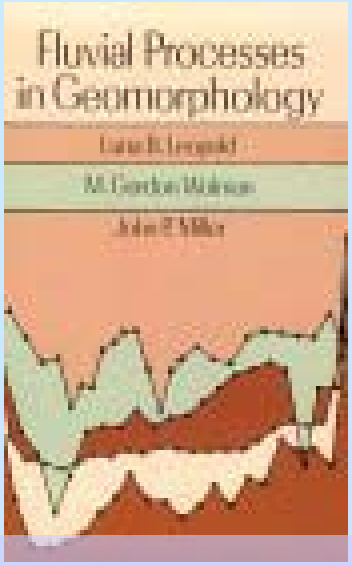
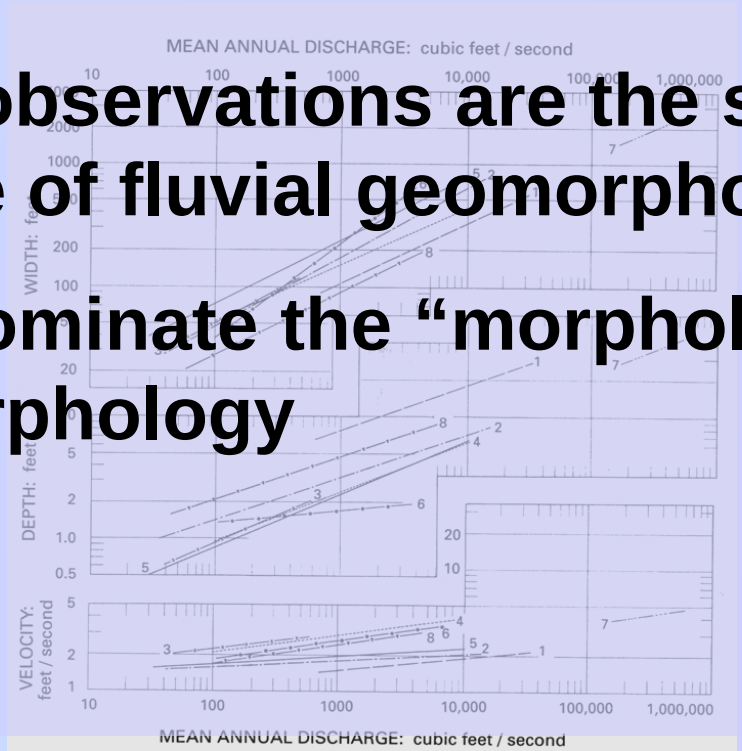
NATIONAL CENTER FOR EARTH-SURFACE DYNAMICS

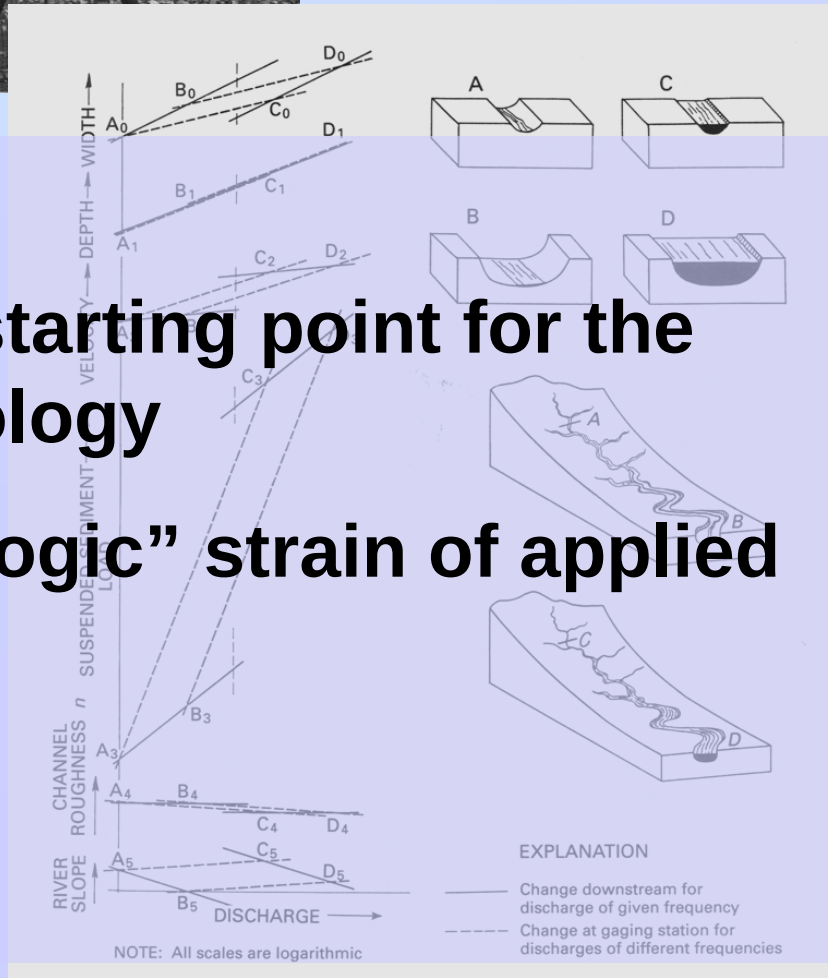
A NATIONAL SCIENCE FOUNDATION SCIENCE & TECHNOLOGY CENTER

Science Basis for Reclamation of Low-Order Streams

Peter Wilcock
Geography & Environmental Engineering
National Center for Earth-surface Dynamics
Johns Hopkins University
Baltimore MD



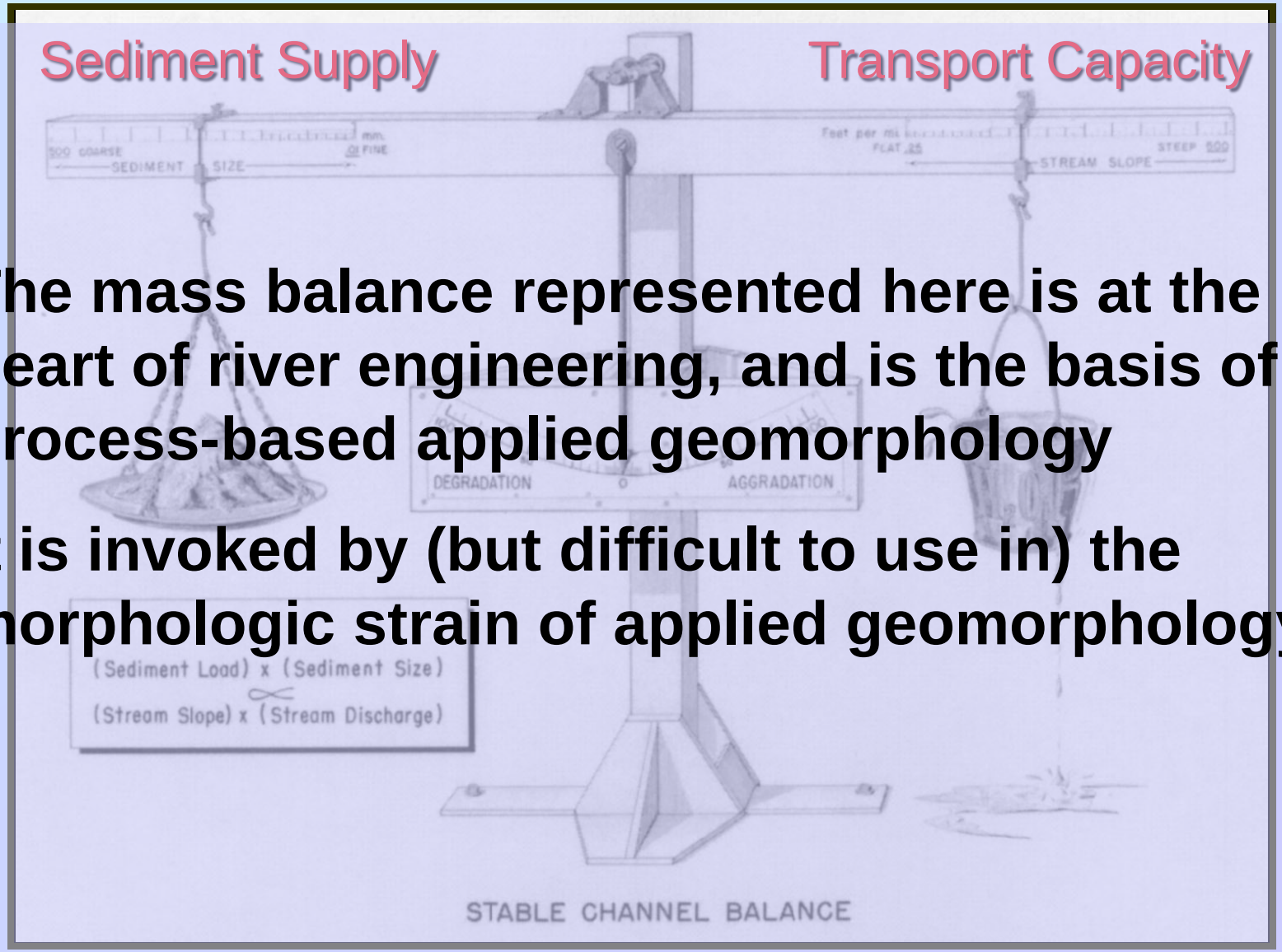




These observations are the starting point for the science of fluvial geomorphology

They dominate the “morphologic” strain of applied geomorphology

The Lane/Borland Stable Channel Balance



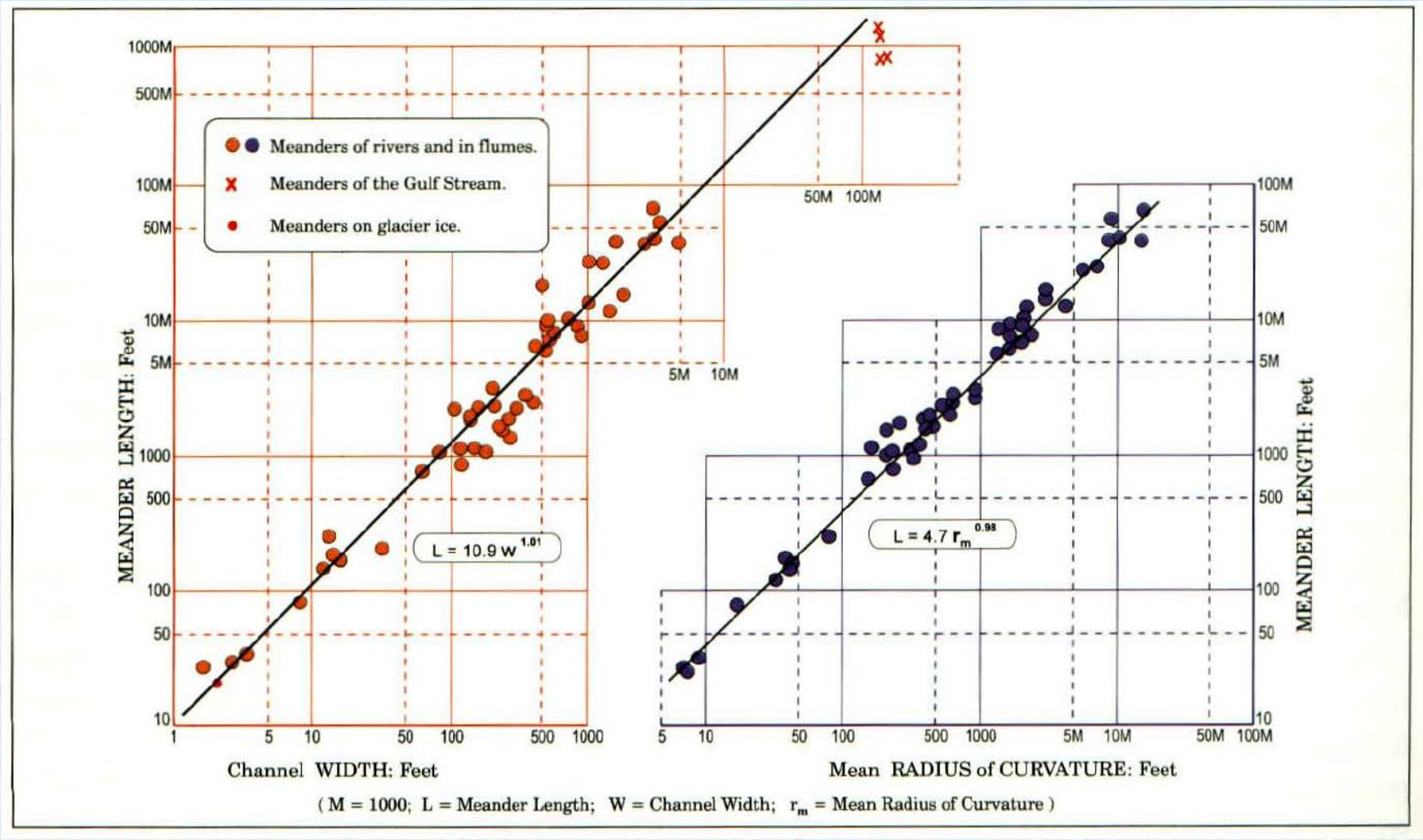
The mass balance represented here is at the heart of river engineering, and is the basis of process-based applied geomorphology

It is invoked by (but difficult to use in) the morphologic strain of applied geomorphology

Borland's stable channel stability relationship illustrated by James Vitaliano, BOR, in 1960.

From Pemberton, E.L. and R.I. Strand, 2005, "Whitney M. Borland and the Bureau of Reclamation, 1930–1972", J. Hydraulic Engineering, May 2005, pp. 339-346.

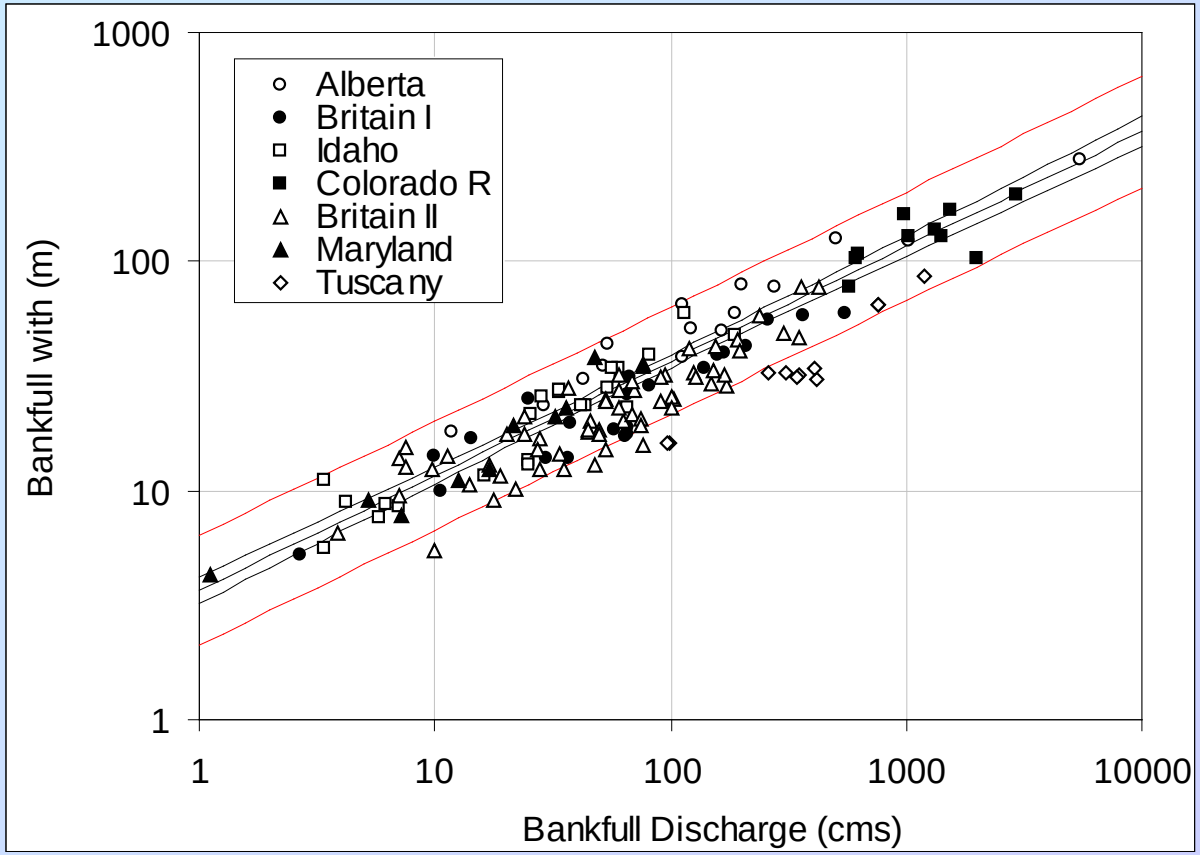
At the core of the template approach is a ***correlation*** between channel geometry, flow, and sediment supply



Leopold, Wolman, & Miller 1964

The width of channels increases very consistently with the square root of discharge.

The flow that moves the most sediment, over time, tends to just fill the channel and occurs ever year or few.



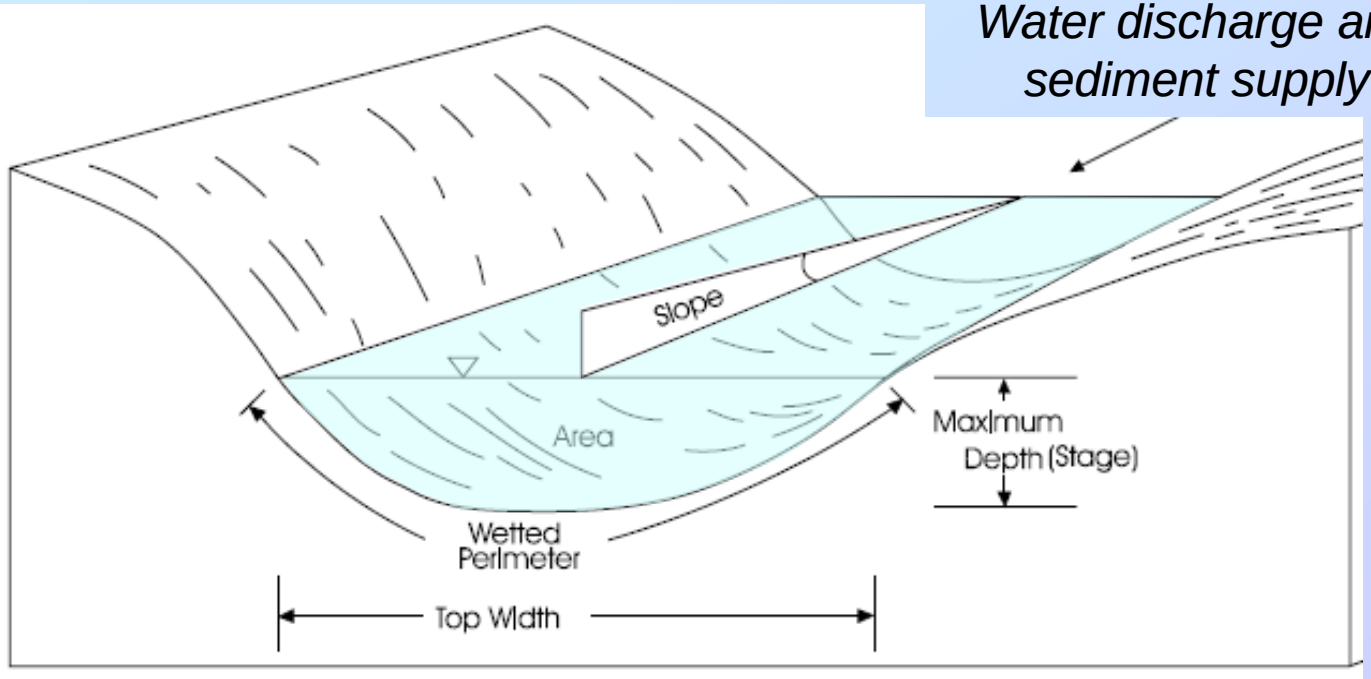
At the core of the template approach is a ***correlation*** between channel geometry, flow, and sediment supply

The correlation ***requires*** that the channels have ***adjusted*** to their water and sediment supply.

Application of process approach: how big the channel?

Given

Water discharge and sediment supply



Find

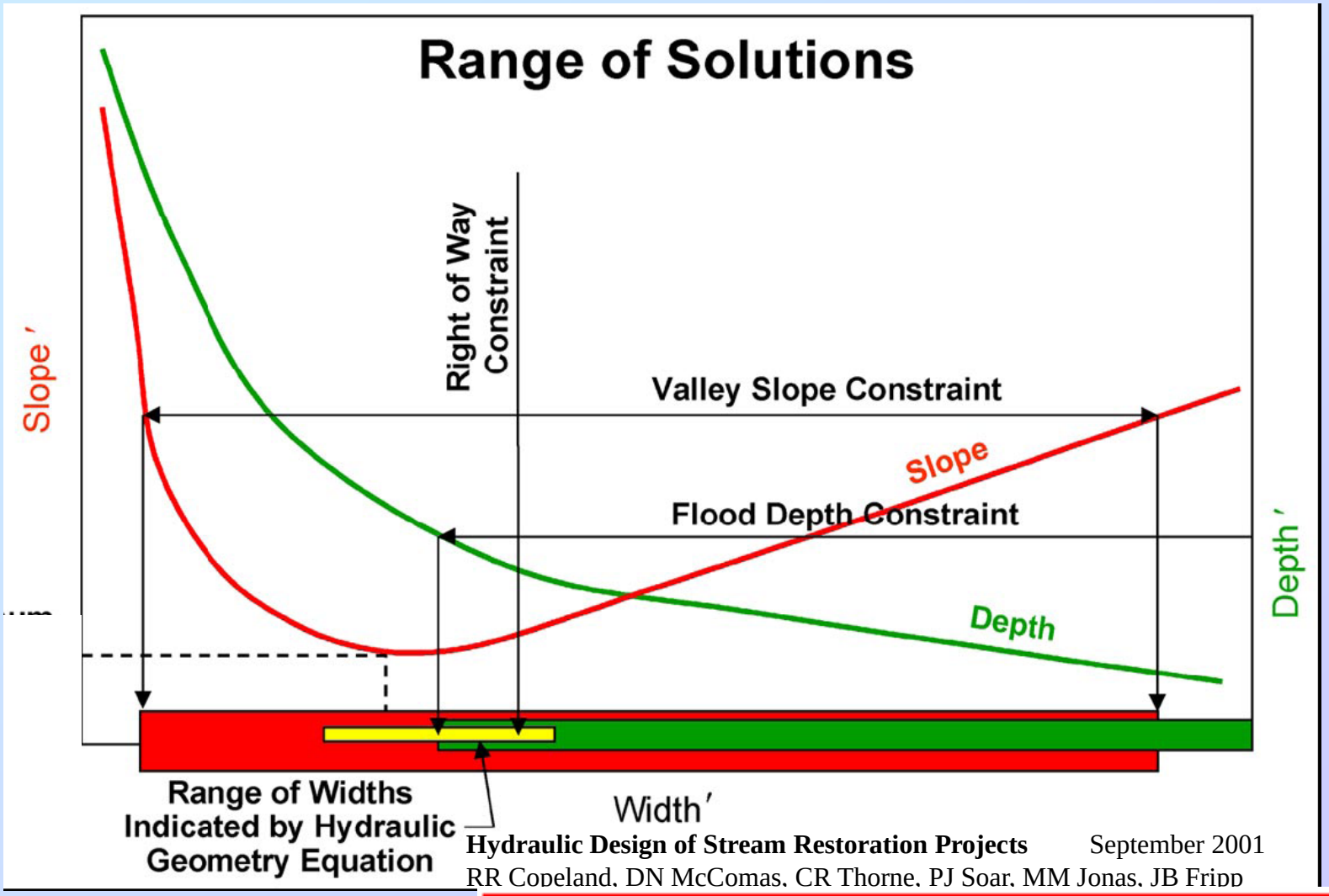
(i) channel slope
(ii) channel depth
(iii) channel width
(iv) mean velocity
(v) boundary shear

We have enough FOUR general relations available
we can solve for all but one of these unknown variables

If we specify channel width, we can solve for the rest of the variables

What slope is needed to transport the supplied sediment with the available water?

For a specified discharge & sediment supply …

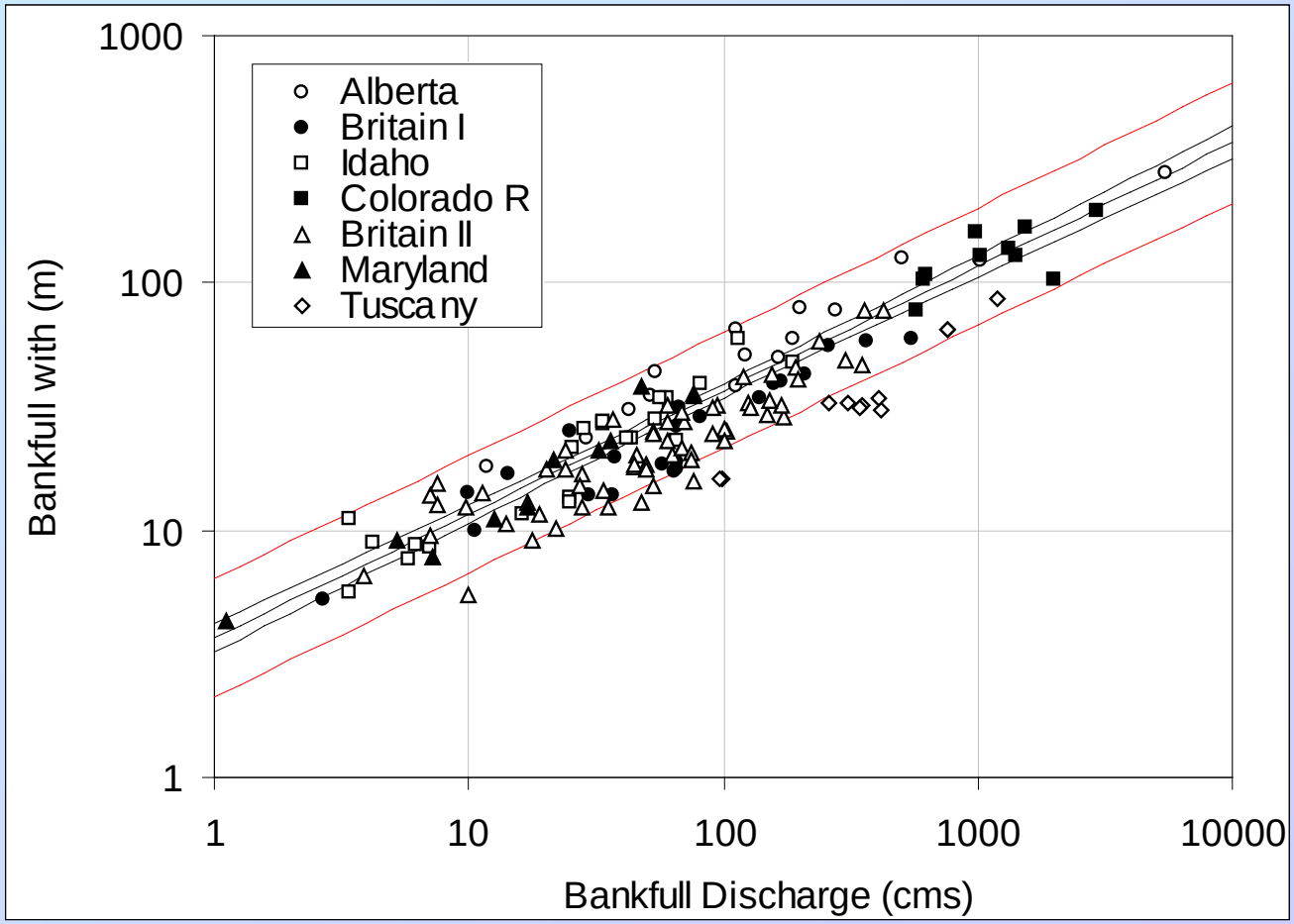


Hydraulic Design of Stream Restoration Projects September 2001
RR Copeland, DN McComas, CR Thorne, PJ Soar, MM Jonas, JB Fripp

Coastal and Hydraulics Laboratory ERDC/CHL TR-01-28

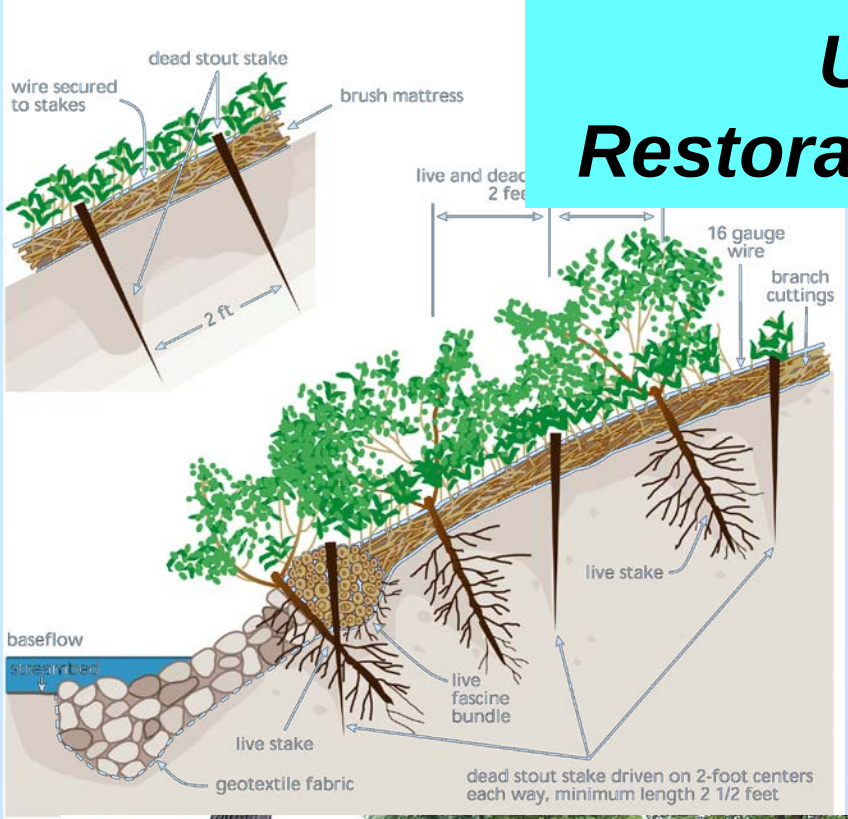
Where does sediment supply fit in the morphological approach?

Hydraulic Geometry = *f*(discharge, not sediment supply)

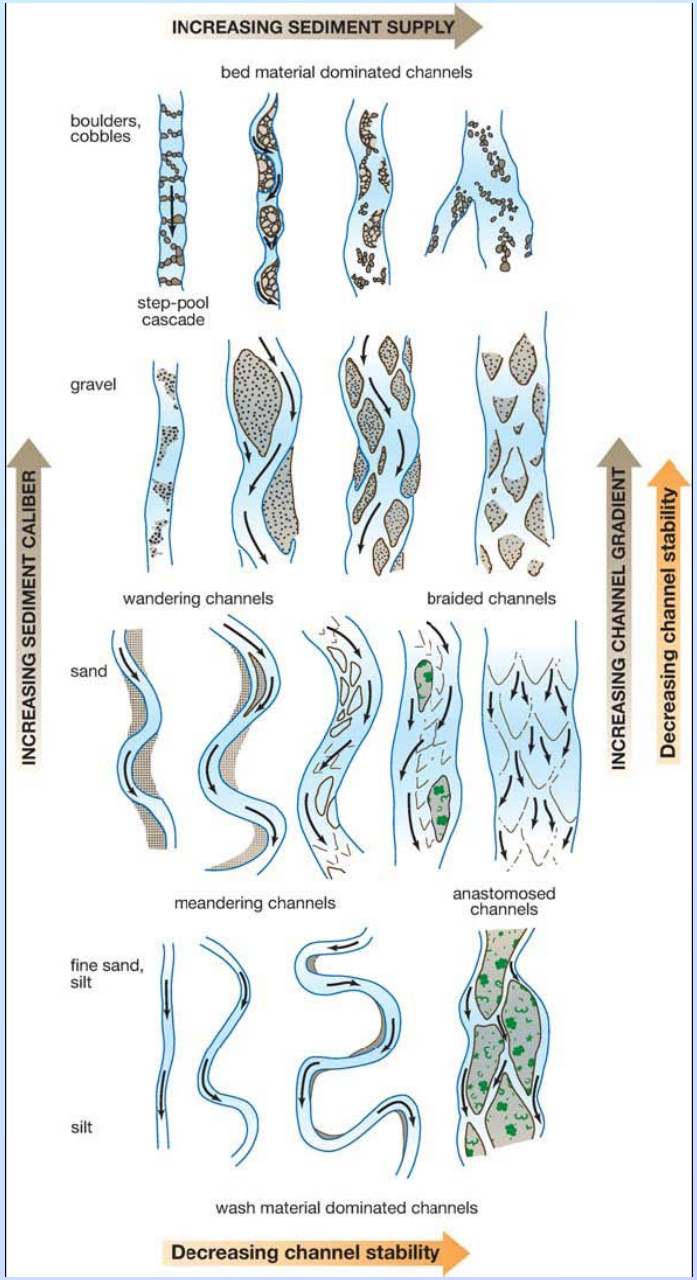


Do we even need to worry about sediment transport?

Urban Restorations



Sediment supply does matter …



Church, Michael. 2006. Bed material transport and the morphology of alluvial river channels. Annu. Rev. Earth. Planet. Sci. 34:325-354.

So, there must be a boundary between cases where sediment supply matters or not

Threshold	**Alluvial**
Bed & banks immobile	Active transport
Easier to model & design Bed & banks must only be strong enough	Harder to design Requires a balance between transport capacity & sediment supply

Nothing new under the sun …

Why we can ‘neglect’ small sediment supply rates

1. Small sediment supply rates → many storms (and many decades) req’d to produce significant aggradation and degradation.
2. Small sediment supply rates → channel morphology and slope required to transport the supplied sediment can be negligibly larger than that of a threshold channel.

So, what is a SMALL sediment supply rate?

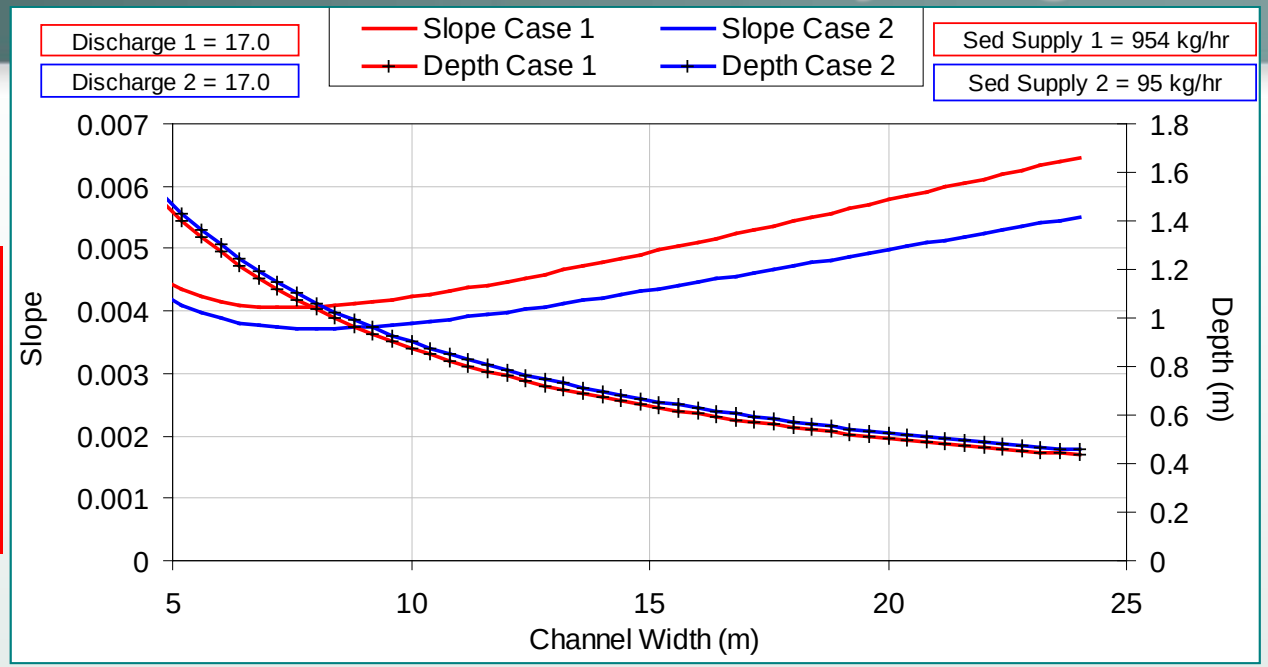
That sounds dangerously like a real question, so first, lets deal with real sediments, which contain a mixture of sizes

For mixed-size sediment, there are complications …

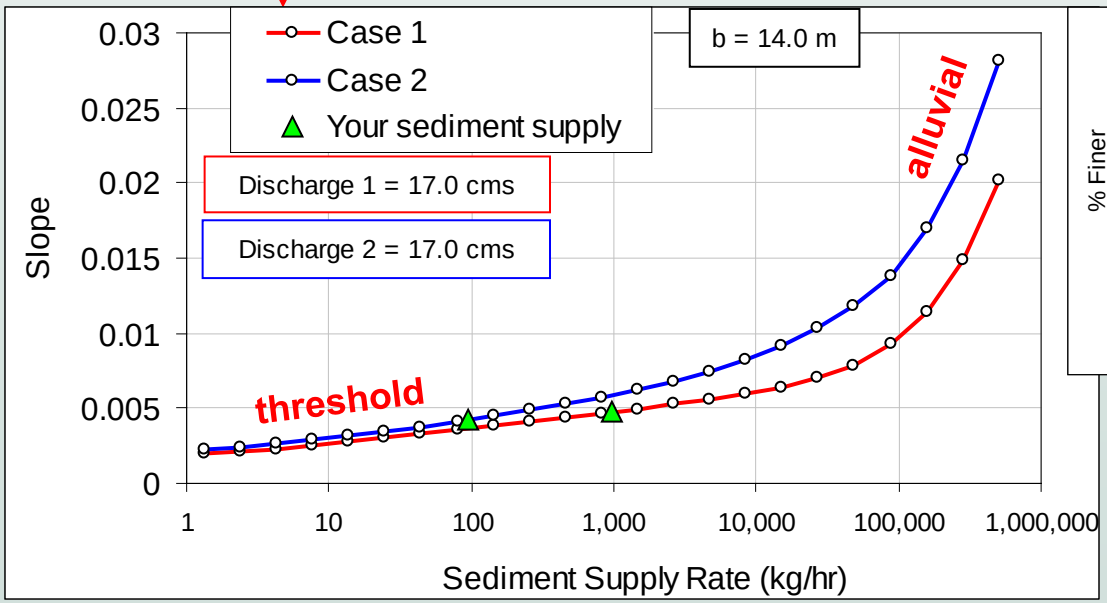
- Grain size of bed ≠ grain size of transport
- Bed is sorted spatially and vertically

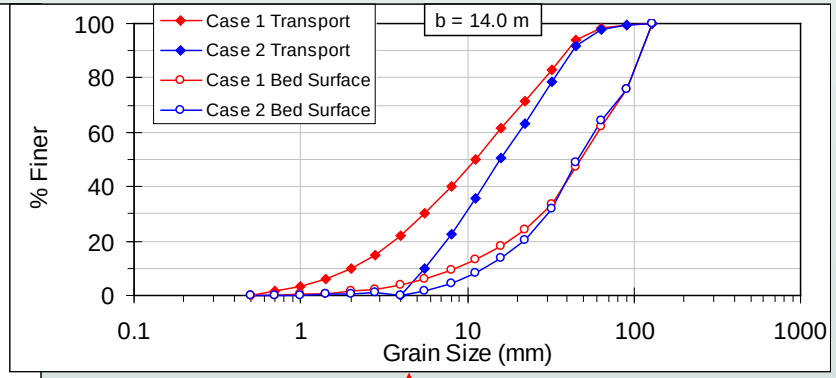
- **Forward**: predict transport rate & grain size
  as function of flow and bed surface grain size
- **Inverse**: predict flow and bed surface grain size
  as function of transport rate & grain size

iSURF Channel Stability Diagram



And get a basis for evaluating consequences of uncertainty in sediment supply!





As a bonus, you get a measure of bed armoring!

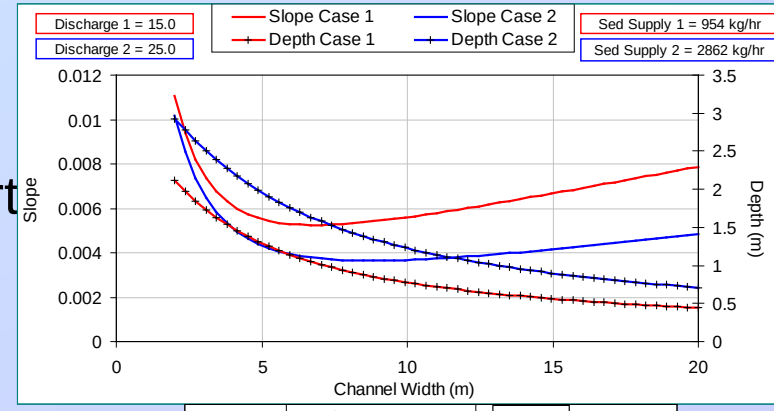
Design steps incorporating sediment supply

1. **Reconnaissance phase**: What is the trajectory of the stream? How has it responded to changes in water and sediment supply over the years?

$$\frac{S_2}{S_1} = \sqrt{\frac{q_{b2}}{q_{b1}}}\left(\frac{D_2}{D_1}\right)^{3/4}\left(\frac{q_1}{q_2}\right)$$

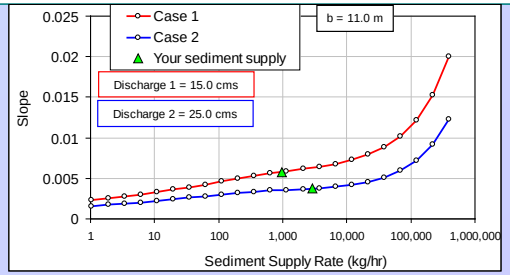
iSURF State Diagrams

2. **Develop flood series, specify flood frequency → Design *Q*.**
   {*Select Q_{bf} for flood frequency specified to maintain riparian ecosystem & prevent vegetation encroachment*}



3. **Estimate sediment supply**

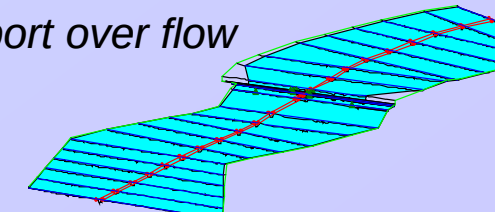
4. **Planning phase**: What slope *S* will transport the sediment supply with the available Q_{bf}? Calculate (b, S) combination {S and valley slope determine sinuosity}



Check if alluvial *v.* threshold channel

5. **Develop flow duration curve**

6. **Design phase**: Evaluate trial designs. Will the sediment supply be routed through the reach over the flow duration curve?
   {*Build 1-d hydraulic model for trial design. Calculate cumulative transport over flow duration curve at each section; evaluate sediment continuity.*}



7. Bottlenecks or blowouts? Adjust for sediment continuity

Linking the two approaches

"Morphological" Approach: Reference reach + hydraulic geometry

Bankfull geometry → Test for flow competence and transport capacity, then match to water & sediment supply

"Process" approach: specify water and sediment supply

Governing physical relations → Bankfull geometry then compare to typical channel geometry

Design channel from a template, then check for transport? OR Incorporate water & sediment supply into the design process?

In either case: the balance between sediment supply & transport capacity needs evaluation.

I

At the core of the template approach is a ***correlation*** between channel geometry, flow, and sediment supply

The correlation ***requires*** that the channels have ***adjusted*** to their water and sediment supply.

But what if channel is currently adjusting, or perpetually adjusting?

How would you know? How long will it take?
Will two channels with the same flow regime
& different sediment supply have the same geometry?

!

A template approach provides no basis for ***linking cause and effect*** in a logically complete and ***testable*** framework.

If a template-designed project "fails",
how is the method to be improved?

If a template approach works in one place,
how do you know it will work in another?

Stream Design Framework

Are objectives & outcomes connected to environmental drivers in an explicit, predictive fashion?

Are objectives linked to design in a quantitative and testable fashion?

Drivers

Water & sediment supply
Pollutant loading
Introduced species

Objectives

Reduce sediment, pollutant loads
Restore aq. & riparian populations
Protect infrastructure & property
Improve aesthetics

Design Variables

Channel geometry & composition
Floodplain elevation & extent
Riparian vegetation
type, density, location

Outcomes

WQ standards
Physical performance
Accepted appearance
Species recovery

Why Predict?

(1) tradeoffs
(2) project costs
(3) judging success
(4) ***learning***

Prediction includes uncertainty

Uncertainty

Is not an excuse

Does not = ignorance

Is pervasive and unavoidable

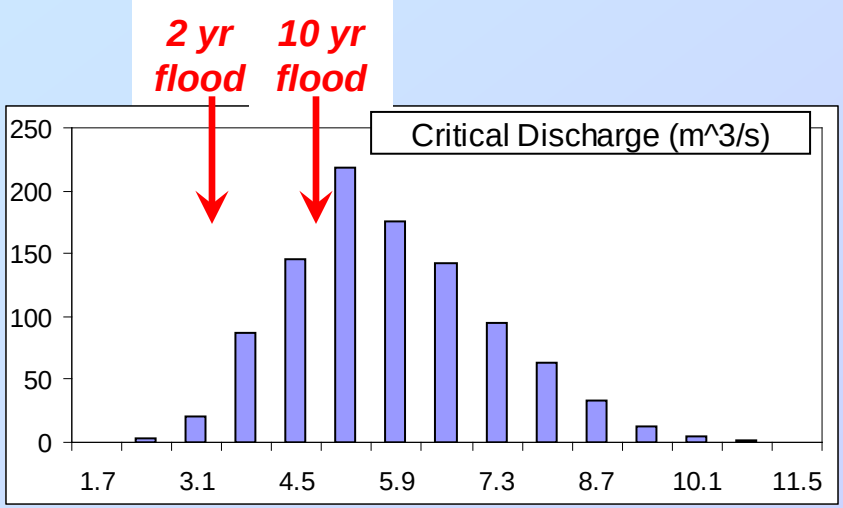
Incorporating Uncertainty in Channel Design

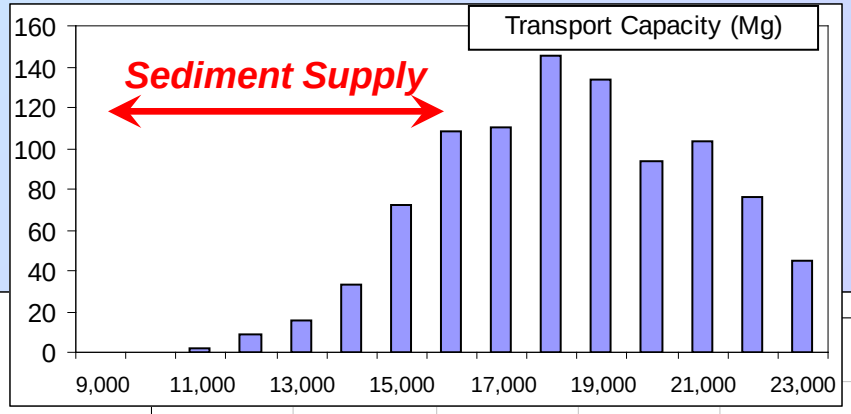
(Large Uncertainty ≠ Unpredictable)

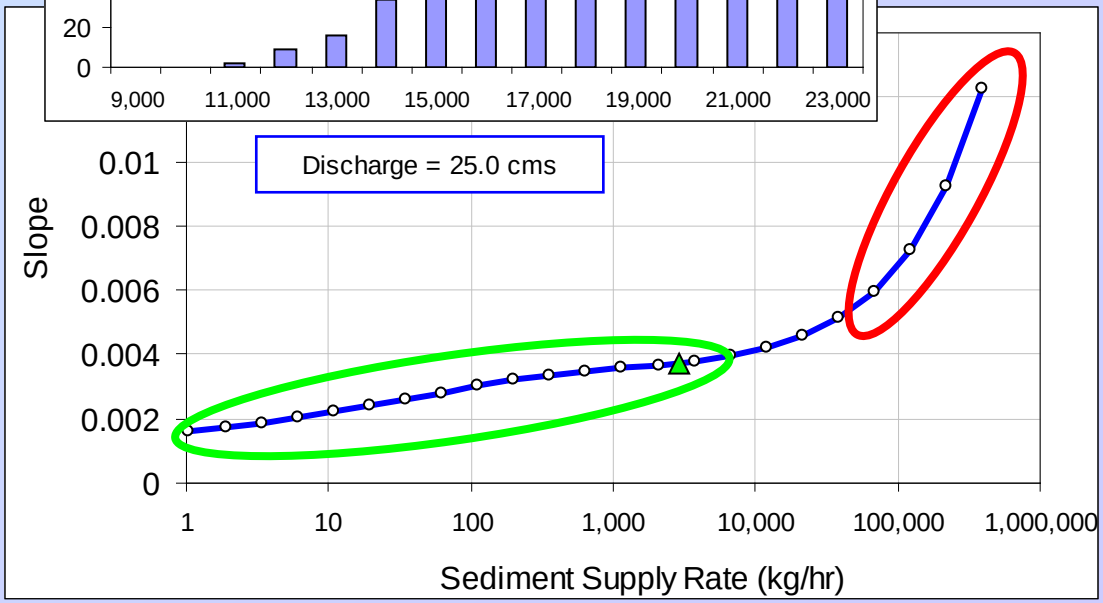
We can evaluate channel stability for flows of specified likelihood.

Or transport capacity relative to uncertainty in sediment supply

We can evaluate whether there is much of a chance that slope is sensitive to sediment supply such that further study is warranted







Stream Design Framework

Are objectives & outcomes connected to environmental drivers in an explicit, predictive fashion?

Are objectives linked to design in a quantitative and testable fashion?

Drivers

Water & sediment supply
Pollutant loading
Introduced species

Objectives

Reduce sediment, pollutant loads
Restore aq. & riparian populations
Protect infrastructure & property
Improve aesthetics

Design Variables

Channel geometry & composition
Floodplain elevation & extent
Riparian vegetation
type, density, location

Outcomes

WQ standards
Physical performance
Accepted appearance
Species recovery

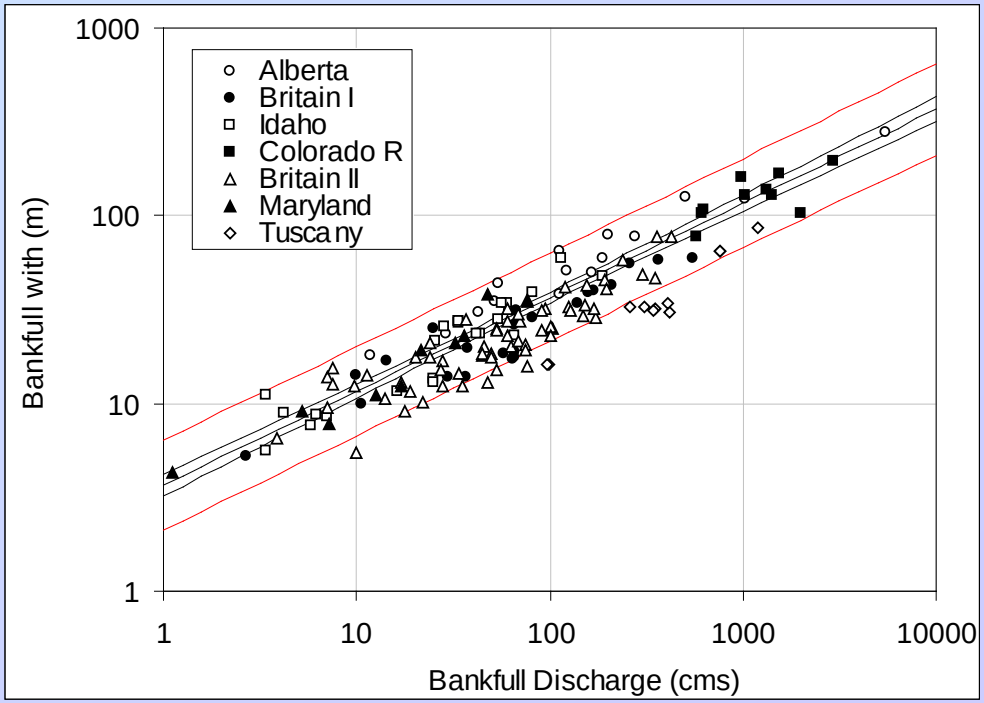
Why Predict?

(1) tradeoffs
(2) project costs
(3) judging success
(4) ***learning***

If we expect a channel to adjust to a particular geometry, why not bypass the adjustment process and just put the channel in its final equilibrium form?

What sets the equilibrium form?

- What flow and sediment supply is used?
- Do you get the same form for any sediment supply?
- In any region? How is this demonstrated?
- If the design performs poorly, what do you change?



If we expect a channel to adjust to a particular geometry, why not bypass the adjustment process and just put the channel in its final equilibrium form?

Will the ‘final’ form be stable with the post-construction riparian vegetation?

If we expect a channel to adjust to a particular geometry, why not bypass the adjustment process and just put the channel in its final equilibrium form?

What about the algae and bugs and fishes and trees?

Using modern design tools and the geomorphic reclamation approach, it's possible to reclaim highly disturbed lands and create fully functional natural systems virtually indistinguishable from their surrounding landscapes.

Morphologic stream design is not ecologic stream design

The classic observations of river geometry provide the observations that have fueled geomorphic research for the subsequent 60 yrs (and counting)

Defined in terms of equilibrium , they are unable to predict transient conditions

Devoid of mechanism, they have no basis for predicting new conditions

With no explicit linkage between cause and effect, they do not support learning by doing

All of these – predicting transient or new conditions and learning – must be and are supported by additional explanation