EFFECTS OF ANTECEDENT WATER CONTENT AND STORM SIZE ON INfiltrATION AND RUNOFF

INTRODUCTION

This exercise gives you experience in applying the Green and Ampt model (Section 6.6.2) for computing infiltration during a rainfall event. Application of the method in this exercise will provide insight into

1. how infiltration and surface detention (potential Hortonian overland flow; see Section 9.2.2) vary with time during a storm

2. how total runoff varies with (a) antecedent soil water content, and (b) storm rainfall.

This exercise is done using the spreadsheet program called GrnAmpt.xls, which is available on the CD accompanying Physical Hydrology (2nd ed.). The implementation of the program follows the discussion in Section 6.6.2 of Physical Hydrology (2nd ed.), specifically equations (6-34), (6-39), (6-41), (6-42), and (6-46). In addition, note the following relations:

\[ f(t) = w \quad \text{for } 0 \leq t \leq t_p \]  
(1)

\[ q(t) = 0 \quad \text{for } 0 \leq t \leq t_p \]  
(2a)

\[ q(t) = w - f(t) \quad \text{for } t_p < t \leq t_w \]  
(2b)

\[ Q(t) = 0 \quad \text{for } 0 \leq t \leq t_p \]  
(3a)

\[ Q(t) = w \cdot t - F(t) \quad \text{for } t_p \leq t \leq t_w \]  
(3b)

\[ W = w \cdot t_w \]  
(4)

where

\[ t \equiv \text{time since beginning of storm} \]

\[ t_p \equiv \text{time of ponding} \]

\[ t_w \equiv \text{time of storm ending} \]

\[ w \equiv \text{rainfall rate} \]
\( W \equiv \text{total rainfall} \)

\( f(t) \equiv \text{infiltration rate} \)

\[ F(t) \equiv \text{cumulative infiltration} = \int_0^t f(t) \, dt \]

\( q(t) \equiv \text{rate of Hortonian overland flow} \)

\[ Q(t) \equiv \text{cumulative Hortonian overland flow} = \int_0^t q(t) \, dt \]

**PROCEDURE**

**Soil Properties**

1. Retrieve the GreenAmpt.xls file as instructed.

2. The soil is Columbia Sandy Loam; Figure 1 is its moisture-characteristic curve. Determine porosity, \( \phi \), and \( |\psi_{ae}| \) from the moisture-characteristic curve. Other properties of this soil are

   - saturated hydraulic conductivity, \( K_h^* = 5 \, \text{cm hr}^{-1} \)
   - pore-size distribution index, \( b = 4.9 \).

3. Enter \( \phi, K_h^*, b, \) and \( |\psi_{ae}| \) where indicated in the spreadsheet.

**Experiment A Procedure**

The object of this experiment is to demonstrate the effect of initial water content ("antecedent conditions") on the timing and amount of infiltration and runoff from a rain storm of a given intensity and duration:

- rainfall rate, \( w = 10 \, \text{cm hr}^{-1} \)
- rainfall duration, \( t_w = 1 \, \text{hr} \).

A1. Enter the above values where indicated in the spreadsheet.

A2. You will make three runs, each with a different initial soil-water content, \( \theta_0 \):

<table>
<thead>
<tr>
<th>Run</th>
<th>( \theta_0 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>0.40</td>
</tr>
<tr>
<td>A2</td>
<td>0.32</td>
</tr>
<tr>
<td>A3</td>
<td>0.25</td>
</tr>
</tbody>
</table>
A3. Enter the first $\theta_0$ value where indicated (“Initial Conditions”). The program automatically calculates all the quantities under “Calculated Quantities” and enters $t_p$ and $F(t_p)$ in the second line of the Infiltration table.

A4. Enter a series of successive values of $F(t)$ in the yellow $F(t)$ column, where $F(t_p) < F(t) < w \cdot t_w$. If you violate the limits for $F(t)$, error messages appear. (Ignore error message below the rows in which you have entered $F(t)$ values.) The calculated values of infiltration rate, $f(t)$, depth to wetting front, $z(t)$, and $t$ appear in the other columns in each row. Enter 6 to 10 $F(t)$ values, with the last one as close as possible (when rounded to 3 significant figures) to the value that gives $t = t_w$. BE SURE EACH SUCCESSIVE $F(t)$ VALUE IS LARGER THAN THE PRECEDING VALUE.

A5. Print out the spreadsheet.

A6. You will be creating graphs of $F(t)$ and $f(t)$ vs. $t$ (see “Analysis” below). You can use the spreadsheet graphics now or exit the program and make the plots by hand later.

A7. Repeat steps A1 – A5 for the $\theta_0$ values indicated for Runs 2 and 3.

**Experiment A Analysis**

A8. Use the program output to plot the following graphs. Show all quantities from $t = 0$ to $t = t_w$. Note that infiltration ceases at $t_w$.
   a. $f(t)$ vs. $t$ for all 3 runs. Show $w$ and $K_h$* on this graph.
   b. $F(t)$ vs. $t$ for all 3 runs.

A9. Determine $F(t_w)$ for each run from the output. Then compute $Q(t_w)$ for each run via Equation (3b) above and plot the following graphs.
   a. $Q(t_w)/(w \cdot t_w)$ vs. $\theta_0$.
   b. $t_p$ vs. $\theta_0$.

**Experiment B Procedure**

The object of this experiment is to demonstrate the effect of storm size on the timing and amount of infiltration and runoff from a rainstorm of a given duration for a given initial water content:

$$t_w = 1 \text{ hr.}$$
$$\theta_0 = 0.32.$$

B1. Enter the above values where indicated in the spreadsheet.
B2. You will make five runs, each with a different rainfall rate, $w$:

<table>
<thead>
<tr>
<th>Run</th>
<th>$w$ (cm/hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>B1</td>
<td>6</td>
</tr>
<tr>
<td>B2</td>
<td>7</td>
</tr>
<tr>
<td>B3</td>
<td>8</td>
</tr>
<tr>
<td>B4</td>
<td>9</td>
</tr>
<tr>
<td>B5</td>
<td>10</td>
</tr>
</tbody>
</table>

Experiment B Analysis

B3. Determine $F(t_w)$ for each run from the output. Then compute $Q(t_w)$ for each run via Equation (3b) above and plot the following graphs.

a. $Q(t_w)/(w \cdot t_w)$ vs. $w$.

b. $t_p$ vs. $w$.

Discussion

Write brief paragraphs discussing the effects of $\theta_0$ and $w$ on the timing and relative and absolute amounts of infiltration and storm runoff as revealed in these experiments.

Figure 1

[Figure 1: MOISTURE CHARACTERISTIC CURVE COLUMBIA SANDY LOAM]