Sediment Transport V: Estimating Bed-Material Transport in Gravel-Bed Rivers

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Target: sediment rating curve $Q_s = f(Q)$

Approaches

- Predict from a flow & transport model
  - We can't measure everything, but
  - Models too fragile
- Sample transport
  - Nothing beats the real thing, but
  - Accuracy poor and a full sampling program too burdensome
- Future: robust models and automated sampling
- *Tracer gravels and scour chains*
- *Measure volumetric change in local topography*

Issues:

1. Dealing with grain size
   (2 fraction; from previous lecture)
2. How do we sample bed material load?
3. Estimating transport rates

Fraction	Mode	Source	Notes
Washload clay, silt, *fine sand*	suspension	?? uplands, banks, backwaters, …	true washload: (a) Transport not predictable (b) too little in bed to affect transport of other fractions
Bed Material – Fine med-crs sand, *pea gravel*	bed load or suspension	interstices, stripes and dunes, subsurface	grain path in near-bed region dominated by larger grains; hard to sample & model
Bed Material – Coarse med-crs gravel, cobble	bed load	bed framework	displacements generally rare and hard to capture
Bed Material – Huge boulder	immobile at typical high flows	bed	Requires decision regarding grains to exclude from the transportable population

2. How to sample the transport of fine and coarse bed material?

Other than building a weir to trap all the transport, the available options are to use hand-held samplers or pits or net-frame samplers installed on the bed.

Sampling I

Transport field highly variable in space & time

→ Need LARGE samples!

Define ***Sampling Intensity*** for a 6.5m stream

Total Transport	[6.5m] X [3600s] = **23,400** m•s	
Hand-held Sampling Transect	[13 * 0.075m] X [120s] = **117** m•s	**(0.5%)**
Pit/Trap Sampler	[5 * 0.305 m] X [3600s] = **5,490** m•s	**(23.5%)**

So, pit or net-frame traps look pretty good …

Pit samplers fill up

at high transport rates

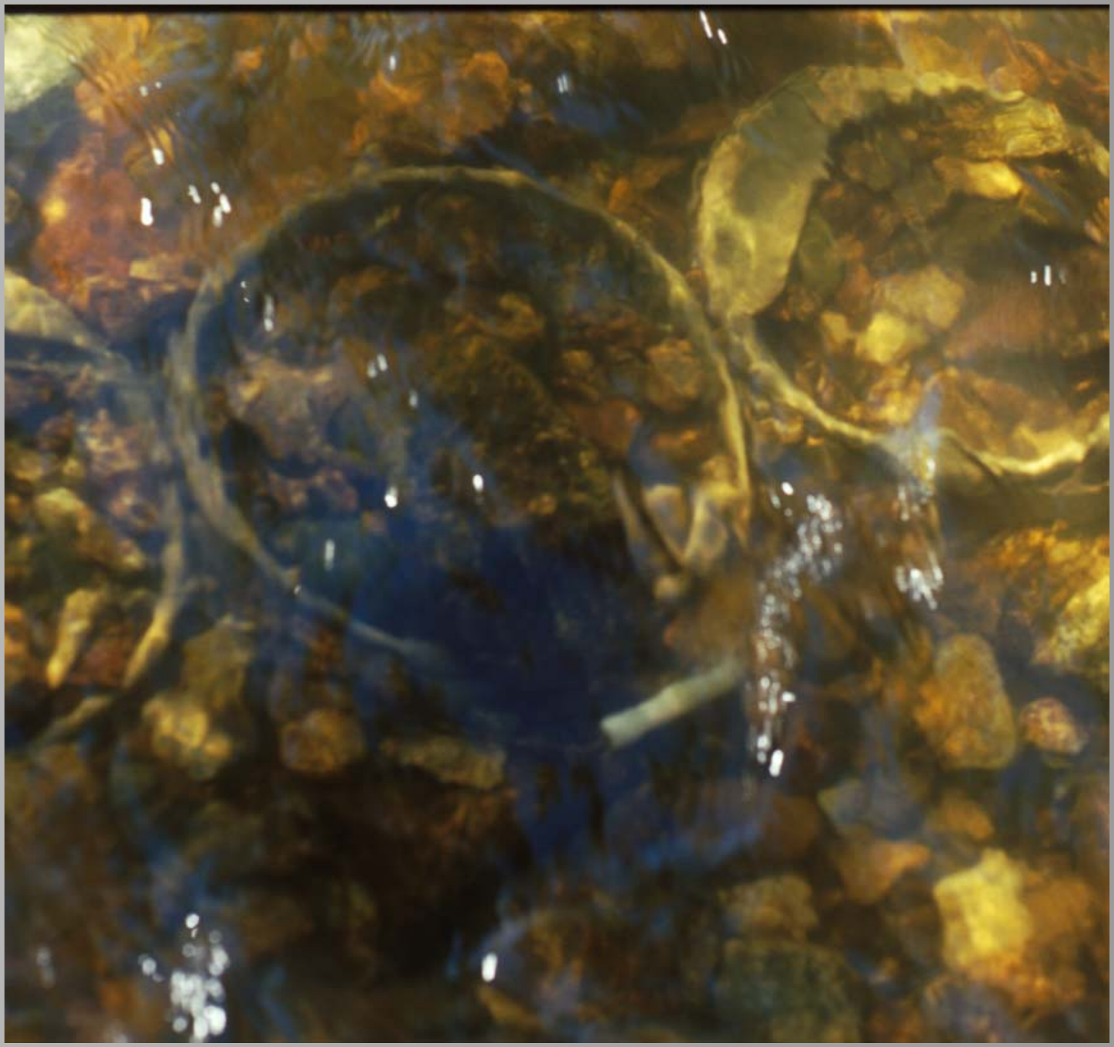


Photo J Pizzuto, U Delaware, home of big samples

So do net-frame samplers

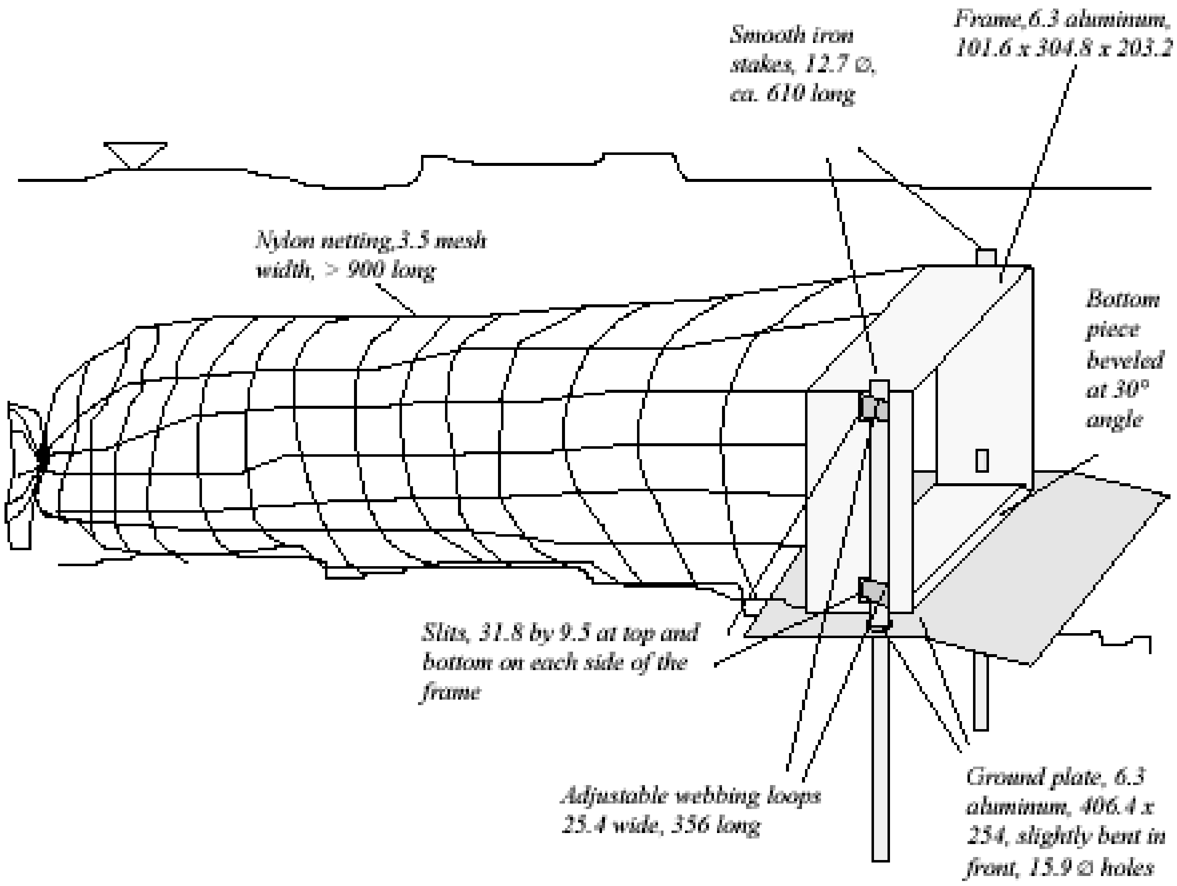


Fig. 1: Schematic diagram of a bedload trap. All measurements in mm (from Bunte 1998).

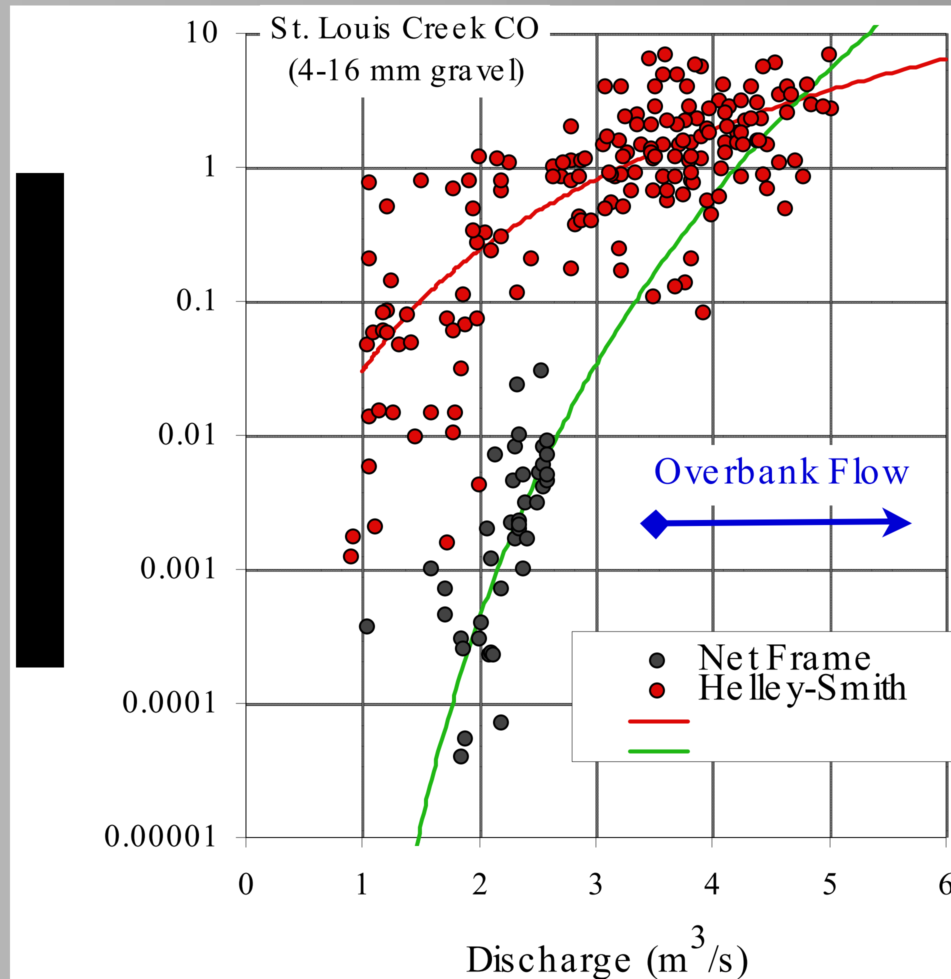
Bunte, K., 1998. Development and field testing of a stationary net-frame bedload sampler for measuring entrainment of pebble and cobble particles, Report prepared for the Stream Systems Technology Center, USDA Forest Service, Rocky Mountain Research Station, Fort Collins, CO, 74 pp.

Sampling II

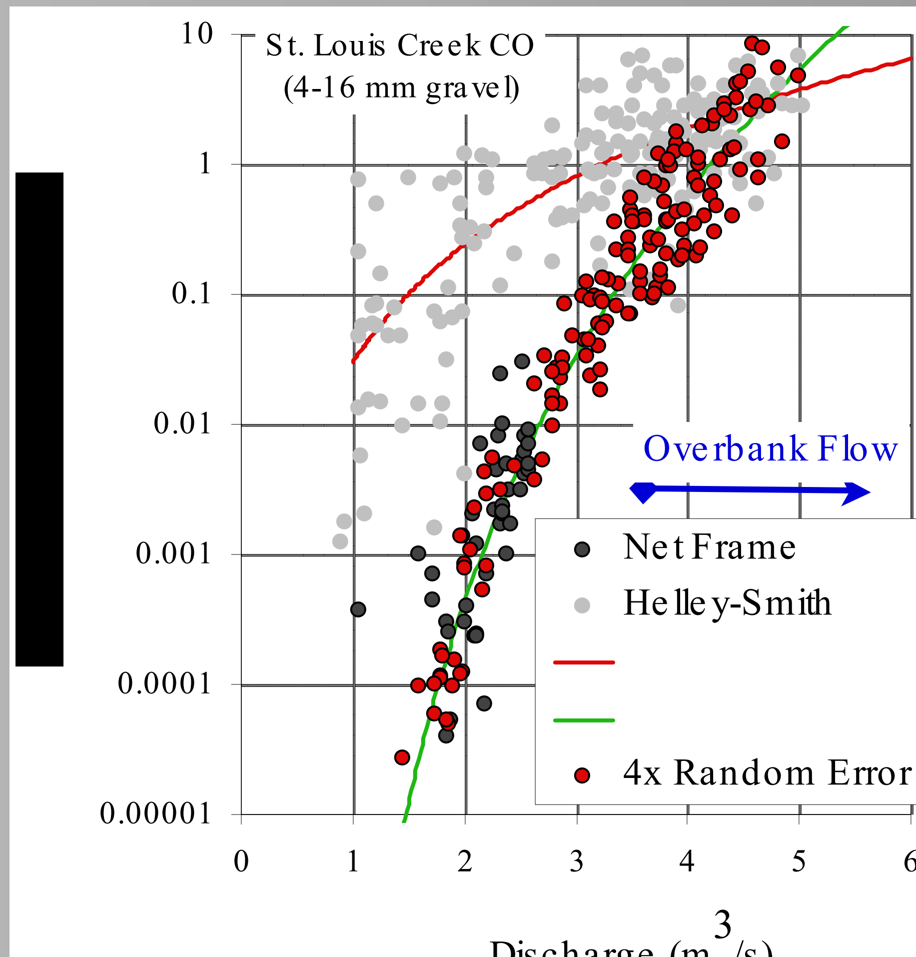
Tiny samples are subject to large bias from small errors. Illustrate with observations from St. Louis Creek CO, for which both Helley-Smith & net-frame sampling has been conducted.

St Louis Creek, CO

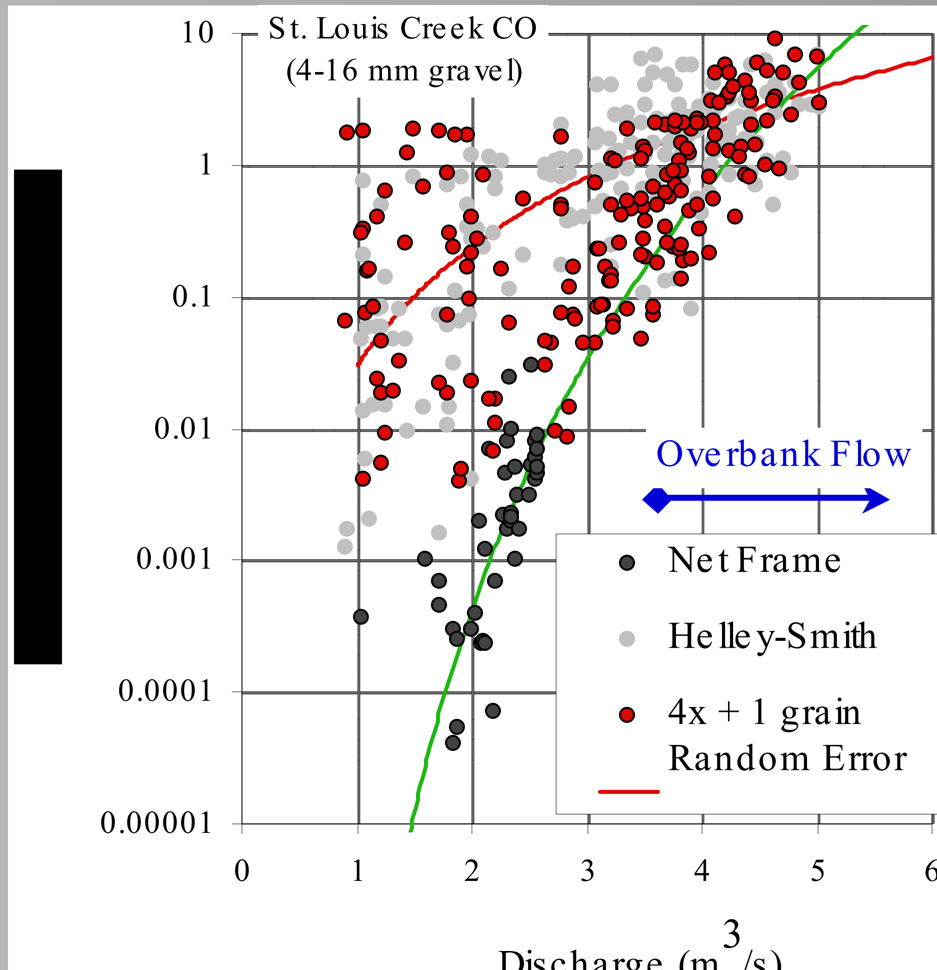
Helley-Smith v. Net-Frame Observations



Add some random error (4x)



Add 0 to 1 grain per sample



FIHSBP

Federal **I**nteragency **H**elley-**S**mith **B**uyback **P**rogram

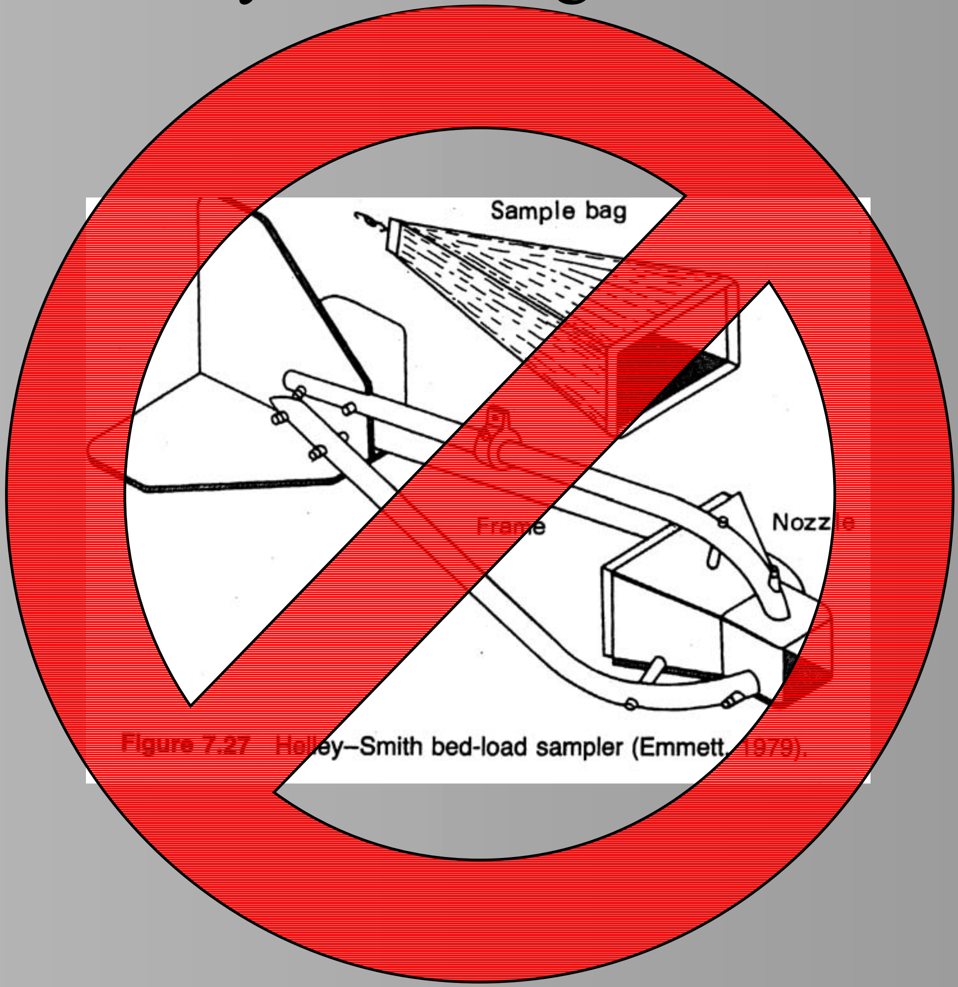


Figure 7.27 Helley–Smith bed-load sampler (Emmett, 1979).

But wait! Before melting down your Helley-Smith sampler—how will you sample the fine bed-material load?

If pits do not trap sand efficiently, and the mesh on net traps is too large, then maybe the Helley-Smith is our best avaiable tool for sampling the fine bed material load.

Transport Fraction	Physical Sampler	Surrogate Sampler
Wash load	Std. suspended sediment samplers	Various sound & light
Fine Bed Material	Helley-Smith	Suction Device?
Coarse Bed Material	Net or pit traps	Acoustic?

3. Estimating Sediment Transport

•Direct sampling

+ gives a direct relation between Q and Qs
- requires a big effort
- cannot predict future conditions
- error: is it random or systematic?
- Handheld samplers: Scooping, perching, limited size grain size & TINY SAMPLES
- Pit/Net-frame samples: better sampling, only at low rates

•Formula predictions

+ can predict future changes
- highly inaccurate
  - flow hard to scale
  - boundary conditions poorly known

The alternative? Join forces.

Need for both accuracy and efficiency indicate that the future is a combination of **simple robust models** and **efficient measurement**.

A first cut, using today's technology

- If pit/trap samplers can collect good samples of small transport rates, why not use these to calibrate a model of coarse bed-material transport
- **GOOD** samples! (long duration, spatially extensive)
- Two sizes: sand and gravel
- Combine in robust framework that is insensitive to major sources of error

Transport Formula (Gravel)

$$W_i^* = \begin{cases} 11.2\left(1 - 0.846\dfrac{\tau_r}{\tau}\right)^{4.5} & \tau > \tau_r \\ 0.0025\left(\dfrac{\tau}{\tau_r}\right)^{14.2} & \tau < \tau_r \end{cases}$$

Calibrate τ_r

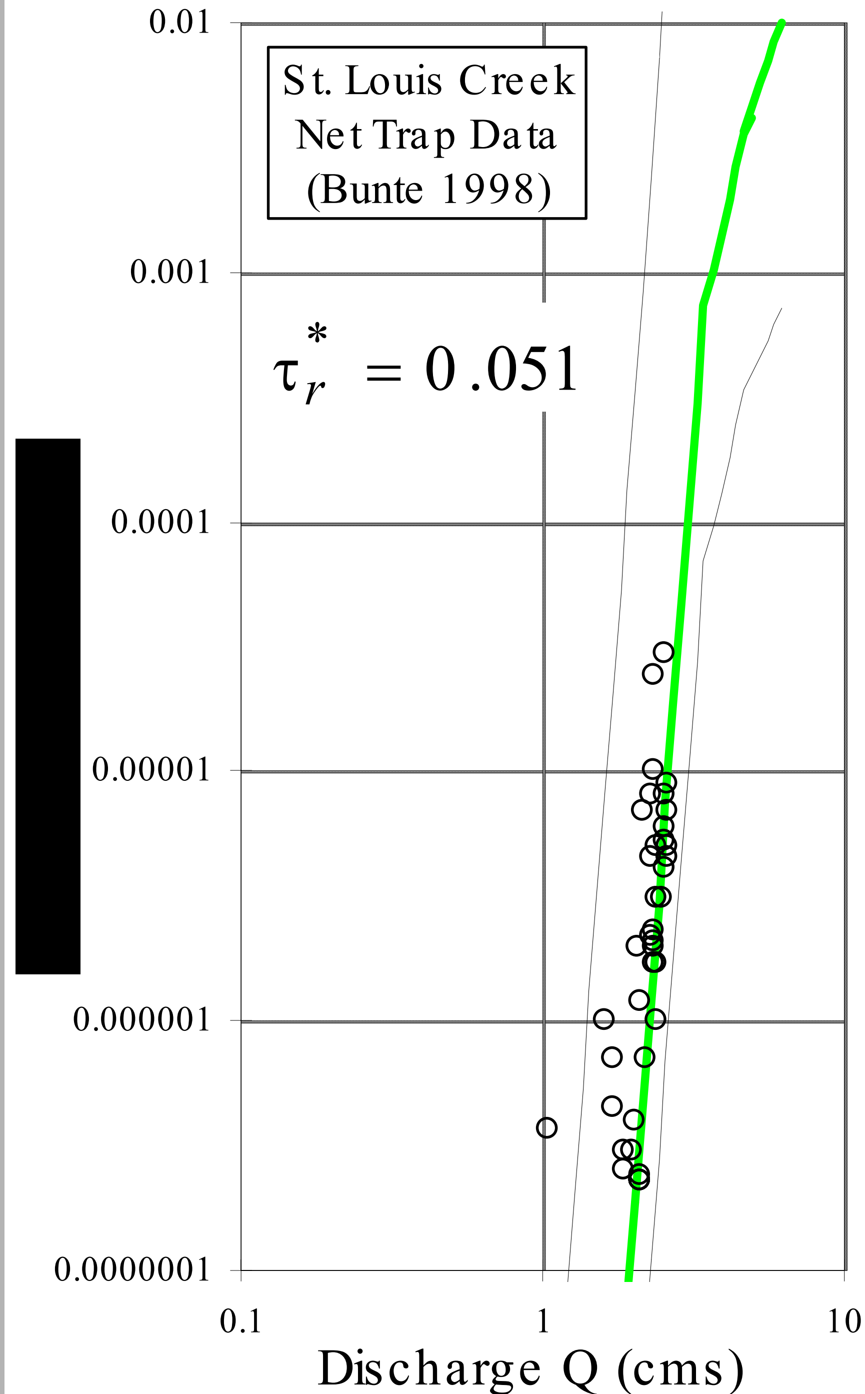
Choice of formula does not make that much difference!

Formula provides the trend,but the samples provide the accuracy

Transport formula based on shear stress τ, so we need a drag partition formula to get grain stress from discharge:

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

- For St. Louis Creek:
- Slope $S = 0.018$
- $D_{65} = 76$ mm
- Mean velocity $U = 0.63\, Q^{0.67}$


St. Louis Creek
Net Trap Data
(Bunte 1998)
$\tau_r^* = 0.051$
[redacted]
0.01
0.001
0.0001
0.00001
0.000001
0.0000001
0.1
1
10
Discharge Q (cms)

Transport samples provide accuracy by providing a basis for scaling the flow!

Calculate grain stress: $\tau = 17(SD_{65})^{0.25} U^{1.5}$

for two different flows & take the ratio: $\frac{\tau_1}{\tau_2} = \left(\frac{U_1}{U_2}\right)^{1.5}$

Suppose $U = aQ^b$

then $\frac{\tau_1}{\tau_2} = \left(\frac{Q_1}{Q_2}\right)^{1.5b}$

If you calibrate, the transport formula is needed only to give the change in transport with the change in discharge.

Most of the transport occurs at high flows & you base your estimate on samples at low flow?

Wilcock, P, 2001. Toward a practical method for estimating sediment transport rates in gravel-bed rivers, *Earth Surface Processes & Landforms* 26, 1395-1408.

Estimating bed-material transport in gravel-bed rivers

- **Conceptual basis**
  - fine and coarse bed material
  - (supply of one affects the transport of the other)
- **Sampling**
  - standard needed for minimum sample size
  - fine bed material – Helley-Smith or ?
  - coarse bed material – pit or net frame samplers
  - big rivers – ???
- **Modeling**
  - 2-fraction model captures essential interaction between fine & coarse & facilitates integral measure of reach grain size
  - But it can't do everything (armoring; change in sand or gravel size)
- **Future**
  - combine simple, robust models with efficient monitoring
  - can be done now in wadeable streams, although effort is non-trivial