New Perspectives on Braided Rivers

Shawn Wheelock

Glacial and Quaternary Geology

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Obligatory Picture

Outside of Seward, Alaska (my photo)

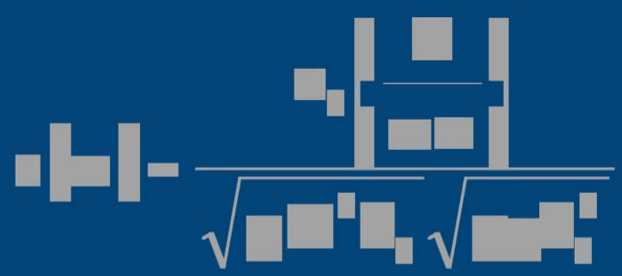
Typical River Morphologies

Meandering River

Braided River

Most rivers will braid when the Width is 60 times depth.

What causes a river to meander or braid?



ε = braiding parameter
m = braiding index
U = velocity
B = channel width
d_0 = flow depth
g = gravitational accel.
τ_0 = bed shear stress
ρ = water density

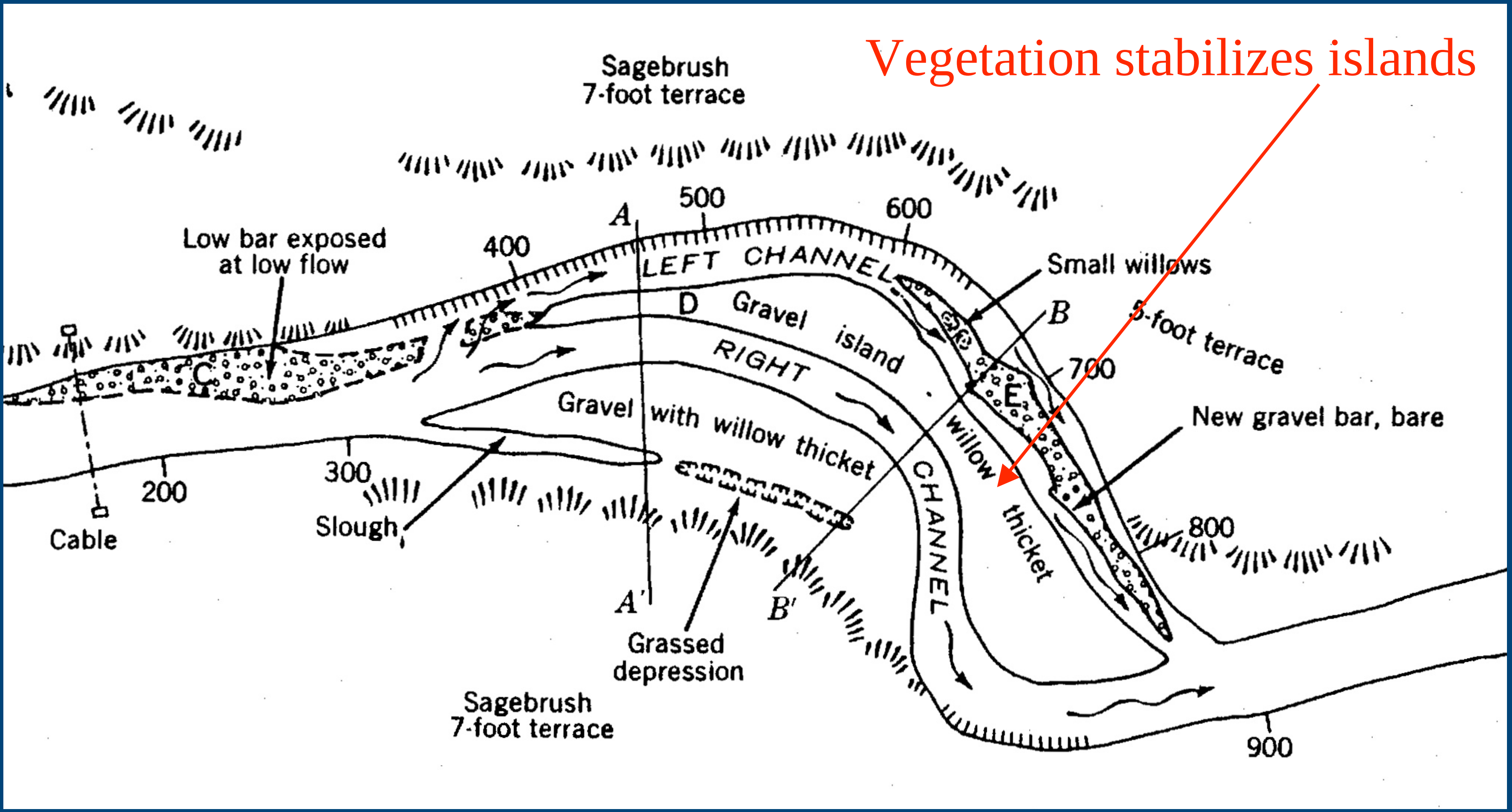
ε is the ratio of work to available energy (potential and kinetic).

- $\varepsilon \ll 1$, extreme meandering
- $\varepsilon < 1$, meandering
- $\varepsilon > 1$, braiding
- $\varepsilon \gg 1$, extreme braiding.

Who's idea was this, anyway?

- In the 1877 Hayden Survey of Western Wyoming, Peale (1879) noticed the strange behavior of Horse Creek as it joined the Green River.
- "[Horse Creek] flows out into a broad valley in which it is side by side with the Green… there are at least 5 islands formed by the two steams…" Peale (1879)

What did he see?



Leopold and Wolman (1957)

What happened next?

- Geographers and Geomorphologists continued to qualitatively study braided rivers (e.g. Melton, 1936)
- In Rubey (1952), discussion began over whether this channel morphology represented an equilibrium state.
- Leopold and Wolman (1957) published a landmark USGS Professional Paper on river morphology which continues to be one of the most cited today.

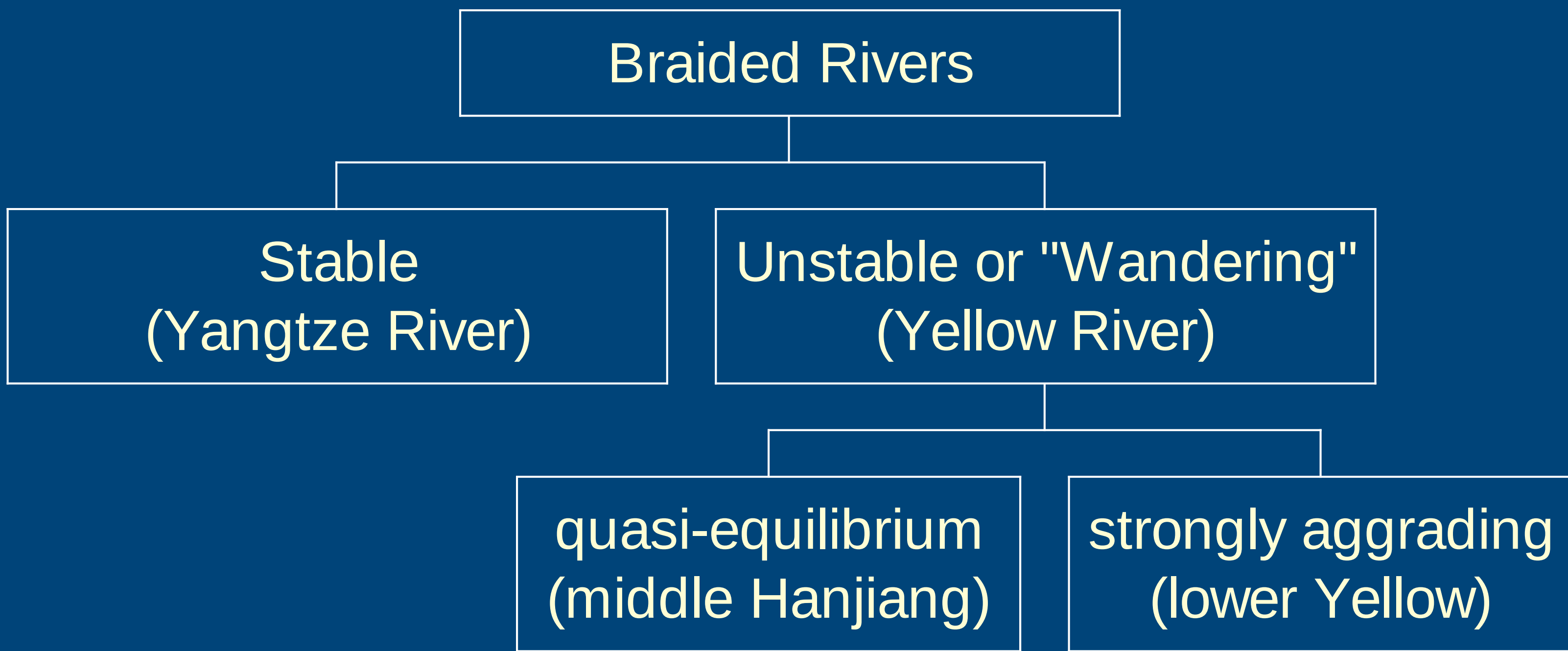
Braided Rivers -- How fast do they change?

"Individual channels and bars in such rivers can evolve, migrate, and switch position within days or hours of competent flow, so that the overall pattern is bewilderingly variable and complex." (Ferguson *et al*, 1992)

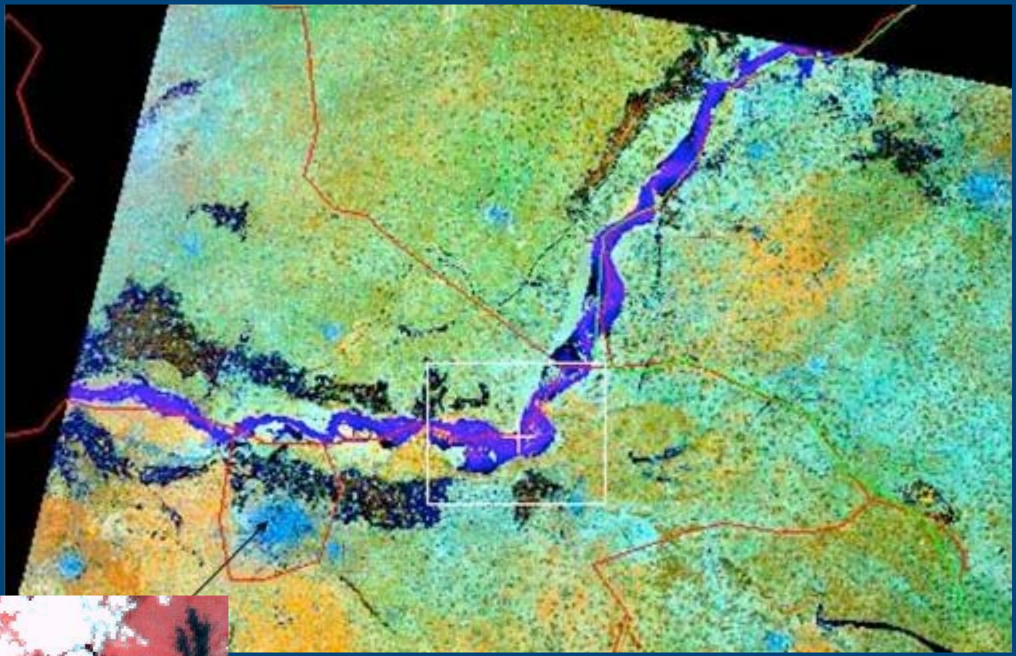
"The islands shown by Peale [in 1879] still exist with but minor changes in form [today in 1957]." (Leopold and Wolman, 1957)

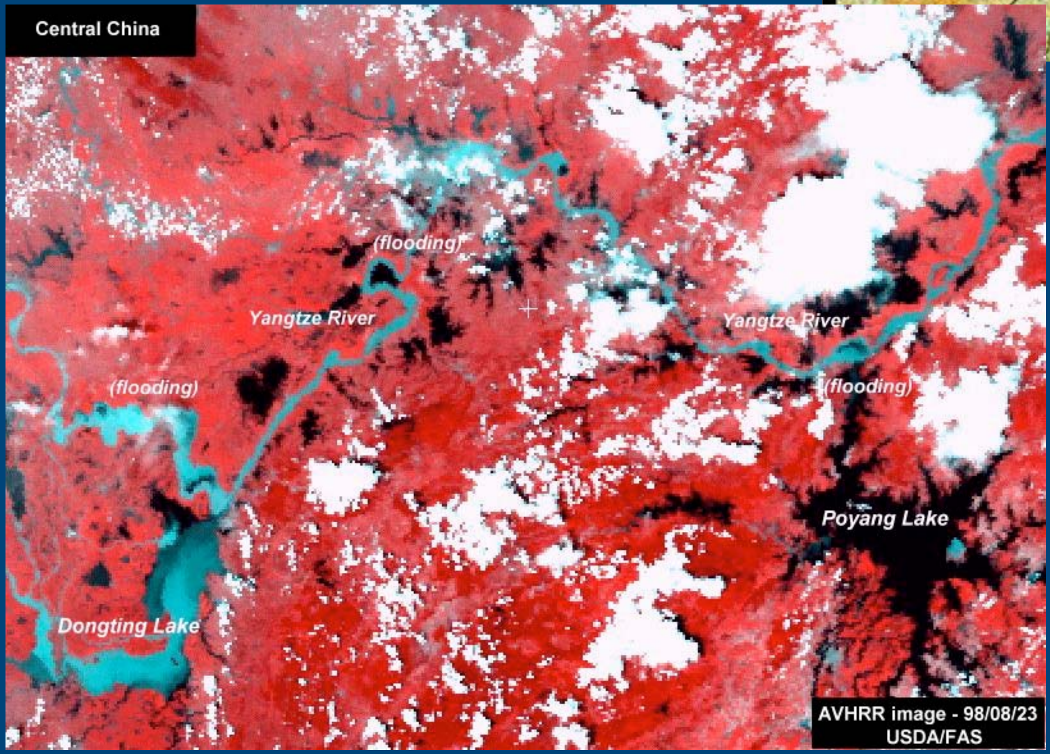
The Braided River Family

as proposed by Chien et al (1987)
and Xu (1996)



Yellow River





Yangtze River

The State of the Science

Why do rivers braid?

- Why do they braid? Steep gradient? Yes. Excess energy? Yes. Excess sediment? No? Maybe?
- One of the major types of braid structures is the mid-channel bar. According to Ashworth (1996), it is still very poorly understood compared with other processes, and it is these that I will focus on here.
- Fluid mechanics suggests that these are *physically* caused by the division of a single flow stream into two or more threads of high velocity within the channel which constitute separate flow systems. This happens *before* any depositional changes. (Richardson and Thorne, 2001)

Brahmaputra-Jamuna River (Bangladesh) velocity profiles

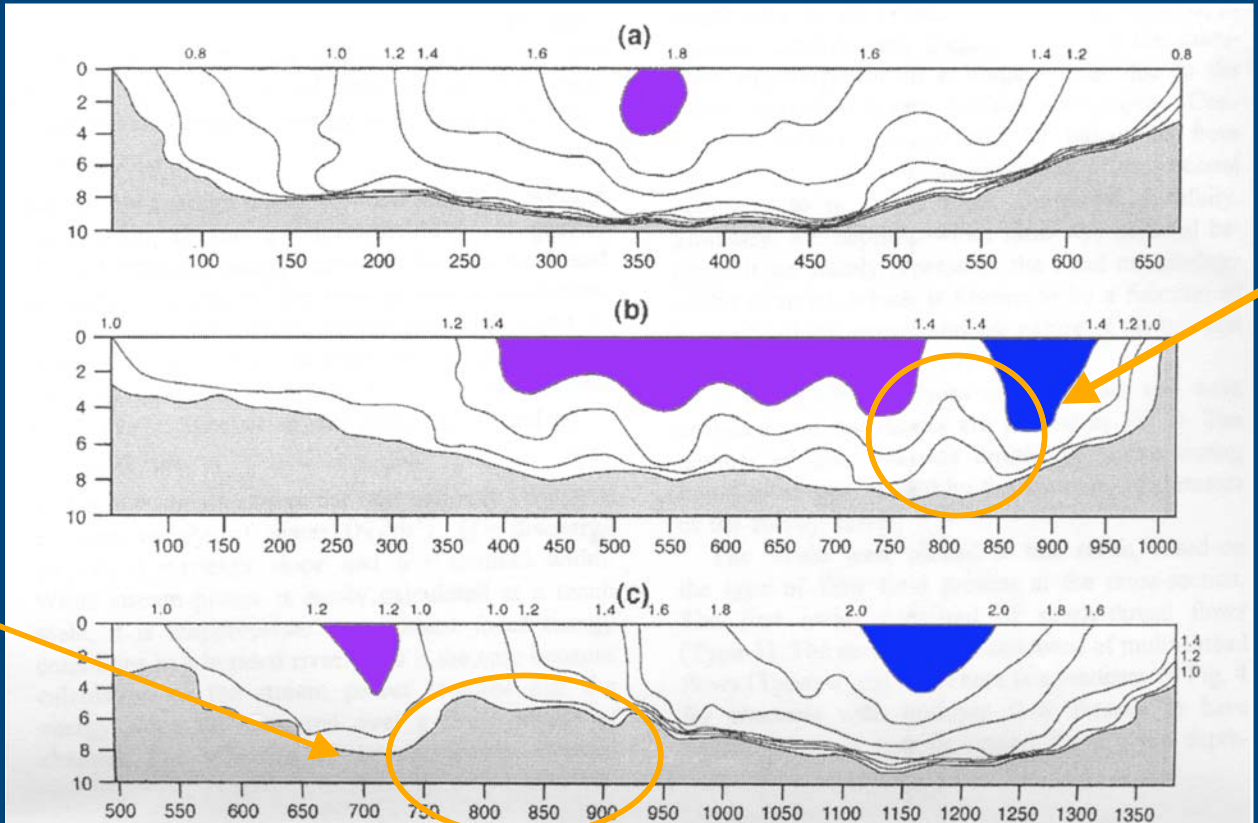


Fig. 3. Primary isovels for: (a) section 5 in May 1994; (b) section 2 in May 1994; (c) section 5 in August 1994.

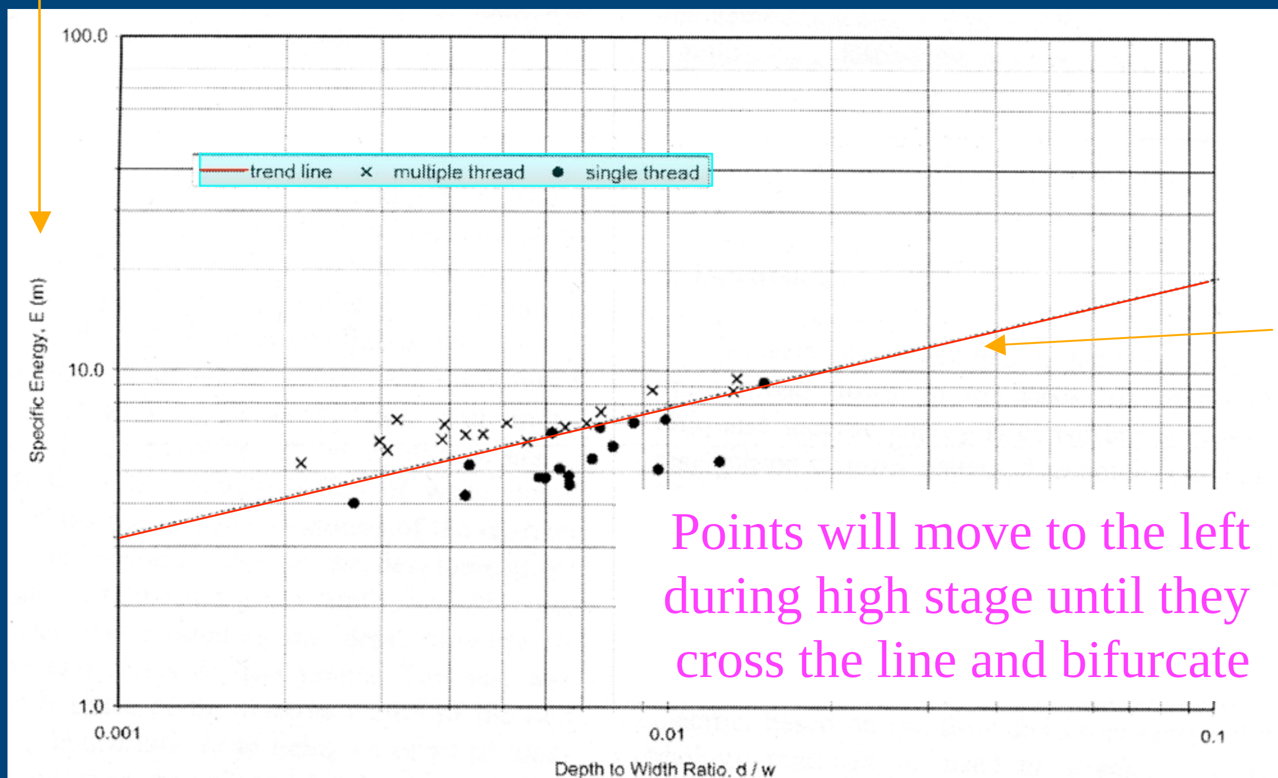
(Richardson and Thorne, 2001)

Note that these are *different* reaches of the river.

When do multiple threads appear?

Specific Energy

v = average velocity
g = gravitational accel.
d = average depth



Line of demarcation

Points will move to the left during high stage until they cross the line and bifurcate

(Richardson and Thorne, 2001)

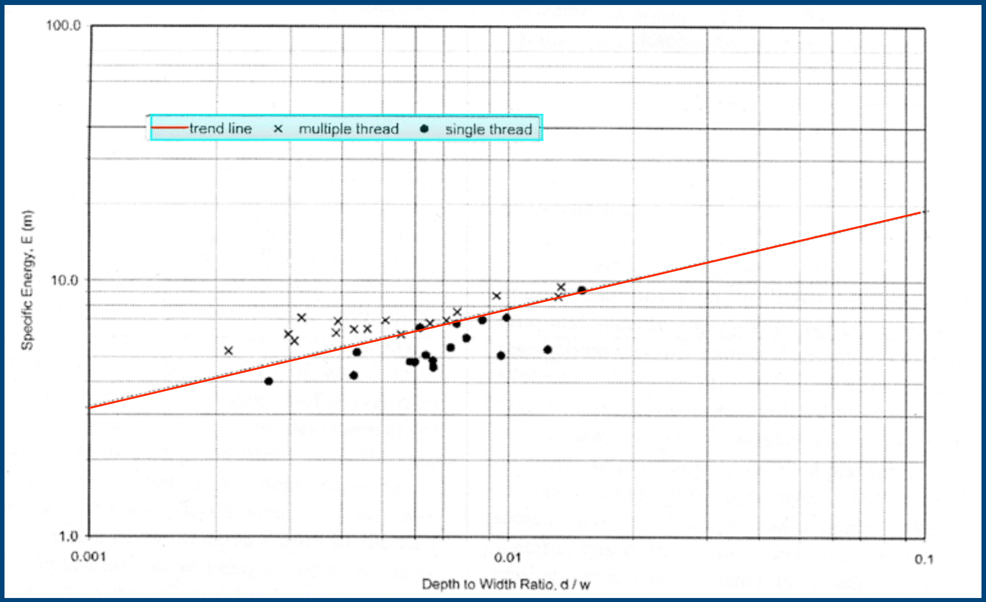
So what *is* the role of sediment?

- Fluid dynamically, sediment is required to initiate an instability, but to the first order, the wavelength of the instability and numbers of braids are not dependent on the amount of sediment present.
  (Parker, 1976 and Germanoski and Schumm, 1993)

•According to flume experiments, when there is a lot of sediment and bars grow, they will do so *slowly* upstream and additional bars will form to its side. Eventually, these will grow together. Indeed, most bars are actually compound structures. (Ferguson *et al*, 1992)

What is the role of discharge?

- As discharge goes up, the specific energy will increase *quadraticaly* on the log-log plot below and there will more high velocity threads and thus mid-channel bars.
- Mosley (1983) noted that based on observations of three braided rivers in New Zealand, that it is unfeasible to predict channel morphology based on discharge, even statistically.

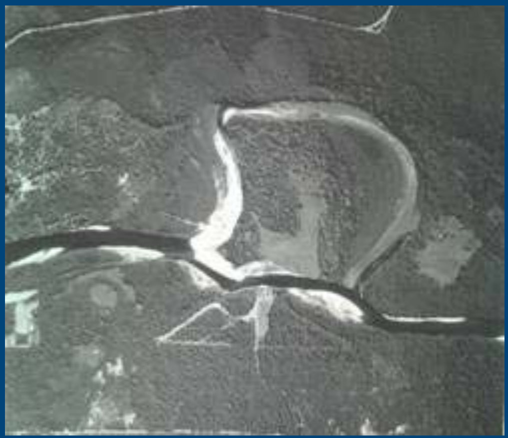


(Richardson and Thorne, 2001)

v = average velocity
g = gravitational accel.
d = average depth

Other causes of channel division

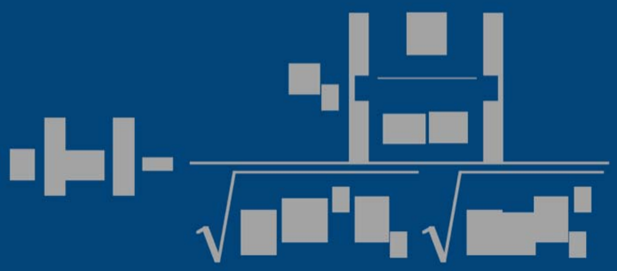
- Mid channel bars are particularly common and poorly understood, but by no means the only method of genesis. Others include:
  - Chute cut-off (erosional): during a flood event a new, lower energy channel is cut, forming an island
  - Chute-lobe (depositional): a constriction is followed by a wider channel, flow slows, and sediment is deposited
  - Lobe dissection (erosional): during high stage, a lobe is cut into multiple pieces
  - Avulsion (erosional): at high flow, the channel wall is penetrated



Energy Considerations and Channel Morphology

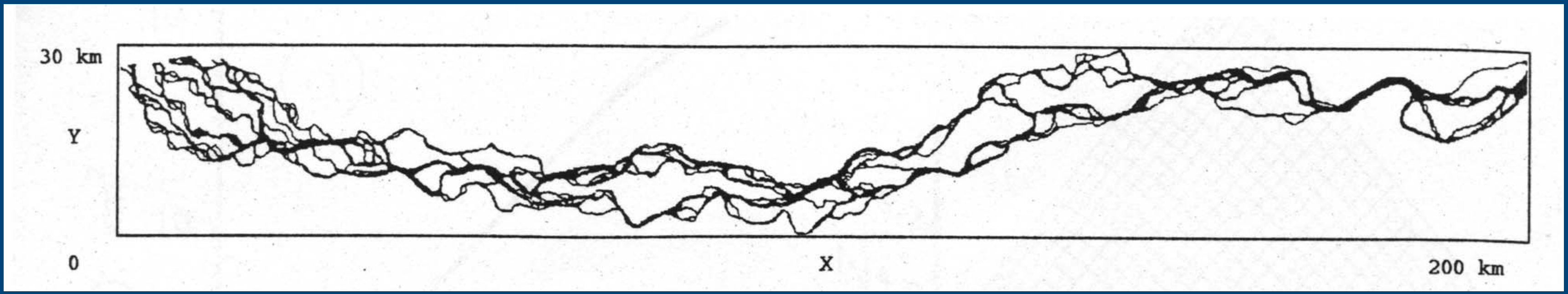
- Bank erosion is caused by excess energy of transverse oscillation, which is inversely proportional to ε .
- ε is a measure of "the ratio of the work that must be done to maintain a mode of oscillation [for] m braids" (Parker, 1976)
- Channel Degradation
  - instead of the banks being eroded, the number of braids will be reduced. Once it is reduced to m=1, then all of the energy difference is dissipated by erosion.

Thus braided channels are generally straighter than meandering ones.



Energy Considerations and Channel Morphology cont.

- Channel Aggradation is just the opposite.
  - As ε drops
    - m will increase
    - More channels will form
    - More bars will form
    - BUT the actual sizes of the bars will not get larger.
  - Size actually increases during *degradation*, because smaller channels are abandoned.
- These results have also been noted in multiple flume experiments. (e.g. Germanoski and Schumm, 1993)



What is a Fractal?

- Each part of the object displaying self-affine behavior is a complete image of the whole scaled differently in the x and y directions

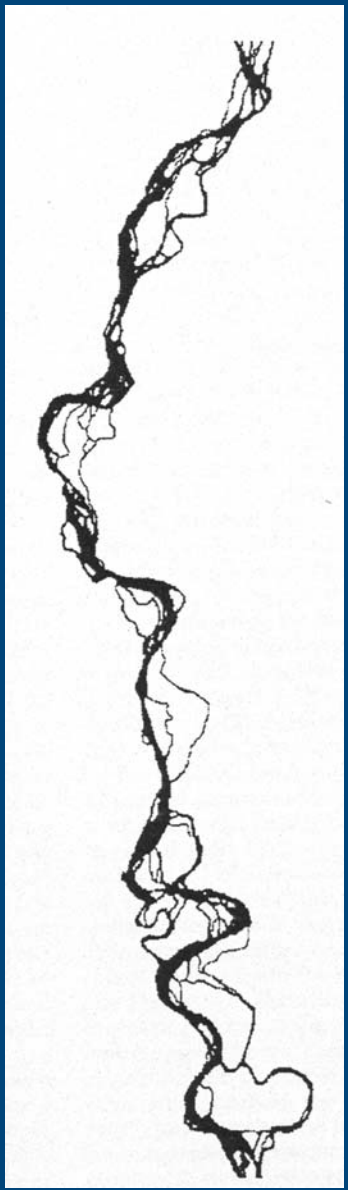
$$M(X,Y) \sim X^{1/v_x} \sim Y^{1/v_y}$$

- The equation demonstrates the role of vx and vy. Note that M is the mass of the object within a rectangle X,Y. (Sapozhnikov and Foufoula-Georgiou 1996)
- This behavior is ONLY in statistical sense, thus one is not likely to see what we usually think of as a self replicating fractal (such as make popular screen savers) when looking at a river in plan form (Nikora 1991)

The Fractal Curio

- Self-affine behavior is caused, simply enough, by the effects of gravity. It forces the streams to scale differently in the direction of the gradient and in the perpendicular direction (Sapozhnikov and Foufoula-Georgiou 1996).
- In absence of morphological constraints, they will self organize.
- “The presence of scaling phenomenon means that statistical properties of the phenomenon at one scale relate to its statistical properties at another scale via a transformation which involves only the ratio of the two scales. This implies a certain invariance of the phenomenon under magnification or contraction.” Sapozhnikov and Foufoula-Georgiou (1996)

The Fractal Curio cont.



	Brahmaputra India	*Aichilik Alaska*	*Tanana Alaska*
Reach width (km)	15	0.5	-
Reach length (km)	200	6.4	-
Mean channel depth (m)	5	1	-
Slope	0.000077	0.001	-
Braiding index	3.8	6.8	-
Fractal Exponent v_x	0.72-0.74	0.72-0.74	0.74-0.77
Fractal Exponent v_y	0.51-0.52	0.51-0.52	-0.47-0.50
Predominant bed material	Sand	Gravel	-

Nykanen *et al* (1998), Sapozhnikovand Foufoula-Georgiou (1996), Nykanen *et al* (1998)

Unanswered Questions

- What are the *precise* physics and circumstances under which high flow threads form? Richardson and Thorne’s treatment in still general due to resolution of available data.
- To what extent would taking into account helicity in vertical movement of water affect the fluid dynamical predictions?
- Why is fractal based self-organization observed?
- Is it possible to statistically predict channel morphology based on physical data and solutions to the wave, mass balance, and motion equations?

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