Determination of Seepage Losses in Unlined Channels

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ABSTRACT
Seepage is one of the most serious forms of water loss in an irrigation channel network. This paper summarizes a literature review of research on determination of seepage losses in unlined channels. An analytical solution is obtained for estimation of seepage from a channel under different conditions with uniform infiltration from free surface zone. The solutions include relations for variation in seepage velocity along the channel perimeter and a set of parametric equations for the location of phreatic line. These solutions are useful in quantifying seepage losses through channels.

Keywords
Unlined channels; canals; seepage;

1. INTRODUCTION
In irrigation canals a substantial part of usable water goes in head of losses due to seepage. Due seepage losses, fresh water resources depleted with causing water logging, salinization, groundwater contamination and health hazards. Simple method is adopted to check seepage is lining but due to various reasons cracks develops in lining and found that seepage from a canal with cracked lining is likely to approach the magnitude of seepage from unlined canal so, optimization of geometric elements of channels to minimize seepage loss is gaining importance (13). Optimization of losses is required in present scenario because water resources are limited & conservation of water is important. During transportation of water through unlined channel, huge quantity lost by seepage. The need to line a canal is decided based on the extent of seepage losses. According to Wilkinson (1986), a canal having seepage less than .031 $m^3/day/m^2$ of wetted area of considered tight while a canal exhibiting losses more than this limit is considered good for lining(2).

The seepage from a channel is governed by the same principle of flow through porous media and controlled by hydraulic conductivity of the subsoil and Soil characteristics, depth of water in the canal, geometry of section, hydraulic gradient between the channel and depth to ground water, amount of sediment in water, velocity in the channel and length of time canal has been operation (5).

2. PREVIOUS STUDIES
A method for the solution of problems involving unconfined seepage by using a special function, now known as Zhukovsky's function (14). Vedernikov (1934) and Pavlovsky (1935) independently proposed a method based on conformal mapping of the region of the complex seepage potential on to the region of the Zhukovsky function for the solution of seepage problems with free surface zone. Vedemikov (1934) investigated the influence of the depth of horizontal permeable layers upon the quantity of seepage from ditches (1).

Vedemikov (1939) solved the problem of seepage from a canal to the symmetrically placed collector drainages, neglecting the effect of the canal water depth and side slopes. Vedernikov (1939) also solved the problem of seepage from a canal with collector on one side (8).

A closed-form solution of seepage from a trapezoidal canal to symmetrically placed drainages in homogenous and isotropic material that is extending up to the infinite depth obtained. Sharma and Chawla (1979) presented a solution of the problem of seepage from a canal to vertical and horizontal drainages symmetrically located at finite distances from the canal in a homogenous medium extending up to a finite depth. The water depth in the canal was assumed negligible in comparison to the width (2).

Wolde-Kirkos (1993) has obtained solutions for seepage from a trapezoidal canal in a homogenous medium extending to infinite depth with asymmetrically placed drainages on either side of the canal. Wolde-Kirkos also obtained solutions for seepage to the drainage on one side of the canal only. Wolde-Kirkos and Chawla (1994) presented the results of the problem of seepage from a canal with negligible water depth to asymmetrical drainages (3).

Numerov (1948) examined the problem of the flow of ground water to a system of a large number of rectilinear horizontal drainages, infinitely thin silts, at unit depth, equidistant and in a previous layer of infinite depth. Numerov considered the effect of infiltration due to rain, irrigation, snowmelt, etc., using a special function. Aravin (1936) had earlier examined the same case with zero infiltration rates. Polubarinova-Kochina (1962) also examined the case of drainage with a rectangular cross section (3).

Unconfined, steady-state seepage from a triangular and a trapezoidal channel in a homogeneous, isotropic, porous medium of large depth using inversion of hodograph and conformal mapping techniques. The solution of a rectangular channel was given by Morel-Seytoux (1964) using conformal mapping and Green- Neumann functions (1). Chahar analyzed seepage from slit and strip channels as special cases of a polygon channel and also presented results for trapezoidal, triangular, and rectangular channels in graphical form (11). An approximate solution using Zhukovsky functions and conformal mapping techniques for a trapezoidal channel in a porous medium of finite depth underlain by a drainage layer suggested by Muskat (8). An analytical solution for seepage from a rectangular channel in a soil layer of finite depth overlying a drainage layer using conformal mapping techniques obtained (7),(8). Bruch and Street (1967a, b) used the same method in computing seepage from a triangular channel underlain by a drainage layer at shallow depth. Seepage from polygon channels has also been estimated by several investigators for different boundary conditions using analytical methods (1).

Approximate solutions by numerical methods have gained importance due to easy availability of high speed digital computers along with specialized software. However, generalized solutions in the functional form are not possible through numerical methods; instead they result only in a numerical value as a problem specific particular solution.

The pioneer in solving the problem of optimization of an earth channel was Preissmann (1957), who took the quantity of seepage loss per unit length of channel Q as an objective function, and the area of flow cross section S as an isoperimetric restriction. For trapezoidal channels, Morel-Seytoux (1964) proposed a solution of the seepage problem in the form of a dimensionless characteristic that made it possible to define a channel shape that is optimal in terms of parameters Q and S. The solution suggested by them is complete in the mathematical sense. Namely, the necessary and sufficient conditions of a global extremum are proved, the unique extremum is obtained in the analytical form, and closeness of optimal channels in the value of Q is shown. In addition to the channel capacity S, the important integral characteristic within the scope of problems of surface flow are considered to be the hydraulic radius R and the discharge m of the water transported through the channel. As for the class of arbitrary channels profiles, attempts to seek an analytical solution for the problem of defining a channel shape with a minimum Q at the specified R or m have not succeeded. The present paper considers this type of optimization for trapezoidal channels. The optimal design of these may be used as a first approximation in iterative algorithms (Cabuk and Modi 1990) for optimization given channel shapes. A dimensionless depth can be determined for a rectangular channel with lined banks, reasoning along similar lines. The channel with a minimum cost takes account of the lost-water and lining costs. It is shown in the following that a unique and stable solution exists for each optimization problem (6).

Further, available analytical solutions for triangular, rectangular, and trapezoidal channels were obtained by different investigators using different methods or different point of openings in the mapping planes, so these solutions differ from expressions obtained as limiting or particular cases of the solution for the most general problem. In the present study, an exact analytical solution for the quantity of seepage from a trapezoidal channel underlain by a drainage layer at a shallow depth has been obtained using an inverse hodograph and Schwarz-Christoffel transformations for one half of the seepage domain

3. SEEPAGE THEOREY

The seepage loss from a channel in a homogeneous and isotropic porous medium, free surface flow in porous media is governed by partial differential equation (navier-stokes equations) and the boundary conditions. A simplification is made that viscosity assumed zero, the differential equations remains nonlinear. The experimental result formulated by Henry Darcy (1856), Darcy's law, expresses a proportionality relationship between the filtration velocity v(also called specific discharge q) and the change in head $\frac{\partial h}{\partial x}$ in the direction of velocity component. H is defined by h=(P/γ) + z where γ is specific weight of water and z is the vertical distance from some datum to the required point thus

v = K($\frac{\partial h}{\partial x}$) where K is constant of proportionality, called the hydraulic conductivity.

The seepage loss from a canal in a homogeneous and isotropic porous medium, when the water table is at a very large depth (10), can be expressed as $q_s = \mathrm{K}yF$ where q_s = seepage discharge per unit length of canal (m2/s); K = hydraulic conductivity of the porous medium (m/s); y = depth of water in the canal (m); F = function of channel geometry (dimensionless); and yF = width of seepage flow at the infinity. Hereafter, F will be referred to as the seepage function.

4. METHODS OF DETERMINATION

Three methods of seepage measurement are in common use at the present, namely: ponding; inflow/outflow; seepage meter. Other methods of seepage detection are also used, such as for example, chemical tracers, radioactive tracers, piezometric surveys, electrical borehole logging, surface resistivity measurements, and remote sensing. These methods suffer from the disadvantage that they are either more difficult to use or interpret. These are the experimental methods but we need when we designing the system so we required analytical solutions which gives optimum mathematical results.

The flow-net can be used to obtain the amount of seepage through a structure, and the pore pressure and the gradient at any point in the flow net. For two dimensional steady state flow solution involved the Laplace's equations and following methods may be used to obtain seepage problems with the help of flow net. (a) Flow net sketching- flow net for a given cross section is obtained by first transforming the cross section, noting the boundary conditions, and then sketching the net by trial and error. The flow lines and the equipotential lines must intersect one another at right angles and the various rules concerning boundary conditions and interfaces between zones of different permeability must be observed. Flow net sketching was first suggested by Forchheimer and further developed by A.Casagrande(1937). This method has the desirable feature of helping the sketcher develop a feel for the problem. The sketcher can readily see how various alterations in the design affect the solution to the problem. (b) Analytical Methods- the best known theoretical solution is one for flow through an earth dam, upstream equipotential is a parabola and the toe drain is a horizontal one, the flow net consists of a system of confocal parabolas. This solution was made by Kozeny in 1933. A. Casagrande has developed approximations to the Kozeny parabola to account for the upstream face of the structure being a straight line rather than a parabola. He also worked out modifications to the Kozeny equations to account for flow that does not end in a horizontal drain. (c) Models- solved by constructing a scaled model and analyzing flow in the model. Practically constructing and placing of required sand particles is difficult so not used. (d) Analogy Methods- Laplace's equation for fluid flow also holds for electrical and heat flow. Although practical difficulties are encountered with trying to use heat flow models to solve fluid flow problems, considerable use has been made of electrical models. In the electrical models voltage corresponds to total head, conductivity to permeability and current to velocity. These models are valuable for instructional purposes, and since they are easier to construct than soil models and can be adapted to a wide variety of boundary conditions and complex problems. (e) Numerical Analysis-can obtain by a series of approximations the total heads at various points in a network. With the computer it will be possible to solve and plot up the results for seepage analysis. The engineer can then get an approximate solution to practical problems by comparing his particular problem with one for which a solution has been obtained.

Numerous analytical solutions are available in the literature for the problem of seepage from canals with different boundary conditions. Researchers have considered problems with different shapes of the canal and symmetrically/asymmetrically placed drainages with finite/infinitely extending soil media.

However, to make the problem amenable to analytical solution, researchers have normally made assumptions such as homogenous, isotropic soil media and considering no infiltration/ evaporation from the free surface zone.

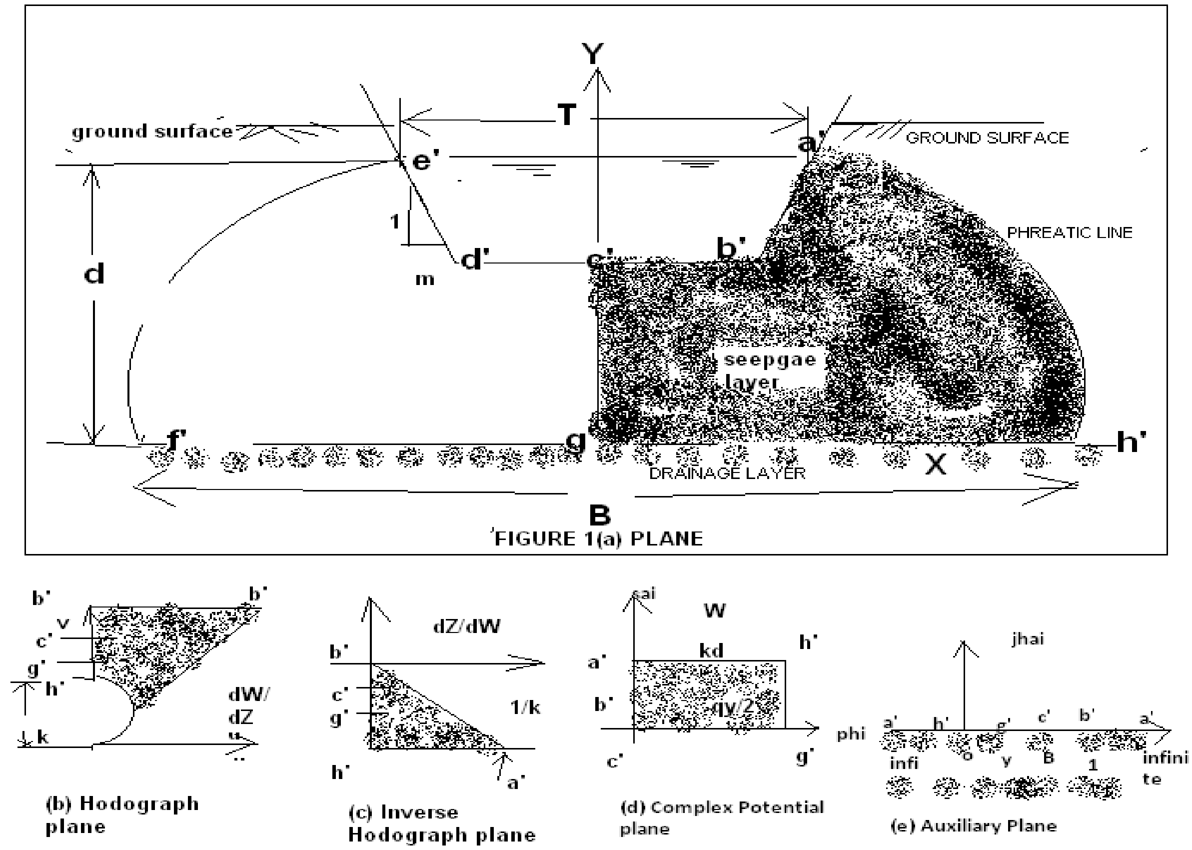

FIGURE 1 : SEEPAGE FROM A TRAPEZOIDAL CHANNEL WITH DIFFERENT PLANES

From study the material mathematical solutions based on method of images, Green's function, Dirac's Delta function and conformal mapping are available from which a sample study of conformal mapping is presented here for understanding the boundary limitations surrounding the channels. Seepage flow may be vertical and may be horizontal and may be both directions depends on the vertical and horizontal strata in vicinity of channel

Consider a trapezoidal channel of bed width *b (*m), depth of water *y(*m), and side slope *m(*1 Vertical: *m* Horizontal) passing through a homogeneous isotropic porous medium of hydraulic conductivity *k (*m/s) underlain by a horizontal drainage layer at a depth *d* (m) below the water surface as shown in Fig. 1(a). The steady seepage discharge per unit length of channel q_s *(*m^2/s) complying with Darcy's law can be expressed in the following simplest form(Chahar 2000; Swamee et al. 2000)

$$q_s = kyF_s \qquad (1)$$

where F_s *(*dimensionless seepage function)function of channe geometry and boundary conditions. The pattern of seepage from the channel is shown in Fig. 1(a). The effects of capillarity, infiltration, and evaporation are ignored. In view of the significant length of the channel, the seepage flow can be considered two dimensional in the vertical plane. It is assumed that the water table is below the top of the drainage layer and hence atmospheric pressure prevails at the bottom of the seepage layer. The seepage domain has symmetry about vertical axis *Y* so half of the domain (*a'b'c'g'h'a'*) has been used in the analysis. Defining complex potential $W=\varphi+i\psi$ (Fig. 1(d)) where φ-velocity potential (m^2/s) which is equal to *k* times the head *h* (m) and ψ-stream function (m^2/s) which is constant along streamlines. If the physical plane is defined as $Z=X+iY$ then Darcy's law yields $u=\frac{\partial \varphi}{\partial X}=-k\frac{\partial h}{\partial X}$ and $v=\frac{\partial \varphi}{\partial Y}=-k\frac{\partial h}{\partial Y}$

where *u* and *v*=velocity or specific discharge vectors (m/s) in *X* and *Y* directions, respectively. The hodograph $dW/dZ=u-iv$ (Fig. 1b) and the inverse hodograph dZ/dW *(*Fig. 1c) for half of the seepage flow domain (*a'b'c'g'h'a')* have been drawn following the standard steps (see Harr 1962). The *dZ*/*dW* plane and *W* plane have been *mapped* on the lower half (ζ≤0) of an auxiliary ζ plane (Fig.1e) using the Schwarz-Christoffel conformal transformation.

Solutions of such problems have given valuable insight into the knowledge about seepage from canals, the effect of various parameters on the seepage discharge, and the profile of the free surface. However, not all the types of boundary conditions normally encountered in the field have been considered. In most of the seepage problems solved by the analytical methods, an assumption has been made that there is no infiltration or evaporation along the free surface. In most natural conditions, however, there is either infiltration/recharge due to irrigation, rain, snowmelt, etc., or there is net evaporation or evapotranspiration from the zone of free surface. Analysis of the problem with such a boundary condition will provide an insight to the effect of infiltration/evaporation on the seepage from the canal and free surface profile.

From different planes seepage quantity is computed as well as variation in seepage velocity computed depends on shape of channel, width and depth of water in channel. F_s has two transformation variables β & γ. For given set of shape factor, b/y and d/y first determined β and γ and from those F_s and drainage layer width B computed and finally q_s computed.

5. CONCLUSIONS

From various methods, an exact analytical solution for the quantity of seepage from a unlined channel underlain by a drainage layer at a shallow depth can be obtained using an inverse hodograph and Schwarz- Christoffel transformation for one half of the seepage domain have contains many variables. From this general solution, other special cases like a trapezoidal channel without a drainage layer, a rectangular channel underlain by a drainage layer at a shallow depth, a triangular channel underlain by a drainage layer at a shallow depth, a rectangular channel without a drainage layer, and a triangular channel without a drainage layer can be deduced. The analysis can also include solutions for the variation in the seepage velocity along the channel perimeter and the quantity of seepage channels. Therefore the solution is exact, complete, consistent, and general. However, the solutions for the quantity of seepage, location of the phreatic line, and width of seepage at the drainage layer contain improper integrals which can only be evaluated by numerical integration.

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