Hydrographs

The hydrograph of this kind which results due to an isolated storm is typically single-peaked skew distribution of discharge and is known variously as storm hydrograph, flood hydrograph or simply hydrograph. It has three characteristics regions:

(i) the rising limb AB, joining point A, the starting point of the rising curve and point B, the point of inflection,
(ii) the crest segment BC between the two points of inflection with a peak P in between,
(iii) the falling limb or depletion curve CD starting from the second point of inflection C.

Lag Time

The time interval from the center of mass of rainfall to the center of mass of hydrograph called lag time $T_L$
Fig. 6.1 Elements of a Flood Hydrograph
Factors affecting flood hydrograph

<table>
<thead>
<tr>
<th>Physiographic factors</th>
<th>Climatic factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a) Shape</td>
<td></td>
</tr>
<tr>
<td>(b) size</td>
<td></td>
</tr>
<tr>
<td>(c) slope</td>
<td></td>
</tr>
<tr>
<td>(d) nature of the valley</td>
<td></td>
</tr>
<tr>
<td>(e) elevation</td>
<td></td>
</tr>
<tr>
<td>(f) drainage density</td>
<td></td>
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<tr>
<td>2. Infiltration characteristics:</td>
<td>2. Initial loss</td>
</tr>
<tr>
<td>(a) land use and cover</td>
<td></td>
</tr>
<tr>
<td>(b) soil type and geological conditions</td>
<td></td>
</tr>
<tr>
<td>(c) lakes, swamps and other storage</td>
<td></td>
</tr>
<tr>
<td>3. Channel characteristics: cross-section,</td>
<td>3. Evapotranspiration</td>
</tr>
<tr>
<td>roughness and storage capacity.</td>
<td></td>
</tr>
</tbody>
</table>
Shape of the basin

Fig. 6.2  Effect of catchment shape on the hydrograph
Drainage Density

Fig. 6.3 Role of drainage density on the hydrograph
Components of a Hydrograph

(i) the rising limb,
(ii) the crest segment, and
(iii) the recession limb

Recession Limb

The storage of water in the basin exists as
(i) surface storage ,
(ii) interflow storage,
(iii) ground water storage, i.e. base- flow storage.
The recession of a storage can be expressed as

\[ Q_t = Q_o \times K_r^t \]

\[ \frac{Q_t}{Q_o} = K_r^t \]

\[ \log\left(\frac{Q_t}{Q_o}\right) = \log K_r^t \]

\[ \log\left(\frac{Q_t}{Q_o}\right) = t \log K_r \]

\[ \log K_r = \frac{1}{t} \log\left(\frac{Q_t}{Q_o}\right) \]
The recession constant $K_r$ can be considered to be made up of three components to take care of the three types of storage as

$$K_r = K_{rs} \cdot K_{ri} \cdot K_{rb}$$

Where $K_{rs}$ = recession constant for surface storage,
$K_{ri}$ = recession constant for interflow and
$K_{rb}$ = recession constant for base flow

Typically the values of these recession constants, when $t$ is in days, are

- $K_{rs} = 0.05$ to $0.20$
- $K_{ri} = 0.50$ to $0.85$
- $K_{rb} = 0.85$ to $0.99$
EXAMPLE 6.1 The recession portion of a flood hydrograph is given below. The time is indicated from the arrival of peak. Assuming the interflow component to be negligible, calculate the baseflow and surface flow recession coefficients.

<table>
<thead>
<tr>
<th>Time from peak (days)</th>
<th>Discharge (m$^3$/s)</th>
<th>Time from peak (days)</th>
<th>Discharge (m$^3$/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
<td>90</td>
<td>3.5</td>
<td>5.0</td>
</tr>
<tr>
<td>0.5</td>
<td>66</td>
<td>4.0</td>
<td>3.8</td>
</tr>
<tr>
<td>1.0</td>
<td>34</td>
<td>4.5</td>
<td>3.0</td>
</tr>
<tr>
<td>1.5</td>
<td>20</td>
<td>5.0</td>
<td>2.6</td>
</tr>
<tr>
<td>2.0</td>
<td>13</td>
<td>5.5</td>
<td>2.2</td>
</tr>
<tr>
<td>2.5</td>
<td>9</td>
<td>6.0</td>
<td>1.8</td>
</tr>
<tr>
<td>3.0</td>
<td>6.7</td>
<td>6.5</td>
<td>1.6</td>
</tr>
</tbody>
</table>

![Graph showing Observed runoff, Base flow, Surface runoff, Time after Peak in Days, Discharge Q in m$^3$/s]  

**Fig. 6.4 Storage recession curve—Example 6.1**
SOLUTION: The data are plotted on a semilog paper with discharge on the log-scale (Fig. 6.4). The part of the curve $AB$ that plots as a straight line indicates the base flow. The surface flow terminates at point $B$, 5 days after the peak. From Eq. (6.1),

$$Q_t/Q_0 = K_{rb}^t$$

$$\log K_{rb} = \frac{1}{t} \log (Q_t/Q_0)$$

The base flow recession is shown by line $ABM$ in Fig. 6.4.

In this figure by taking the initial discharge at 1 day after the peak as $Q_0 = 6.6 \text{ m}^3/\text{s}$ and $t =$ time interval as 2 days, $Q_t =$ discharge at a time interval of $t = 2$ days, i.e. 3 days after the peak = $40 \text{ m}^3/\text{s}$. This leads to

$$\log K_{rb} = \frac{1}{2} \log \left( \frac{4.0}{6.6} \right)$$

$$K_{rb} = 0.778 \ \text{say} \ 0.78$$

From the curve $PA$, the base flow recession $ABM$ is subtracted to get the surface runoff. Fig. 6.4. shows the surface runoff depletion plot as a straight line. Now by taking $Q = 26 \text{ m}^3/\text{s}$ and $t = 2$ days with corresponding $Q = 2.25 \text{ m}^3/\text{s}$ the recession constant for surface storage $K_{rs}$ is given by

$$\log K_{rs} = \frac{1}{2} \log \left( \frac{2.25}{26.0} \right)$$

Thus

$$K_{rs} = 0.29.$$
Base Flow Separation

Fig. 6.5 Base flow separation methods
Method I – Straight-Line Method

\[ N = 0.83 \ A^{0.2} \]

Direct Runoff Hydrograph (DRH)

The surface runoff hydrograph obtained after the base-flow separation is also known as direct runoff hydrograph (DRH).
EXAMPLE 6.2. Rainfall of magnitude 3.8 cm and 2.8 cm occurring on two consecutive 4-h durations on a catchment of area 27 km$^2$ produced the following hydrograph of flow at the outlet of the catchment. Estimate the rainfall excess and $i$ index.

<table>
<thead>
<tr>
<th>Time from start of rainfall (h)</th>
<th>6</th>
<th>0</th>
<th>6</th>
<th>12</th>
<th>18</th>
<th>24</th>
<th>30</th>
<th>36</th>
<th>42</th>
<th>48</th>
<th>54</th>
<th>60</th>
<th>66</th>
</tr>
</thead>
<tbody>
<tr>
<td>Observed flow (m$^3$/s)</td>
<td>6</td>
<td>5</td>
<td>13</td>
<td>26</td>
<td>21</td>
<td>16</td>
<td>12</td>
<td>9</td>
<td>7</td>
<td>5</td>
<td>5</td>
<td>4.5</td>
<td>4.5</td>
</tr>
</tbody>
</table>

SOLUTION: The hydrograph is plotted to scale (Fig. 6.7). It is seen that the storm hydrograph has a base-flow component. For using the simple straight-line method of base-flow separation, by Eq. (6.4)

$$ N = 0.83 \times (27)^{0.2} = 1.6 \text{ days} = 38.5 \text{ h} $$

However, by inspection, DRH starts at $t = 0$, has the peak at $t = 12$ h and ends at $t = 48$ h (which gives a value of $N = 48 - 12 = 36$ h). As $N = 36$ h appears to be more satisfactory than $N = 38.5$ h, in the present case DRH is assumed to exist from $t = 0$ to 48 h. A straight line base flow separation gives a constant value of 5 m$^3$/s for the base flow.

Area of DRH = \((6 \times 60 \times 60) \left[ \frac{1}{2} (8) + \frac{1}{2} (8 + 21) + \frac{1}{2} (21 + 16) + \frac{1}{2} (16 + 11) + \frac{1}{2} (11 + 7) \\
+ \frac{1}{2} (7 + 4) + \frac{1}{2} (4 + 2) + \frac{1}{2} (2) \right] \\
= 3600 \times 6 \times (8 + 21 + 16 + 11 + 7 + 4 + 2) \\
= 1.4904 \times 10^6 \text{ m}^3 \\
= \text{total direct runoff due to storm}
Fig. 6.7 Base flow separation—Example 6.2

Runoff depth = \( \frac{\text{runoff volume}}{\text{catchment area}} = \frac{1.4904 \times 10^6}{27 \times 10^6} \)

= 0.0552 m

= 5.52 cm = rainfall excess

Total rainfall = 3.8 + 2.8 = 6.6 cm

Duration = 8 h

\( \phi \) index = \( \frac{6.6 - 5.52}{8} = 0.135 \text{ cm/h} \)