Flow Energy, Time, and Evolution of Dynamic Fluvial Systems: Implications for Stabilization and Restoration of Alluvial Streams

(…A Review…)

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Introductory Points

- Alluvial streams are open systems that dynamically adjust to variations in flow energy and sediment supply.
- Streams adjust their morphology to imbalances between available force and sediment supply as a function of the resistance of the boundary sediments to hydraulic and geotechnical forces.
- Thus, two (reference?) channels of similar morphology disturbed by an identical perturbation can attain different equilibrium morphologies
- Also, diverse streams subject to diverse perturbations can respond similarly.

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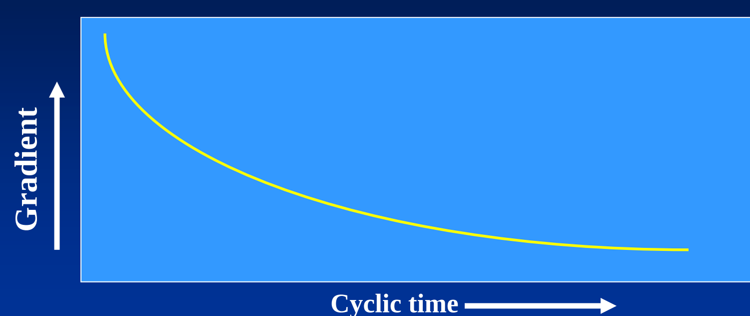
We Restore Unstable Channels
(usually in unstable systems)

- Stream restoration is conducted on unstable channels (systems) where regime relations are not valid and bankfull dimensions are dynamic or even indefinable
- Because unstable streams are dynamic, it is essential to know where in the adjustment cycle the stream is so that upstream sediment supply can be accounted for
- Although adjustments make alluvial streams particularly dynamic, response is not chaotic but proceeds in a systematic and predictable way
- Therefore, one must account for the spatial and temporal aspects of adjustment when designing a restoration project

Compression of Time Scales



Compression of time scales following large-scale disturbances: "natural" or anthropogenic

1,000,000 years = 25 - 100 years

Minimization of Energy Dissipation

Channels adjust such that their geometry provides for a minimum rate of energy dissipation given the constraints of the upstream sediment load, roughness and boundary materials

If this holds true and given the compressed time scales for adjustment, then we should be able to track this over time in disturbed, adjusting streams

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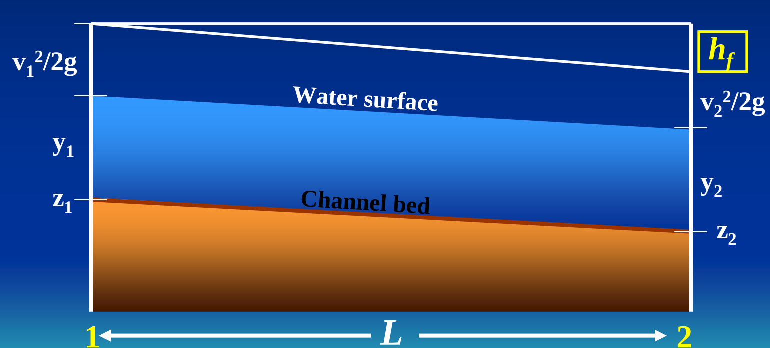
Flow Energy and Energy Dissipation

$E = z + \gamma y + v^2/2g$

$h_f = (z_1 + \gamma y_1 + v_1^2/2g) - (z_2 + \gamma y_2 + v_2^2/2g)$



Energy slope: $S_e = h_f / L$

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Processes That Effect Components of Total Mechanical Energy (*E*)

For each parameter comprising ***E***,
what processes would result in a
reduction in those values?

- **z:** **degradation**
- **γy:** **widening, aggradation**
- **$v^2/2g$:** **widening, increase in relative roughness, growth of vegetation, aggradation,**

Thus, different and often opposite processes can have the same result. Which dominate where?

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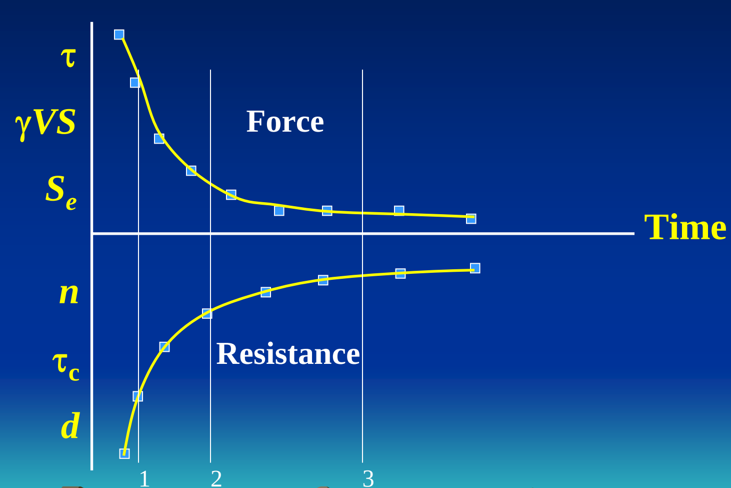
Idealized Adjustment Trends

For a given discharge (Q)



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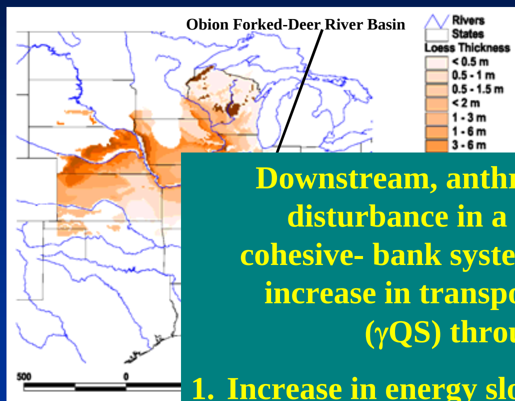
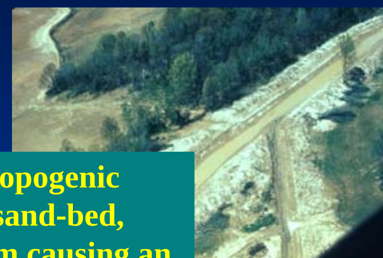
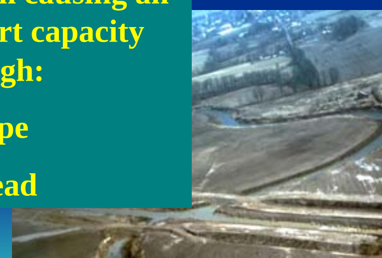
Coastal-Plain System



Modified

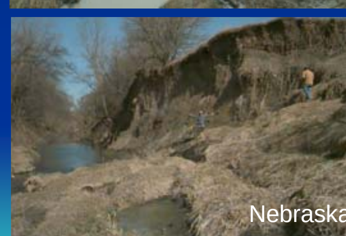




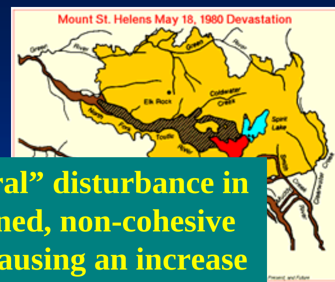
Downstream, anthropogenic disturbance in a sand-bed, cohesive- bank system causing an increase in transport capacity (γQS) through:

1. Increase in energy slope
2. Increase in velocity head

Adjustment Processes

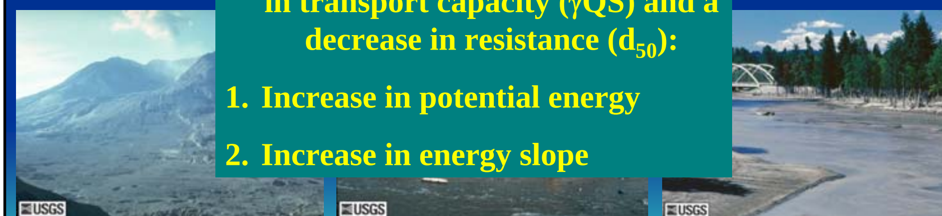


Sub-Alpine System



Upstream "natural" disturbance in a coarse-grained, non-cohesive bank system causing an increase in transport capacity (γQS) and a decrease in resistance (d_{50}):

1. Increase in potential energy
2. Increase in energy slope



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Adjustment Processes

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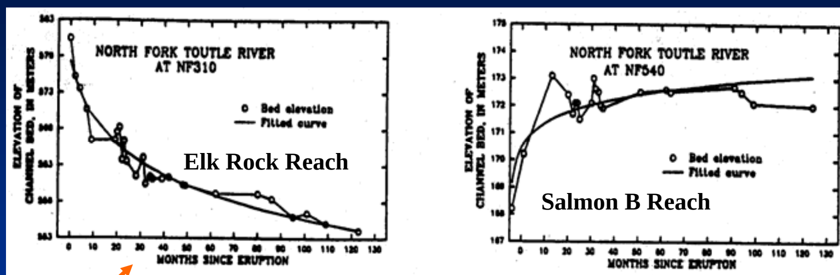
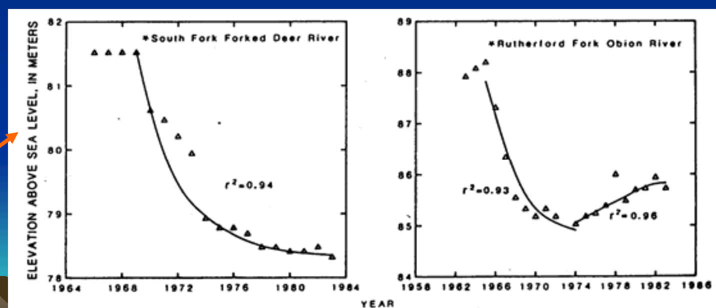
Trends of Bed-Level Change



Mt. St Helens



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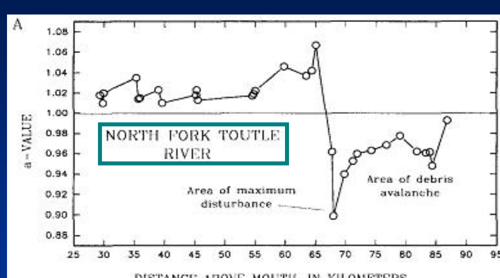
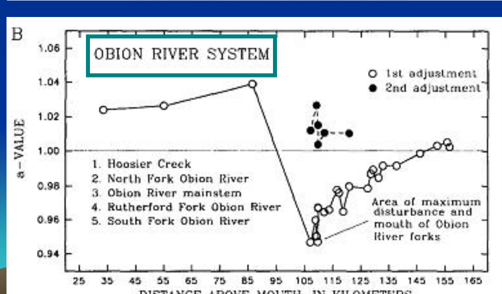
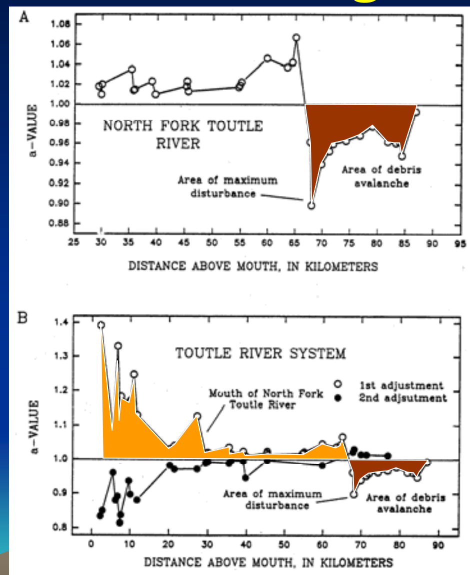
Trends of Bed-Level Change





Trends of Bed-Level Change

Coarse-grained material for aggregation derived from bank sediment.



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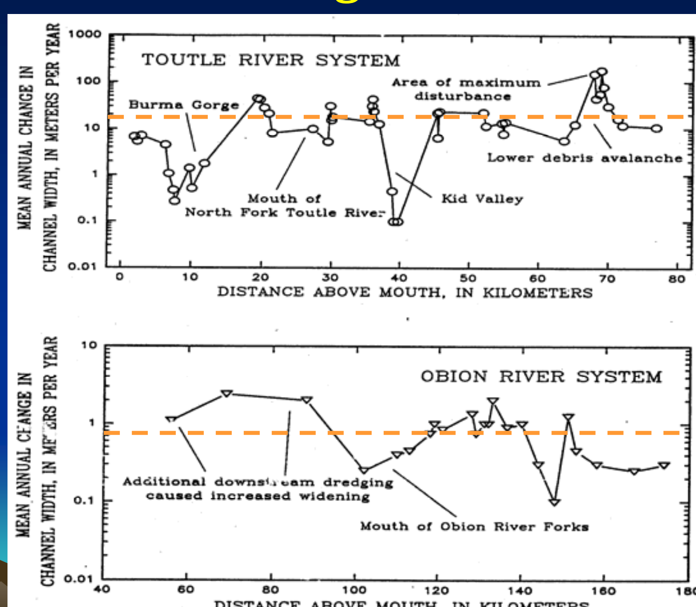
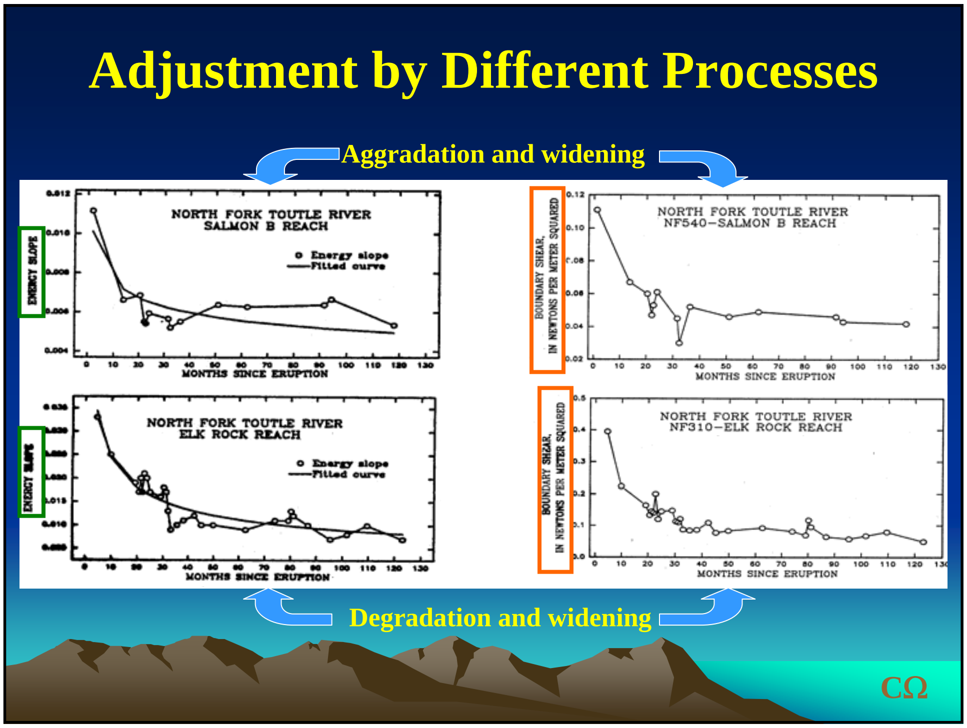
Widening



But why are they so different ?

Resistance


Adjustment by Different Processes
Aggradation and widening
NORTH FORK TOUTLE RIVER
SALMON B REACH
Energy slope
Fitted curve
ENERGY SLOPE
MONTHS SINCE ERUPTION
NORTH FORK TOUTLE RIVER
NF540–SALMON B REACH
BOUNDARY SHEAR,
IN NEWTONS PER METER SQUARED
MONTHS SINCE ERUPTION
NORTH FORK TOUTLE RIVER
ELK ROCK REACH
Energy slope
Fitted curve
ENERGY SLOPE
MONTHS SINCE ERUPTION
NORTH FORK TOUTLE RIVER
NF310–ELK ROCK REACH
BOUNDARY SHEAR,
IN NEWTONS PER METER SQUARED
MONTHS SINCE ERUPTION
Degradation and widening
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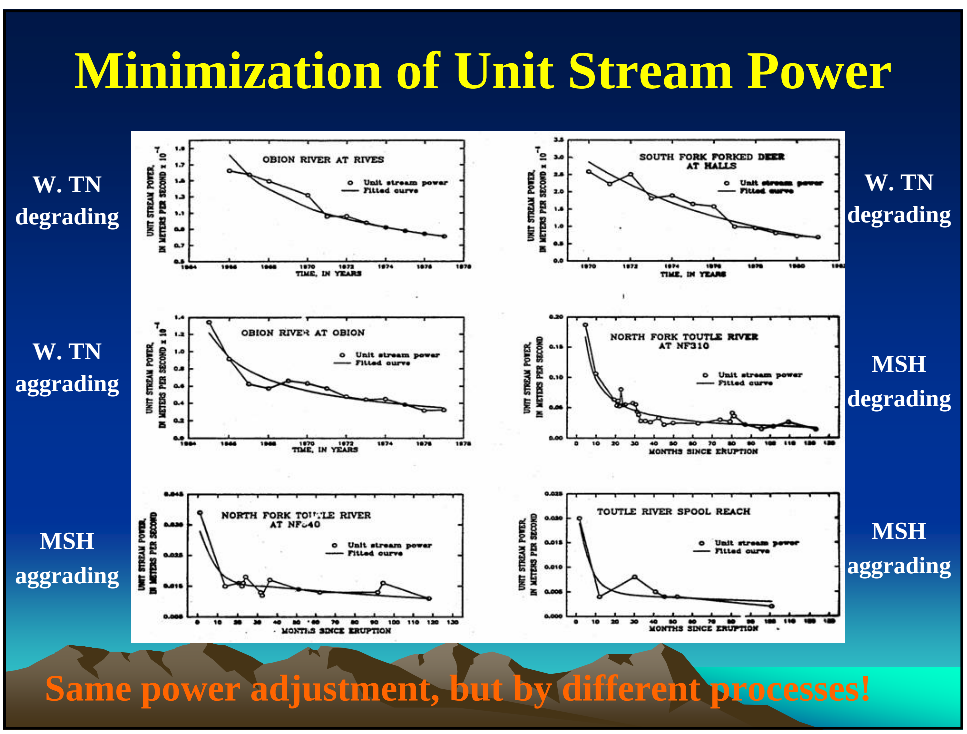
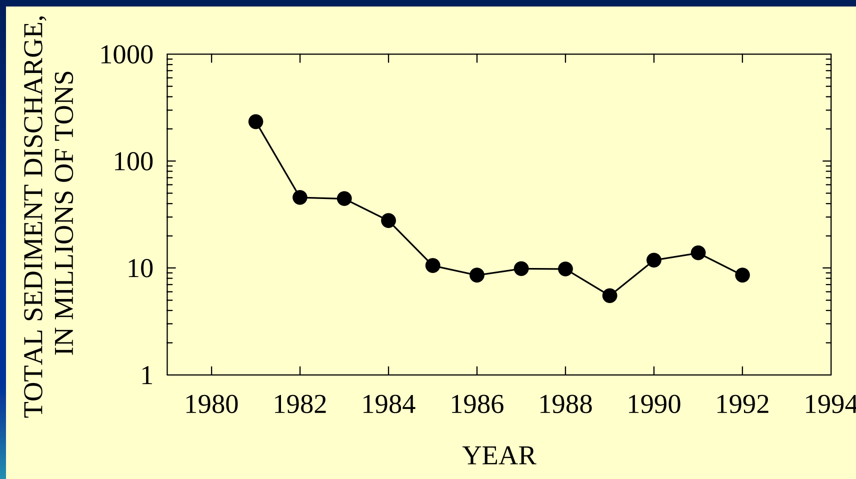

Minimization of Unit Stream Power
W. TN
degrading
OBION RIVER AT RIVES
Unit stream power
Fitted curve
TIME, IN YEARS
SOUTH FORK FORKED DEER
AT HALLS
Unit stream power
Fitted curve
TIME, IN YEARS
W. TN
degrading
W. TN
aggrading
OBION RIVER AT OBION
Unit stream power
Fitted curve
TIME, IN YEARS
NORTH FORK TOUTLE RIVER
AT NF310
Unit stream power
Fitted curve
MONTHS SINCE ERUPTION
MSH
degrading
MSH
aggrading
Unit stream power
Fitted curve
MONTHS SINCE ERUPTION
TOUTLE RIVER SPOOL REACH
Unit stream power
Fitted curve
MONTHS SINCE ERUPTION
MSH
aggrading
Same power adjustment, but by different processes!

Results of Energy Minimization (Sediment Discharge)



Consider this as an analog to upstream sediment supply in a recovering system

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Implications of Not Distinguishing Between Bank Materials

- **Assume that $\gamma QS \propto Q_s d_{50}$ is balanced**
- **How does a channel respond if disturbed?**
- **Will the channel incise?**
- **Will the channel fill?**
- **Will the channel widen?**
- **Will the channel narrow?**
- **Will it equilibrate to the same geometry?**

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Disturbing the C5 Channel

- Assume that $\gamma QS \ \alpha \ Q_s d_{50}$ becomes un-balanced
- $Q_s d_{50}$ = 0.5 * capacity
- Slope = 0.005
- Width/depth ratio = 13.5

Bank material	Bed d_{50} (mm)	Bank cohesion (kPa)	Friction angle (°)	Sand content (%)
Sand	1.0	4.0	32.5	100
Silt	1.0	7.5	32.5	20
Clay	1.0	40.0	32.5	10

Additional cohesive strength can also be used as an analog for the root-reinforcement (mechanical) effects of vegetation on bank stability

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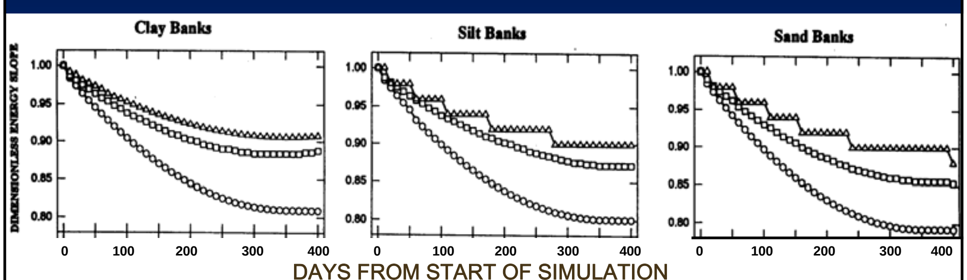
Adjustment in Energy Slope for Different Boundary Materials and Slopes



- ▲ 0.00005 @ 0.90
- ■ 0.0005 @ 0.87
- ● 0.005 @ 0.80

Energy adjustment is similar at given slope!

Do each of these channels reach equilibrium similarly?

Adjustments for Different Boundary Materials

Gradient	0.005 m/m
Degradation	3.51
Widening	0
W_o/D_o	13.5
W_f/D_f	5.62
τ_o	103
τ_f	98.7
Degradation	2.74
Widening	11.3
W_o/D_o	13.5
W_f/D_f	8.62
τ_o	103
τ_f	69.3
Degradation	0.35
Widening	13.1
W_o/D_o	13.5
W_f/D_f	16.4
τ_o	103
τ_f	64.8

Clay-bank channel

Silt-bank channel

Sand-bank channel

From Simon and Darby (1997)

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Response of the Channel

- How Does the channel respond? It depends!
- How much will the channel incise*? 0.4 – 3.5 m
- How much will the channel widen*? 0 – 13 m
- What is the stable W/D ratio*? 5.6 – 16.4

And this is knowing the upstream sediment supply!

* For a given initial slope of 0.005 m/m

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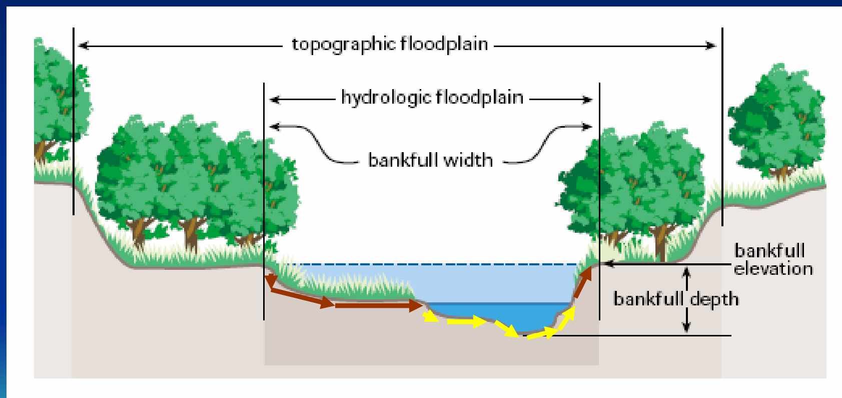
Implications for a Form-Based System: Bed or Channel Material?

(two different populations)



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Why is this Important?

- Sites may not classified correctly: Example:

  "C" channel shape: gravel bed, silt/clay banks
  "C" channel shape: sand bed, sand banks } **C5**

These two C5's represent very different transport regimes

- As we have seen, differences in bank materials are critical to predicting channel response and stable geometries
- Particle-size data cannot be used for incipient motion or transport analysis
- Extensive data sets collected by various agencies cannot be used for analysis of hydraulic erosion, geotechnical stability, or channel response

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Perhaps Explains Why…

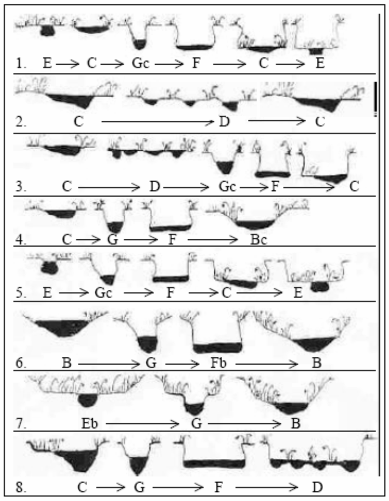

Figure 1. Various Stream Type Evolution Scenarios

"The consequence of a wide range of stream channel instability can be described and quantified through an evolution of stream types (Figure 1)." Rosgen (2001)

- **E to E**
- **C to C; C to Bc; C to D**
- **B to B**
- **Eb to B**

From Rosgen (2001)

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Forcing a Form-Based System to Describe Process

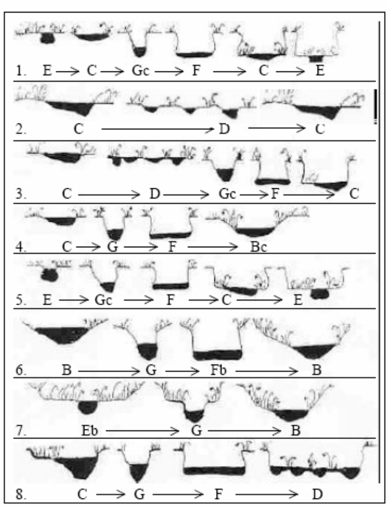

Figure 1. Various Stream Type Evolution Scenarios

"The consequence of a wide range of stream channel instability can be described and quantified through an evolution of stream types (Figure 1)." Rosgen (2001)

- **E to E**
- **C to C; C to Bc; C to D**
- **B to B**
- **Eb to B**

Can this be predicted a priori?

What does this mean for the reference reach-based approach?

From Rosgen (2001)

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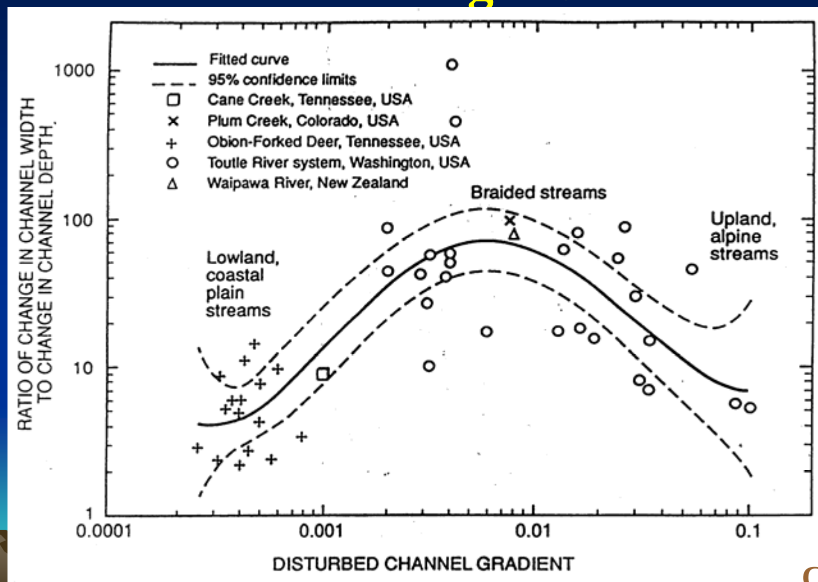
These Changes Occur at Different Rates and Magnitudes



Conclusions

- Restoration has to be in the context of the condition of the watershed and the channel system… spatial and temporal aspects of the instability

- Restoration of an unstable reach within an dynamic, unstable system will not likely be successful

- A deterministically-based approach that accounts for bed and bank processes provides a reliable means of analyzing adjustment processes and predicting stable-channel geometries in unstable systems.

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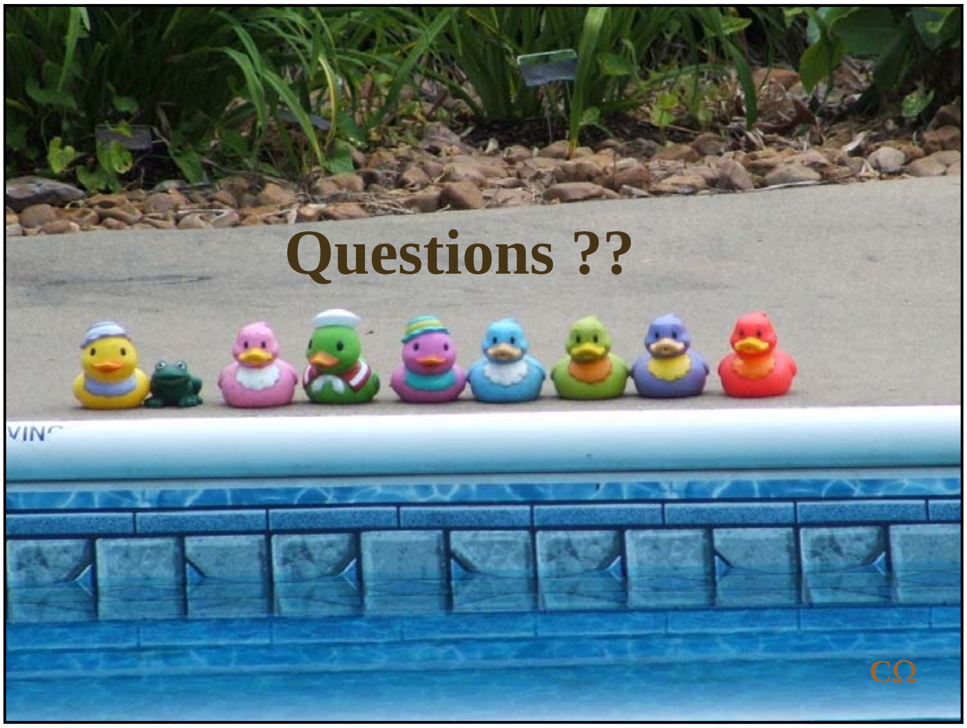
Questions ??
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