GROUNDWATER has become a major source of drinking, industrial, and agricultural water. Groundwater supplies will become an even more important natural resource as the world continues its effort to resolve the dilemma of meeting ever-growing demands for water with rapidly depleted and, at times, polluted surface water supplies. The growing concern over acute and chronic health affects resulting from contaminants in drinking water has brought the degradation of groundwater to the forefront of public attention. Groundwater quality is a primary environmental concern not only for health reasons, but because of the decrease in crop productivity, which can often accompany the use of poor quality irrigation water. The ability to model the migration of pollutants through the vadose zone is an essential tool in combating the degradation of our groundwater.

Over the past three decades numerous conceptual models for the movement of solutes through the unsaturated zone have been developed. Several reviews of these transport models have recently appeared in the literature (Addiscott and Wagenet, 1985; Nielsen et al., 1986; van Genuchten and Jury, 1987; Engesgaard and Christensen, 1988; Feddes et al., 1988). Basically two groups of transport models are recognized: deterministic and stochastic. Within these two categories there are additional subcategories of models. Functional models are a group of deterministic models that utilize simplified treatments of solute and water flow while making no claim to a fundamental description of the mechanisms involved in the transport process. As such, functional models require less input data and computer expertise for their application. Several functional models have been presented in the literature (Bressler, 1967; Tanji et al., 1972; Burns, 1975, 1976; Addiscott, 1977; Rose et al., 1982; Bond and Smiles, 1988).

More than ever before, there is a need for simple, management-oriented models for interpreting and simulating solute movement by leaching. This need for functional transport models arises from two limitations found in more theoretically rigorous mechanistic models of transport. First, the soil data needed for sophisticated analytical and numerical models are typically well beyond the capacity of most real-world users, such as the USEPA, Soil Conservation Service or Agricultural Extension Service. Second, the spatial variability typical of field soils limits the accuracy of application of exact transport theory under field management situations. As pointed out by Bond and Smiles (1988), "...the assumptions used to derive most flow equations presented in the literature are not satisfied in field soils, and analytical solutions of these equations are appropriate only to a very restricted set of initial and boundary conditions." Stochastic transport models do not provide a viable alternative for

A Functional Model of Solute Transport that Accounts for Bypass

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ABSTRACT

Public awareness of groundwater contamination has created renewed interest in solute transport models that can be practically applied as groundwater quality management tools. Because of their simplicity with regard to input requirements, functional models of solute transport are excellent groundwater quality management tools. A functional model of one-dimensional solute transport that accounts for hydraulic bypass is presented. The transport model, TETTrans, simulates the vertical movement of nonvolatile solutes (i.e., trace elements and nonvolatile organic chemicals) through the vadose zone. Plant water uptake is taken into account assuming no solute uptake by the plant. TETTrans requires minimal input data for its operation. Since TETTrans uses a mass-balance approach to solute transport, it offers the speed of an analytical solution and the versatility of a numerical approach without the need for input parameters, which are difficult to measure. TETTrans is able to account for bypass with a single term, the mobility coefficient. The mobility coefficient, \(\gamma\), represents the fraction of the soil liquid phase, which is subject to piston-type displacement; therefore, \(1 - \gamma\) represents the fraction of the liquid phase that is bypassed. The mobility coefficient is a temporally and spatially variable parameter (within a range of 0 to 1), which is calculated from the deviation of the measured chloride concentration from the predicted concentration assuming piston displacement and assuming complete mixing of the resident soil solution and incoming water for a given irrigation and volume of soil. A constant mobility coefficient for a given depth or entire profile can be determined by averaging temporally varying mobility coefficients or averaging spatially and temporally varying mobility coefficients, respectively. In essence, the mobility coefficient simplistically accounts for three physical transport phenomena in a single term. On a microscopic level there is flow through cracks and macropores that bypasses small and dead-end pores. On a macroscopic level there is the flow of a mobile water phase independent of stagnant immobile phase of water, and the phenomenon of dispersion-diffusion. Simulations of chloride movement through a soil lysimeter column for an 1100-d period were compared to measured chloride concentrations in the soil solution at field capacity. A constant mobility coefficient significantly improved the capability of TETTrans to describe the data when compared to simulations performed assuming complete piston-type displacement. However, the best simulation to the measured chloride data was for the use of a spatially and temporally variable mobility coefficient.

amounts of solute and water content rather than rates
user. 1
signed for real-world transport applications where a
TETrans (Trace Element
ments and nonvolatile organic chemicals through the
which simulates the vertical movement of trace ele-
ical model of one-dimensional transport is presented,
consideration of bypass flow, a simplified mathemat-
ise of mass-balance applied by Burns (1975) and on
Coats and Smith, 1964; Deans, 1963). It is only the
water phase and a mobile water phase (Turner, 1958;
In addition, soil water is be-
the flow of solutes. In this case, flow can deviate sig-
In aggregated soil or soil high in clay, bypass flow paths
of these models it was assumed that no bypass
(1982), and Bond and Smiles (1988). However, in
most real-world applications since again the data upon
developed on this premise by Burns (1975), Rose et al.
curves is required. Previous models have been devel-
and a knowledge of field capacity. Using this simplified
approach, no quantitative knowledge of the soil's hy-
and simply calculated using water-balance accounting
spiration and evaporative losses from the soil surface,
(iii) water uptake by the plant root resulting from tran-
taneous chemical equilibration for reactive solutes,
solute chemical interactions, TETrans predicts the av-
ory movement of reactive or nonreactive solutes in
solute transport in the unsaturated zone under transient-
homogeneous physical and chemical characteristics.

On a microscopic scale, bypass can result when
A. Infiltration and drainage

1. Before an irrigation (B/) or precipitation, 
   \[ \text{T}_{\text{B1}} = \text{Ts}_{\text{t}} + \text{T}_{\text{an}} = \text{V}_{\text{t}} \left[ \text{OBIC}_{\text{n}} + \text{o}_{\text{n}} \text{C}_{\text{n}} \right] = \text{V}_{\text{n}} \text{C}_{\text{n}} \]

2. After an irrigation and drainage to field capacity (A/),
   \[ \text{V}_{\text{o}, \text{t}} = \text{V}_{\text{e}, \text{t}} + \text{V}_{\text{o}, \text{t}} \]

3. For a schematic of this situation, then
   \[ \text{c}_{\text{e}} = \left( \text{v}_{\text{o}, \text{c}_{\text{e}}}, + \text{ve}_{\text{e}}, \text{c}_{\text{e}} \right) / (\text{v}_{\text{o}, \text{c}_{\text{e}}} + \text{c}_{\text{e}}) \]

4. If \( \text{c}_{\text{e}} > \text{c}_{\text{e}} - \text{V}_{\text{c}_{\text{e}}} \) (see Fig. 1b for a schematic of this situation), then
   \[ \text{c}_{\text{e}} = \left( \text{c}_{\text{e}}, + \text{V}_{\text{e}, \text{c}_{\text{e}}} \right) / (\text{v}_{\text{o}, \text{c}_{\text{e}}} + \text{c}_{\text{e}}) \]

5. If \( \text{V}_{\text{c}_{\text{e}}} = 0 \) and \( \text{c}_{\text{e}} = 0 \), then
   \[ \text{c}_{\text{e}} = \text{c}_{\text{o}, \text{c}_{\text{e}}} \]

6. If \( \text{V}_{\text{c}_{\text{e}}} = \text{v}_{\text{o}, \text{c}_{\text{e}}} + \text{v}_{\text{e}, \text{c}_{\text{e}}} \), then
   \[ \text{c}_{\text{e}} = \left( \text{c}_{\text{e}}, + \text{V}_{\text{e}, \text{c}_{\text{e}}} \right) / (\text{v}_{\text{o}, \text{c}_{\text{e}}} + \text{c}_{\text{e}}) \]

\[ \text{c}_{\text{e}} = \left( \text{c}_{\text{e}}, + \text{V}_{\text{e}, \text{c}_{\text{e}}} \right) / (\text{v}_{\text{o}, \text{c}_{\text{e}}} + \text{c}_{\text{e}}) \]

\[ \text{c}_{\text{o}, \text{c}_{\text{e}}} = \text{c}_{\text{e}} \]

\[ \text{c}_{\text{e}} = \left( \text{c}_{\text{e}}, + \text{V}_{\text{e}, \text{c}_{\text{e}}} \right) / (\text{v}_{\text{o}, \text{c}_{\text{e}}} + \text{c}_{\text{e}}) \]

\[ \text{c}_{\text{e}} = \left( \text{c}_{\text{e}}, + \text{V}_{\text{e}, \text{c}_{\text{e}}} \right) / (\text{v}_{\text{o}, \text{c}_{\text{e}}} + \text{c}_{\text{e}}) \]
If $0 < y \leq 1$ and $V_i > V_{fc} - (1.0 - y) V_{at}$, then

\[ \frac{\partial V_t}{\partial t} = \frac{v}{\rho} \left( V_{at} - V_t \right) \]

After Irrigation

If $y = 0$ (complete bypass), and $V_i > V_{fc} - V_{BI}$, then

\[ v = V_{fc} + \frac{V_{BI}}{2} \]

Solute concentration of the exiting water (kg/m³); $-\theta$ the mobility coefficient, or more specifically, the fraction of $V_{++I}$ that is subject to piston-flow (where, $0 < \theta < 1$ represents total bypass, $\theta = 0$ represents complete piston-type flow); $1.0 - \theta$ is the fraction of $V_{++I}$ that is subject to bypass; $V_m$ is the volume of soil water in $V_t$ after an irrigation (m³); and $V_{+}$ is the volume of water in $V_t$ at field capacity (m³).

B. Chemical equilibration

Chemical equilibration involves the partitioning of a reactive solute into the solution and adsorbed phases. Since chloride is a nonreactive solute, no partitioning into solution and adsorbed phases is described herein (see Corwin et al., 1991, unpublished data, for a complete discussion of the partitioning of a reactive solute).

C. Plant water uptake

A knowledge of the total amount of evapotranspiration between irrigation events and the plant root distribution of a crop is needed for TETrans. The plant water uptake model simulates the net loss of water from each depth increment within the root zone of a maturing plant. Root growth is assumed to occur linearly from the date of planting to the date of maturity. If the plant is harvested and the root system is terminated, all subsequent loss of water from the root zone occurs by a simulation of evaporative loss from the soil surface. TETrans does not account for the upward movement of solute resulting from the processes of evaporation or transpiration. Evapotranspiration is only viewed as a sink for water loss that results in the concentration of the solute within the root zone. It is not viewed as creating a potential gradient that results in the net upward or downward movement of the solute between depth increments.

In TETrans the distribution of the removal of water by the plant root is fitted with the option of two models: linear or exponential distribution. The linear distribution was used for the simulations in this paper. The linear root water uptake model is that of Perrochet (1987), which is a synthesis of previous models and work presented by Molz and Remson (1970), Feddes et al. (1978), Hoagland et al. (1981), Ritchie (1984), Ritchie and Otter (1984), and Prasad (1988).
the integral of the volumetric extraction function from optimal; consequently, the reducing factor, \( r(x_L) \), is equal. It is assumed in TETrans that moisture conditions are optimized so that its integral over \( L \) is unity. It is expressed by either Eq. [17] or [18], which are a representation of the lowest volume of water within \( V \), which lies above the water content at the wilting point and can be withdrawn below a minimum volume of water, given depth increment, the residing soil water cannot be inclusive within the bypass phenomenon, and composed of preferential movement through large macropores and from the movement of a mobile water phase, thereby bypassing small dead end pores and a stagnant immobile phase of water. Though dispersion deviation is assumed to be attributed in large part to piston-type displacement of solute. In TETrans this is when

\[
U_e(-7) = \left( e^{-a_{\text{L}}} \right) \left( z - z_1 \right)
\]

\[
U_e(0) = \left( e^{-a_{\text{L}}/L} \right) - \left( 1/L \right) \left( z - z_2 \right)
\]

\[
U_e(z) = \left( e^{-a_{\text{L}}/L} \right) L - \left( 1/L \right) z
\]

By definition \( 0 \leq \sigma \leq 1 \), so if \( \sigma \) is calculated to be outside its defined range. Anomalous situations could arise where \( \sigma \) is less than 0, then \( \sigma \) is set equal to 0. Similarly, if \( \sigma \) is calculated by Eq. [21] to be outside its defined range. The possible reasons for \( \sigma \) extending beyond the variable mobility coefficients is based upon the deviation of measured soil solution chloride concentrations of reactive solutes. (see Corwin et al., 1991, unpublished data, for discussion of the reequilibration of reactive solutes).

D. Chemical reequilibration

Concomitant with the removal of water by the roots is observed to occur after any ET event. The actual water uptake; \( V_{\text{at}} \) is adjusted to

\[
V_{\text{at}} = V_{\text{m}} + (V_{\text{fc}} - V_{\text{c}}) \sigma
\]

\[
V_{\text{at}} = V_{\text{c}} + (V_{\text{fc}} - V_{\text{c}}) \sigma
\]

\[
V_{\text{at}} = V_{\text{m}} + (V_{\text{fc}} - V_{\text{c}}) \sigma
\]

\[
V_{\text{at}} = V_{\text{c}} + (V_{\text{fc}} - V_{\text{c}}) \sigma
\]

Solutes remain behind as the water is extracted. Therefore, evapotranspiration results in the concentration of solutes within the root zone. For a nonreactive solute, the degree to which the solute is concentrated can be approximated by multiplying the concentration of the solute. During the extraction process, the chloride concentration of the soil solution at field capacity (for a nonreactive solute, the chloride concentration is given by

\[
T_{\text{at}} = V_{\text{fc}} C_{\text{fc}} - V_{\text{c}} C_{\text{c}}
\]

Since \( T_{\text{at}} \) can be calculated from the measurement of a transport experiment which extended over an 1100-d time period was conducted to test TETrans' ability to account for bypass. The study used weighing soil lysimeter columns. The columns were constructed of PVC and stood 1.52 m tall with a radius of 0.227 m. The columns were filled with Arlington loam (Haplic Durixerol). Soil solution extracted from calculated concentrations assuming complete reequilibration. Anomalous situations could arise where \( \sigma \) is less than 0, then \( \sigma \) is set equal to 0. Similarly, if \( \sigma \) is calculated to be outside its defined range. The possible reasons for \( \sigma \) extending beyond the variable mobility coefficients is based upon the deviation of measured soil solution chloride concentrations of reactive solutes. (see Corwin et al., 1991, unpublished data, for discussion of the reequilibration of reactive solutes).

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\]

\[
V_{\text{at}} = V_{\text{m}} + (V_{\text{fc}} - V_{\text{c}}) \sigma
\]

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\[
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\]

Since \( T_{\text{at}} \) can be calculated from the measurement of...
tion and the general chemical composition of the synthesized water (i.e., San Joaquin Valley drainage water, which is low in salts and boron) was initially applied prior to planting each crop. This was followed by irrigating with a poor quality water and when it was applied to the soil column. The fluctuation of salts (major cation and anions, including chloride) and boron through the root zone for various irrigation management strategies.

The data needed to test the hydraulic aspect of TETrans' simulation capability included; initial chloride concentration occurring in several other columns was present and that a anomalous water flow behavior (presumed to be bypass) also taken when a given depth reached field capacity as measured horizontally along the side of the soil column at depths of 0.075, 0.225, 0.375, 0.525, and 0.675 m. A free-flow drain was at the bottom of the column. The lysimeter column design and observation are shown in Fig. 5. The soil solution samples were taken at the midpoint (i.e., 0.075, 0.225, 0.375, 0.525, and 0.675 m) of each depth increment: 0 to 0.15, 0.15 to 0.30, 0.30 to 0.45, 0.45 to 0.60, and 0.60 to 0.75 m. Because TETrans determines the average movement of salts (major cation and anions, including chloride) and boron through the root water content-matric potential relationships, and dispersivity models that require a knowledge of hydraulic conductivities, transport models, especially previous numerical determinations of hydraulic conductivity, are readily obtained than those needed for most other transport models, especially those 2, 3 and 4, and Table 3 are a compilation of all the input data for TETrans.

ET rate multiplied by time). Table 3 shows miscellaneous input parameters for TETrans. Through the root penetration (ra): wheat 0.90 milo 0.90 ratio 3 July 1984 550 wheat 21 Dec. 1984 721 milo 19 June 1985 901 milo 3 Oct. 1983 276 wheat 5 June 1984 522 milo 27 Nov. 1984 695 wheat 7 June 1985 889 milo 10 Oct. 1985 1014 wheat 18 Jan. 1984 1.3 3.1 0.1 2.2 3.0 1.5 0.3

The measured chloride concentrations in the soil solution for each of the five depth increments under irrigation water qualities were cycled. The total evapotranspiration, and plant root distribution for each crop. Figures 2, 3 and 4, and Table 3 are a compilation of all the input parameters for TETrans. Though seemingly formidable in its input requirements, TETrans is far less parameter intensive than most other transport models. In addition, the input parameters are more readily obtained than those needed for most other transport models, especially previous numerical determinations of hydraulic conductivity.
redundancy, any future discussion will be restricted for the most part to the shallowest and deepest increments: 0.0 to 0.15 and 0.60 to 0.75 m.

Figures 6, 7, and 8 show a gradual improvement in the predictive quality of TETrans to simulate chloride movement using different mobility coefficients. Each figure compares the measured chloride concentration in the soil solution to the predicted concentration for a given depth over the 1100 d of the study. Figure 8a-c shows the best simulation to the measured chloride soil solution data using temporally and spatially variable mobility coefficients. However, the use of a single mobility coefficient, $m = 0.498$, which is an average of all the temporally and spatially variable mobility coefficients used in Fig. 8 likewise shows an extremely close simulation to the measured data (see Fig. 7a-c). The mobility coefficient provides useful information regarding temporal and spatial changes in bypass. Table 1 shows the average and standard deviation of the mobility coefficients: 0.25, 0.20, 0.15, 0.10, 0.05, 0.00

Fig. 2. Irrigation times (days) and amounts (m).

Fig. 3. Chloride concentration (meq/L) of the applied irrigation waters.

Fig. 4. Average evapotranspiration rate (mm/day) between irrigations.

Fig. 5. Measured chloride concentration (meq/L) in the soil extract taken at depths of 0.075, 0.225, 0.375, 0.525 and 0.675 m.

Fig. 6. (a) Comparison of measured chloride concentrations and predicted concentrations assuming complete piston-type displacement ($m = 1.0$) for the depth increment 0-0.15 m. (b) Comparison of measured chloride concentrations and predicted concentrations assuming complete piston-type displacement ($m = 1.0$) for the depth increment 0.60-0.75 m.
DISCUSSION OF RESULTS

Figure 5 shows the measured chloride concentration in the soil extract taken at field capacity at depth increments of 0.30 m starting with a depth of 0.15 m. A general cyclical trend in chloride is seen that roughly follows the trend of evapotranspiration (see Fig. 4). As the evapotranspiration increases during the summer months, so does the chloride concentration particularly at the shallower depths. This could be a consequence of extracting soil solution samples at a water content drier than field capacity or due to a cyclical change in bypass. Because particular caution was taken to obtain soil solution extracts at field capacity by taking continuous TDR measurements, it is unlikely that soil solution extraction error was significant. However, a cyclical trend in bypass does seem likely. High temperatures and low humidity in the summer months produced a noticeably drier soil surface for the top few centimeters (0-0.075 m) of soil, which produced surfaces cracks not noticeable during the winter months. The dry soil surface due in large part to surface evaporation resulted in increased cracking at the surface compared with the winter months. Furthermore, an analysis of the seasonal-average mobility coefficient for each depth increment shows greater bypass to oc-
Table 4. Average mobility coefficients and associated evapotranspiration. The fact that less bypass occurred during the summer months than in the winter months indicated a rapid initial movement of water along the side of the lysimeter. However, cracks extended as far down as 0.5 m and may have even gone deeper. However, an effort was made to minimize bypass down the side of the lysimeter by filling those cracks adjacent to the column with soil. Though all of the factors of the design of the lysimeter, the problem discrepancies that are seen in Fig. 6a and 6b. However, anion exclusion would not seem to cause the major cracks crisscrossing the soil surface were usually present at the time of irrigation, particularly in the summer months when the soil surface would dry out to a greater extent than during the winter months. These cracks would visibly extend 0.15 m to as much as 0.30 m into the soil. So, not only did the flow of irrigation water down the sides of the column occur, but flow pand away from the soil, thereby causing greater bypass. From TDR measurements it could be seen that pressures that would naturally occur as a result of wetting and drying were at times noticeable from TDR measurements. Using a constant mobility coefficient of 0.5 for all increments are shown in Fig. 8a, 8b, and 8c. There are several potential reasons why the mobility coefficient was at times noticeable from TDR measurements. Since these were considered to represent fissured of PVC, it is reasonable to believe that the struts that would naturally occur as a result of wetting and drying were at times noticeable from TDR measurements. This was noticeable in the upper half of the lysimeter. However, the mobility coefficient from 0.30 to 0.45 m the level of bypass was fairly constant regardless of the season was greatest for the top two increments, 0 to 0.15 and 0.15 to 0.30 m. Below pass was greater during the summer months, and re-
any one or a combination of processes, such as dispersion, diffusion, and anion exclusion, as well as from experimental errors in obtaining a true measure of the average chloride concentration for a depth increment. Spatially variable mobility coefficients were either less than 0 or greater than 1, and thereby, had to be set to 0 and 1, respectively. The reason for this occurring more temporal variability shows less temporal variability with increased depth. The cracks at the surface are expected because of root channels. As the root system increases over the maturation of the plant, the channeling of water would become more pronounced. Harvesting the plant would result in root death and shrinkage leaving an open channel. With time, these channels would fill with fine soil particles that filter through the soil and diminish the root channels. As the root system increases over the maturation of the plant, the channeling of water would become more pronounced.

Results showed that the use of a single adjustable parameter for plant water uptake portions of the model. Using a weighing lysimeter the model was tested for its ability to simulate the movement of a non-reactive solute, chloride, in order to verify the water flow. The only laboratory analysis required is the routine and quick measurement of chloride in soil solution. Soil solution extractors installed at several depths at a location can be determined from temporal and spatial measurements of chloride concentration in the soil solution. Soil solution extractors installed at several depths can be used to provide an estimation of evapotranspiration from more readily available meteorological data. A lysimeter experiment for various ET models and their performance was forward in time and TETrans can be used for predictions of water flow (i.e., as demonstrated by the excellent simulations of water flow). Currently, subroutines of various ET models are being incorporated into TETrans source code to provide an estimation of evapotranspiration. For field applications, the degree of bypass occurring is the total evapotranspiration. Currently, subroutines are either easily estimated (e.g., plant root water uptake distribution, maximum plant root penetration) or available from quick and routine methods of measurement (e.g., bulk density; amount of applied water; or available from quick and routine methods of measurement (e.g., bulk density; amount of applied water; or available from quick and routine methods of measurement). A lysimeter experiment for various ET models was performed in order to verify the water flow. The only laboratory analysis required is the routine and quick measurement of chloride in soil solution. Soil solution extractors installed at several depths at a location can be determined from temporal and spatial measurements of chloride concentration in the soil solution. Soil solution extractors installed at several depths at a location can be determined from temporal and spatial measurements of chloride concentration in the soil solution. Soil solution extractors installed at several depths at a location can be determined from temporal and spatial measurements of chloride concentration in the soil solution. Only for reactive solutes do additional analytical parameters need to be considered. These factors would result in a changing level of solute bypass, which is relatively quick, easy, and cost effective for its ability to simulate the movement of a non-reactive solute, chloride, in order to verify the water flow. The only laboratory analysis required is the routine and quick measurement of chloride concentration. Using a subroutine within TETrans, the deviation of the measured chloride concentration from the predicted concentrations assuming a constant mobility coefficient can then be projected forward in time and with depth.
Effective since the measurement of soil solution chloride is one of the most routine and inexpensive soil chemical analysis to perform. Presumably the use of a mobility coefficient(s) determined from chloride data should improve TETrans' ability to model the movement and distribution of a reactive solute because of the improved accuracy in simulating the water flow and plant water uptake aspects of transport. Corwin et al. (1991, unpublished data) test this hypothesis with a lysimeter experiment that evaluates the performance of TETrans' solute transport simulation capabilities for the movement of boron with the use of both constant and variable mobility coefficients.

**APPENDIX**

Terms Used in this Article with Definitions

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Linear plant root distribution coefficient (—1 &lt; a, &lt; 0)</td>
<td>Exponential plant root distribution coefficient (a &gt; 0)</td>
</tr>
<tr>
<td>Mobility coefficient, or more specifically, the fraction of $V_B$ that is subject to piston-flow (where $0 &lt; \mu &lt; 1$, $\mu = 0$ represents total bypass, $\mu = 1$ represents complete piston-type flow)</td>
<td>Fraction of $V_{BI}$ that is bypassed</td>
</tr>
<tr>
<td>Soil bulk density (kg/m$^3$)</td>
<td>Soil-water suction head (m)</td>
</tr>
<tr>
<td>Volumetric water content immediately before an irrigation (cm$^3$/cm$^3$)</td>
<td>Volumetric water content at field capacity (cm$^3$/cm$^3$)</td>
</tr>
<tr>
<td>Root distribution function</td>
<td>Plant root penetration depth (m)</td>
</tr>
<tr>
<td>Potential volumetric transpiration (m$^3$)</td>
<td>Reducing factor</td>
</tr>
<tr>
<td>Integral of the volumetric extraction function from the soil surface ($z = 0$) to the depth of root penetration ($z = L$)</td>
<td>Volumetric root extraction function</td>
</tr>
<tr>
<td>Total amount of adsorbed solute in $V$, (kg)</td>
<td>Total amount of solute in a volume, $V$, after an irrigation (kg)</td>
</tr>
<tr>
<td>Total amount of solute in a volume, $V$, immediately before an irrigation (kg)</td>
<td>Total amount of solute in the soil water of $V_t$ (kg)</td>
</tr>
<tr>
<td>Total amount of solute entering $V$, (kg)</td>
<td>Total amount of solute leaving $V$, (kg)</td>
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