ESTIMATION OF SEEPAGE FROM CANALS BY TRACER TECHNIQUE

BY

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1.0 INTRODUCTION

Loss of water due to seepage from irrigation canals constitutes a substantial percentage of the total usable water. By the time the water reaches the field, it has been estimated that the seepage losses are of the order of 45 percent of the water supplied at the head of the canal. Of the various factors which influence seepage loss from a canal, the most important are the boundary conditions of the flow domain and permeability of the medium. Only after a correct assessment of the coefficient of permeability and boundary conditions, the seepage losses can be estimated either by numerical method or by analytical technique. Needless to say that it is very difficult to determine the insitu coefficient of permeability of the porous medium. In order to avoid the difficult task of estimating the coefficient of permeability and the prevailing sub-surface boundary conditions experimental techniques like ponding method and inflow outflow method have been used for estimation of seepage losses. In recent years, tracer technique has also been used to estimate seepage loss from water bodies because of its comparatively easy operation in respect to other experimental methods. The temporal variation of concentration of a tracer is observed in a bore hole near a canal which furnishes the Darcy velocity of flow. Making use of the Darcy velocity and assessing the area of flow, seepage loss from the canal is estimated.

2.0 PROBLEM DEFINITION

A canal is running in an area where the ground water table is encountered at shallow depth. A borehole is made at a distance 'd' from the centre of the canal as shown in Figure 1. In the borehole a tracer is added and its concentration is measured with respect to time. It is aimed to find the seepage loss from the canal making use of the variation of the concentration of tracer in the borehole with time.

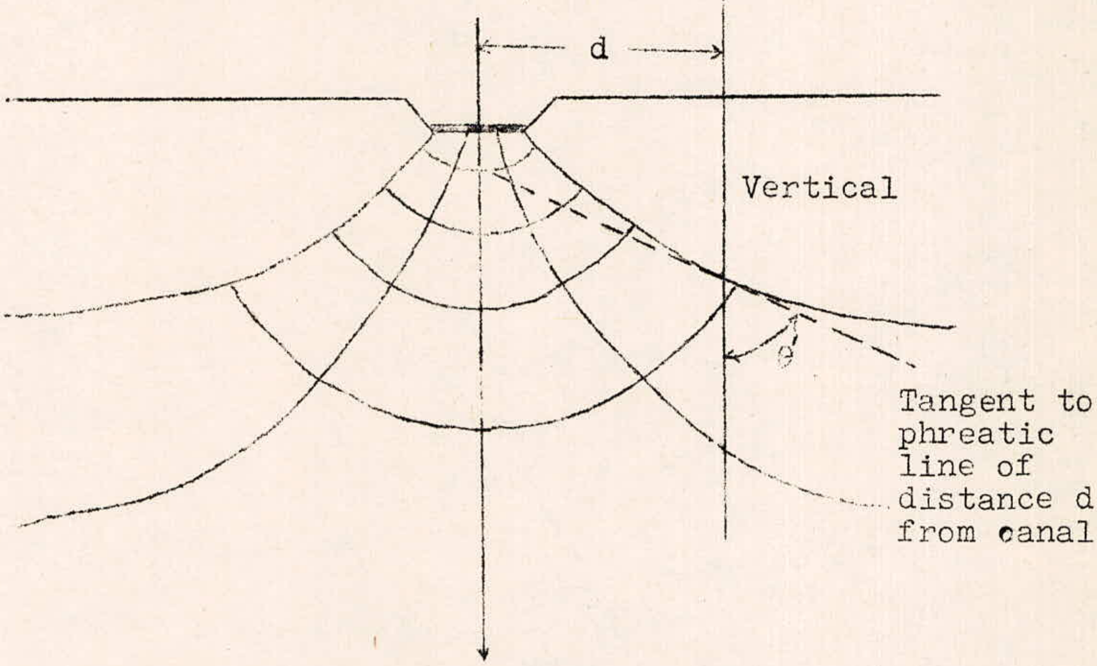

FIGURE 1 - IDEALIZED FLOW CONFIGURATION

3.0 METHODOLOGY

The following assumptions are made while deriving the formula:

i) The canal is treated as a line source.

ii) The flow lines are radial and equipotential lines are circular.

iii) The porous medium at any reach has constant permeability which may vary from reach to reach.

iv) The plane of flow is normal to the canal axis.

Let the variation of concentration of the tracer with time be measured in the vertical borehole which is located at a distance 'd' from the centre of the canal. The the diameter of the borehole is D and the borehole has been taken to a depth H' below t water table. The volume of water V in the borehole is equal to $\pi D^2 H'/4$. Let c is the concentration of the tracer at any time t. Assuming that the water entering to the borehole is free from the tracer used, the mass balance for a period from t to $t+\Delta t$ can be written as:

Total inflow of tracer to the borehole in time Δt = total outflow of tracer from the borehole in time Δt+ change in concentration of the solution in borehole x volume of solution in borehole.

If q_i is the total inflow of water into the borehole in unit time, the mass balance euqation can be written as:

$$0 = q_i c. \Delta t + V. \Delta c$$

$$\text{or } \frac{V}{q_i} \frac{dc}{c} = -dt \qquad \ldots (1)$$

Let the time be measured from the instant the tracer is added to the water in the borehole. Integrating and applying the initial condition that at t=0, $c=c_0$, the following expression can be derived:

$$t = \frac{V}{q_i} \log_e \frac{c_0}{c} \qquad \ldots (2)$$

Assuming that the distortions in the flow pattern due to presence of the borehole are occurring in a plane normal to borehole axis and that there is no distortion below the bottom of the borehole, the total flow rate q_i entering to the borehole can be approximated to (McWhorter et al, 1975, Appendix I)

$$q_i = D\, V_a\, H\alpha \qquad \ldots (3)$$

in which

V_a = Darcy velocity in a direction normal to the canal axis at larger distance from the borehol

α = a factor for hydrodynamic field deformation.

The above relation has been derived on the assumptions that water flows with a uniform gradient at large distance from the borehole and the aquifer has infinite areal extent. Replacing the value of q_i and V in equation 2,

$$\log_e \frac{c}{c_0} = \frac{4\alpha V_a}{\pi D} t \qquad \ldots (4)$$

Thus when logarithm of concentration is plotted at various times, the resulting graph is a straight line with slope equal to $4\alpha V_a/\pi D$.

Let m be the slope of the graph. Hence,

$$V_a = \frac{m\pi D}{4\alpha} \qquad \ldots (5)$$

Knowing m, the Darcy velocity V_a can be determined. Once the Darcy velocity is determined the seepage loss from the canal can be derived as follows:

An idealized configuration of stream lines and equipotential lines is shown in Figure 1. Let θ' be the angle made by the tangent to the phreatic line with the vertical at the borehole. θ' can be approximately known by knowing positions of water table at two nearby points. In the absence of the borehole the water will move in the radial direction. Since V_a is the component of velocity along horizontal direction, the superficial velocity in radial direction is given by V_a cosec θ'.

The total segmental circular area = $2.d.\theta'$.

Hence the total seepage loss from the canal per unit length is given by

$$q = 2.d.\theta'.\text{cosec}\,\theta'\ V_a \qquad \ldots (6)$$

Replacing V_a by equation (5)

$$q = \frac{\pi}{2\alpha}.m.d.\theta'.\text{cosec}\,\theta' \qquad \ldots (7)$$

Using equation (7), the seepage loss from a canal can be determined after knowing the value of m from tracer studies.

APPENDIX I

DISRUPTION IN FLOW PATTERN DUE TO PRESENCE OF BOREHOLE

The presence of borehole causes a disruption in the original flow pattern. The actual flow pattern in a disrupted aquifer is quite complex. It depends upon the original flow pattern, time, geometry of the disrupted area, the location of the disrupted area with respect to aquifer boundaries, the distribution of hydraulic conductivity in the disturbed and undisturbed portions of the aquifer. A first approximation to the post borehole flow pattern can be derived (McWhorter et al, 1975) by assuming that:

1) the aquifer is very large in areal extent,
2) the flow in the aquifer is uniform and one-dimensional at large distance from the borehole,
3) the borehole is a disturbed zone with very high permeability and the flow pattern in the presence of borehole can be obtained as a limiting case,
4) the hydraulic conductivity K_0 of the undisturbed portion of the aquifer is a constant,
5) the geometry of the disturbed portion of the aquifer is that of a cylinder with axis normal to the plane of the flow and
6) the flow is two-dimensional and steady.

The distribution of piezometric head outside and inside the borehole area are given by

$$h_o = -\frac{V_a x}{K_0}\left\{1+\left(\frac{K_0-K_i}{K_0+K_i}\right)\left(\frac{R^2}{x^2+y^2}\right)\right\} \qquad \ldots (1)$$

and

$$h_i = \frac{-2V_a x}{K_0+K_i} \qquad \dots (2)$$

respectively. In equations 1 and 2, h_0 is the piezometric head outside the borehole, h_i is the piezometric head inside the borehole, V_a is the Darcy velocity in the x-direction at large distance from the borehole, R is radius of the borehole, K_0 is the hydraulic conductivity outside the borehole, K_i is the hydraulic conductivity inside the borehole, x and y are coordinate directions with the origin at the centre of the borehole. h_0 and h_i both satisfy the Laplace equation i.e.

$$\frac{\partial^2 h_0}{\partial x^2} + \frac{\partial^2 h_0}{\partial y^2} = 0$$

and

$$\frac{\partial^2 h_i}{\partial x^2} + \frac{\partial^2 h_i}{\partial y^2} = 0$$

At the periphery of the circle i.e. at $x^2+y^2=R^2, h_i=h_0$. Using equations 1 and 2, the velocity potential function for inside and outside the borehole area can be written as

$$\phi_i = K_i \frac{2V_a x}{K_0+K_i} \qquad \dots (3)$$

$$\phi_0 = V_a x \left\{1+\left(\frac{K_0-K_i}{K_0+K_i}\right)\left(\frac{R^2}{x^2+y^2}\right)\right\} \qquad \dots (4)$$

Using the Cauchy Reimann conditions i.e.

$$\frac{\partial \phi}{\partial x} = \frac{\partial \psi}{\partial y} \qquad \dots (5)$$

and

$$\frac{\partial \phi}{\partial y} = -\frac{\partial \psi}{dx} \qquad \ldots (6)$$

where ψ is the stream function. ψ_i from equation (3) is found to be

$$\psi_i = \frac{2V_a K_i y}{K_O + K_i} \qquad \ldots (7)$$

The total quantity of flow to the borehole per unit depth is

$$q = \frac{4V_a K_i R}{K_O + K_i} \qquad \ldots (8)$$

In the limiting case when $K_i \rightarrow \infty$, the quantity of flow entering to the borehole is given by

$$q = 4V_a R \qquad \ldots (9)$$

Thus because of the disruption the normal quantity of flow is doubled in the disrupted zone.

REFERENCES

McWhorter, D.B., Skogerboe, R.K., and Skogerboe, G.V. (1975), 'Water Quality Control in Mine Spoils', Upper Colorado River Basin, Environmental Protection Technology Series, Environmental Protection Agency, Pub.670.