The core questions:
What is the supply of water and sediment?
What do you want to do with it?

More precisely,
1. What is the water discharge $Q(t)$ and sediment supply rate $Q_s(t)$ and grain size $D(t)$ delivered to the upstream end of the design reach?
2. How will the available flow move the supplied sediment through the design reach?

The core questions are often replaced by other questions

The imaginary: What is the dominant discharge? Why only one flow?

The wishful: $Q_{bf}$ (field) $\approx Q_{bf}$ (DA) $\approx Q_{eff} \approx Q_{1.5}$?

Basis for connecting to core questions?

The core questions may be difficult to answer But we cannot wish them away & ignoring them is the basis for project failure
How is sediment transport used in channel design?

The Template Problem – How to size a channel?

The standard: Choose \textbf{bankfull geometry} from a template:
a reference reach, regional hydraulic geometry

\begin{align*}
\text{resistance eqn.} & \rightarrow \text{bankfull flow} \\
\text{flood frequency curve} & \rightarrow \text{flood frequency} \\
\text{incipient motion criterion} & \rightarrow \text{flow competence}
\end{align*}

The alternative: specify flood frequency \textit{AND} sediment supply

\begin{align*}
\text{flood frequency curve} & \rightarrow \text{bankfull flow} + \\
\text{hydraulic \\& transport relations} & \rightarrow \text{channel slope \\& width} + \\
\text{channel shape relations} & \rightarrow \text{bankfull geometry}
\end{align*}

Are you actually balancing the sediment supply \& transport capacity or not?

But there is a more fundamental problem

A ‘template’ definition of design channel geometry is based on a correlation between channel geometry, flow, and sediment supply

This correlation \textit{is} remarkable:
\textbf{The flow that moves the most sediment, over time, tends to just fill the channel and occurs ever year or few. The width of channels increases very consistently with the square root of discharge.}

Why? How is possible? For which streams? Would one include in this compilation a stream draining a recently erupted volcano, or a recently burned forest, or a new suburban development?

The key: these correlations imply – \textbf{require} – that the channels have \textbf{adjusted} to their water and sediment supply. \textbf{But what if the channel is currently adjusting, or perpetually adjusting?}

Are you seeking the future adjusted channel geometry? Is there field evidence – discoverable now – for this channel geometry?

What is the basis for this? What is the “bankfull channel for the present regime” if \textbf{the present regime is changing \&/or the channel is still adjusting}?
ALLUVIAL SEDIMENTATION AND EROSION IN AN URBANIZING WATERSHED, GWINNS FALLS, MARYLAND

Mark F. Colman and Peter B. Wilcock
When does a disturbance here show up here? Is that before, during, or after the impact from a disturbance here?

Where is steady state found in a real watershed?
Stream stability is morphologically defined as the ability of the stream to maintain, over time, its dimension, pattern, and profile in such a manner that it is neither aggrading or degrading and is able to effectively transport the flows and sediment delivered to it by its watershed.

Sediment balance
often invoked, occasionally calculated, rarely predicted

Connecting sediment supply to the design problem

1. **Reconnaissance phase:** What is the trajectory of the stream? How has it responded to changes in water and sediment supply over the years? (Henderson relation → mixed-size sed)

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

3. **Estimate sediment supply**

4. **Planning phase:** What slope \( S \) is needed to carry the sediment supply with the available flow?
   (How does \( S \) vary with \( Q_s \) and width \( b \)?)

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.)
The Lane Balance, quantified almost 40 yrs ago by Henderson (1966, Open Channel Flow)

Einstein-Brown depth-slope continuity Chezy
\[ q^* \propto (\tau^*)^3 \quad \tau \propto RS \quad q \propto UR \quad U \propto \sqrt{RS} \]
\[ q_b \propto \frac{\tau^3}{D^{3/2}} \]
\[ q_b \propto \frac{(RS)^3}{D^{3/2}} \]
\[ q_b \propto \frac{q^2 S^2}{D^{3/2}} \]
\[ S \propto \sqrt{\frac{q_b D^{3/4}}{q}} \]

What if \( q_b \) increases and \( D \) decreases?
Lane’s balance is indeterminate.

or for two cases
\[ \frac{S_2}{S_1} = \sqrt{\frac{q_{b2}}{q_{b1}}} \left( \frac{D_2}{D_1} \right)^{3/4} \left( \frac{q_1}{q_2} \right) \]

Interpretation, for evaluating stream history
Steady state: sediment supply balanced by transport capacity. Slope is stable.

Increase sediment supply
Sediment supply > transport capacity
\[ S_2 > S_1 \quad \text{sediment accumulates} \]

Increase water supply
Sediment supply < transport capacity
\[ S_2 < S_1 \quad \text{sediment evacuates} \]

\[ \frac{S_2}{S_1} = \sqrt{\frac{q_{b2}}{q_{b1}}} \left( \frac{D_2}{D_1} \right)^{3/4} \left( \frac{q_1}{q_2} \right) \]
Effects of land-use change on channel morphology in northeastern Puerto Rico

Jeffrey J. Clark
Department of Geography and Environmental Engineering, Johns Hopkins University, Baltimore, Maryland 21218, USA

Peter R. Wilcox
Department of Geography, Lawrence University, Appleton, Wisconsin 54912, USA

ABSTRACT

Between 1930 and 1980 much of northeastern Puerto Rico was cleared for agriculture. Runoff increased by more than an order of magnitude. Much of the land clearance extended to steep valley slopes, resulting in widespread gullying and landslides and an increased load of coarse sediments delivered to the stream channels. A shift from agriculture to industrial and residential land uses over the past 50 yr has maintained the elevated runoff while sediment supply has decreased, allowing the rivers to begin removing coarse sediment stored within their channels. The size, abundance, and stratigraphic elevation of in-channel gravel bars decrease downstream, and the frequency of overbank flooding decreases downstream along those channels. This is presumed to be a transient state and continued transport will lead to degradation of the bed in downstream sections as the channel adjusts to the modern supply of water and sediment. A downstream decrease in channel size is contrary to the expected geometry of self-adjusted channels, but is consistent with the presence of partially eroded sediment remaining from the earlier agricultural period. Reverse (downstream-decreasing) channel morphology is not often cited in the literature, although consistent observations are available from areas with similar land-use history. Identification of reverse channel morphology along individual streams is important for identifying channel disequilibrium and anticipating future channel adjustments.

Keywords: channel response, geomorphology, land use, Puerto Rico, sediment supply.
NE Puerto Rico:
Very steep hillslides, cleared for subsistence agriculture.

Intense precipitation during hurricanes

Exceptionally high sediment yields, including a large fraction of coarse sediment from debris flows and gullying

<table>
<thead>
<tr>
<th>Land Use</th>
<th>Percent in each land use*</th>
<th>Runoff [t/a to surface runoff under complete forest cover]</th>
<th>Soil loss [t/a to loss under complete forest cover]</th>
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<td></td>
<td>Presettlement (1828)</td>
<td>Settlement (1836)</td>
<td>Agricultural (1948)</td>
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<tr>
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<tr>
<td>Forest 25%-50%</td>
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</tr>
<tr>
<td>Dense urban</td>
<td>0</td>
<td>0</td>
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</table>


Reference state is 100% forest cover during presettlement era. For each land use, change in runoff and soil loss relative to complete forest cover estimated using U.S. Department of Agriculture curve numbers and cropping factors calibrated for Puerto Rico (Haege et al., 1984; Lat, 1990). For each era, change in runoff and soil loss relative to presettlement conditions calculated using averages weighted by percent in each land use. 1928 land use from Spanish forest inventory (Widmer, 1950; Bledsoe and Weaver, 1987); land use in 1936, 1954, and 1969 from analysis of aerial photographs (Thomson et al., 1997).
Figure 5. Downstream trends in channel geometry for alluvial sections of the Rio Manueyes, Rio Sabana, and Rio Fajardo. No sections were measured in upstream portions of these streams or in a bedrock-confined reach between stations 5500 and 6800 on the Rio Sabana. The Rio Manueyes and Rio Sabana show a distinct decrease in channel size in the downstream direction, whereas there is no significant downstream trend in channel size for the Rio Fajardo. Note different scales used in each panel.

Figure 3. Schematic cross section showing main morphologic and sedimentologic features of northeastern Puerto Rican streams. Channels typically exhibit a compound form with a gravel deposit found within the channel. A silt cap overlies a cobble layer and a mottled clay layer where present. The top of the cobble layer is used as a reference datum to measure relative elevation between the thalweg (TW), silt cap (SC), and inset deposit (ID). The estimated cross-sectional area of the inset deposit is filled with a cross-hatched pattern. Channel dimensions were determined by using the top of the silt and cobble bank to define the channel-filling elevation. Representative radiocarbon sample locations are denoted by asterisks. Calendar years before radiocarbon present (cal. B.P.) are given in parentheses and two standard deviation confidence intervals are also shown (Table 3).
Figure 5. Downstream trend in the top of the thalweg, alluvial, and inset deposit elevation relative to the top of the cobbles layer found in the banks of alluvial sections of the Rio Maneyes, Rio Sabana, and Rio Fajardo. In all cases the top of the cobbles layer is plotted at an arbitrary elevation of 0. The ordinate is the difference between the elevation of the top of the cobbles layer and the tops of the other units. Only cross sections for which the cobbles layer was surveyed were included. Both the top of the inset deposits and the thalweg increase in relative elevation in the downstream direction. The alluvial exhibits a weak, but statistically insignificant increase in relative elevation (thickness) as well. Note different scales used on each ordinate axis.

Figure 8. Downstream trend in channel-filling discharge for alluvial sections of the Rio Maneyes, Rio Sabana, and Rio Fajardo. Locations of U.S. Geological Survey gages are denoted by *. The 1.5, 2, and 5 yr recurrence interval flows are shown as solid, long dashed, and short dashed lines, respectively. The slopes of the lines for the Rio Sabana and Rio Fajardo were determined by regional drainage area vs. discharge relationships from 9 gages in and around the study area (Table 1). The lines for the Rio Maneyes were determined using the two gages located on that river. In each case, the channel-filling discharge decreases and occurs more frequently as one moves downstream. Note different scales used on each ordinate axis.
The ‘width problem” – using the open channel toolbox to think about predicting (or designing) channel geometry

"Given": \( Q, Q_s, D, \rho, \rho_s, g, n, n_D \)

"Find": \( U, h, \tau, B, S \)

- Conservation Relations
  - Water Mass \( \dot{Q} = UA \)
  - Momentum \( \tau = \rho g RS \)

- Constitutive Relations
  - Flow resistance \( U = \frac{\sqrt{S}}{n} AR^{2/3} \)
  - Sediment transport \( q^* = 8 \left( \tau^* - \tau_c^* \right)^{3/2} \)

- We are short one relation
  - … for channel width \( B = aQ^b \)

### Mean depth
\( H = \frac{A}{B} \)

### Hydr. Radius
\( R = \frac{A}{P} \)
What slope is needed to carry the sediment supply with the available flow?

Given \( Q, Q_s, b, n, n_D, \tau_c^* \) and \( D \), find \( \tau', U, h, R \) and \( S \) from

\[ \tau' = (s-1)\rho g D \left( \tau_c^* + \frac{Q_s}{b} \frac{1}{8\sqrt{(s-1)gD^3}} \right)^{2/3} \]

\[ U = \frac{\sqrt{S}}{n} R^{2/3} \]

\[ h = \frac{Q}{U b} \]

\[ R = \frac{b h}{b + 2h} \]

\[ S = \frac{\tau'(n/n_D)^{3/2}}{\rho g R} \]

Meyer-Peter & Muller & Manning & Continuity & Depth-slope
We can easily incorporate uncertainty in the input:

What slope is needed to carry the sediment supply with the available flow?

Given $Q, Q_s, b, n, n_D, \tau^*_c$, and $D$, find $\tau', U, h, R$ and $S$ from

\[
\tau' = (s-1)\rho g D \left( \frac{Q_s/b}{8\sqrt{s-1}gD^2} \right)^{2/3}
\]

\[
U = \frac{\sqrt{S}}{n} R^{2/3}
\]

\[
h = \frac{Q}{Ub}
\]

\[
R = \frac{bh}{b + 2h}
\]

\[
S = \frac{\tau'(n/n_D)^{3/2}}{\rho g R}
\]

Planning

This is BIG!
Do we even need to worry about sediment transport?
Hydraulic Geometry = \( f(\text{discharge, not sediment supply}) \)

Channel Adjustment Below Dams

*often driven by flow releases and vegetation establishment*

Trinity River below Trinity Dam

(Image courtesy A. Krause)
Sediment supply does matter …

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

<table>
<thead>
<tr>
<th>Threshold</th>
<th>Alluvial</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bed &amp; banks immobile</td>
<td>Active transport</td>
</tr>
<tr>
<td>Easier to model &amp; design</td>
<td>Harder to design</td>
</tr>
<tr>
<td>Bed &amp; banks must only be strong enough</td>
<td>Requires a balance between transport capacity &amp; sediment supply</td>
</tr>
</tbody>
</table>

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, let’s deal with real sediments, which contain a mixture of sizes
requires decision regarding grains to exclude from the transportable population bed immobile at typical high flows

Bed Material – Coarse
med-crs gravel, cobble

Bed Material – Huge
boulder

Bed Material – Fine
med-crs sand, pea gravel

Washload
clay, silt, fine sand

Bed Material – Fine
coarse med-crs gravel, cobble

Bed Material – Coarse
grin path in near-bed region dominated by larger grains; hard to sample & model

Bed Material – Huge
boulder

Bed load or suspension
interstices, stripes and dunes, subsurface

Bed load
bed framework

immobile at typical high flows
bed

Notes

Source

Mode

<table>
<thead>
<tr>
<th>Fraction</th>
<th>Mode</th>
<th>Source</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Washload</td>
<td>suspension</td>
<td>?? uplands, banks, backwaters, …</td>
<td>true washload: (a) Transport not predictable (b) too little in bed to affect transport of other fractions</td>
</tr>
<tr>
<td>Bed Material – Fine</td>
<td>bed load or suspension</td>
<td>interstices, stripes and dunes, subsurface</td>
<td>grain path in near-bed region dominated by larger grains; hard to sample &amp; model</td>
</tr>
<tr>
<td>Bed Material – Coarse</td>
<td>bed load</td>
<td>bed framework</td>
<td>displacements generally rare and hard to capture</td>
</tr>
<tr>
<td>Bed Material – Huge</td>
<td>immobile at typical high flows</td>
<td>bed</td>
<td>Requires decision regarding grains to exclude from the transportable population</td>
</tr>
</tbody>
</table>

Estimating Bed Material Transport
How Many Sizes? How about 2?

- Minimum useful number of fractions; matches fine/coarse bed material distinction
- Allows integral measure of bed material – define mean size of two fractions map facies defined on proportions
- Two fractions capture - Interaction between fine and coarse sizes - important sedimentation impacts (increased sand supply from fire, reservoir flushing, dam removal, urbanization, …)

These interactions and inputs cannot be ignored
Some experimental evidence

- 5 sediments, add sand to gravel
- Sand: 0.5 – 2.0 mm
- Gravel: 2.0 – 64 mm
- Sand Content: 6, 14, 21, 27, & 34%
- 9 or 10 runs with each sediment, wide range of transport rates
- Depth & width held constant, primary variables are sand content & flow strength

Effect of sand content on gravel transport rate
The sand effect on transport is captured by a reduced critical shear stress for incipient motion of the gravel.

For $D > 4$ mm,

\[
\tau_c^* = \frac{\tau_c}{(s-1)\rho gD} \cong 0.045
\]

\tau_c^* \text{ for } \tau_c

Reducing $\tau_c^*$ by a factor of four will increase the transport rate by much, much more.
Test sand effect in a sediment feed flume

Feed gravel (2-32 mm) at same rate in each run; Increase sand feed rate from much less to much more than gravel

**Results**

As sand feed increases, bed gets sandier & slope decreases: less stress required to carry same gravel load & increased sand load

---


The point?

Adding sand can have a huge effect on gravel transport rates

& there are lots of reasons why sand supply to a gravel-bed river might be increased

There is an *interaction* between sand/gravel content and the transport rates of each fraction

A two fraction approach captures this effect in a tractable framework

But there are more reasons to like a two-fraction transport model!

*Robust!*

*Mappable!*

*Captures sand/gravel interaction!*

Little Granite CK, nr Bondurant WY
Excessive loading of fine sediment – the most serious impairment of California coastal rivers

S. Fk Eel river heavily loaded 1950s-1970s, and from natural sources

Lots of data on impacts of fine sediments on eggs and emerging fry, but no experimental data on effects on juvenile rearing. Juveniles may be bottleneck for recovery of chinook populations...(Kareiva et al. 2000, Science 290: 977) and other west coast salmonids....
Effect of fine (< 2 mm) sediments on juvenile steelhead and the food webs that support them (Suttle, Power, Levine, McNeely, Sapp, Sorenson)

6 levels: 0, 20, 40, 60, 80 and 100% embedded

2 m x 0.5 m flow through channels

Replicated at 4 sites over ca. 4 km of S. Fk. Eel

Growth in length and mass decreased linearly with proportion of fine sediment in the bed

Growth in length and mass decreased linearly with proportion of fine sediment in the bed

Length gain ($R^2 = 0.63$, $P < 0.0001$)
Mass gain similar ($R^2 = 0.59$, $P < 0.0001$)
This occurred in part, because benthic invertebrate assemblages in more embedded treatments were made up of less available taxa.

...and in part because fish were more active (and aggressive towards each other) on the flat, featureless beds in embedded treatments,

Mortality increased with embeddedness, and was associated with wounds from fighting.
But there are more reasons to like a two-fraction transport model!

- Robust!
- Mappable!
- Captures sand/gravel interaction!

What about more fractions?

Many-fraction models available: including ones based on the grain size of the bed surface, which allows for the prediction of transient conditions.

These models are fragile – output is sensitive to the quality of the input.

For the practical problem of estimating transport at a particular location, at a particular time, better to go with a few measurements & two fractions.

Use a many fraction model to ask more general questions:
  - e.g. change in bed composition & transport with a change in flow releases from dams or a change in sediment supply from dam removal for channel design.
For mixed-size sediment, there are complications

- Grain size of bed ≠ grain size of transport
- Bed is sorted spatially and vertically
- Transport is a function of the grains on the bed surface

A transport model referenced to the bed surface is needed to predict transient conditions & the ultimate channel size and slope.

Surface-based Transport Model for Mixed-Size Sediment

Peter R. Wilcock, M.ASCE, and Joanna C. Grove

48 flume runs w/ 5 sediments
Incorporates sand
And effect of sand on transport of other sizes
Tested against field data
Surface-based transport model can be used in both forward & inverse forms

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

*Don’t try this with a subsurface–based model!*

We can use an inverse transport model to forecast, or design, a steady state channel that will transport a specified sediment supply rate \textit{and} grain size with the available flow (!)

Presenting ….

![iSURF](image)

1. **State Diagram I** –
   \( \text{transport v. discharge} \), lines of constant slope
2. **State Diagram II** –
   \( \text{transport v. slope} \), lines of constant discharge
3. **Channel Stability Diagram**

   - **Inverse Model**: predict $\tau$ and bed surface grain size as fn(transport rate & grain size)
   - Specify discharge and basic channel geometry and solve for slope (\& depth)
Stream State Diagrams

"Given": \( q, q_T, P_i, s, \rho, \rho_s, g \)

"Find": \( U, h, \tau(S), F_i, n \)

- Conservation Relations
  - Water Mass \( q = U h \)
  - Momentum \( \tau = \rho g h S \)

- Constitutive Relations
  - Roughness relation \( n = f(F_i) \)
  - Sediment transport \( iSBTM \) gives \( \tau, F_i \)
  - Flow resistance \( U = \frac{\sqrt{S}}{n} h^{2/3} \)

We are working per unit width ...

The iSBTM routine calculates bed shear stress and bed surface grain size for a specified transport rate and transport grain size. Each transport rate and grain size and, therefore, shear stress and bed surface grain size, can be produced by different combinations of unit discharge \( q \) and slope \( S \). The state diagrams present families of curves giving either transport rate and water discharge for specified values of \( S \), or transport rate and \( S \) for specified values of water discharge.
State Diagram II – lines of constant $q_w$

Interpretation, for evaluating stream history

Steady state: sediment supply balanced by transport capacity. Slope is stable.

Increase sediment supply
Sediment supply $> \text{transport capacity}$
$S_2 > S_1$ sediment accumulates

Increase water supply
Sediment supply $< \text{transport capacity}$
$S_2 < S_1$ sediment evacuates

$S_2 \approx \frac{qb_2 D_2}{qb_1 D_1} \frac{D_2}{D_1}^{3/4} \left( \frac{q_1}{q_2} \right)$
Channel adjustments in streams with coarse, mixed-size sediment: what slope is needed to transport the supplied sediment with the available water?

These are the transport rates where slope takes off

State Diagram II
lines of constant $q_w$

If your sediment supply is safely below the boundary between “low” slope and “high” slope, channel slope is relatively insensitive to sediment supply – you are less likely to accumulate or evacuate sediment in response to a change in supply (the channel is less sensitive to changes in water and sediment supply)

and that’s what a SMALL sediment supply rate is …
**iSURF**

**Channel Stability Diagram**

What slope is needed to transport a specified transport rate of specified size distribution with a specified discharge through channels of different widths?

Given $Q_s, (p_i, D_i), Q, n_s, z, b$

Find $\tau_b, (F_i, D_i), n_D, U, h, S$

Using transport, continuity, momentum, resistance, & Strickler

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<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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<td>FIRST water discharge</td>
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<tr>
<td>$Q_{1s}$</td>
<td>0.001</td>
<td>FIRST sediment feed rate</td>
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<tr>
<td>$Q_{2s}$</td>
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<td>SECOND water discharge</td>
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<td>$b_{max}$</td>
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<td>Maximum bottom width</td>
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<table>
<thead>
<tr>
<th>D (mm)</th>
<th>FIRST Transport CDF GSD (% Finer)</th>
<th>SECOND Transport CDF GSD (% Finer)</th>
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**Channel Stability Diagram**

And get a measure of where you are relative to the threshold/alluvial channel boundary!

As a bonus, you find out how armored the bed becomes!
1. **Reconnaissance phase**: What is the trajectory of the stream? How has it responded to changes in water and sediment supply over the years? *(Henderson relation)*

\[
\frac{S_2}{S_1} = \left(\frac{q_{b2}}{q_{b1}}\right)^{3/4} \left(\frac{D_2}{D_1}\right)^{1/4}
\]

2. **Develop flood series, specify flood frequency** → \(Q_{bf}\).

*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 \(\{S \text{ and valley slope determine sinuosity}\) what grain size? which section?

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

---

**Connecting sediment supply to the design problem**

**Alluvial Channel Design - Outline**

Step-backwater model gives \(S(Q), U(Q)\) at each section

Grain stress: \(\tau = 17 (SD_{65})^{1/4} U^{3/2}\)

Calculate transport over the flow dur. curve at each section

Adjust \(x/s\) transport for lateral variation in \(\tau\)

Query potential bottlenecks, blowouts transport < capacity?

flow model reliable?

erosion/deposition desirable?

Adjust channel dimensions & shape to match supply, within tolerance level & design objectives.

Use transport modeling to:

* Evaluate design, esp. \(\Delta Qs\) from section to section

* Determine if more accurate transport modeling is needed
Incorporating Uncertainty in Channel Design

(Large Uncertainty ≠ Unpredictable)

- Threshold transport
- Critical discharge
- Sediment loads
- Channel geometry
Software and text can be found at

www.nced.umn.edu

or

https://jshare.johnshopkins.edu/pwilcoc1/public_html/