8. Flood routing

Evaluating the risk of flood requires hydrologic studies.
- Risk evaluation under current landuse
- Prediction of the impact of landuse change

Storage and transmission of floodwater
Floodwater moves downstream along a channel. Flood occurs when the channel storage capacity is exceeded.

(a) Simple translation
The flood wave moves without changing its shape. This tendency is dominant in steep, straight streams. Flow velocities are high and relatively constant.

(b) Attenuation
The wave is attenuated by storage within the channel and the valley floor. A reservoir is a good example.

(c) Combination
Most natural rivers have both tendencies.

D&L, Fig. 10-1.
Flood prediction

Important considerations.
(a) Volume of storm runoff
(b) Peak flood discharge
(c) Flood height
(d) Time distribution of storm hydrograph
(e) Area of inundation
(f) Velocity of flow across the valley bottom

Practical procedures.
(1) Estimate runoff generation, e.g. W-index method.
(2) Synthesize a hydrograph, e.g. unit hydrograph method.
(3) Simulate downstream propagation of floodwater.

The last step is called “flood routing”. Suppose we have done (1) and (2) above. Our concern now is;
“Given a inflow hydrograph at the upper end of a section of stream, what is the outflow hydrograph at the lower end?”

D&L, Fig. 10-2.
Water balance
(Inflow rate - Outflow rate) $\Delta t = \text{Storage change}$

$$(I - O) = \Delta S/\Delta t$$

For a time interval $\Delta t = t_2 - t_1$, the average flow rates are;

$$I_{av} = (I_1 + I_2)/2 \quad O_{av} = (O_1 + O_2)/2$$

The storage change during $\Delta t$ is;

$$\Delta S = S_2 - S_1$$

Therefore;

$$(I_1 + I_2)/2 - (O_1 + O_2)/2 = (S_2 - S_1)/\Delta t$$

This is the water balance equation for a stream segment, which is commonly used in flood routing.

Reservoir routing

$O$ is a function of water level, and water level a function of storage.

$$\therefore O = f(S)$$

The relationship is given by a discharge rating curve.

e.g. see Fig.16-4 in D&L (p.597).

In reservoir routing, we re-arrange the balance equation;

$$(S_2/\Delta t + O_2/2) = (S_1/\Delta t - O_1/2) + (I_1 + I_2)/2$$

Given, $I_1$, $I_2$, and $(S_1/\Delta t - O_1/2)$, we want to estimate the left hand side.
The first step is to determine the relationships between the water stage ($H$), $S$ and $O$. Topographic or bathymetric survey can be used to obtain $H$-$S$ relationship. Stream discharge measurement is conducted to determine $H$-$O$ relationship.

Suppose we have obtained such data (see the table below).

For any given $\Delta t$, we can calculate $S/\Delta t$ etc. from the data. An example with $\Delta t = 7200$ s is shown below.

<table>
<thead>
<tr>
<th>$H$ (m)</th>
<th>$S$ ($10^6 m^3$)</th>
<th>$O$ (m$^3$/s)</th>
<th>$S/\Delta t$ (m$^3$/s)</th>
<th>$S/\Delta t - O/2$ (m$^3$/s)</th>
<th>$S/\Delta t + O/2$ (m$^3$/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.15</td>
<td>0.07</td>
<td>1.1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.3</td>
<td>0.14</td>
<td>2.9</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.45</td>
<td>0.21</td>
<td>5.3</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

These relationships can now be used for reservoir routing.
Methods of calculation

(1) $I$ is given for all time interval. $O$ is equal to $I$ at $t = 0$, which is just before the storm starts.

(2) Calculate $(I_1 + I_2)/2$ for $t_1 = 0$ and $t_2 = 2$, and enter it in Cell-C4. From $O$ at $t = 0$, calculate $S_1/\Delta t - O_1/2$ and enter it in Cell-D4.

(3) Calculate $(S_2/\Delta t + O_2/2) = (S_1/\Delta t - O_1/2) + (I_1 + I_2)/2$ and enter it in Cell-E4.

(4) From $S_2/\Delta t + O_2/2$, calculate $O$ and enter it in Cell-F4.

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>t</td>
<td>I</td>
<td>$(I_1+I_2)/2$</td>
<td>$S_1/\Delta t - O_1/2$</td>
<td>$S_2/\Delta t + O_2/2$</td>
</tr>
<tr>
<td>2</td>
<td>(hr)</td>
<td>(m$^3$/s)</td>
<td>(m$^3$/s)</td>
<td>(m$^3$/s)</td>
<td>(m$^3$/s)</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
<td>2.6</td>
<td>------</td>
<td>------</td>
<td>------</td>
</tr>
<tr>
<td>4</td>
<td>2</td>
<td>4.1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>4</td>
<td>12.5</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

An example of calculated $O$ is shown below.
Channel routing: Muskingum method

We want to simulate the propagation of a flood wave along a channel. Storage is the function of both $I$ and $O$.

Profiles of water flowing in a channel reach during the rising limb (a) and recession limb (b) of a flood wave (D&L, Fig. 10-46).

Assume that storage can be approximated as;

$$S = K[xI + (1 - x)O]$$

where $K$ [s] is a constant, and $x$ is a weighting factor. $K$ is approximately equal to the “residence time” of the flood wave within the stream reach. The weighting factor $x$ represents the degree of attenuation. For example:

a) $x = 0$. This is the case of a reservoir. Large attenuation.

b) $x = 0.5$. In this case, $S = K(I/2 + O/2)$. But we also have

$$\frac{(I_1 + I_2)}{2} - \frac{(O_1 + O_2)}{2} = \frac{(S_2 - S_1)}{\Delta t}$$

When $\Delta t = K$, we can show that $O_2 = I_1$. The wave is simply translated with a lag time $K$. No attenuation.
For most river channels, \(0.1 < x < 0.3\). The values of \(K\) and \(x\) have to be determined in each channel reach. One can measure \(I\) and \(O\) in the reach during a storm, calculate \(S\) from cumulative \(I\) and \(O\), and plot \(S\) against \(xI + (1 - x)O\) for several values of \(x\).

<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
<th>I</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>t</td>
<td>I</td>
<td>(I_{av} = (I_1 + I_2)/2)</td>
<td></td>
<td>Cum. I</td>
<td>(O_{av} = (O_1 + O_2)/2)</td>
<td></td>
<td>Cum. O</td>
<td>(S) (x = 0.1) (xI + (1-x)O)</td>
</tr>
<tr>
<td>2</td>
<td>hr</td>
<td>(m³/s)</td>
<td>(m³/s)</td>
<td></td>
<td>(m³)</td>
<td>(m³)</td>
<td></td>
<td>(m³)</td>
<td>(10⁶ m³)</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
<td>2.6</td>
<td>-----</td>
<td>0</td>
<td>2.6</td>
<td>-----</td>
<td>0</td>
<td>0</td>
<td>-----</td>
</tr>
<tr>
<td>4</td>
<td>2</td>
<td>4.1</td>
<td>3.4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>4</td>
<td>12.5</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
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<td></td>
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</tr>
</tbody>
</table>

Note that Table 10-21 in D&L (p.359) contains an error in column (11).

When a suitable value of \(x\) is used, the plot appears to follow a straight line (see the figure below), otherwise it appears to be a loop. The slope of the straight line is \(K\).
Once $K$ and $x$ are determined, we can rout flood waves using the Muskingum method. The balance equation:

$$(I_1 + I_2)/2 - (O_1 + O_2)/2 = (S_2 - S_1)/\Delta t$$

But we also have

$$S_2 - S_1 = K[x(I_2 - I_1) + (1 - x) (O_2 - O_1)].$$

Combining the two equations and re-arranging terms,

$$O_2 = C_0I_2 + C_1I_1 + C_2O_1$$

where

$$C_0 = -(Kx - 0.5\Delta t)/(K - Kx + 0.5\Delta t)$$

$$C_1 = (Kx + 0.5\Delta t)/(K - Kx + 0.5\Delta t)$$

$$C_2 = (K - Kx - 0.5\Delta t)/(K - Kx + 0.5\Delta t)$$

$$C_0 + C_1 + C_2 = 1$$

**Methods of calculation**

(1) $I$ is given for all time interval. $O$ is equal to $I$ at $t = 0$.

(2) Determine $K$, $x$, $C_0$, $C_1$, and $C_2$.

(3) Using $I_1$(Cell-B3), $I_2$(B4) and $O_1$(F3), calculate $O_2$ and enter it in Cell-F4.
A note on channel routing

Channel routing is widely used in flood forecasting. Large projects, like the one used during the Red Deer River flood in 2005, use sophisticated computer simulations, but their algorithm is based on channel routing. So, it is important to understand the concept.

When there are no gauging stations in a given stream reach, it is useful to set up gauging stations and obtain at least one inflow and outflow hydrograph by planners themselves.

Once the hydrographs are obtained, planners can calculate $K$ and $x$ from the data and simulate the propagation of a design flood.

$K$ has a unit of time, and is a rough measure of the residence time of flood peak in the channel reach. Change in channel morphology may change the value of $K$. 