Computing Phi-index using Direct Runoff Hydrograph and Rainfall Hyetograph

For an observed storm event, direct-runoff hydrograph at 15 mins interval is shown below.

The total depth of direct run-off (calculations not shown), as computed by Equation 1, is equal to 0.72 inch.

\[ r_d = \frac{\sum Q_i \Delta t}{A} \quad (1) \]

Where \( r_d \) is the run-off depth, \( Q_i \) is the direct runoff ordinate at \( i^{th} \) time step, \( \Delta t \) is the time step for each \( Q_i \), and \( A \) is the watershed area. The data used here is for Hall Creek in Indiana with a watershed area of 21.8 square miles. The unit for direct runoff for the Hall Creek data is cfs and time interval is 15 mins. The area is converted to square feet and \( \Delta t \) is 15*60 seconds. The answer that we get from Eq. 1 is then in ft, which is multiplied by 12 to get the answer in inch. As mentioned above, the direct runoff depth for the hydrograph shown above is 0.72 inch. This also means that the rainfall contributing to this direct runoff must produce a total excess rainfall depth of 0.72 inch. The rainfall hyetograph corresponding to this event is given below.

<table>
<thead>
<tr>
<th>Time (mins)</th>
<th>15</th>
<th>30</th>
<th>45</th>
<th>60</th>
<th>75</th>
<th>90</th>
<th>105</th>
<th>120</th>
<th>135</th>
<th>150</th>
<th>165</th>
<th>180</th>
<th>195</th>
</tr>
</thead>
<tbody>
<tr>
<td>P (inch)</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
<td>0.4</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
</tr>
</tbody>
</table>

The total rainfall depth from this event is 1.6 inch, which means 0.88 inch \((1.6 - \text{observed total runoff depth of 0.72})\) was lost in the form of infiltration or abstractions. The equation for computing phi-index is given below

\[ r_d = \sum_{m=1}^{M} (R_m - \phi \Delta t) \]

Where \( M \) is the total number of ordinates in the excess rainfall hyetograph, \( R_m \) is the \( m^{th} \) ordinate in the total rainfall hyetograph and \( \phi \) is the phi index. Because there are two unknowns in the above equation (\( M \) and \( \phi \)), this equation is solved by trial and error by assuming values for \( M \) and computing \( \phi \).

To begin, assume \( M = 13 \), which means the total number ordinates in excess rainfall hyetograph is equal to that in the total rainfall hyetograph. A value of \( M = 13 \) gives,
\[ 0.72 = (0.1+0.1+0.1+0.1+0.1+0.1+0.4+0.1+0.1+0.1+0.1+0.1+0.1+0.1-13\phi\Delta t) \]

\[ \phi\Delta t = (1.6-0.72)/13 = 0.068 \text{ inch} \] or \[ \phi = 0.068 \times (60/15) = 0.272 \text{ inch/hr}. \]

Plotting of a line corresponding to 0.068 on the rainfall hyetograph shows that the assumption of \( M = 13 \) is correct because we end up with 13 ordinates in the excess rainfall hyetograph.