1. **Given:**

Example problem 5.10 with the following changes:

- The land use of the watershed is meadow
- The average overland slope is 2%
- The hydraulic length is 5,000 feet

**Required:**

Use a single triangle unit hydrograph and the SCS curve number method to develop a storm hydrograph for the 1-hr storm event. Find:

1. Total runoff in inches
2. Time lag in minutes
3. Time to peak in minutes
4. The peak flow of the unit hydrograph
5. Plot the unit hydrograph
6. Determine the area under the unit hydrograph
7. The peak flow of the storm hydrograph
8. Plot the storm hydrograph
9. Determine the area under the storm hydrograph

2. **Given:**

- Watershed area = 600 ac
- HSG = D
- Land use = cultivated land with conservation treatment
- Average land slope = 1%
- Hydraulic length = 7000 ft
- 1 hour storm event = 2.25” total with rainfall recorded in 15 minute increments as follows:

<table>
<thead>
<tr>
<th>T (min)</th>
<th>Rain (in.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 - 15</td>
<td>0.50</td>
</tr>
<tr>
<td>15 - 30</td>
<td>1.00</td>
</tr>
<tr>
<td>30 - 45</td>
<td>0.50</td>
</tr>
<tr>
<td>45 - 60</td>
<td>0.25</td>
</tr>
</tbody>
</table>

**Required:**

Use multiple single triangle unit hydrographs to develop a storm hydrograph for this one-hour storm.

**Find:**
1. Develop a table similar to Table 5.9
2. Plot the incremental triangular unit hydrographs and the storm hydrographs as shown in Figure 5.22
rock areas along the streams, precipitation directly on the streams, or rapid interflow. A delayed response is conceptualized as due to streamflow, overland flow delayed by bed litter (duff), or delayed interflow. To account for the delayed response due to interflow, several scientists and engineers have proposed using a double-triangle concept to represent the runoff hydrograph (Tennessee Valley Authority [TVA], 1973; Overton and Troxler, 1978; A.D. Ward et al., 1980; Wilson et al., 1983). Examples of double-triangle unit hydrographs for different land uses are presented in Figure 5.20.

**Example 5.10**

Use a single-triangle unit hydrograph procedure to develop a storm hydrograph for a 1-h storm event on a proposed 500-acre commercial and business watershed with soils in Hydrologic Soil Group D. The watershed has an average overland slope of 1% and a hydraulic length of 6000 ft. The rainfall depth during the 1-h storm event was 2.5 in.

**Solution**

Use the NRCS curve number method (Equation 5.3 and Equation 5.4) to develop a rainfall excess (runoff) hydrograph.

\[ S = \frac{1000}{CN} - 10 \]

From Table 5.1, CN = 95 (Hydrologic Soil Group D, commercial land use). Assume Antecedent Moisture Condition II, then

\[ S = \frac{1000}{95} - 10 = 0.53 \text{ inches} \]

and

\[ Q = \frac{(2.5 - (0.2 \times 0.53))^2}{2.5 + (0.8 \times 0.53)} = 1.96 \text{ inches} \]

Assume a triangular unit hydrograph and determine the lag time and time to peak using Equation 5.6 and Equation 5.9:

\[ t_L = \frac{L^3 Y (S + 1)^{0.7}}{1900 \times Y^{0.5}} \]

\[ L = 6000 \text{ ft}, Y = 1\%, \text{ and } S = 0.53 \text{ in.:} \]

\[ t_L = \frac{6000^3 (0.53 + 1)^{0.7}}{1900 \times 1^{0.5}} \]

\[ t_e = 0.75 \text{ hrs (45 minutes)} \]

and

\[ t_p = t_e + \frac{D}{2} = 45 + \frac{60}{2} = 75 \text{ minutes} \]

The peak flow of the unit hydrograph is determined from Equation 5.16:

\[ q_p = \frac{484 A}{t_p} \]

and

\[ q_p = \frac{484 \times 500 \text{ acres}}{640 \times \frac{60}{75 \text{ minutes}}} = 302.5 \text{ cfs (per inch of runoff)} \]

Note that the 500 acres are divided by 640 to convert them to square miles, and the 75 min are divided by 60 to convert them to hours.

The peak flow is simply 302.5 ft/sec times 1.96 in. of runoff, which gives 592.9 ft/sec. The base time of the unit hydrograph is 2.67 \[ t_e = 2.67 \times 75 = 200 \text{ min.} \]

**Answer**

The hydrograph contains a runoff depth of 1.96 in., has a peak flow of 592.9 ft/sec at a time of 75 min, and has a total runoff time of 200 min. The hydrograph is illustrated in Figure 5.21.

In Example 5.10, the storm duration was longer than the lag time (60 min vs. 45 min). This causes an error in the solution as the shape of the hydrograph is primarily a function of the storm duration rather than the watershed characteristics. This problem can be prevented if knowledge is available of the rainfall time distribution. The design storm rainfall depth is generally associated with a synthetic rainfall time distribution (refer to Figure 5.5).

Rainfall excess can be determined using an infiltration equation or a procedure such as the NRCS curve number method (Equation 5.4). The rainfall event should be divided into blocks of time that have a duration \( D \) that is not longer than one third the time to peak of the unit hydrograph. Incremental storm hydrographs are then developed for each block of rainfall excess (Figure 5.22). The incremental runoff hydrograph ordinates are equal to the volume of runoff for each block of rainfall excess times
the unit hydrograph ordinates. The incremental storm hydrographs each start at the beginning of the block of rainfall excess with which they are associated.

When all the incremental storm hydrographs have been established, the storm runoff hydrograph is obtained by adding the ordinates of the incremental hydrographs at each point in time. This is a time-consuming activity subject to mathematical errors and is best performed by a computer program. The approach presented in Example 5.10 is commonly used and consists of approximating the storm hydrograph using a single time block for the whole event; determining a time to peak and peak runoff rate for the unit hydrograph based on the single time block; and simply multiplying the ordinates of the unit hydrograph by the rainfall excess for the single block. This approach will underestimate the peak flow rate and will result in a base time for the storm hydrograph that is longer than that obtained if the hydrograph is developed from several incremental time blocks. The best approach is to subdivide the storm event into as many time blocks as practical rather than using as few as possible.

**Example 5.11**

For the same watershed and storm evaluated in Example 5.10, use a unit hydrograph procedure to develop a storm hydrograph. In this case, it is known that the rainfall during each 15 min of the event was 0.5, 1.0, 0.75, and 0.25 in.
<table>
<thead>
<tr>
<th>Time (min)</th>
<th>Incremental Hydrograph 1</th>
<th>Incremental Hydrograph 2</th>
<th>Incremental Hydrograph 3</th>
<th>Incremental Hydrograph 4</th>
<th>Stormwater Hydrograph a</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>15</td>
<td>21.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>21.0</td>
</tr>
<tr>
<td>30</td>
<td>42.0</td>
<td>103.7</td>
<td>0.0</td>
<td>0.0</td>
<td>145.7</td>
</tr>
<tr>
<td>45</td>
<td>62.9</td>
<td>207.4</td>
<td>87.6</td>
<td>0.0</td>
<td>357.9</td>
</tr>
<tr>
<td>52.5</td>
<td>73.4</td>
<td>259.3</td>
<td>131.5</td>
<td>14.8</td>
<td>479.0</td>
</tr>
<tr>
<td>60</td>
<td>67.2</td>
<td>311.1</td>
<td>175.3</td>
<td>29.6</td>
<td>583.2</td>
</tr>
<tr>
<td>67.5</td>
<td>60.9</td>
<td>362.9</td>
<td>219.1</td>
<td>44.5</td>
<td>687.4</td>
</tr>
<tr>
<td>75</td>
<td>54.6</td>
<td>331.8</td>
<td>262.8</td>
<td>59.3</td>
<td>708.5</td>
</tr>
<tr>
<td>82.5</td>
<td>48.3</td>
<td>300.7</td>
<td>306.7</td>
<td>74.0</td>
<td>729.7</td>
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<tr>
<td>90</td>
<td>42.0</td>
<td>269.6</td>
<td>280.5</td>
<td>88.8</td>
<td>680.9</td>
</tr>
<tr>
<td>97.5</td>
<td>35.8</td>
<td>238.5</td>
<td>254.1</td>
<td>103.7</td>
<td>632.1</td>
</tr>
<tr>
<td>105</td>
<td>29.6</td>
<td>207.4</td>
<td>227.8</td>
<td>94.8</td>
<td>559.6</td>
</tr>
<tr>
<td>120</td>
<td>16.8</td>
<td>145.2</td>
<td>175.3</td>
<td>77.0</td>
<td>414.3</td>
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<tr>
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<td>82.9</td>
<td>122.7</td>
<td>59.3</td>
<td>269.1</td>
</tr>
<tr>
<td>150</td>
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<td>20.7</td>
<td>70.1</td>
<td>41.3</td>
<td>132.1</td>
</tr>
<tr>
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<td>0.0</td>
<td>17.5</td>
<td>23.7</td>
<td>41.2</td>
</tr>
<tr>
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<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>5.9</td>
<td>5.9</td>
</tr>
</tbody>
</table>