

B3. Green-Ampt Model for Layered Systems (GALAYER)

A. Description

The Green-Ampt Model has been modified to calculate water infiltration into nonuniform soils by several researchers (Bouwer, 1969; Fok, 1970; Moore, 1981; Ahuja and Ross, 1983). In this section, the Green-Ampt model for layering systems (GALAYER) developed by Flerchinger *et al.* (1989) was selected to calculate water infiltration over time in vertically heterogeneous soils. Two simulation scenarios were selected in the application. The first scenario was to estimate water infiltration into a soil with two layers (sand and loam), while the second scenario was to estimate the water infiltration into a soil with three layers (with sand, loam, and clay in sequence). Comparison of the two scenarios for water infiltration was also provided.

B. Definition of Variables

$K_1 := 1$	Hydraulic conductivity (cm/h) for layer 1 (Top layer)
$K_2 := 0.5$	Hydraulic conductivity (cm/h) for layer 2 (Middle layer)
$K_3 := 0.1$	Hydraulic conductivity (cm/h) for layer 3 (Bottom layer)
$t := 1 \dots 24$	Time for infiltration (h)
$\Delta\theta_{n1} := 0.2$	Change in volumetric water content as wetting front passes in last layer for Scenario 1 (cm ³ /cm ³)
$K_{n1} := K_2$	Hydraulic conductivity for last layer in Scenario 1 (cm/h)
$H_{n1} := 3000$	Potential head (cm) as the wetting front passes last layer for Scenario 1.
$n := 2$	Number of soil layers
$Z_1 := 10$	Depth of layer 1 (cm)
$Z_2 := 10$	Depth of layer 2 (cm)
$\Delta\theta_{n2} := 0.1$	Change in volumetric water content as wetting front passes in last layer for Scenario 2 (cm ³ /cm ³)
$K_{n2} := K_3$	Hydraulic conductivity for last layer in Scenario 2 (cm/h)
$H_{n2} := 7000$	Potential head (cm) as the wetting front passes last layer for Scenario 2.
$Z_3 := 10$	Depth of layer 3 (cm) for scenario 2 with n=3

C. Equations and Results

a. Scenario 1

$n := 2$
 $n1 := n$

$$td(t) := \frac{K_{n1} \cdot t}{\Delta\theta_{n1} \cdot \left(H_{n1} + \sum_{i=1}^{n-1} Z_i \right)}$$

Dimensionless time since wetting front penetration. (1)

$$zd := \frac{K_{n1}}{\left(H_{n1} + \sum_{i=1}^{n-1} Z_i \right)} \cdot \sum_{i=1}^{n-1} \frac{Z_i}{K_i}$$

Dimensionless depth accounting for the thickness and conductivity of layers behind wetting front. (2)

$$Fd(t) := \frac{1}{2} \cdot \left[td(t) - 2 \cdot zd + \sqrt{(td(t) - 2 \cdot zd)^2 + 8 \cdot td(t)} \right]$$

Dimensionless accumulated infiltration. (3)

$$fd(t) := \frac{Fd(t) + 1}{Fd(t) + zd}$$

Dimensionless infiltration rate. (4)

$$fl(t) := fd(t) \cdot K_{n1}$$

Infiltration rate. (5)

t =	fl(t) =
1	12.618
2	9.036
3	7.448
4	6.501
5	5.855
6	5.378
7	5.007
8	4.708
9	4.461
10	4.251
11	4.071
12	3.914
13	3.775
14	3.652
15	3.541
...	...

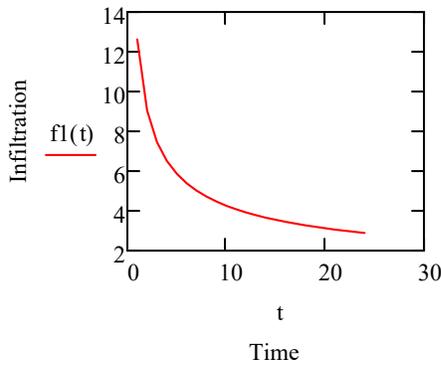


Figure B3-1. Water infiltration as a function of time through the layered soil profile in Scenario 1.

b. Scenario 2

$$n := 3$$

$$n2 := n$$

$$td(t) := \frac{K_{n2} \cdot t}{\Delta\theta_{n2} \left(H_{n2} + \sum_{i=1}^{n-1} Z_i \right)}$$

Dimensionless time since wetting front penetration. (6)

$$zd := \frac{K_{n2}}{\left(H_{n2} + \sum_{i=1}^{n-1} Z_i \right)} \cdot \sum_{i=1}^{n-1} \frac{Z_i}{K_i}$$

Dimensionless depth accounting for the thickness and conductivity of layers behind wetting front. (7)

$$Fd(t) := \frac{1}{2} \cdot \left[td(t) - 2 \cdot zd + \sqrt{(td(t) - 2 \cdot zd)^2 + 8 \cdot td(t)} \right]$$

Dimensionless accumulated infiltration. (8)

$$fd(t) := \frac{Fd(t) + 1}{Fd(t) + zd}$$

Dimensionless infiltration rate. (9)

$$f2(t) := fd(t) \cdot K_{n2}$$

Infiltration rate. (10)

t =	f2(t) =
1	5.996
2	4.262
3	3.494
4	3.036
5	2.724
6	2.493
7	2.314
8	2.169
9	2.049
10	1.948
11	1.861
12	1.785
13	1.718
14	1.658
15	1.604
...	...

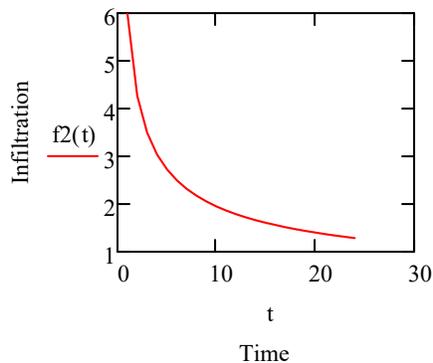


Figure B3-2. Water infiltration as a function of time through the layered soil profile in Scenario 2.

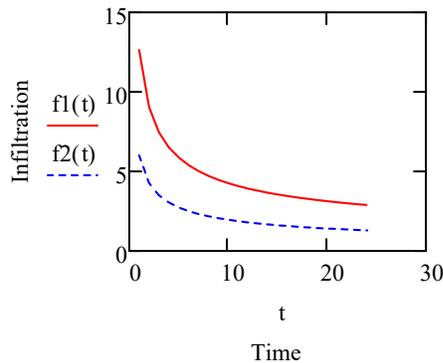


Figure B3-3. Comparison of water infiltration between Scenarios 1[solid line] and 2 [dash line].

E. Discussion

Water Infiltration into a two-layer soil (Scenario 1) and a three-layer soil (Scenario 2) as a function of time is given in Figures B3-1 and B3-2, respectively. These figures show that the infiltration rate is relatively high at the onset of the infiltration, then decreasing, and eventually approaching a constant rate at $t > 20 h$. Comparison of the two scenarios revealed that water infiltration is faster in the two-layer soil than in the three-layer soil.

F. Sensitivity of Infiltration Rate to $\Delta\Theta$

This section shows the sensitivity coefficient (S_s) and the relative sensitivity (S_r) of the surface infiltration rate to the change in volumetric water content. The expressions were obtained by applying Equations 3 and 4 in Section B2 (PHILIP2T model) to Equation 5 in this section. The input parameters were the same as in Scenario 2 except for $\Delta\Theta$ and t as shown below.

F1. Input Data

$$n := 3$$

$$n2 := n$$

$$\Delta\theta_n := 0.1, 0.11 \dots 0.2$$

$$t := 5$$

F2. Sensitivity Calculation Equations

$$td(\Delta\theta_n) := \frac{K_{n2} \cdot t}{\Delta\theta_n \cdot \left[H_{n2} + \left(\sum_{i=1}^{n-1} Z_i \right) \right]} \quad \text{Dimensionless time since wetting front penetration.} \quad (11)$$

$$zd(\Delta\theta_n) := \frac{K_{n2}}{\left(H_{n2} + \sum_{i=1}^{n-1} Z_i \right)} \cdot \sum_{i=1}^{n-1} \frac{Z_i}{K_i} \quad \text{Dimensionless depth accounting for the thickness and conductivity of layers behind wetting front.} \quad (12)$$

$$Fd(\Delta\theta_n) := \frac{1}{2} \cdot \left[td(\Delta\theta_n) - 2 \cdot zd(\Delta\theta_n) + \sqrt{\left(td(\Delta\theta_n) - 2 \cdot zd(\Delta\theta_n) \right)^2 + 8 \cdot td(\Delta\theta_n)} \right] \quad (13)$$

$$fd(\Delta\theta_n) := \frac{Fd(\Delta\theta_n) + 1}{Fd(\Delta\theta_n) + zd(\Delta\theta_n)} \quad (14)$$

$$f(\Delta\theta_n) := fd(\Delta\theta_n) \cdot K_{n2} \quad (15)$$

$$S_s(\Delta\theta_n) := \frac{d}{d\Delta\theta_n} f(\Delta\theta_n)$$

Sensitivity (16)

F.3. Results

$\Delta\theta_n =$	$S_s(\Delta\theta_n) =$
0.1	13.24
0.11	12.624
0.12	12.086
0.13	11.612
0.14	11.189
0.15	10.81
0.16	10.466
0.17	10.154
0.18	9.867
0.19	9.604
0.2	9.361

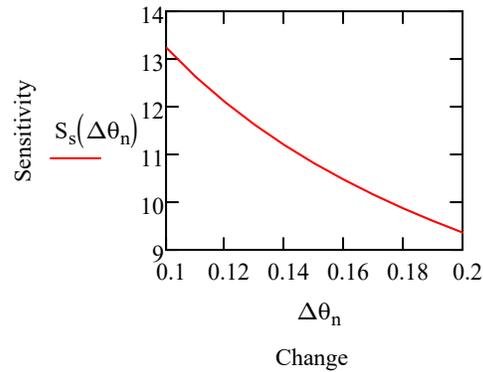


Figure B3-4. Sensitivity of infiltration rate for different values of the change in volumetric water content at the wetting front at $t = 5 h$.

F.4. Discussion

Figure B3-4 shows a sensitivity of the infiltration rate for different values of $\Delta\theta_n$. The sensitivity decreased as $\Delta\theta_n$ increased. A ten-fold increase in $\Delta\theta_n$ resulted in 30% decrease in sensitivity for conditions used in this application.

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