GEOG415  Lecture 10: River Channels

Importance of channel characteristics

Prediction of flow was the sole purpose of hydrology, and still is a very important aspect of hydrology.

- Water balance gives an input of water (m³ s⁻¹)
- Channel characteristics determine the velocity, depth, etc.

Significance?

Hydraulic radius, \( R = \frac{A}{P} \)

For a wide rectangular-shaped channels \((w \gg d)\),

\[
A = \quad P = \quad R =
\]

\( R \) is generally close to the mean depth, \( d_{av} \).
Why is $R$ called “radius”?  

What is the significance?

Discharge, $Q$: volumetric flow rate (m$^3$ s$^{-1}$)

$$Q = Au \cong wd_{av}u$$  

Bankfull discharge, $Q_{bkf} = A_{bkf} u_{bkf}$

**Conservation of mass**

Discharge needs to remain constant along a stream section without tributaries, but velocity and cross-sectional area may change significantly.

Dunne and Leopold (1978, Fig. 16-20)

Dunne and Leopold (1978, Fig. 16-21)
**Dissipation of energy**

Mechanical energy = elevation + pressure + kinetic energy

Energy contained in a unit mass of stream water:

\[ = g(z + d) + u^2/2 = \text{potential} + u^2/2 \]

\[ g: \text{gravitational acceleration (} = 9.8 \text{ m s}^{-2}) \]

Mechanical energy is dissipated by friction and turbulence.

Friction coefficient, \( f \) (dimensionless) represents the relative amount of potential loss along the channel with respect to kinetic energy. This concept was originally developed by Darcy and Weisbach for low-velocity flow in pipes.

\[ f = 4 \times \text{hydraulic radius} \times \text{potential gradient} / \text{kinetic energy} \]

\[ f = 4R \frac{g(d + z)/L}{u^2/2} = \frac{8RgS}{u^2} \approx \frac{8d_{av}gS}{u^2} \]

where \( S \) is potential gradient (or the slope of the water surface), which can be approximated by the slope of channel bed.

It is straightforward, in principle, to determine \( f \) in the field.

e.g. \( A = 8 \text{ m}^2, \quad P = 17 \text{ m}, \quad s = 0.001, \quad u = 0.8 \text{ m s}^{-1} \)

\[ f = ? \]
Experimentally determined $f$ is very close to theoretical values for low-velocity flow in regular-shape pipes.

→ Engineering applications?

However, is $f$ useful for hydrological predictions?

What is $f$ dependent on?

It is usually impossible to estimate $f$ except in some simple cases (see DL, Eq. 16-7). Note that $f$ is still a very useful tool that bridges the empirical and theoretical aspects of flow.

More empirical Chezy formula is used in hydrology:

$$u = C R^{1/2} S^{1/2}$$

where $C$ is a coefficient representing the effects of friction. Coefficient $C$ is commonly estimated by Manning’s equation:

$$C = R^{1/6} / n$$  \hspace{1cm} \text{SI unit (metre for length)}

$$= 1.49 \, R^{1/6} / n$$  \hspace{1cm} \text{imperial unit (foot for length)}

where $n$ is a dimensionless roughness factor.
Using Manning’s equation, Chezy formula can be written:

\[ u = \frac{R^{2/3} S^{1/2}}{n} \]

\( R \) and \( S \) are in [m], and \( u \) is in [m s\(^{-1}\)].

This equation is called Manning formula.

Dunne and Leopold (1978, Table 16-1)

<table>
<thead>
<tr>
<th>BOUNDARY</th>
<th>MANNING ROUGHNESS, ( n )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Smooth concrete</td>
<td>0.012</td>
</tr>
<tr>
<td>Ordinary concrete lining</td>
<td>0.013</td>
</tr>
<tr>
<td>Vitrified clay</td>
<td>0.015</td>
</tr>
<tr>
<td>Shot concrete, untroweled, and earth channels in best condition</td>
<td>0.017</td>
</tr>
<tr>
<td>Straight unlined earth canals in good condition</td>
<td>0.020</td>
</tr>
<tr>
<td>Rivers and earth canals in fair condition—some growth</td>
<td>0.025</td>
</tr>
<tr>
<td>Winding natural streams and canals in poor condition—considerable moss growth</td>
<td>0.035</td>
</tr>
<tr>
<td>Mountain streams with rocky beds and rivers with variable sections and some vegetation along banks</td>
<td>0.040–0.050</td>
</tr>
</tbody>
</table>

Example: Concrete-lined irrigation canal, \( w = 10 \) m, \( d = 2 \) m. Slope = 10 m over 2 km.

\[ R = \phantom{000} \]

\[ n = \phantom{000} \]

\[ u = \phantom{000} \]

\[ Q = \phantom{000} \]
Manning formula is a useful tool for channel design or rough estimate of stream discharge. However, it cannot be used for accurately determining discharge in natural channels.

Why?

**Water stage and rating curve**

Stage: elevation of the water surface above an arbitrary datum.

Rating curve: relation between stage and discharge.

A stream gauging station is equipped with continuous stage recorder installed in a stilling well.

Stilling well - connected to the stream by an underground pipe.

Water level recorder - float + pulley system

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Dunne and Leopold (1978, Fig. 16-2)

Goudie (1985. Encyclopaedic dictionary of physical geography, p.185)
How is a rating curve determined?
How do we measure discharge?

Area-velocity method

A cross-section is divided into strips. Why?

Average velocity ($v$) in each strip is represented by the velocity measured at “six-tenth” depth.

$$Q = A_1 v_1 + A_2 v_2 + \ldots$$
Float method

Measurement of surface velocity ($v_s$) using a float combined with a survey of cross-sectional area ($A$).

\[ Q = 0.8v_sA \]

Assumption: average velocity ($u$) is about 80% of the surface velocity in the central part of stream.

V-notch weir

V-notch weir has a well-defined stage-discharge relation:

\[ Q = C_w g^{1/2} \tan(\theta/2) h^{5/2} \]

$C_w$: weir coefficient (= 0.43 for a perfect weir, but should be determined by field calibration)

Goudie (1985, p.474)
Floodplain and bankfull stage

Floodplain: Flat area adjoining a river channel. Constructed under the present condition. Flooded at times of high discharge.

Bankfull: Water surface is level with the floodplain.

Terrace: Formed under different conditions. No longer flooded.

Dunne and Leopold (1978, Fig. 16-9)
The flat valley floor is constructed by the lateral migration of river channel $\rightarrow$ sequential erosion and deposition.

Flooding of the floodplain is a natural process maintaining the morphologic characteristics of channels.

What size flood is most effective at shaping the channel? $\rightarrow$ 100-yr flood?
Require large enough, but also frequent enough floods. → Bankfull discharge.

What is the return period of bankfull discharge?

Bankfull discharge roughly corresponds to 1.5-yr flood.

Implications?

![Graph showing relationship between discharge and drainage area.](image)

Dunne and Leopold (1978, Fig. 16-15)

Relation of bankfull discharge to drainage area

Larger drainage area \(D_A\) should result in larger bankfull discharge \(Q_{b kf}\). Why?
A (Washington): $Q_{bkf} = 55D_A^{0.93}$

E (Idaho): $Q_{bkf} = 28D_A^{0.69}$

Why is bankfull discharge in Idaho much smaller than that in Washington?

Why is the exponent not one?

**Mean annual discharge**

Mean annual discharge ($Q_{ave}$) generally increases linearly with the drainage area.

$$Q_{ave} = cD_A^{1.0}$$

*c*: proportionality constant

What is the physical meaning of *c*?

Exceptions?