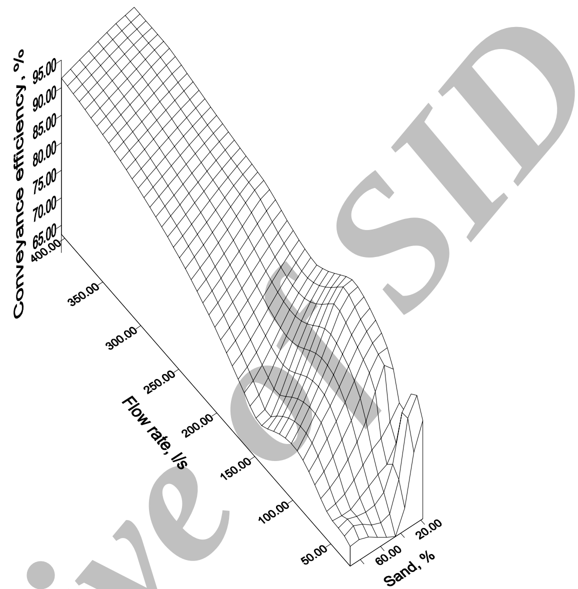

Fig. 2. Relationship between conveyance efficiency, flow rate and soil sand content

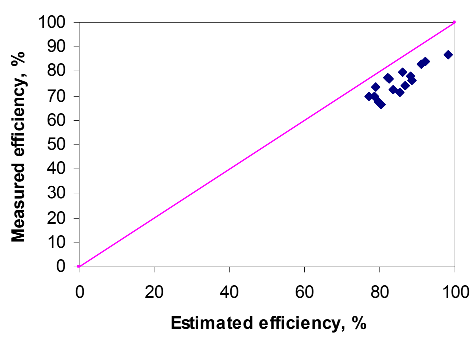

Fig. 3. Relationship between estimated and measured conveyance efficiencies (solid squares) and 1:1 line (solid line)

In medium to heavy texture soils, the e_c was high (95.8 %), therefore, economically there may be no justification to increase the conveyance efficiency by lining earth canals [2]. In this case, the actual cost of water must be considered before lining canals can be justified. Nowadays, a new canal is preferably lined, wherever feasible, for several reasons [7]. Checking seepage is one of these reasons, but lining does not remain perfect as it deteriorates with time and cracks develop in it. A well maintained canal with 99% perfect lining reduces seepage about 30-40% [8] only.

4. CONCLUSION

Conveyance efficiency (e_c) in distributary earth canals with a sandy loam soil was 67.3% and for a clay loam soil in the tributary earth canal was 95.8 %. The vegetation cover in the earth canal did not affect the e_c value. Therefore, it is concluded that in traditional earth canals with medium to heavy soils, lining may not be economically justified due to high e_c value. Furthermore, a multiple regression model was presented to estimate the e_c value based on the flow rates in distributary and tributary earth canals and sand content in soil.

REFERENCES

1. Bos, M. G. & Nugteren, J. (1982). *On irrigation efficiencies*. 3rd ed. ILRI, Wageningen.
2. Doorenbos, J. & Pruitt, W. O. (1977). Crop water requirement. Irrigation and Drainage Paper No. 24 (2nd Ed.). FAO, Rome, Italy, p.144.
3. Heerman, D. F., Wallender, W. W. & Bos, M. G. (1990). Irrigation efficiency and uniformity. In: G. J. Hoffman, T.A. Howell, and K. H. Solomon. (eds.). Management of Farm Irrigation System. ASAE Monograph. 125-149.
4. Kraatz, D. B. (1977). Irrigation canal lining. FAO Land and Water Development Series No. 1, FAO, Rome. 199 P.
5. Salemi, H. R., Sepaskhah, A. R. & Maamanpoosh, A. R. (1999). Modification of empirical equation for seepage loss estimation in small earth canals in Roodasht-Isfahan areas. Research Project Report, No. 146. Research Institute of Agricultural Engineering, Ministry of Agriculture. 40 P. (in Farsi).
6. Salemi, H. R. & Sepaskhah, A. R. (2001). Modification of empirical equation for seepage loss estimation in small earth canals. *Iran. J. Sci. Tech. (Trans. B) 25*, 661-668.
7. Swamee, P. K., Mishra, G. C. & Chabar, B. R. (2000). A comprehensive design of minimum cost irrigation canal sections. *J. Irrig. Drain. Eng. 126*(5), 322-327.
8. Wachyan, E. & Rushton, K. R. (1987). Water losses from irrigation canals. *J. Hydrol. 92*(3, 4), 274-288.