By introducing an average value for \( \theta \) calculated from the water content distribution and the values of the other parameters, the dimensional value for the travel time \( (t) \) can be calculated.

5. Philip adopted \( u/\theta, v/\theta \) as the components of travel velocity in his analysis in which \( \theta \) may be adopted as either the midrange or the mean value of \( \theta(x,z) \). In his soil example (Yolo light clay) the range of the water content is 0.4397 < \theta < 0.4950. As he stated, this soil exhibits a much slower decrease of the moisture diffusivity with \( \theta \) than do many soils. The equations given by Philip (Eq. [60] and [65]) can only calculate the travel times in \( x \)- and \( z \)-directions, respectively, by assuming an average water content in the whole flow field. Generally, in nature the water contents may take values in the range 0.10 < \theta < 0.50. For this general case, the average water content will be 0.30 with an error of 40%. Under these conditions, the simple exact solutions for travel times developed by Philip may be used for the type of soils like Yolo light clay. But in the method used by Batu and Gardner (1978) proposed by Jury (1975), the only limitation is that we have to consider average water contents between the streamlines, not an average water content in the whole flow field.

References


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VEDAT BATU

Reply to “Comments on ‘Nonuniform Leaching from Nonuniform Steady Infiltration’”

I reply to the five points of Batu in sequence. I welcome, in particular, points 3 and 4, though I fear his points 1 and 2 are without substance.


2. I cannot divine Batu’s worry. Does he require an explanation that the stream function \( \phi \) involves a constant of integration which we fix by taking \( \phi = 0 \) on the streamline \( x = 0 \)?

3. I thank Batu for pointing out the misprint in Eq. [32] of Philip (1984). \( 2/\pi \) should indeed read \( 2/L \).

4. I am interested in Batu’s remarks on how Batu and Gardner (1978) calculated their travel time \( T \). I regret that I misunderstood their original presentation. The confusion arose because their published definition of \( T \) was not Eq. [2] of Batu’s “Comments” but

\[
T = (t \nu_{\text{max}}/\theta_B)^{1/2}
\]

It is now revealed that \( \theta_B \) was a misprint for \( \theta B \). I read \( \theta B \) as “\( \theta \) sub \( B \)” and presumed (wrongly, it turns out) that it was intended to denote some average value of \( \theta \). The \( \theta \) itself, is defined by Batu and Gardner (1978) as “the water content”, a function of \( x \) and \( z \). Batu now discloses, however, that the \( \theta \) in his Eq. [2] is not the local moisture content, but is an average between streamlines. Regardless of the status of \( \theta \), the promotion of \( B \) from a suffix to a symbol in its own right undoubtedly makes the \( T \) of Batu and Gardner (1978) dimensionless. Accordingly, the two sentences on p. 747 of Philip (1984) reading, “Note that Batu and Gardner ...... centimeters.” should be disregarded and, indeed, deleted.

5. It should be recognized that there is a simple connexion between the travel time function computed in the approximation \( \theta = \bar{\theta} = \text{constant} \), \( t(x,z) \), and the exact travel time function, \( t(x,z) \). We have immediately that, along any streamline

\[
\frac{dt}{ds} = \frac{v}{\theta}, \quad \frac{dt}{ds} = \frac{v}{\theta},
\]

with \( s \) arc length along the streamline. Dividing the second equation by the first, and integrating with respect to \( t \), we obtain

\[
t(x,z) = \bar{\theta}^{-1} \int_{0}^{t(x,z)} \theta(t_1) \, dt_1.
\]

Integration of \( \theta(t_1) \) is taken along the streamline containing \( (x,z) \). Equation [1] converts analytical results for \( t \) into results for \( t \) which take full account of the spatial variation of \( \theta \). The approximation \( \theta = \bar{\theta} \) can thus be removed from the travel time results of Philip (1984), if this is desired. It remains arguable whether, for the flows studied, this extra calculation is justified. As Philip (1984) states, the \( \theta \)-range found for Yolo light clay, although small, is greater than it would be for most soils (with diffusivity decreasing more rapidly with \( \theta \)). Batu’s stated range 0.1 < \( \theta \) < 0.5 will apply to some other circumstances (and use of the above Eq. [1] may then be warranted), but it is most improbable in the (fairly moist) leaching context we address. The virtue of the analytical approach, as we have seen, is to give with relative ease an instructive picture of the interactions between the pattern of surface source nonuniformity, soil properties (characterized by \( \alpha \)), water table depth, and nonuniformity of leaching travel times.

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