# River Confluences and Bifurcations

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Kuala Lumpur - May 2006

## Objectives

Brief overview of River Confluences and Bifurcations:

1. Theoretical Background;
2. Numerous Examples.

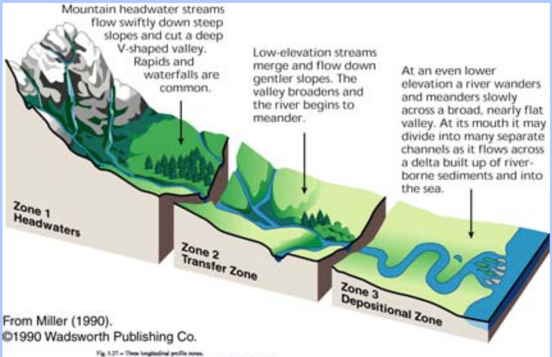
## Active River Systems

- 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 Miller (1990).
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## Downstream Hydraulic Geometry

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

$$h = 0.133 Q^{\frac{1}{3m+2}} d_s^{\frac{6m-1}{6m+4}} \tau_*^{\frac{-1}{6m+4}}$$

$$W = 0.512 Q^{\frac{2m+1}{3m+2}} d_s^{\frac{-4m-1}{6m+4}} \tau_*^{\frac{-2m-1}{6m+4}}$$

$$V = 14.7 Q^{\frac{m}{3m+2}} d_s^{\frac{2-2m}{6m+4}} \tau_*^{\frac{2m+2}{6m+4}}$$

$$S = 12.4 Q^{\frac{-1}{3m+2}} d_s^{\frac{5}{6m+4}} \tau_*^{\frac{6m+5}{6m+4}}$$

## Fundamental Equations

For Hydraulic Geometry:

**1.** $Q = WhV$

**3.** $\tau_* = \dfrac{hS}{(G-1)d_s}$

**2.** $V = a\sqrt{g}\left(\dfrac{h}{d_s}\right)^m h^{1/2} S^{1/2}$

**4.** $\tan\lambda = b_r \left(\dfrac{h}{d_s}\right)^{2m} \dfrac{h}{W}$

$$where,\ m = \frac{1}{\ln\left(12.2h/d_s\right)} \approx \overbrace{1/6}^{Manning's\ /\ Strickler}$$

$$and, b_r = \left[\left(a^2 W\right)/\left(\Omega_R R\right)\right]$$

For Sediment Transport:

$$Q_s \cong 18W\sqrt{g}\, d_s^{3/2} \tau_*^2 \qquad C_{mg/L} = 10^6 G\left(Q_s/Q\right)$$

# Theoretical Background

The final downstream equations are;

$$h \cong 1.1Q^{0.34} d_s^{0.13} C_{mg/L}^{-0.12}$$

$$W \cong 12Q^{0.47} d_s^{-0.15} C_{mg/L}^{-0.15}$$

$$W/h \cong 10.91Q^{0.13} d_s^{-0.28} C_{mg/L}^{-0.03}$$

$$V \cong 0.075Q^{0.19} d_s^{0.02} C_{mg/L}^{0.27}$$

$$S \cong 4.4x10^{-5} Q^{-0.08} d_s^{0.19} C_{mg/L}^{0.69}$$

# Confluences in Equilibrium

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

$$\overset{\uparrow}{W} \cong 12\overset{\uparrow}{Q}\underline{^{0.47}}\cancel{d_s^{-0.15}}\cancel{C_{mg/l}^{-0.15}}$$

$$\overset{\uparrow}{h} \cong 1.1\overset{\uparrow}{Q}\underline{^{0.34}}\cancel{d_s^{0.13}}\cancel{C_{mg/l}^{-0.12}}$$

$$\overset{\uparrow}{\tau_s} \cong 3x10^{-5}\overset{\uparrow}{Q}\underline{^{0.26}}\cancel{d_s^{-0.67}}\cancel{C_{mg/l}^{0.57}}$$

$$\overset{\uparrow}{V} \cong 0.075\overset{\uparrow}{Q}\underline{^{0.19}}\cancel{d_s^{0.02}}\cancel{C_{mg/l}^{0.27}}$$

$$\overset{\downarrow}{S} \cong 4.4x10^{-5}\overset{\uparrow}{Q}\underline{^{-0.08}}\cancel{d_s^{0.19}}\cancel{C_{mg/l}^{0.69}}$$

# 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
    - Riverbed slope

$$\overset{\downarrow}{W} \cong 12\overset{\downarrow}{Q}\underline{^{0.47}}\cancel{d_s^{-0.15}}\cancel{C_{mg/l}^{-0.15}}$$

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# Theoretical Background

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

$$\frac{h_{D.S.}}{h_{U.S.}} = \left(\frac{1}{\xi}\right)^{0.34} \qquad \frac{W_{D.S.}}{W_{U.S.}} = \xi\left(\frac{1}{\xi}\right)^{0.47}$$

$$\frac{V_{D.S.}}{V_{U.S.}} = \left(\frac{1}{\xi}\right)^{0.19} \qquad \frac{S_{D.S.}}{S_{U.S.}} = \left(\frac{1}{\xi}\right)^{-0.08}$$

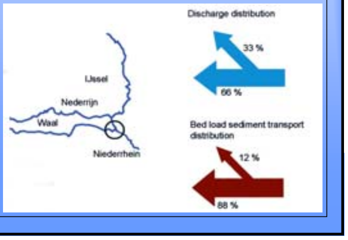
$$\frac{W/h_{D.S.}}{W/h_{U.S.}} = \left(\frac{1}{\xi}\right)^{0.13}$$

Where $\xi$ is the number of downstream channels.

# Rhine River Bifurcations Effect on Sediment Supply

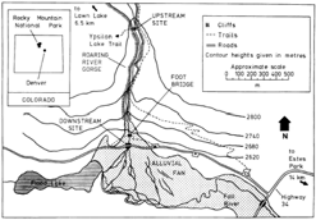
- Historical bifurcations dating back to Holocene
- Bifurcations are naturally unstable due to aggradation at bifurcation point

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



# Roaring River Alluvial Fan:
## Dramatic change in sediment supply

$\downarrow Q_s$ since flood has resulted in reduced number of bifurcations and a central channel is forming.



After Bathhurst and Ashiq (1998)

## Large River Confluences and Branches: Brahmaputra-Jamuna River, Bangladesh

After Best et al, 2003

- DA = 550,000 km$^2$
- Mean Annual Q = 20,000 m$^3$/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)

**-Deposition of central bars**

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

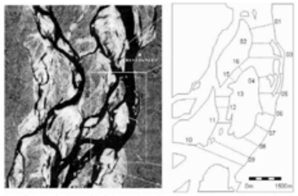
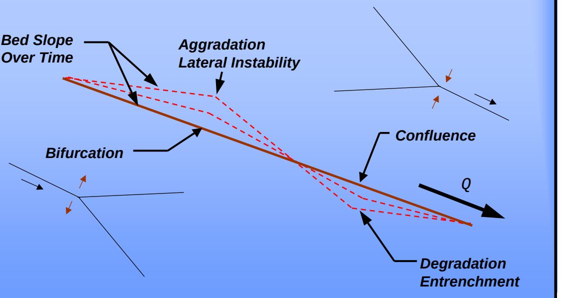


Fig. 1. Landsat-TM image of study area of the Brahmaputra-Jamuna River, January 1994 (courtesy of Tim Martin, EGIS II, Dhaka, Bangladesh).

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

## Physical Result



*Bed Slope Over Time*

*Aggradation Lateral Instability*

*Bifurcation*

*Confluence*

*Q*

*Degradation Entrenchment*


WonDong
Mulgeum
Busan
Gupo


Kolyma (Russia)
Ob (Russia)
Tunguska (Russia)
Songhua (China)
Indus (Pakistan)
Brahmaputra (Tibet, Bangladesh)
Krishna (India)


Klang River Delta, Kuala Lumpur, Malaysia
Google

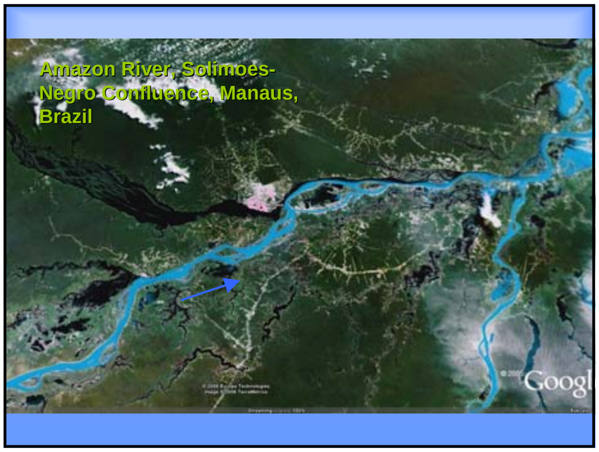
Gobak-Klang Confluence,
Kuala Lumpur, Malaysia

Gobak-Klang Confluence,
Kuala Lumpur, Malaysia

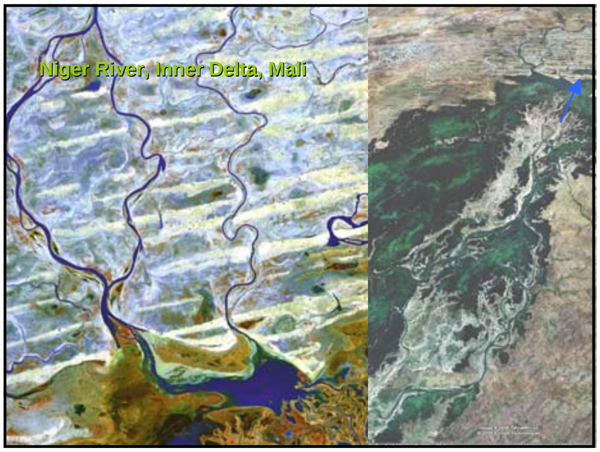
Desert Wadis, Jordan

Nile River Confluence, Karthoum, Sudan

Amazon River, Solimoes-Negro Confluence, Manaus, Brazil



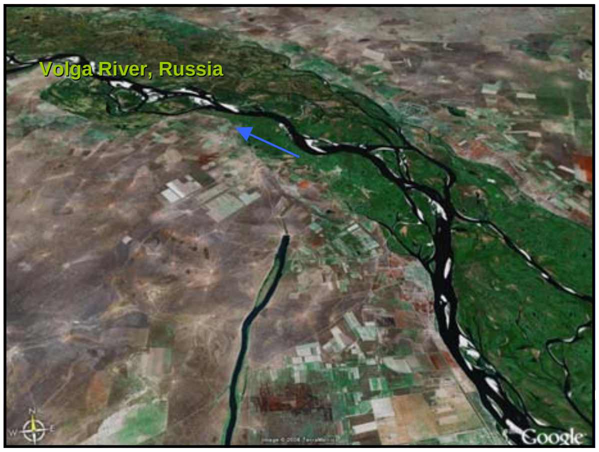
Amazon River, Solimoes-Negro Confluence, Manaus, Brazil



Niger River, Inner Delta, Mali

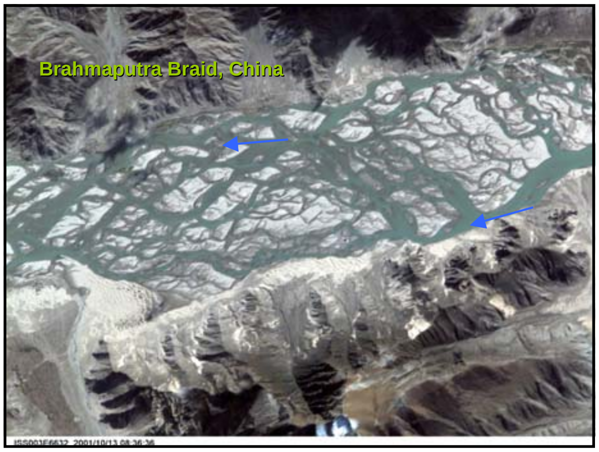
Songhua River, Harbin, China

Ob River, Siberia, Russia


Volga River, Russia


Kolyma River, Siberia, Russia


Waimakariri River,
Christchurch, New Zealand



Brahmaputra Braid, China

Betsiboka Estuary (Normal), Madagascar

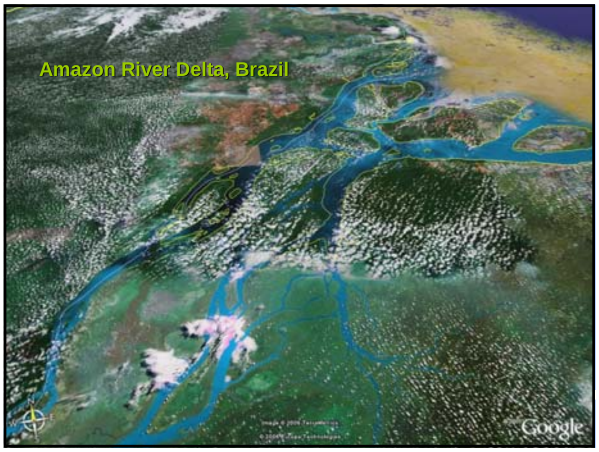
Betsiboka Estuary (Flooded), Madagascar

Nile Delta, Egypt

Nile Delta, Alexandria, Egypt

Mississippi Delta, Louisiana, U.S.A.

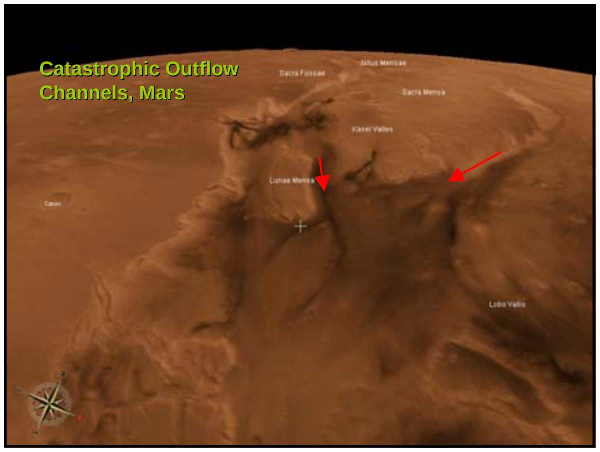
Mississippi Delta, Louisiana, U.S.A.



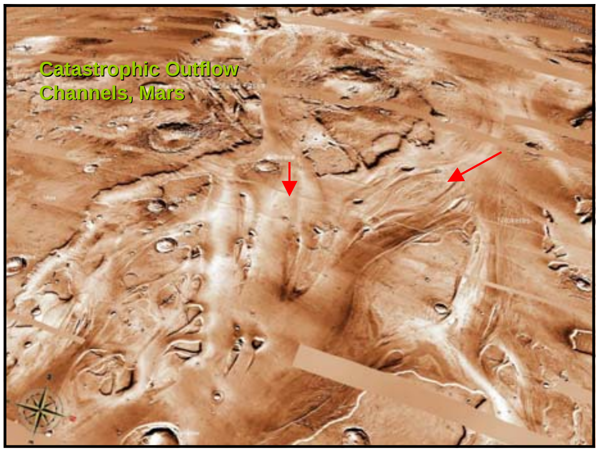
Amazon River Delta, Brazil

Rhine River, Nederlands

Rhine River, Nederlands



Catastrophic Outflow Channels, Mars


Catastrophic Outflow Channels, Mars

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- NASA
- Google Earth

## Acknowledgments

- Dan Baker (CSU)
- Jaime Goode (CSU)
- James Halgren (CSU)
- Christina Omdahl (CSU)
- Paul Sclafani (CSU)

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**THANK YOU**
**for your**
**Attention!**