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A steady state solution for ditch drainage problem with special reference to seepage face and unsaturated zone flow contribution: Derivation of a new drainage spacing eqaution

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The seepage face is an important feature of the drainage process when recharge occurs to a permeable region with lateral outlets. Examples of the formation of a seepage face above the downstream water level include agricultural land drained by ditches. Flow problem to these drains has been investigated extensively by many researchers (e.g. Rubin, 1968; Hornberger et al. 1969; Verma and Brutsaert, 1970; Gureghian and Youngs, 1975; Vauclin et al., 1975; Skaggs and Tang, 1976; Youngs, 1990; Gureghian, 1981; Dere, 2000; Rushton and Youngs, 2010; Youngs, 2012; Castro-Orgaz et al., 2012) and may be tackled either using variably saturated flow models, or the complete 2-D solution of Laplace equation, or using the Dupuit-Forchheimer approximation; the most widely accepted methods to obtain analytical solutions for unconfined drainage problems.
However, the investigation reported by Clement et al. (1996) suggest that accounting for the seepage face alone, as in the fully saturated flow model, does not improve the discharge estimate because of disregarding flow the unsaturated zone flow contribution. This assumption can induce errors in the location of the water table surface and results in an underestimation of the seepage face and the net discharge (e.g. Skaggs and Tang, 1976; Vauclin et al., 1979; Clement et al., 1996).
The importance of the flow in the unsaturated zone has been highlighted by many authors on the basis of laboratory experiments and/or numerical experimentations (e.g. Rubin, 1968; Verma and Brutsaert, 1970; Todsen, 1973; Vauclin et al., 1979; Ahmad et al., 1993; Anguela, 2004; Luthin and Day, 1955; Shamsai and Narasimhan, 1991; Wise et al., 1994; Clement et al., 1996; Boufadel et al., 1999; Romano et al., 1999; Kao et al., 2001; Kao, 2002). These studies demonstrate the failure of fully saturated flow models and suggested that the error made when using these models not only depends on soil properties but also on the infiltration rate as reported by Kao et al. (2001).
In this work, a novel solution based on theoretical approach will be adapted to incorporate both the seepage face and the unsaturated zone flow contribution for solving ditch drained aquifers problems.
This problem will be tackled on the basis of the approximate 2D solution given by Castro-Orgaz et al. (2012). This given solution yields the generalized water table profile function with a suitable boundary condition to be determined and provides a modified DF theory which permits as an outcome the analytical determination of the seepage face. To assess the ability of the developed equation for water-table estimations, the obtained results were compared with numerical solutions to the 2-D problem under different conditions. It is shown that results are in fair agreement and thus the resulting model can be used for designing ditch drainage systems.
With respect to drainage design, the spacings calculated with the newly derived equation are compared with those computed from the DF theory. It is shown that the effect of the unsaturated zone flow contribution is limited to sandy soils and The calculated maximum increase in drain spacing is about 30%.

Keywords: subsurface ditch drainage; unsaturated zone; seepage face; water-table, ditch spacing equation