River Confluences and Bifurcations

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Objectives

Brief overview of River Confluences and Bifurcations:

1. Theoretical Background;
2. Numerous Examples.

Active River Systems

• Bifurcation
  – The forking or diverging of a river into distributaries.

• Confluence
  – The meeting of two or more streams.
  – Usually refers to a tributary joining a larger river.

Testa River, India
Red and Assiniboine rivers, Canada
Concept of Equilibrium

From fundamental hydraulic equations, downstream hydraulic geometry for non-cohesive alluvial channels with hydraulically rough flow is described by:

\[ h = 0.133Q^{0.527}d_s^{0.641} \left( \frac{1}{\tau_s} \right)^{0.12} \]

\[ W = 0.512Q^{0.318}d_s^{0.58} \left( \frac{1}{\tau_s} \right)^{0.22} \]

\[ V = 14.7Q^{0.48}d_s^{0.77} \left( \frac{1}{\tau_s} \right)^{0.23} \]

\[ S = 12.4Q^{0.5}d_s^{0.77} \left( \frac{1}{\tau_s} \right)^{0.23} \]

Fundamental Equations

1. \( Q = WhV \)
2. \( V = \alpha \left( \frac{b}{d} \right)^m \left( \frac{h}{S} \right)^{3/2} \)
3. \( r_s = \frac{AS}{(Q - 1) \gamma} \)
4. \( \tan \lambda = \phi \left( \frac{b}{W} \right)^{1/2} \)

where, \( m = \frac{0.53}{\ln \left( \frac{d}{D} \right)} = \sqrt{b_0} \) and \( b_0 = \left[ \frac{b}{W} \right] (\Omega, R) \)

For Sediment Transport:

\[ Q_s \geq 18W \sqrt{d_s^2 \gamma^2} \]

\[ C_{m_0} = 10^6 \left( \frac{Q_s}{Q} \right) \]
Theoretical Background

The final downstream equations are:

\[ h \approx 1.1 Q^{0.34} d_s^{0.13} C_{avg}^{-0.12} \]
\[ W \approx 12 Q^{0.47} d_s^{-0.19} C_{avg}^{-0.15} \]
\[ W/h \approx 10.9 Q^{0.15} d_s^{-0.25} C_{avg}^{-0.01} \]
\[ V \approx 0.075 Q^{0.10} d_s^{0.02} C_{avg}^{-0.27} \]
\[ S \approx 4.4 \times 10^{-3} Q^{-0.08} d_s^{0.10} C_{avg}^{0.69} \]

Confluences in Equilibrium

- Flow will increase when multiple rivers converge
  - Significant increase in Bankfull width
  - Moderate increase in Flow depth
  - Slight increase in Shear stress
  - Slight increase in Mortal depth
  - Slight decrease in Velocity
  - Slight increase in Riverbed slope

\[ W \approx 12 Q^{0.35} d_s^{0.61} C_{avg}^{-0.10} \]
\[ h \approx 1.1 Q^{0.34} d_s^{0.55} C_{avg}^{-0.12} \]
\[ \tau_s \approx 3 \times 10^{-3} Q^{2.32} d_s^{0.77} C_{avg}^{-0.57} \]
\[ V \approx 0.075 Q^{0.10} d_s^{0.02} C_{avg}^{-0.27} \]
\[ S \approx 4.4 \times 10^{-3} Q^{0.08} d_s^{0.57} C_{avg}^{-0.66} \]

Bifurcations in Equilibrium

- Flow will decrease when a rivers diverges
  - Significant decrease in Bankfull width
  - Moderate decrease in Flow depth
  - Shear stress
  - Slight decrease in Velocity
  - Slight increase in Riverbed slope

\[ W \approx 12 Q^{0.25} d_s^{0.61} C_{avg}^{-0.10} \]
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Theoretical Background

These equations can be used to find the ratio of channel parameters downstream to upstream of the bifurcation:

\[
\frac{h_{D,s}}{h_{U,s}} = \left( \frac{1}{\xi} \right)^{0.54} \quad \frac{W_{D,s}}{W_{U,s}} = \left( \frac{1}{\xi} \right)^{0.47} \\
\frac{V_{D,s}}{V_{U,s}} = \left( \frac{1}{\xi} \right)^{0.34} \quad \frac{S_{D,s}}{S_{U,s}} = \left( \frac{1}{\xi} \right)^{0.08} \\
\frac{h_{D,W}}{h_{U,W}} = \left( \frac{1}{\xi} \right)^{0.13}
\]

Where \( \xi \) is the number of downstream channels.

Rhine River Bifurcations Effect on Sediment Supply

- Historical bifurcations dating back to Holocene
- Bifurcations are naturally unstable due to aggradation at bifurcation point

- Fraction of flow ≠ Fraction of sediment
- Smaller channel receives lower sediment concentration

Roaring River Alluvial Fan:
Dramatic change in sediment supply

\( Q_s \) since flood has resulted in reduced number of bifurcations and a central channel is forming.
Large River Confluences and Branches: Brahmaputra-Jamuna River, Bangladesh

DA = 950,000 km²
Mean Annual Q = 20,000 m³/s
Large braided sand-bed river
Between 2 and 3 braids at low flow
Channel width varies between 5 and 17 km.
Frequent lateral migration: 500 m/yr.

Braid bar (after Best et al., 2003)

Morphological evolution of channel bifurcations: Brahmaputra-Jamuna River
Richardson and Thorne (2001)

- Hypothesis: Bifurcation of a single channel results from inherent flow instability, which drives the deposition of bed material load in the channel center.

- Goal: To determine the conditions under which a flow with a single maximum velocity location divides to produce two or more high velocity threads.

Deposition of central bars

Physical Result

- Bed Slope Over Time
- Aggradation Lateral Instability
- Confluence
- Degradation Entrenchment
Sources
• NASA
• Google Earth

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