

## RESEARCH ARTICLE

## Estimation of canal seepage under shallow water table conditions

S.K. Singh<sup>1</sup>, Chhedi Lal<sup>2</sup>, N.C. Shahi<sup>3</sup> and Khan Chand<sup>3\*</sup>

<sup>1</sup>Faculty of Engineering and Technology, Gautam Buddha Technical University, IET Campus, Sitapur Road, Lucknow-221001 (U.P.); <sup>2</sup>Senior Scientist and Ex. Professor, Central Soil Salinity Research Institute, Regional Research Station, Jail Road, Near Manyvar Shree Kanshi Raam Smarak Sthal, P.O. Alambagh, Lucknow-226005; <sup>3</sup>Dept. of Post Harvest Process and Food Engineering, G.B. Pant University of Agriculture and Technology, Pantnagar (Uttarakhand), India  
adsksingh@gmail.com; lalc\_verma@yahoo.com; ncshahi2008@gmail.com; kcphpfe@gmail.com; +91 7500734737

### Abstract

Measurement of seepage from large canals by ponding method is practically impossible due to continuous running and large widths of canals. Inflow-outflow method is also not suitable for canal seepage measurement in short reaches of canals due to small differences. Seepage meter technique may require large number of measurement to arrive at an average value of canal seepage. Analytical solutions are over simplified for estimation of canal seepage due to several assumptions which are rarely met in field. Estimation of saturated hydraulic conductivity and selection of a representative value itself is tedious task. It is difficult to incorporate large variations of saturated hydraulic conductivity within a short reach of canal for seepage estimation. Tracer technique may result in erroneous seepage value in the area where seepage is partially flowing to some drain. Thus, available methods of canal seepage estimation are having limitations either for its application in large canals or its use in designing subsurface drainage or bio-drainage belt for combating water logging. Canal seepage was estimated by calculating subsurface flow and subsurface storage along the canal. The method is suitable for the area where water table is shallow and shallow observation wells can be installed easily. From water table fluctuation data of study area the subsurface flow and subsurface storage was calculated and seepage was estimated. The canal seepage was calculated to be 3622.21 m<sup>3</sup>/d per km of canal reach. Proposed method is simple and suitable for small and large reaches of canals simply by putting a series of shallow open observation wells. Method may be also useful in studying evaporational losses from adjoining area of the canal under different weather conditions.

**Keywords:** Canal seepage, unlined canal, drainable porosity, subsurface flow, soil storage.

### Introduction

Irrigation had played an important role in increasing food grain production in India making country self reliant in agricultural production. Nearly 70% of freshwater use is for irrigation (Hotchkiss *et al.*, 2001) and share may go as high as 80 to 85% for many developing nations. India has a vast network of canals which helped a lot in bringing first green revolution. Besides its importance, several problems are associated with canal irrigation such as water logging and salinization. Extensive water logging has taken place in almost all large irrigation projects where irrigation was introduced without giving due consideration to drainage. Canals are mostly unlined in India consequently appreciable amount of water goes as waste due to excessive seepage. Seepage water slowly makes the adjoining area waterlogged if internal drainage of the area is not sufficient to tackle canal seepage. Area once waterlogged has tendency to accumulate salts in root zone due to continuous evaporation of water if rainfall amount is not sufficient to leach down the salts annually. More than 4.5 million hectare of (M ha) land is waterlogged and 8.5 M ha is salt affected in India (Singh, 1992). Waterlogged and salt affected soils can be reclaimed by improving surface and subsurface drainage.

Bio-drainage is use of quick growing and high water demanding plants (exotic trees) is also advocated to avoid water logging and salinization. Bio-drainage is suitable for difficult terrain with poor water transmission characteristics. In the area where natural drainage outlet is not available and water quality is poor for recycling, bio-drainage becomes only the available drainage option for controlling water logging and salinization. Drainage coefficient is an essential input parameter for calculating drain spacing of subsurface drainage or for designing surface drains in waterlogged areas. For estimation of drainage coefficient or drainage load on drainage systems including bio-drainage, canal seepage data are required. In India, the seepage loss has been estimated to account for 45% of the water diverted into canal systems (Sharma and Chawla, 1979). In Pakistan, seepage losses from canals have been estimated to range between 15 and 45% of the total diverted volume (Van der Leen *et al.*, 1990). Seepage losses from canals in the former U.S.S.R. have been reported to be 40-50% of the transported water (Kacimov, 1992). Analytical solutions available for calculating canal seepage involve number of assumptions and require saturated hydraulic conductivity as an input parameter which is highly variable in the field.

*In situ* determination of saturated hydraulic conductivity at several locations and finally selecting a representative value for selected model may still yield erroneous values of seepage as the soil type at different section of canal embankment may be changing and cannot be taken homogenous. Analytical solutions are based on certain assumptions which are rarely met under field conditions. Numerical techniques too require soil parameters at different locations having similar limitations. Direct measurement of seepage using ponding test approach does not seem feasible in large canals (Bouwer, 1961). Inflow-outflow method may not yield satisfactory result over a short length of canal when discharge is too high (Dukker *et al.*, 1994; Skogerboe *et al.*, 1999). Seepage meter measures localized seepage and for getting a reliable data, a large number of measurements would be required. Tracer technique may yield erroneous result if employed in the area where seepage water is partially flowing to some drains. Current meter may give high error which measuring inflow and outflow discharge in a canal section (Kolupaila, 1964). Against these backdrops, this study was aimed to estimate the canal seepage under shallow water table conditions through water balance approach with water table fluctuation data.

**Materials and methods**

**Study area:** Sharda Sahayak canal system is a large canal taking off water from the right bank of the lower Sharada Barrage and supply irrigation water to a vast area of 2.0 M ha. Lower Sharda Barrage is built across the Mahakali River in district Nainital (Uttarakhand) in India. The Mahakali River is the natural boundary between India and Nepal. The command area of this canal extends over a vast area to the west and south of the Karnali River (known as the Ghaghra River in India). The total length of the branch, secondary and tertiary canal is 8704 km. The capacity of canal is 650 m<sup>3</sup>/s. The study area is located in Sharada Sahayak Canal Command at Kashrawan village of Bachhrawan block in district Raibareli, U.P., India (Fig. 1). The area on either side of the canal is waterlogged coupled with sodicity. Water table depth fluctuates from 0.00 m to 1.5 m below ground surface throughout the year. Soil pH ranges 8.5 to 10.5 in the area. The bottom width of canal at the site is 46 m and canal depth is 2.2 m with side slope of 1:2. Canal discharge at full supply level at this reach of canal is 170 m<sup>3</sup>/s.

**Method:** A straight canal section of 650 m was selected for estimating canal seepage. Experimental area was taken as 650 m along and 465 m across the canal. A battery of observation wells of 10 cm diameter were installed in four lines perpendicular to the canal (Fig. 2). All the four lines started from 25 m away from the toe of the canal. Distance between first and second lines of observation wells is 200 m, second and third lines are 350 m and third and fourth lines are 100 m.

Fig. 1. Aerial satellite map of the experimental area.



Fig. 2. Layout of observation wells in study area.

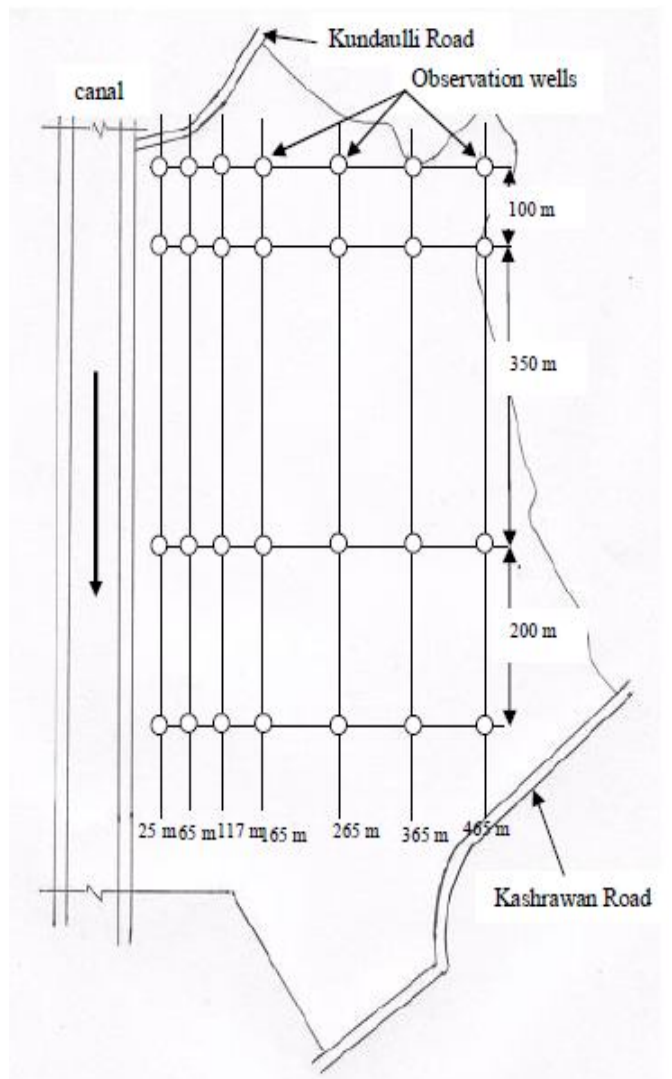


Fig. 3. Canal running from Jan 2005 to May 2005.

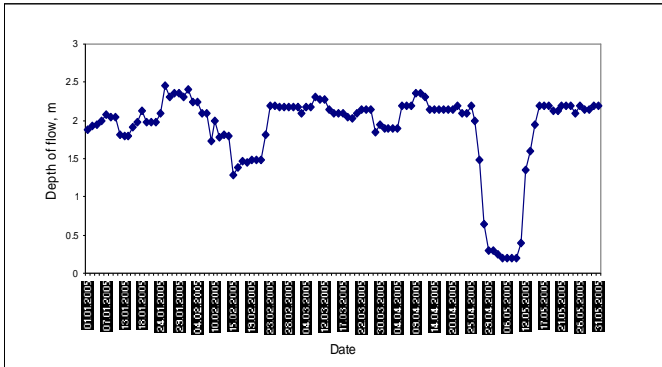
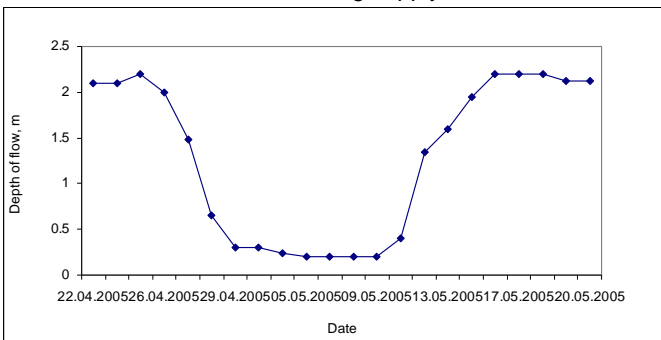


Fig. 4. Depth of water flow in canal after closure and restoring supply.



Seven observation wells were made on each line at a distance of 25 m, 65 m, 117 m, 165 m, 265 m, 365 m, 465 m from toe of canal. Thus, whole area was divided into 18 grids by joining lines to observation wells horizontally and vertically. The distance between observation wells over a line perpendicular to the canal was kept as 40 m, 52 m, 48 m, 100 m, 100 m and 100 m.

**Drainable porosity:** Soil samples were collected at all the points where observation wells were installed for measuring drainable porosity of different soil layers. Drainable porosity measured at each observation well site ranged from 0.0412 to 0.0514 cm<sup>3</sup>/cm<sup>3</sup> up to soil depth of 0-0.5 m and 0.0756 to 0.0834 cm<sup>3</sup>/cm<sup>3</sup> for soil depth of 1.5-2.0 m. First clay layer was found at an average depth of 3.0 m below ground surface.

**Canal water supply:** Water depth fluctuations in canal from Jan to May 2005 are shown in Fig. 3. The canal generally runs throughout the year except for a closure of 15 to 30 d in a year. Figure 3 shows a closure from 25 Apr 2005 to 09 May 2005. Enlarged view of canal closure and restoration of supply are shown in Figure 4. The moment canal supply ceases, water table starts declining in the adjoining area after restoration of supply starts rising. Water table fluctuations in the observation wells located over the line across the canal are shown in Figure 5a, 5b, 5c and 5d. Decline in water table depths in adjoining area after canal closure is due to subsurface flow and evaporation from the ground surface.

Fig. 5a. Water table fluctuation in observation well at first line.

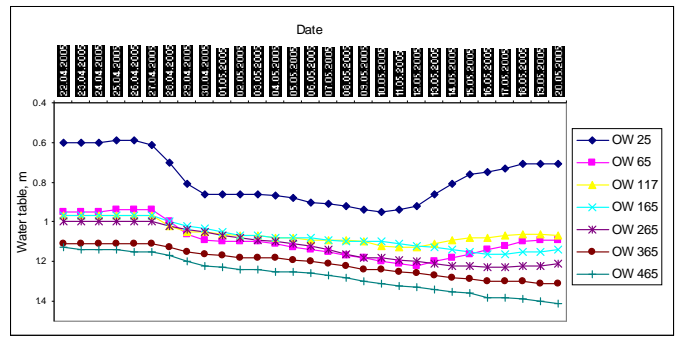


Fig. 5b. Water table fluctuation in observation well at second line.

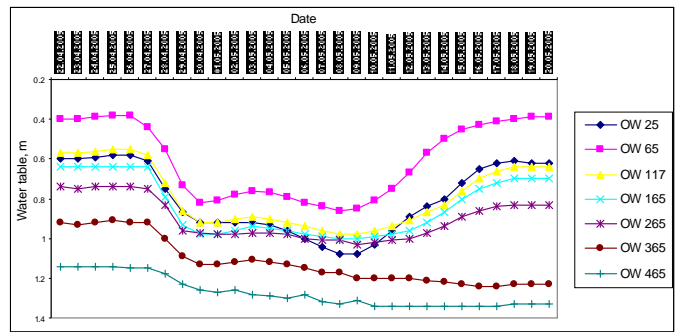


Fig. 5c. Water table fluctuation in observation well at third line.

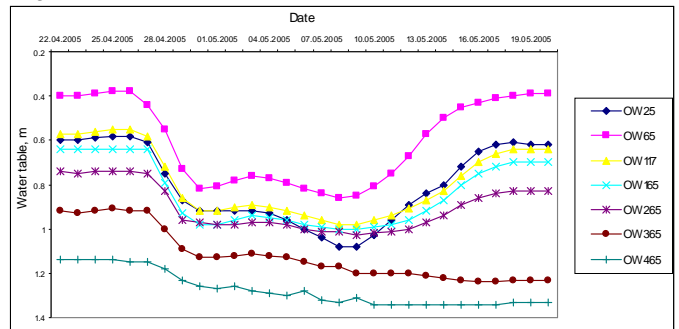
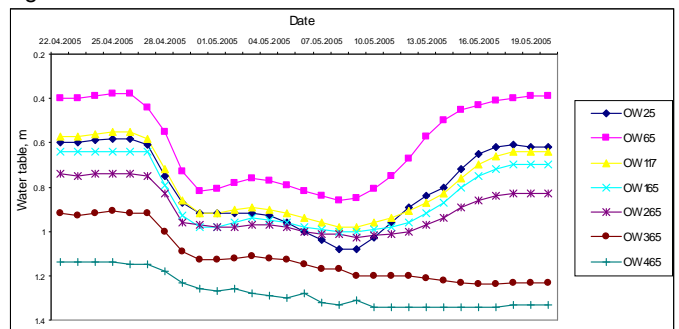


Fig. 5d. Water table fluctuation in observation well at fourth line.



**Water table fluctuation in study area:** Water table fluctuations in the study area during canal closures and after restoration of supply level is shown in Figure 5a to 5d. Water table fluctuations at first line of observation wells are shown in Figure 5a and at fourth line in Figure 5d.

It may be seen from Figure 5a-d that water table receded rapidly after the canal closure and got almost stabilized within 4 to 5 d. As soon as canal restored supply water table started rising and got stabilized within 7 to 8 d. During canal closure water table kept on receding at a slow rate compared to water table drop after closure. Fluctuation of water table depth followed the similar trend for all the lines of observation wells. It may be further seen that the observation wells located 365 m away from the canal remain almost unaffected.

**Subsurface flow:** Seepage from running canal can be calculated by estimating subsurface flow and water storage in soil profile.

Canal seepage = Subsurface flow from the area + Water storage in the soil profile.

The subsurface flow is a continuous process and needs to be estimated for making water balance of the area for seepage calculation. Measurement of subsurface flow when there is no change in water table depth requires different approach than the one which can be employed when water table is receding after a canal closure. When canal supply is closed, water table of the area will start declining steadily and when supply is restored water table will start rising. Recession of water table is mainly due to water loss from the area in form of subsurface flow and secondly due to continuous evaporation from the soil surface. Subsurface flow is dependent on water table depth. High the water table depth more will be the subsurface flow and vice versa. Since during canal closure there is no water entry in the study area due to seepage, subsurface flow can be calculated by making simply a water balance of receding water table of the area in various grids. Water table drop at the corners of each grid was calculated by deducting respective water table depths for a period of one day. Average water table drop of each grid was calculated and multiplied with average drainable porosity and area of grid in order to calculate water loss due to subsurface flow from each grid. The total water lost from each grid was summed up to calculate daily subsurface flow. The calculated subsurface flow from experimental area is plotted against average water table depth along the canal (Fig. 6). It is evident from Figure 6 that subsurface flow is high initially i.e. after canal closure and low at later stages as water table depth declines and gradient of flow becomes increasingly small. Figure 6 may be used for calculating subsurface flow at any stage of water table depth along the canal.

**Subsurface storage:** The water table in study area starts rising when water supply is restored in the canal. The water storage in the soil profile during water table buildup in study area was calculated by multiplying average rise in water table of each grid with respective area and average drainable porosity of the grid.

Fig. 6. Variation of subsurface flow with water table depth after canal closure.

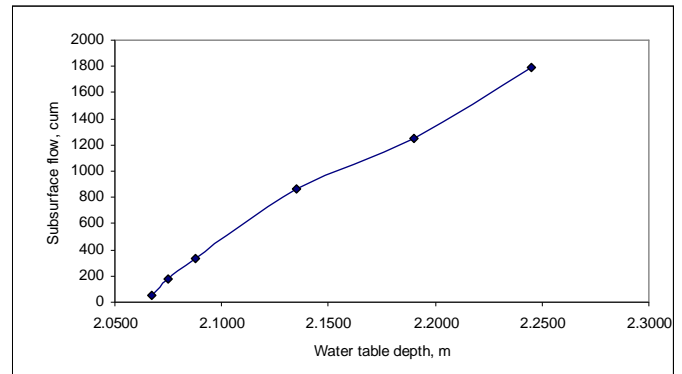
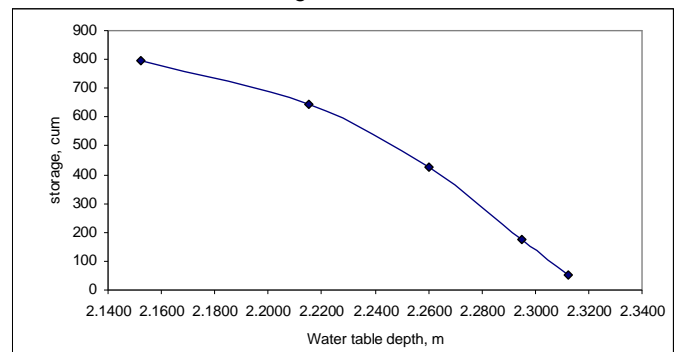


Fig. 7. Storage of seepage water in soil profile during rising water table.



Total volume of water stored in soil profile of the experimental area was worked out by summing water storage of each grid. Variation of water storage against average water table depth along the canal is shown in Figure 7.

**Assessment of canal seepage:** During water table build up subsurface flow continues as a function of average water table depth along the canal as shown in Figure 6 and subsurface storage take place simultaneously. Therefore, canal seepage was calculated by adding subsurface flow and subsurface storage at a particular water table depth. Effect of evaporation was ignored at this stage. Measurement of evaporation from soil surface in lysimetric study will be useful in calculating total seepage from the canal.

**Use of empirical formula:** Two empirical formulas were also used to assess the canal seepage to see the efficacy of the formulas. Following formulas were used in the study.

1. Punjab formula

Seepage from the canal (Q) can be calculated as under  $Q = C_p AD$  (1)

Where, Q is the seepage loss over the wetted canal area,  $m^3/s$ ,

A is the wetted area, million  $m^2$ ,

D is the depth of water in canal, m,

$C_p$  is the coefficient for heavy soil 1.2.

2. Egypt formula

Egypt formula for seepage calculation is given as below.  
 $Q = C_e L P R^{1/2}$  (2)

Where,

L is the canal length, km,

P is the wetted perimeter, m,

R is the hydraulic radius, m,

$C_e$  is the coefficient for clay soil, 0.0015.

**Results and discussion**

*Subsurface flow:* Calculated subsurface flow from study area in absence of canal seepage against average water table depth along the canal is shown in Figure 6. It may be seen from Figure 6 that subsurface flow decreased with decrease in water table height above impervious layer. Maximum subsurface flow was calculated to be 1790.22 m<sup>3</sup>/d against 2.24 m water table height and minimum subsurface flow as 49.54 m<sup>3</sup>/d against 2.06 m water table height. A quadratic fit between subsurface flow and water table height above impervious layer was found most appropriate with regression coefficient  $r = 0.9972$  and coefficient of variance  $c = 65.38$  among all other fits. The regression equation is written as below.

$$Q_{sub} = 47058.44h - 8675.58h^2 - 60121.35 \quad (3)$$

Where,

$Q_{sub}$  = subsurface flow from study length of canal, m<sup>3</sup>/s,

h = water table height above impervious layer, m.

*Subsurface storage:* Calculated subsurface storage from the study area after canal restored supply is shown in Figure 7 as a function of water table height above impervious layer. It may be seen from Figure 7 that subsurface storage decreased with increase in water table height above impervious layer as rate of rise decreases significantly. Maximum subsurface storage was calculated as 796.83 m<sup>3</sup>/s against 2.15 m water table height and minimum of 50.89 m<sup>3</sup>/s against 2.31 m water table height. Like subsurface flow, quadratic fit was found most appropriate with regression coefficient  $r = 0.9998$  and coefficient of variance  $c = 8.0141$  among all other fits. The regression equation is written below.

$$Q_{sub} = 97823.07h - 22960.5h^2 - 103385.23 \quad (4)$$

Where,  $Q_{stor}$  = subsurface storage from study length of canal, m<sup>3</sup>/s.

*Canal seepage:* Calculation of canal seepage is shown in Table 1. It may be seen from Table 1 that calculated canal seepage which is sum of subsurface flow and subsurface storage at particular water table height above canal approaches a constant value within a day or two. Calculated values of seepage are almost identical and range from 1772.59 m<sup>3</sup>/d to 2359.45 m<sup>3</sup>/d for a canal reach of 650 m.

Table 1. Calculation of canal seepage.

Date	Average water table depth, m	Storage, m <sup>3</sup> /d	Subsurface, m <sup>3</sup> /d	Seepage, m <sup>3</sup> /d
14.05.2005	2.15	796.83	975.76	1772.59
15.05.2005	2.22	642.94	1548.76	2191.70
16.05.2005	2.26	426.36	1919.34	2345.70
17.05.2005	2.30	176.16	2183.29	2359.45
18.05.2005	2.31	50.89	2307.29	2358.18

Final canal seepage was calculated taking the average of daily canal seepage ignoring the first two values which is marginally lower compared to the last three values. Calculated canal seepage is 2354.44 m<sup>3</sup>/d which an average of last three seepage values. Thus the canal seepage came out to be 3622.21 m<sup>3</sup>/d per km of canal length and 129.75 m<sup>3</sup>/d per 1000 m<sup>2</sup> wetted area.

*Seepage calculation from empirical formulas:* Wetted perimeter of canal section with an average water depth of 2.2 m was calculated to be 55.83 m and wetted area was calculated to be 3.629515 x 10<sup>-2</sup> million m<sup>2</sup> for 650 m canal reach. Cross sectional area of canal was calculated as 110.88 m<sup>2</sup> and corresponding hydraulic radius was calculated to be 1.98 m. Coefficient for Punjab formula was taken as 1.2 and for Egypt 0.0015. Canal seepage calculated from Punjab formula came out to be 4095.36 m<sup>3</sup>/d and by Egypt formula was found to be 3308.93 m<sup>3</sup>/d from 650 m canal reach. Both the formulas calculated higher values of canal seepage. Punjab formula estimated 73.94% higher and Egypt formula 40.54% higher values of seepage. Coefficient of canal seepage estimation for Punjab formula is calculated to be 0.6898 and that of Egypt is 0.00106 respectively.

**Conclusion**

Present method of seepage calculation in a specific reach of the canal will give a quick and better estimate of canal seepage for designing bio-drainage belt or subsurface drainage for successful crop production. Available methods are either time consuming or not fit for many field situations. Estimation of subsurface flow and subsurface storage along the canal area can provide better estimate of canal seepage. In this study canal seepage was estimated to be 2354.44 m<sup>3</sup>/d from 650 m canal reach which is equivalent 3622.21 m<sup>3</sup>/d/km. Canal seepage calculated from empirical Punjab formula came out to be 4095.36 m<sup>3</sup>/d and that by Egypt formula 3308.93 m<sup>3</sup>/day from the same reach of the canal. Egypt formula gave 40.54% higher and Punjab formula 73.94% higher estimate of canal seepage. Egypt and Punjab formulas are empirical and their use at other sites will be restricted. The value of seepage calculated by using present approach is superior over the other estimates.

## References

1. Bakry, M.F. 2004. Practical estimation of seepage losses along earthen canals in Egypt. *Water Resour. Management*. 11(3): 197-206.
2. Bouwer, H. 1961. Variable head technique for seepage meters. *J. Irrigat. Drain. Div.* ASCE, IRI, Proc. Paper 2775, pp.31-44.
3. Dukker, P., Bhutta, M.N., Roos, P. and Javed, I. 1994. Seepage Losses from Lower Gugera Branch Canal, Punjab, Pakistan. IWASRI, Publication No. 134, Lahore, pp.24-25.
4. Hotchkiss, R.H., Wingert, C.B. and Kelly, W.E. 2001. Determining irrigation canal seepage with electrical resistivity. *ASCE J. Irrigat. Drain.* 127: 20-26.
5. Kacimov, A.R. 1992. Seepage optimization for trapezoidal channel. *ASCE J. Irrigat. Drain.* 118: 520-526.
6. Kolupaila, S. 1964. Discussion on accuracy of current meter measurements. *J. Hydraul. Div.* 1: 352-355.
7. Sharma, H.D. and Chawla, A.S. 1979. Canal seepage with boundary of finite depth. *ASCE J. Hydrogen Energy*. 105: 877-897.
8. Singh, N.T. 1992. Land degradation and remedial measures with reference to salinity, alkalinity, water logging and acidity. In *Natural resource Management for sustainable Agriculture and Environment*. Deb, D.L. (Ed.), Angker Pub., New Delhi, p.442.
9. Skogerboe, G.V., Aslam, M., Khan, M.A., Mehmood, K., Mehmood, S. and Khan, A.H. 1999. Inflow-outflow channel losses and canal lining cost-effectiveness in the Fordwah Eastern Sadiqia (South) Project. Report No. R-85. International Water Management Institute, Lahore, pp.3-8.
10. Van der Leen, F., Troise, F.L. and Todd, D.K. 1990. *The water encyclopedia*. Lewis, Chelsea, Michigan.