Effect of Parallel Strip Water Sources Spacing On Lateral Infiltration Flux

M. García-Serrana[1], J. L. Nieber[2], J. S. Gulliver[1]
1. University of Minnesota, Civil, Environmental and Geo- Engineering, Minneapolis, MN, USA
2. University of Minnesota, Bioproducts and Biosystems Engineering, St. Paul, MN, USA

Introduction: This analysis evaluates the importance of the lateral component of flow on the infiltration of water from parallel strip sources of water on the soil surface. Flows from such sources will be two-dimensional, having both a vertical and a lateral component, and thereby the infiltration through the surface will also be affected by the nature of the flow pattern. Historically the infiltration through the surface can be approximated by a one-dimensional infiltration equation with one or more terms added to account for the accompanying lateral flow component. The general form of the analytical expression for infiltration due to two-dimensional flow is expressed as $i_{2D} = i_{1D} + i_{Edge}$, where i_{1D} is the term for vertical flow and $i_{Edge} = \gamma\ i_{Horiz}$ is the term for capillary- driven lateral flow, also called the 'edge effect'. The i_{Edge} term is composed of a term for horizontal infiltration (i_{Horiz} ; purely capillary-driven flow), and a scale factor γ that accounts for the geometry of the flow. An equation of this form was developed and presented by Warrick et al. (2007) for infiltration into an irrigation furrow. The image shown in Figure 1 illustrates the flow from a single surface strip source. This image was created by the numerical solution of the two-dimensional Richards equation. The main flow is vertical below the source (wettest zone), and the lateral flow due to capillarity is clearly seen. The i_{Edge} term is dependent on the capillarity of the soil, and also the actual geometry of the two-dimensional flow. The geometry of the flow is affected by the width of the strips and the spacing between strips. Generally the edge effect term can be determined only by very complex mathematical analysis or by numerical solution methods to provide a factor (e.g., γ) to scale the magnitude of the horizontal flow term.

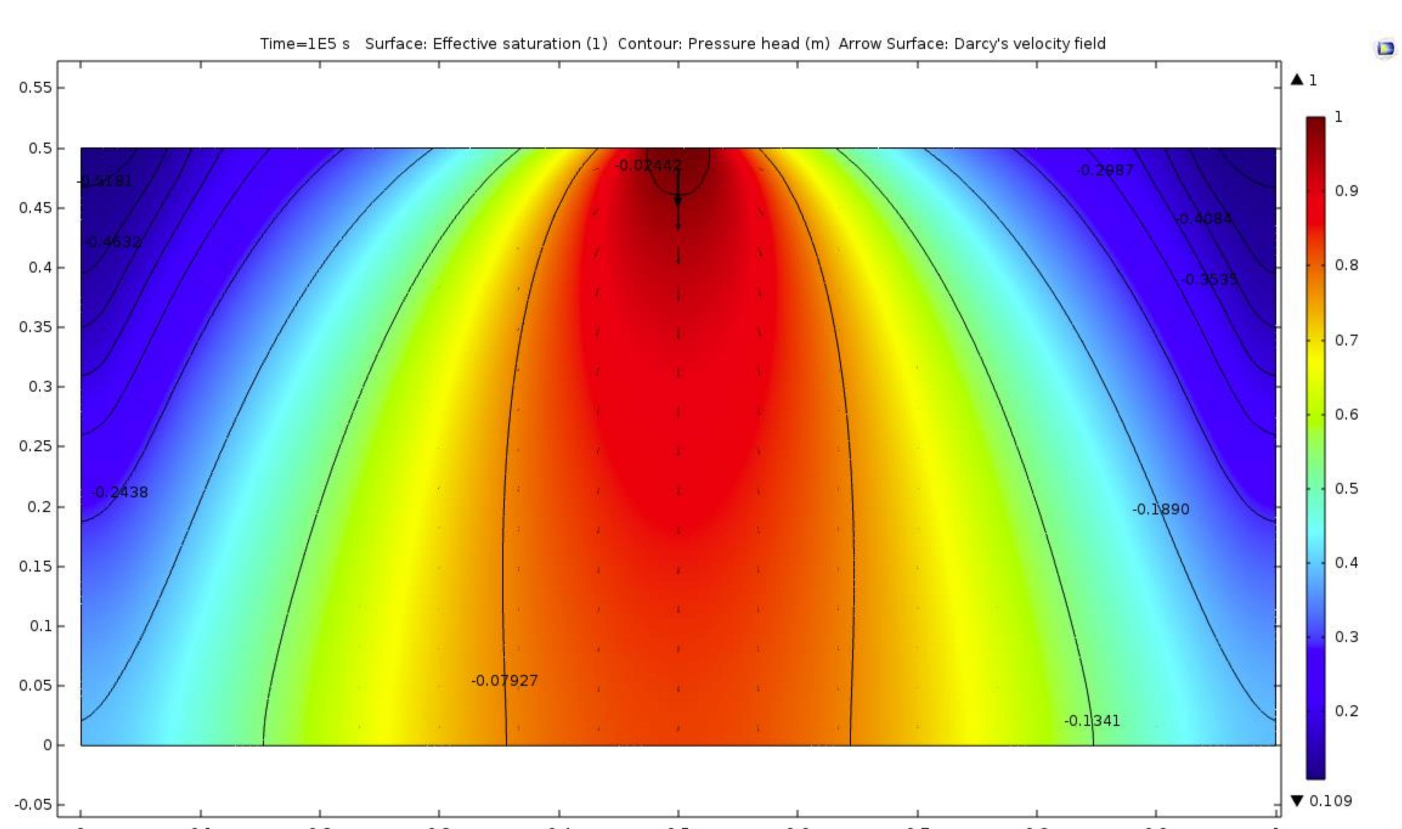

Figure 1. Soil moisture pattern beneath a single strip source of water for steady flow conditions.

Methods: In our analysis we examined the effect of spacing between strip sources on the relative importance of the edge effect. The importance of this effect will be partially affected by the capillary properties of the soil. It is hypothesized that the edge effect will decrease as the soil becomes coarser textured. For the analysis we used COMSOL's Subsurface Flow Module with the governing equation given by the Richards equation (see below). The time-dependent form of the equation was solved until steady state conditions were achieved.

$$\frac{\partial}{\partial t}(\epsilon_p \rho) + \nabla \cdot (\rho \boldsymbol{u}) = Q_m$$

$$\boldsymbol{u} = -\frac{k}{\mu}(\nabla p + \rho g \nabla D)$$

The boundary conditions for the solution are:

1. Specified pressure (zero gage) on the strip source on the soil surface, $p = 0$
2. Zero flux on the vertical boundaries and the soil surface outside of the strip source, $\frac{\partial}{\partial n}(p + \rho g D) = 0$
3. Specified unit hydraulic gradient at the bottom boundary, $\frac{\partial p}{\partial n} = 0$

The relative importance of the edge effect was quantified by taking the ratio of the infiltration (per strip source) with multiple sources to the infiltration from a single isolated strip source.

Results: The infiltration from strip water sources was modeled using various strip spacings and soil textural classes. In this instance we did not examine the effect of strip source width. It is observed that for the multiple strip source case (Figure 2) the flow from each of the parallel strips interacts with the adjacent strips. This interaction effectively reduces the lateral flow beneath the individual strips and this in effect reduces the vertical flux (infiltration) through each strip. The interaction between strips will be zero for strips spaced infinite distance apart, and the maximum edge effect and thereby the maximum infiltration through the strip will occur for that case. For a given strip spacing the amount of interaction increases, and the infiltration decreases, as the soil tends to a finer texture. Our results showing a relation between strip spacing and the edge effect for three soil textures is illustrated in Figure 3.

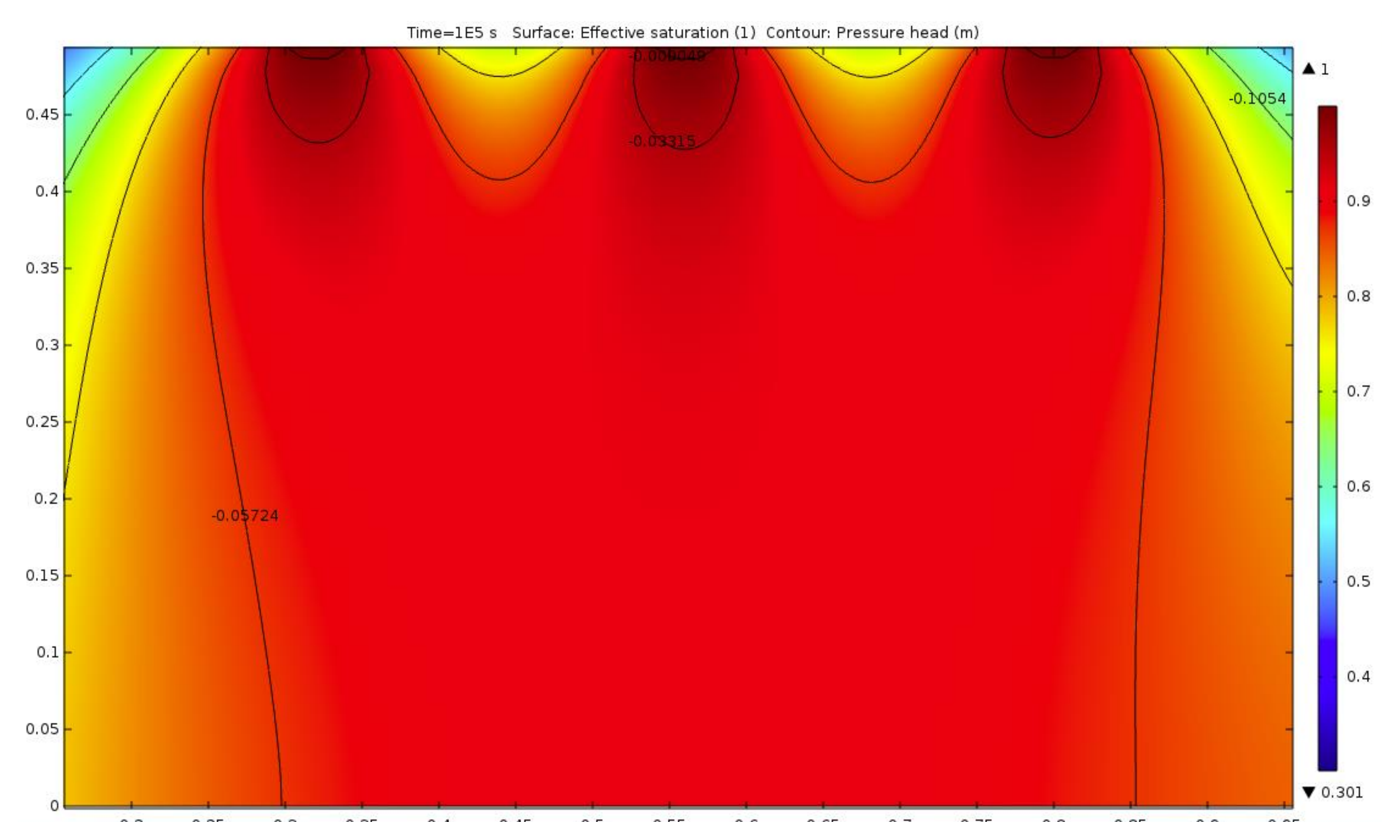

Figure 2. Soil moisture pattern beneath three parallel strip sources of water spaced 0.21m apart for steady flow conditions.

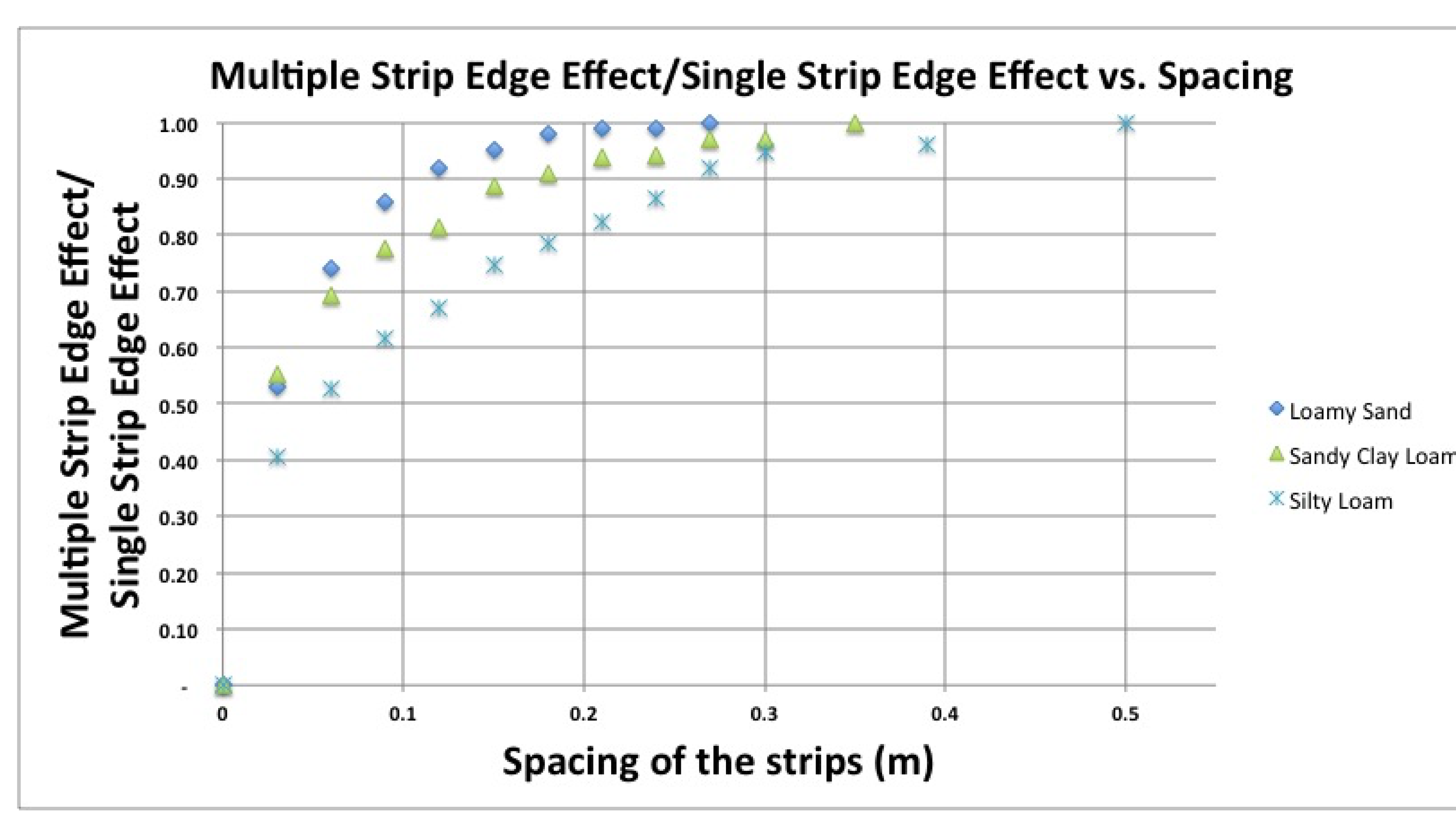

Figure 3. The influence of the strip source spacing on the edge effect as impacted by soil texture.

The plot shows that as the strip spacing increases the edge effect also increases. It is also observed that as the soil become more coarse-textured the influence of spacing on the edge effect is reduced. The results show that there is a specific separation between strips, different for each soil texture class, where there is no effective interaction between them. The effect disappears at a spacing of 0.26 m for the loamy sand, 0.35 for the sandy clay loam, and 0.5 m for the silt loam.

Limitations: The results presented here are for steady-state flow. The amount of interaction between strips will be a function of time in the transient flow case, with the interaction being *nil* or very small initially, and then reaching the maximum value possible at steady-state. Additional analyses will need to be conducted to examine the effect of time on the edge effect.

Conclusions: This research facilitates the calculation of steady-state infiltration from parallel strip sources using a 1-D approximation with a factor to account for the enhancement of infiltration introduced by the actual 2-D flow.

Reference: Warrick, A.W., Lazarovitch, N., Furman, A., and Zerihun, D., Explicit infiltration function for furrows, J. Irrig. Drain. Eng, 133, 307-313 (2007)

Excerpt from the Proceedings of the 2015 COMSOL Conference in Boston