

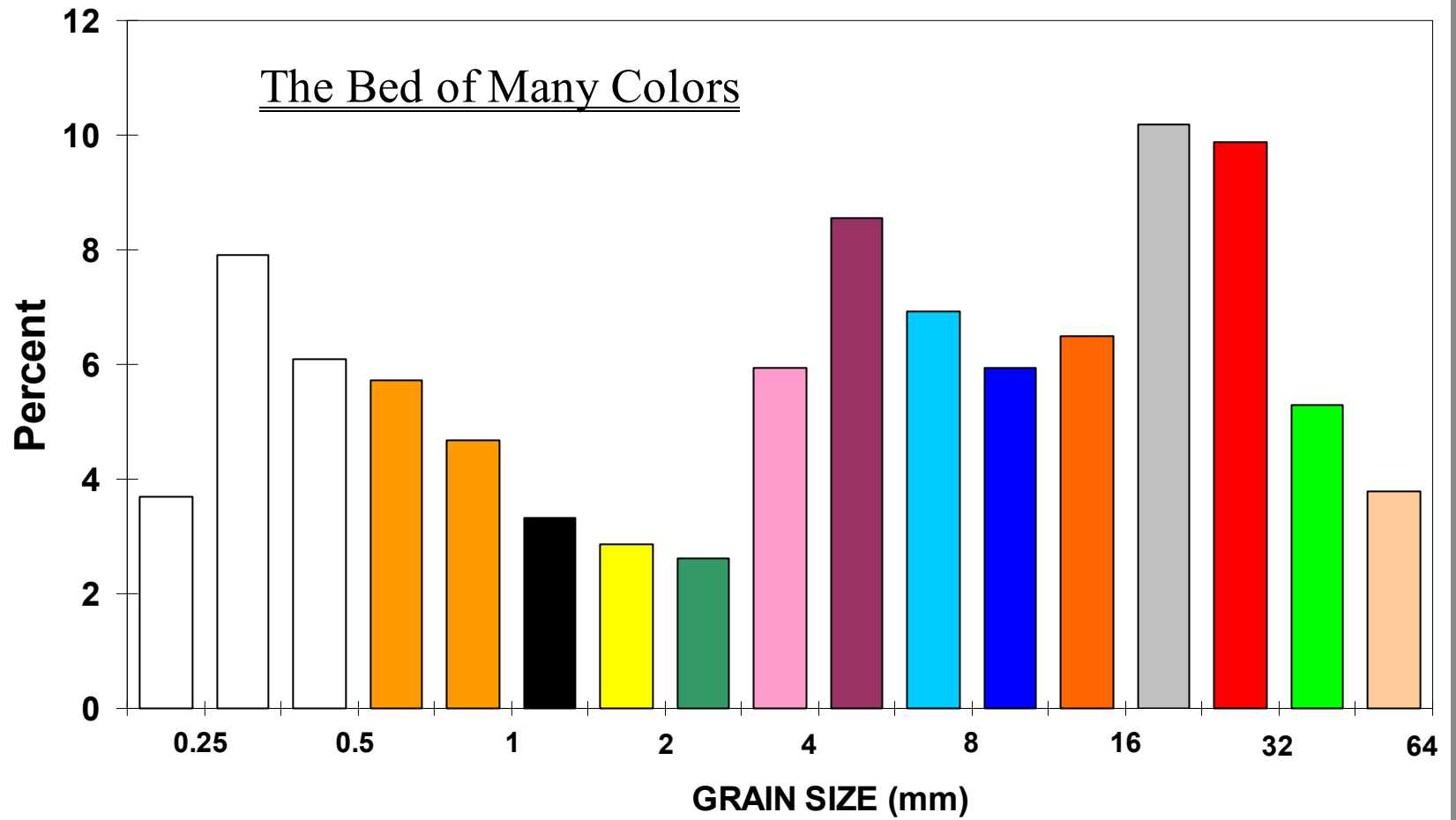
Sediment Transport IV

Mixed-Size Sediment Transport

1. Partial Transport: frequency & implications
using field and laboratory evidence
2. Armor layer persistence
investigated using a surface-based transport
model.
3. Effect of adding sand to a gravel-bed river
leading to a two-fraction transport model



The Bed of Many Colors



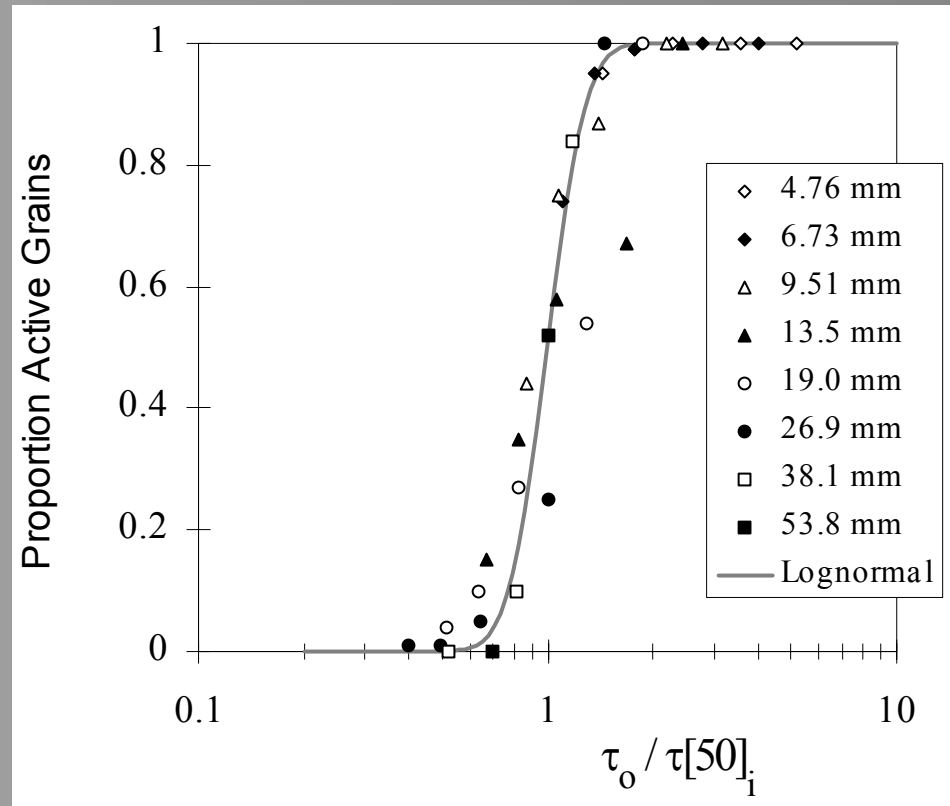
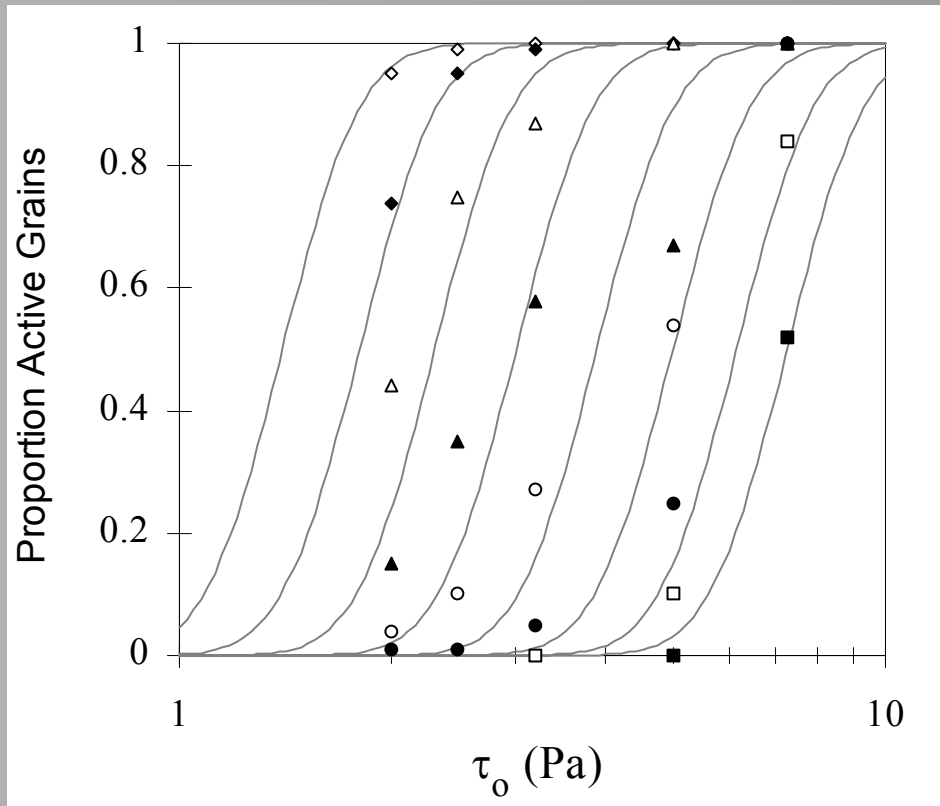
1. Bed Entrainment & Partial Transport



Partial Transport

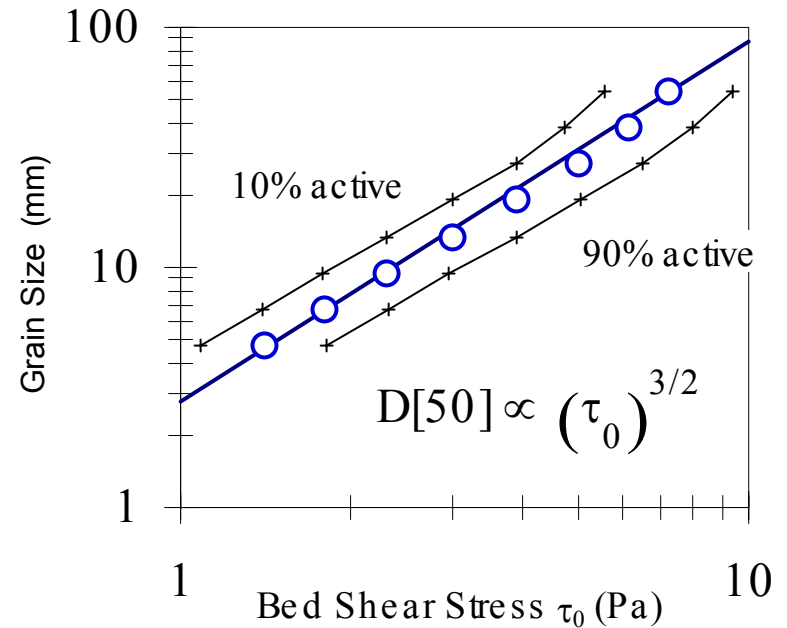
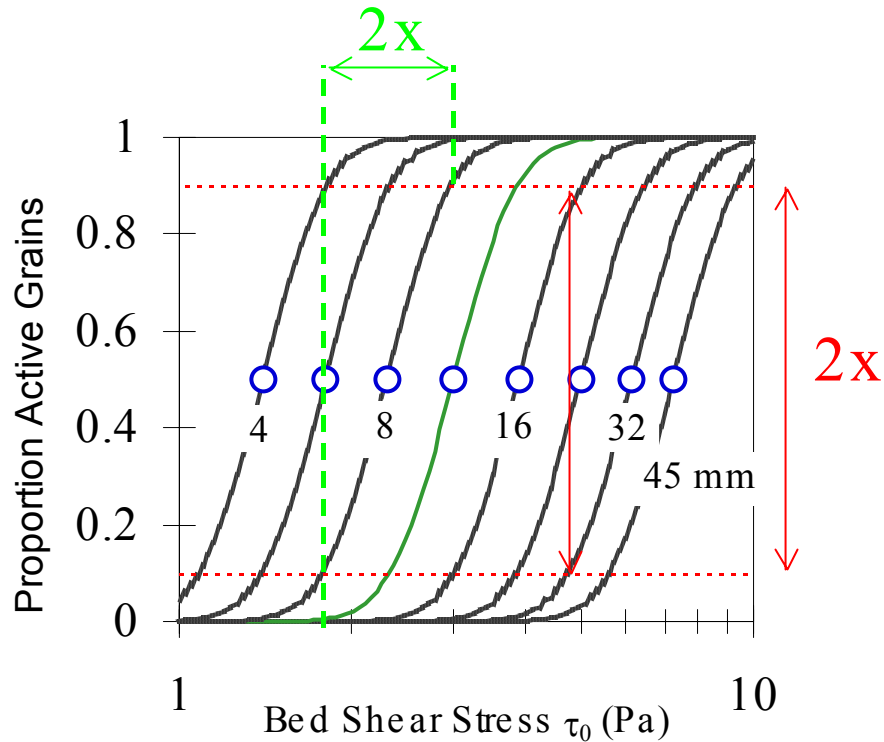
- Some grains remain immobile over the course of a transport event
- Implications for benthic disturbance, bed dynamics & subsurface flushing
- but occurrence, prevalence undocumented

Measure partial transport in lab, using time series of bed photographs

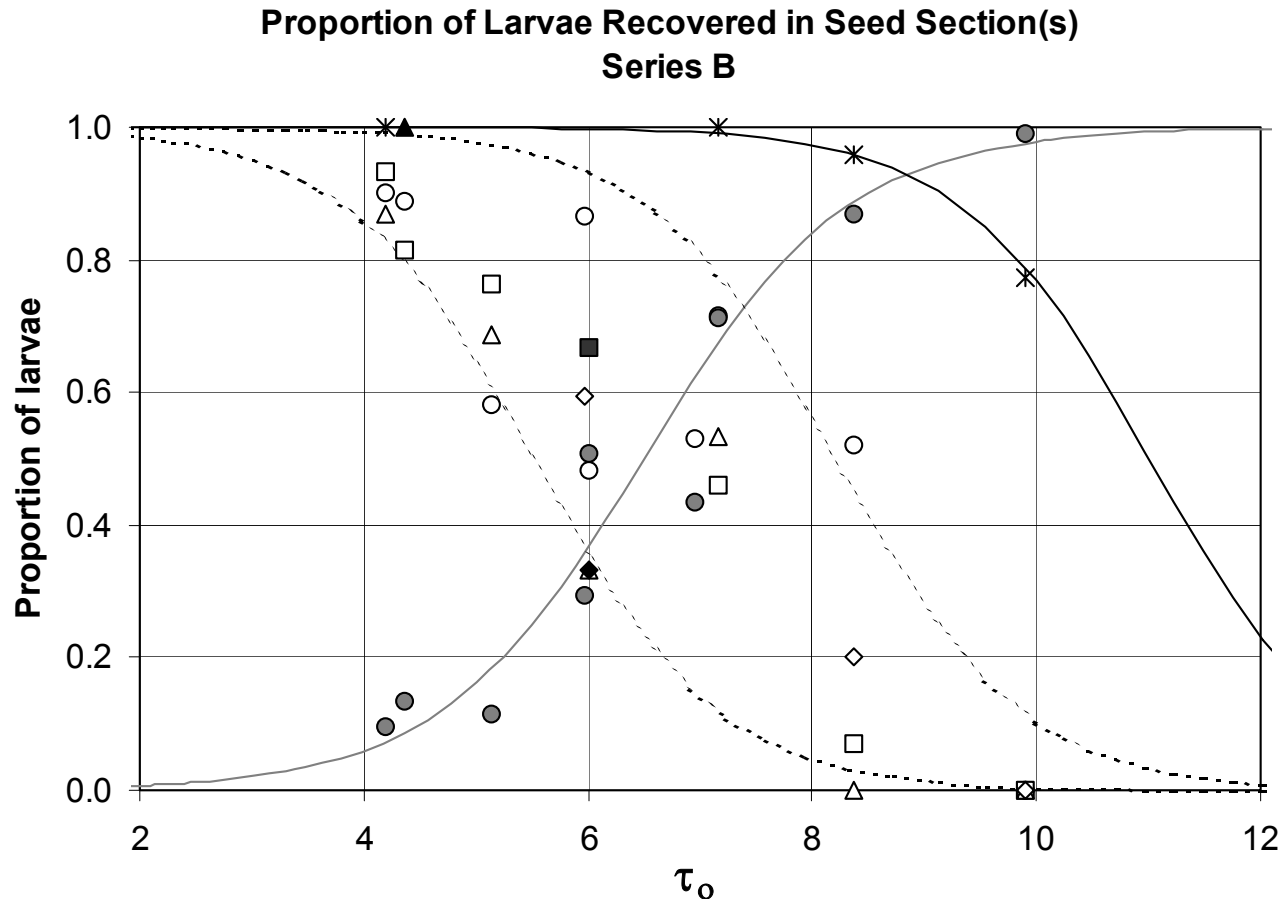


When Brian McArdell went blind (and a little nuts)

The domain of partial transport



Partial transport & the entrainment of benthic invertebrates (Steve Kenworthy)



○ Hydropsychidae

□ Psephenidae

△ Perlidae

◇ Ephemerellidae

* Atherix

● E

Field Observations of Partial Transport (1)

Carnation Ck, BC

3000 magnetically
tagged stones

Judy
Haschenburger,
U. Auckland



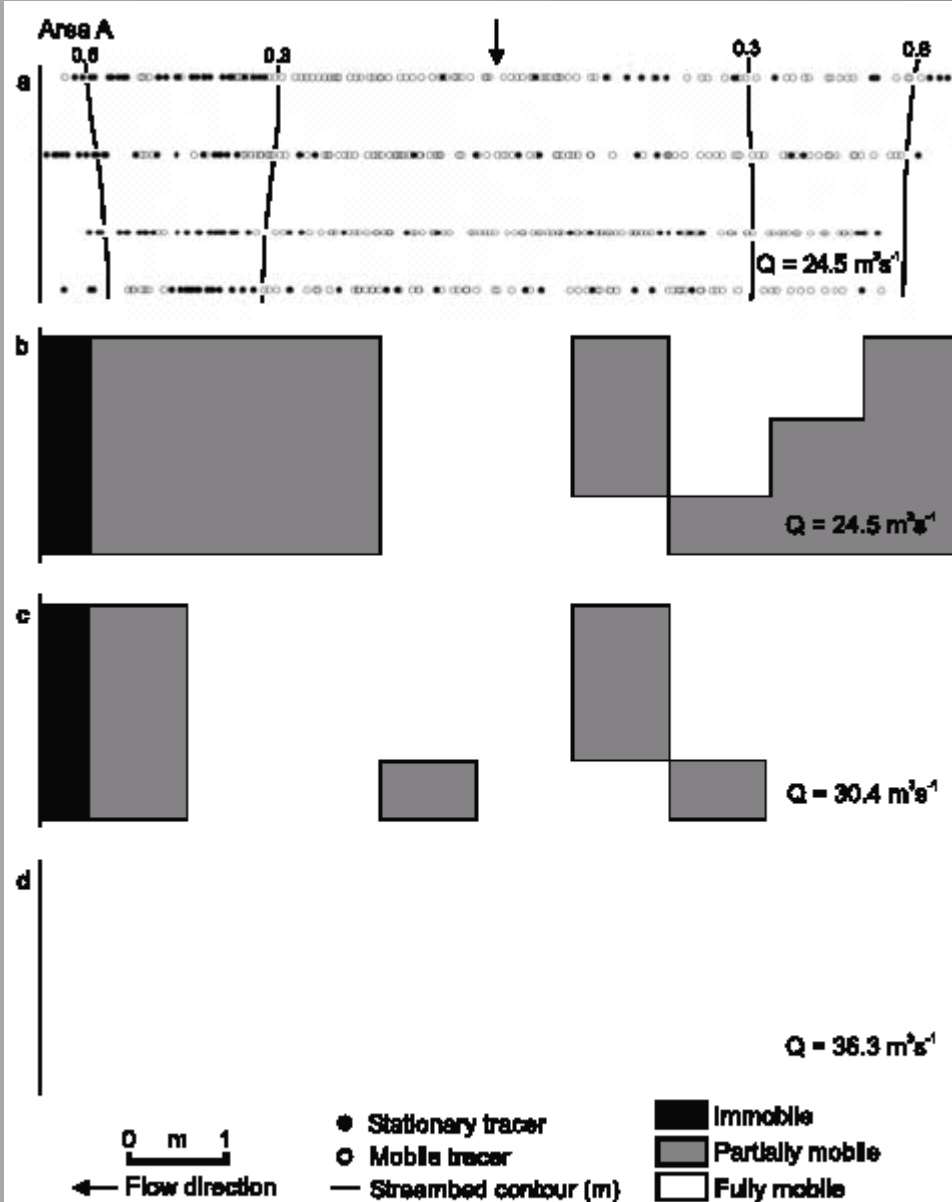


Figure 2. Maps for bed area A in upper deployment area. (a) Map indicating mobility of individual tracers for the $24.5 \text{ m}^3 \text{ s}^{-1}$ peak and activity maps for (b) $24.5 \text{ m}^3 \text{ s}^{-1}$ peak, (c) $30.4 \text{ m}^3 \text{ s}^{-1}$ peak, and (d) $36.3 \text{ m}^3 \text{ s}^{-1}$ peak.

2 yr flood

7 yr flood

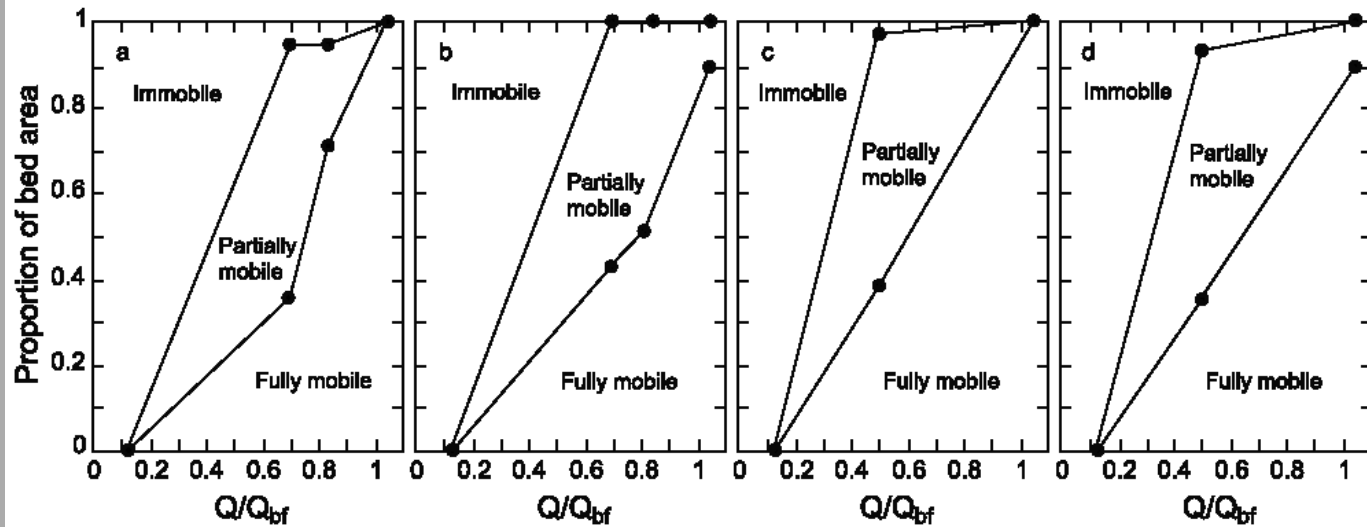


Figure 6. Proportional bed activity as a function of scaled peak discharge: (a) upper A area, (b) upper B area, (c) upper D area, and (d) lower E area. Q is the maximum peak discharge for a given tracer recovery, and Q_{bf} is the approximate bank-full discharge of $35 \text{ m}^3 \text{ s}^{-1}$.

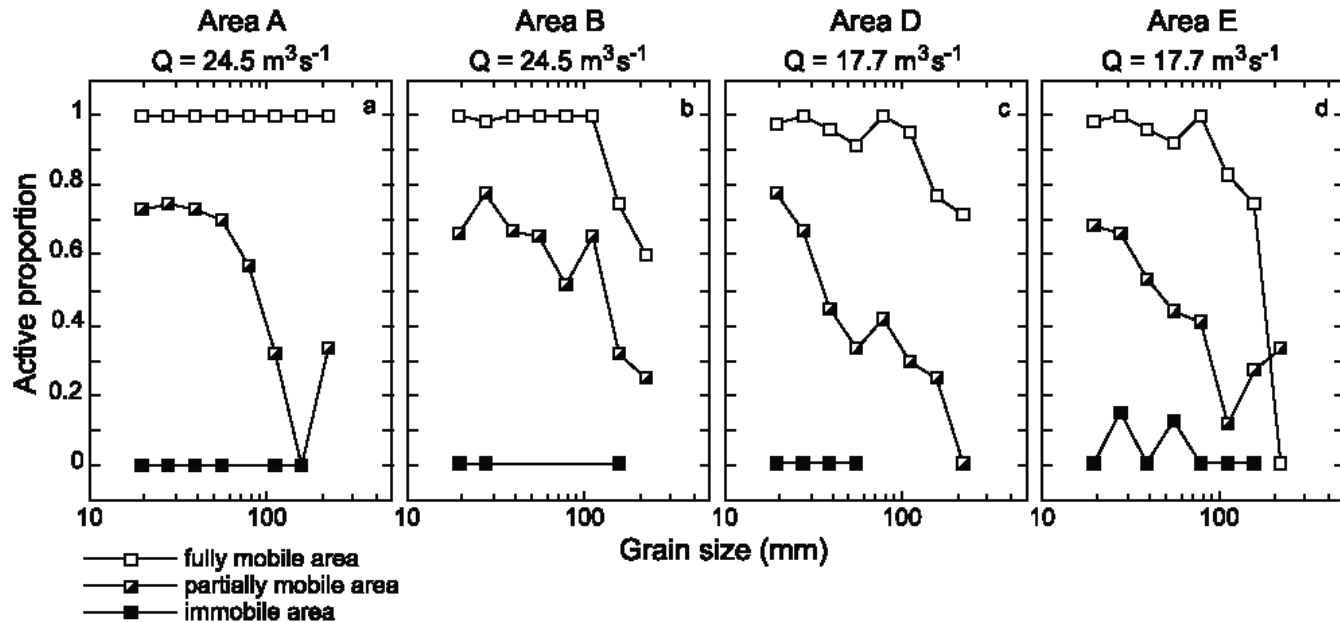


Figure 7. Active proportion of surface grains as a function of grain size; (a) upper A area, (b) upper B area, (c) upper D area, and (d) lower E area.

Field Observations of Partial Transport (2)

Harris Ck, BC

CHURCH AND HASSAN: MOBILITY OF BED MATERIAL IN HARRIS CREEK

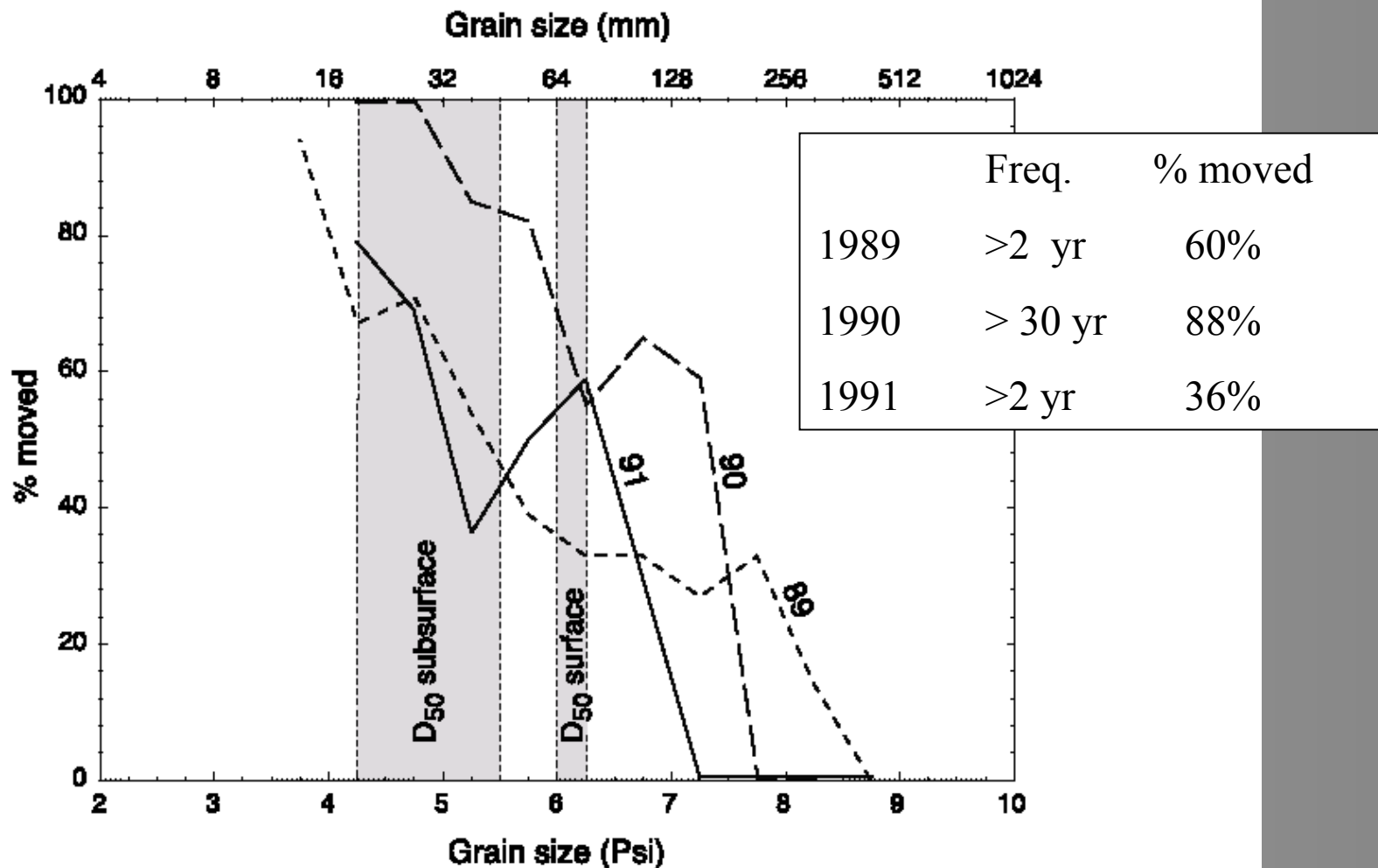


Figure 6. Percent of moved tracers as a function of grain size for three freshet seasons in Harris Creek. Shading denotes the range in the median size of the surface and subsurface material.

- **Bed mobilization increases consistently with flow and grain size**
- **Substantial transport occurs over a partially mobile bed**
- **Partial transport persists from year to year
complete disturbance not an annual event**



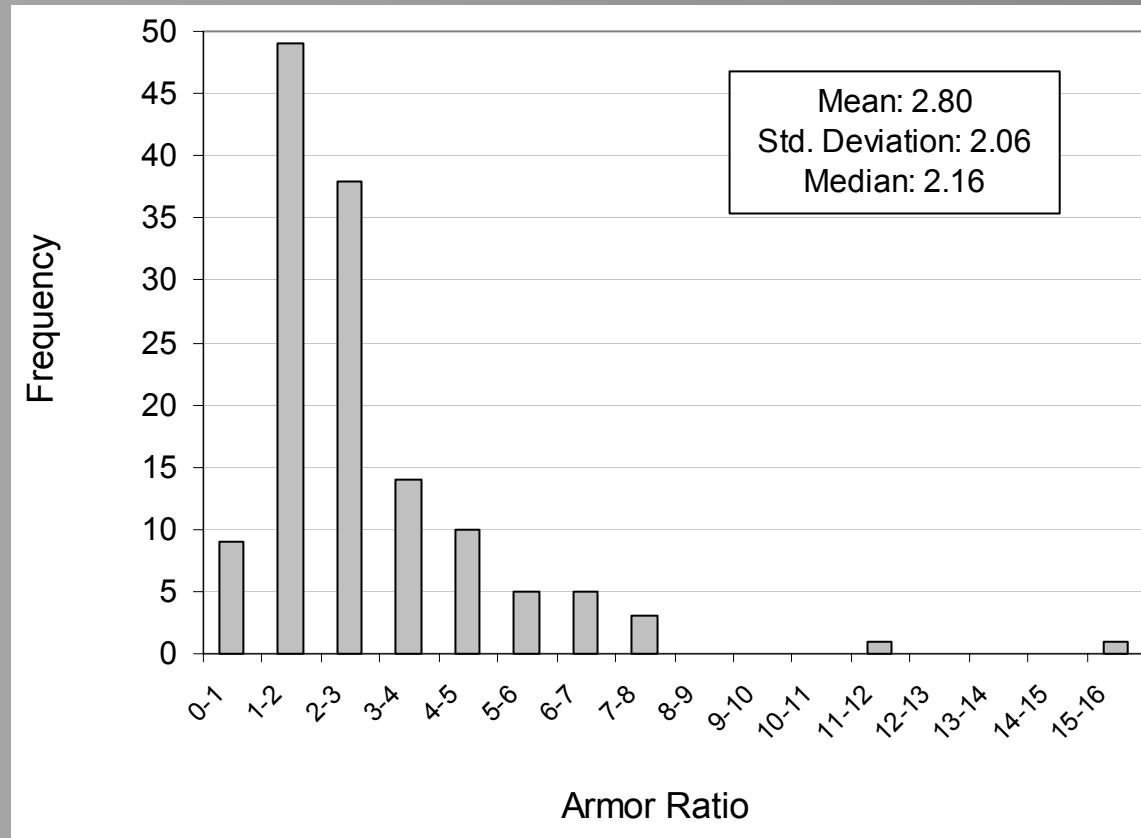
2. Bed surface composition: Armoring & the problem of predicting transport rates



Streambed Armoring

Stream-bed armoring is pervasive in gravel-bed streams

$$\text{Armor Ratio} = \frac{\text{D50 (surface)}}{\text{D50 (subsurface)}}$$



Bed surface composition determines

- grains available for transport
- hydraulic roughness
- bed permeability
- living conditions for bugs & fish

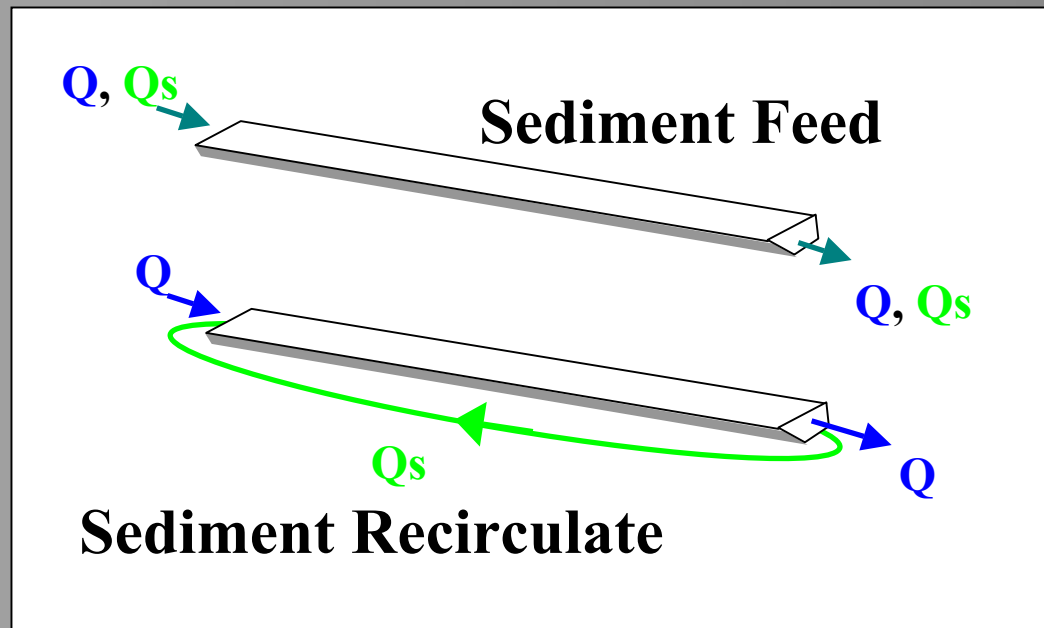
The armor problem

- We can measure the bed surface size at low flow, but not at flows moving sediment, so
- We don't know what the bed surface looks like at the flows that create it
- *Does the armor layer stay or go during floods?*

With no field observations of armor change, we turn to the lab for guidance on armor persistence

Doing this will sharpen our thinking about how rivers work at different scales of space and time

- Two ways to run flumes experiments:
Feed Sediment
Recirculate Sediment

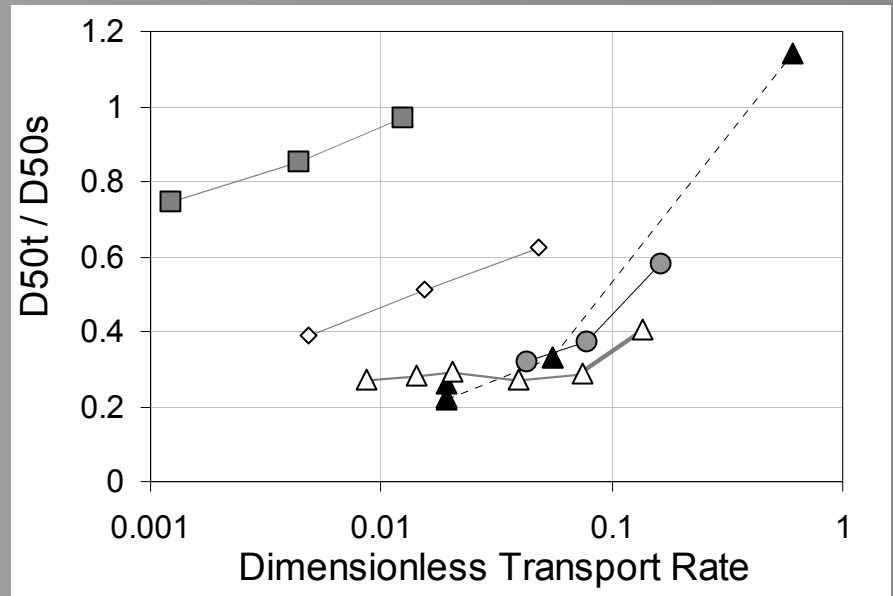
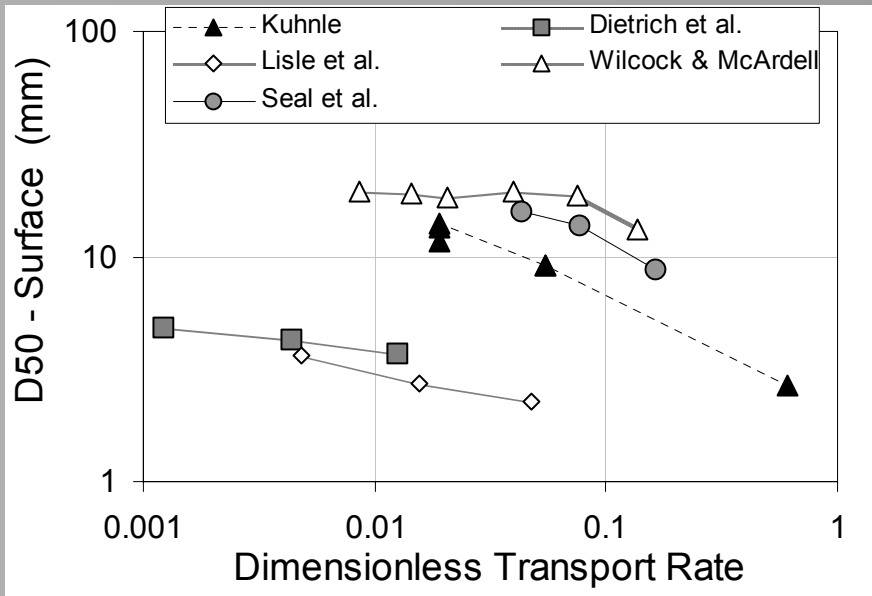


Sediment Feed Experiments

As feed (transport) rate increases,

bed surface becomes finer

And approaches size of transport (and bed subsurface)

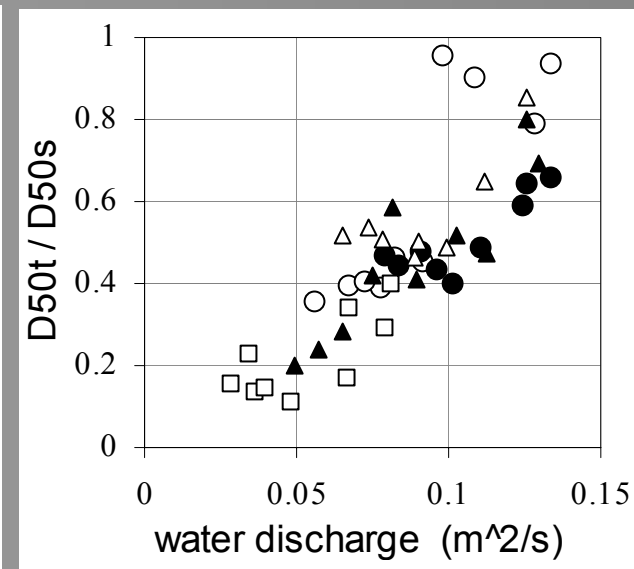
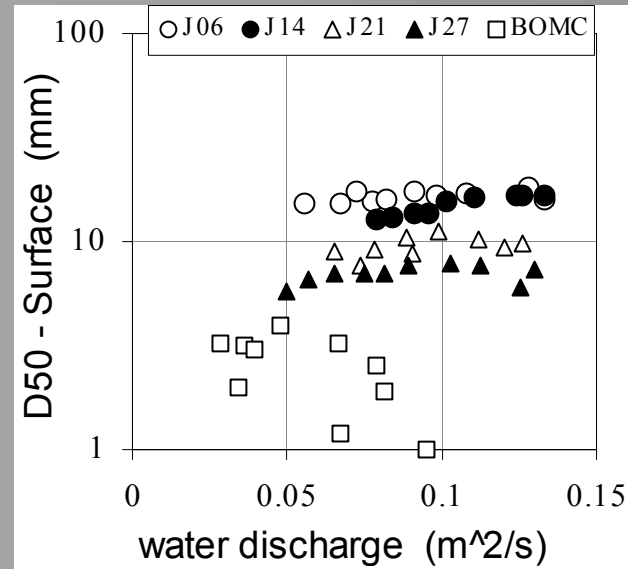
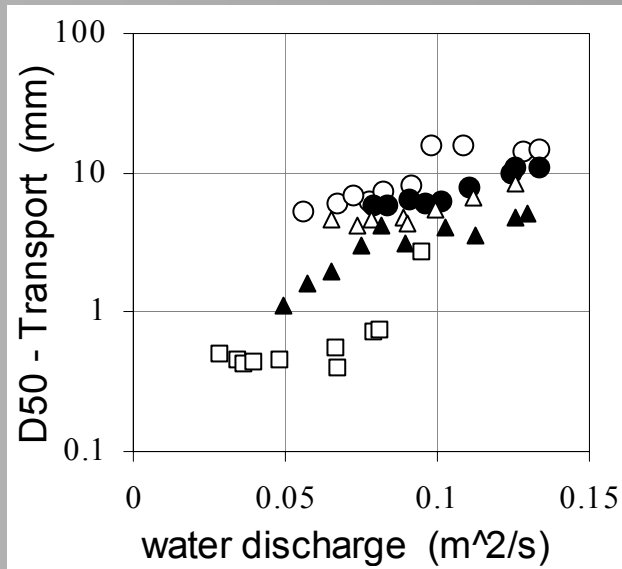


Sediment Recirculation Experiments

As flow (∴ transport) increases,

Transport grain size increases, while
bed surface grain size remains relatively constant

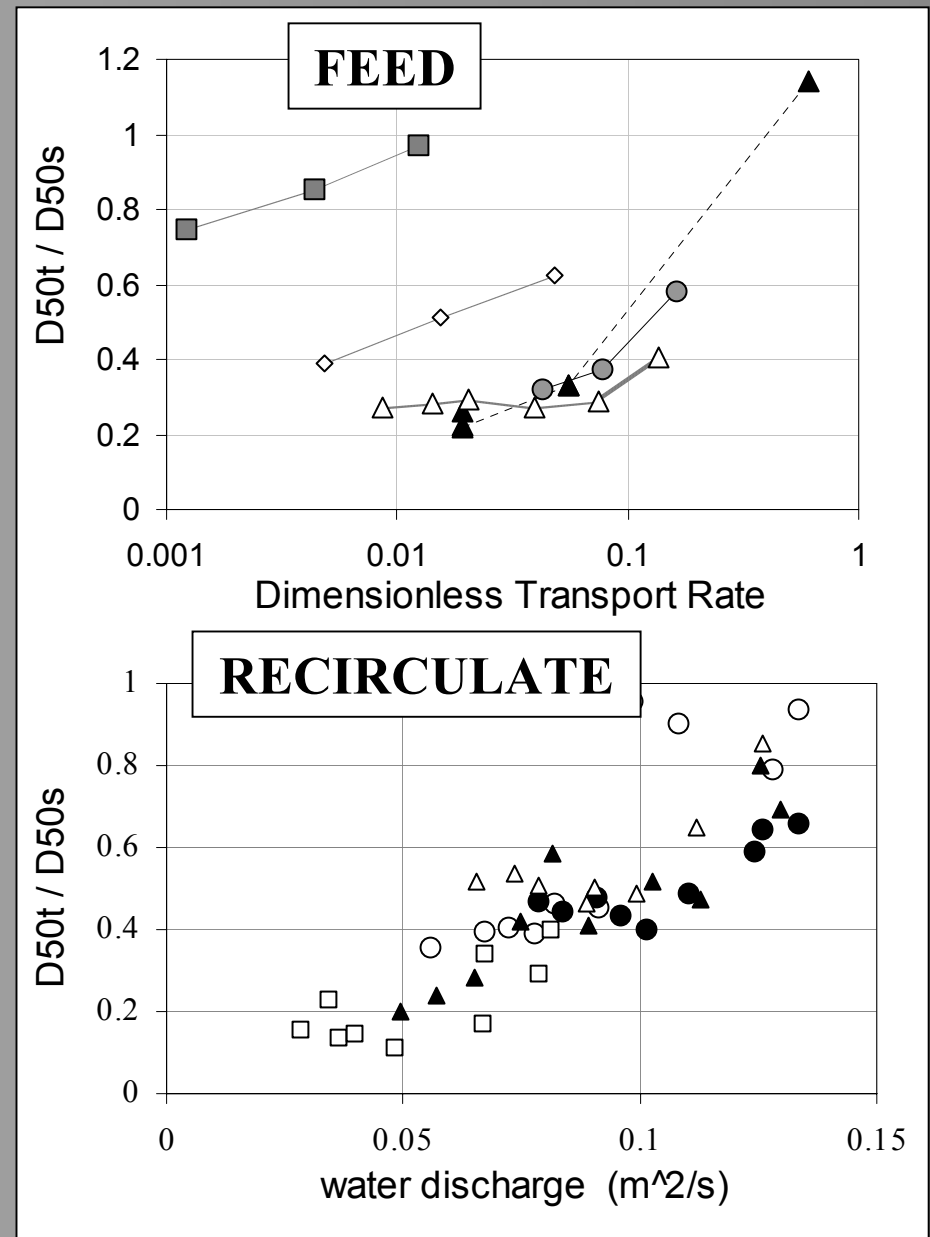
Approaching the size of the bed subsurface



In both cases, as transport rate increases, the transport coarsens relative to the bed surface

In the feed flume, this is accomplished via fining of the bed surface

In the recirculating flume, this is accomplished via coarsening of the transport

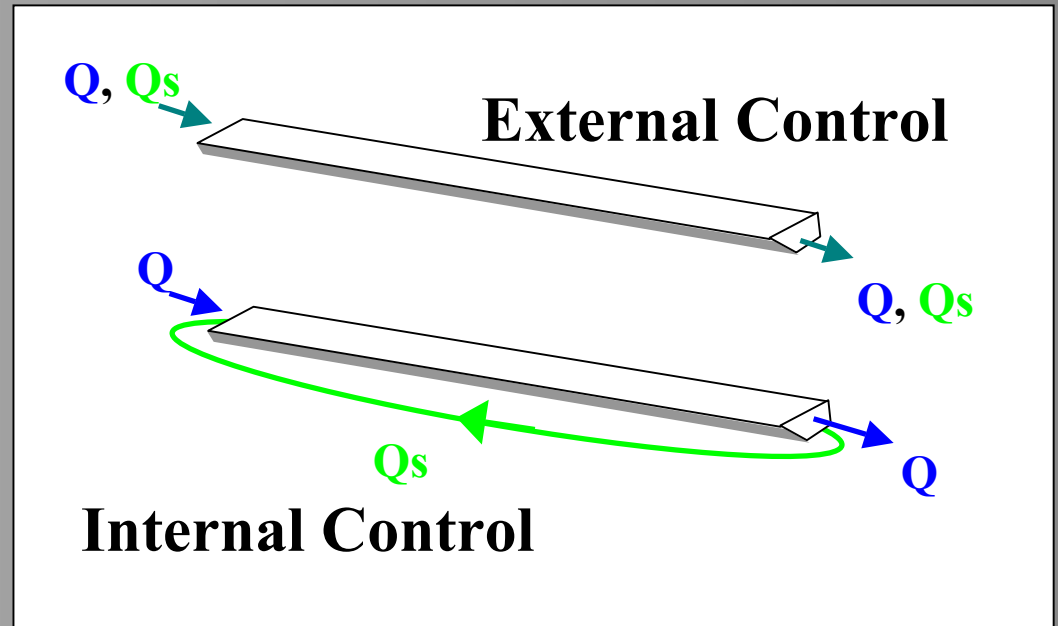


So, does armor stay or go?

Does it depend on how you think a river works?

Depends on time & space scale of the problem

Consider the essential “flaws” of the two flume types:



Feed

Transport has constant grain size

Recirculate

Final equilibrium sensitive to initial conditions

To address the armor problem, we have to tackle the transport problem

- Transport rates depend on transport of grains available for transport on bed surface
- But nearly all transport data provide composition of the bed *subsurface, not surface!*
- This means that the resulting transport models must somehow implicitly account for surface sorting (armoring)
NOT a good way to build a general model

Transport Modeling Basics - 1

Given fully rough flow with boundary stress τ , sediment of mean size D_m , with individual fractions of size D_i and proportion f_i . Transport rate q_{bi} depends on

$$q_{bi} = fn(f_i, D_i, D_m, \tau, \text{sed})$$

where sed = other sediment properties. We search a transport model of form

$$\frac{q_{bi}}{f_i} = fn_1(\tau, \tau_{ri})$$

$$\tau_{ri} = fn_2(D_m, D_i / D_m, \text{sed})$$

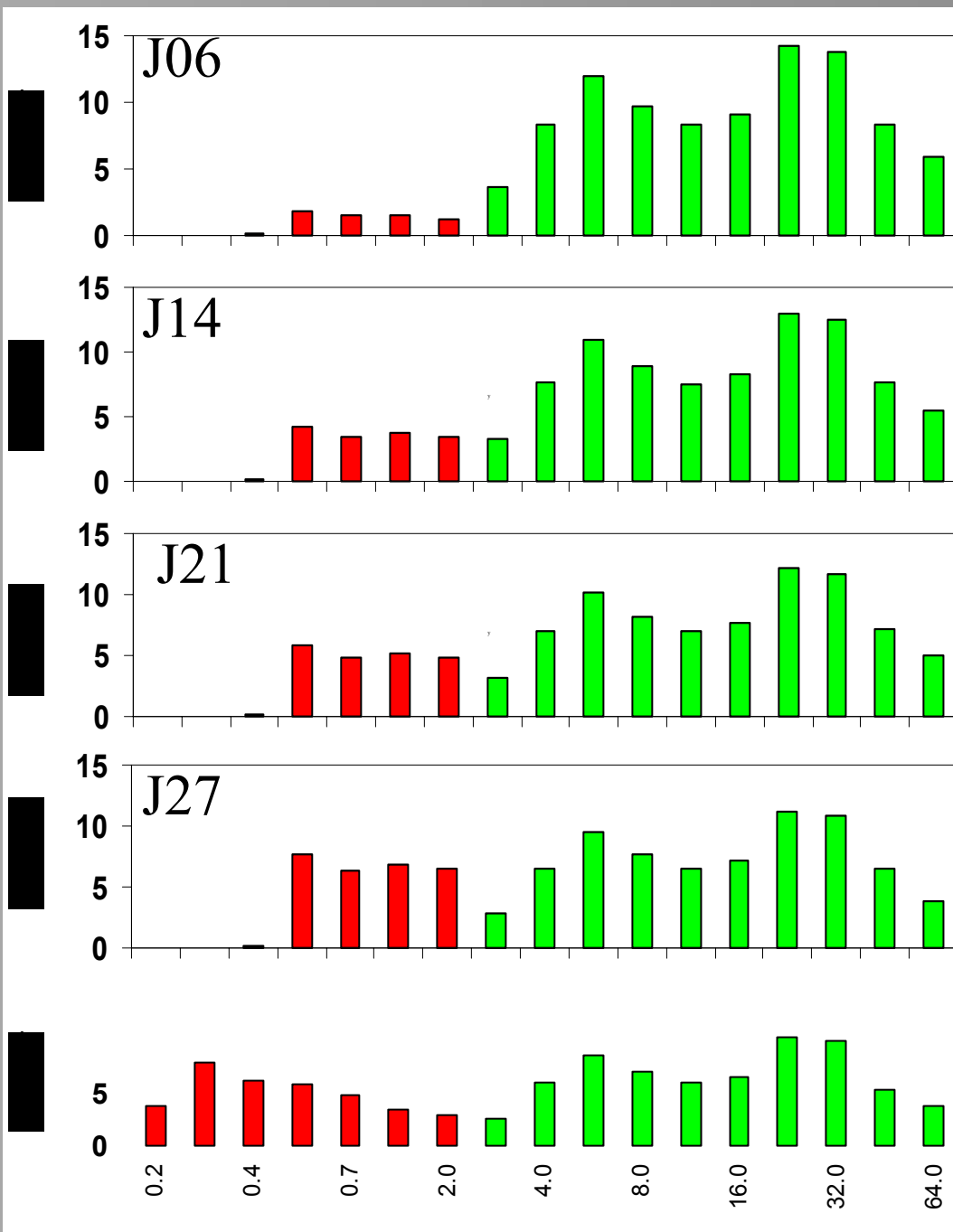
where τ_{ri} is a reference value of τ near the onset of sediment motion

But, what size distribution should we use for f_i ?

ans: surface

There are essentially no surface-based transport observations, so we made some

- Built five sediments, adding 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, over a wide range of transport rates
- Depth & width held constant, primary variables are sand content & flow strength
- Every run: measure flow, transport rate & grain size, and *bed surface grain size* (point counts of photos of colored grains)



Transport Modeling Basics - 2

To develop a general transport model, we nondimensionalize

$$\frac{q_{bi}}{F_i} = fn_1(\tau, \tau_{ri})$$

in the form of a similarity collapse $W_i^* = fn_3\left(\frac{\tau}{\tau_{ri}}\right)$

where
$$W_i^* = \frac{(s-1)gq_{bi}}{F_i(\tau/\rho)^{3/2}}$$

F_i surface proportion;

g gravity;

ρ water density;

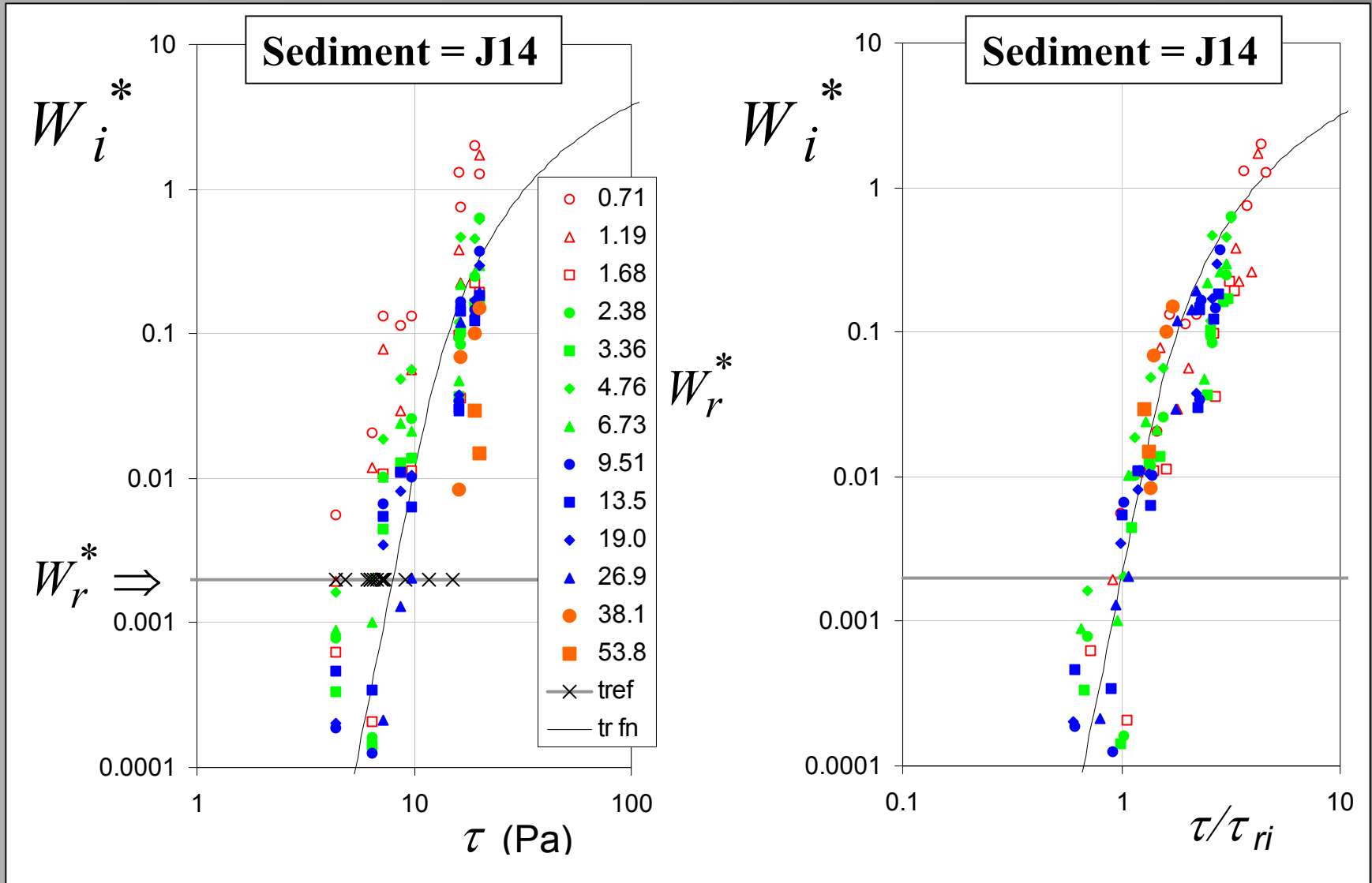
s sed spec. gr.

The Point:

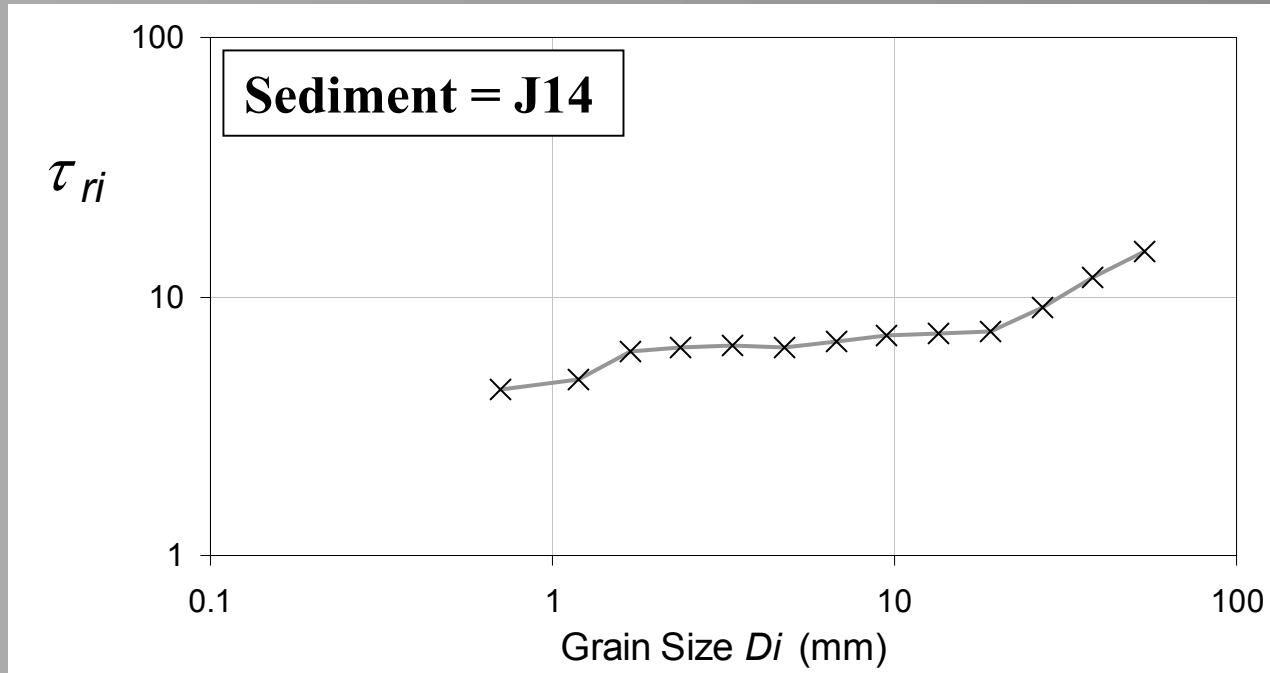
The transport function does not contain grain size!

How to make a transport model

(1) Plot W_i^* vs τ ; (2) Find τ_{ri} at W_r^* ; (3) Plot W_i^* vs. τ/τ_{ri} ; (4) Stand back, admire



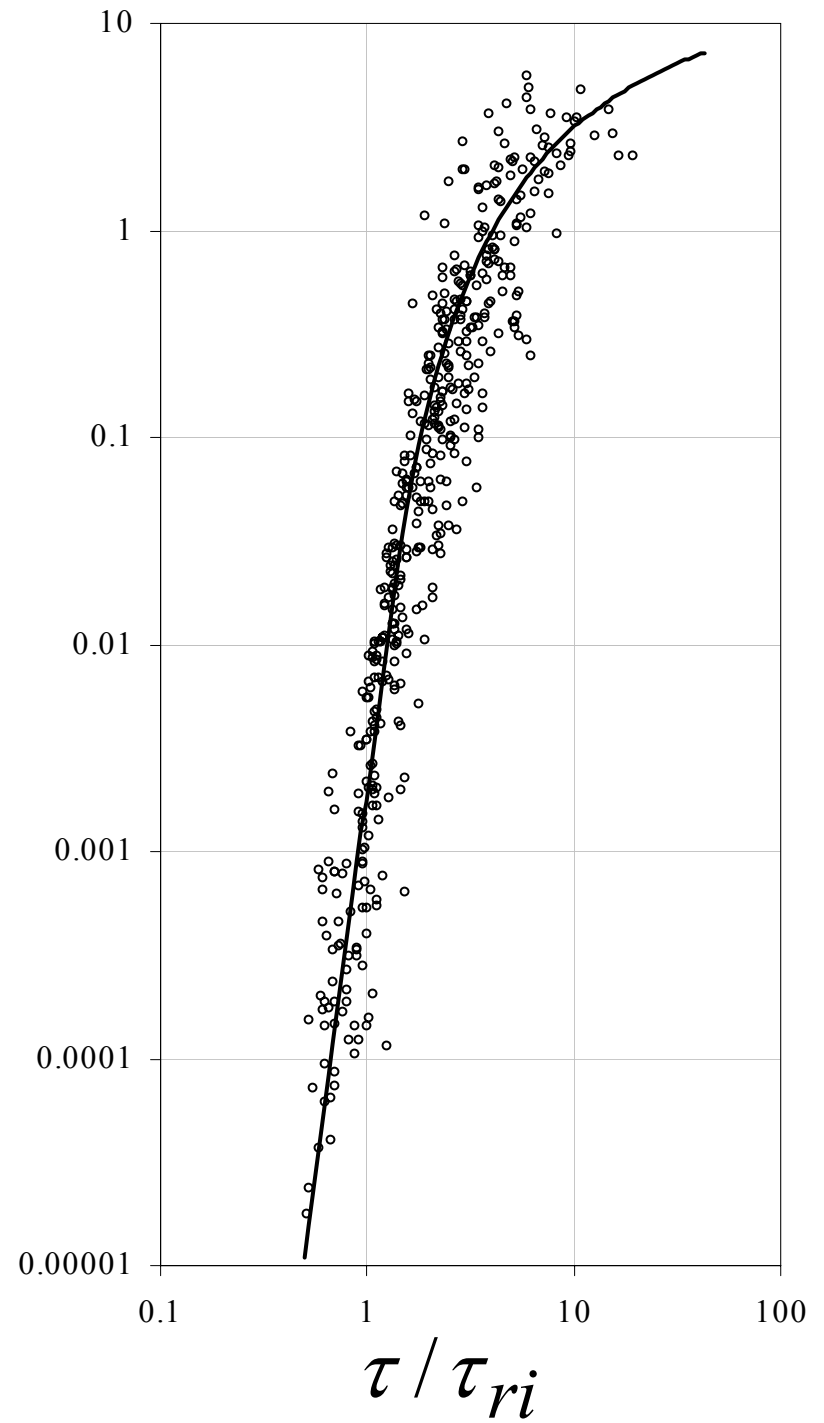
All that remains is to explain τ_{ri} ...



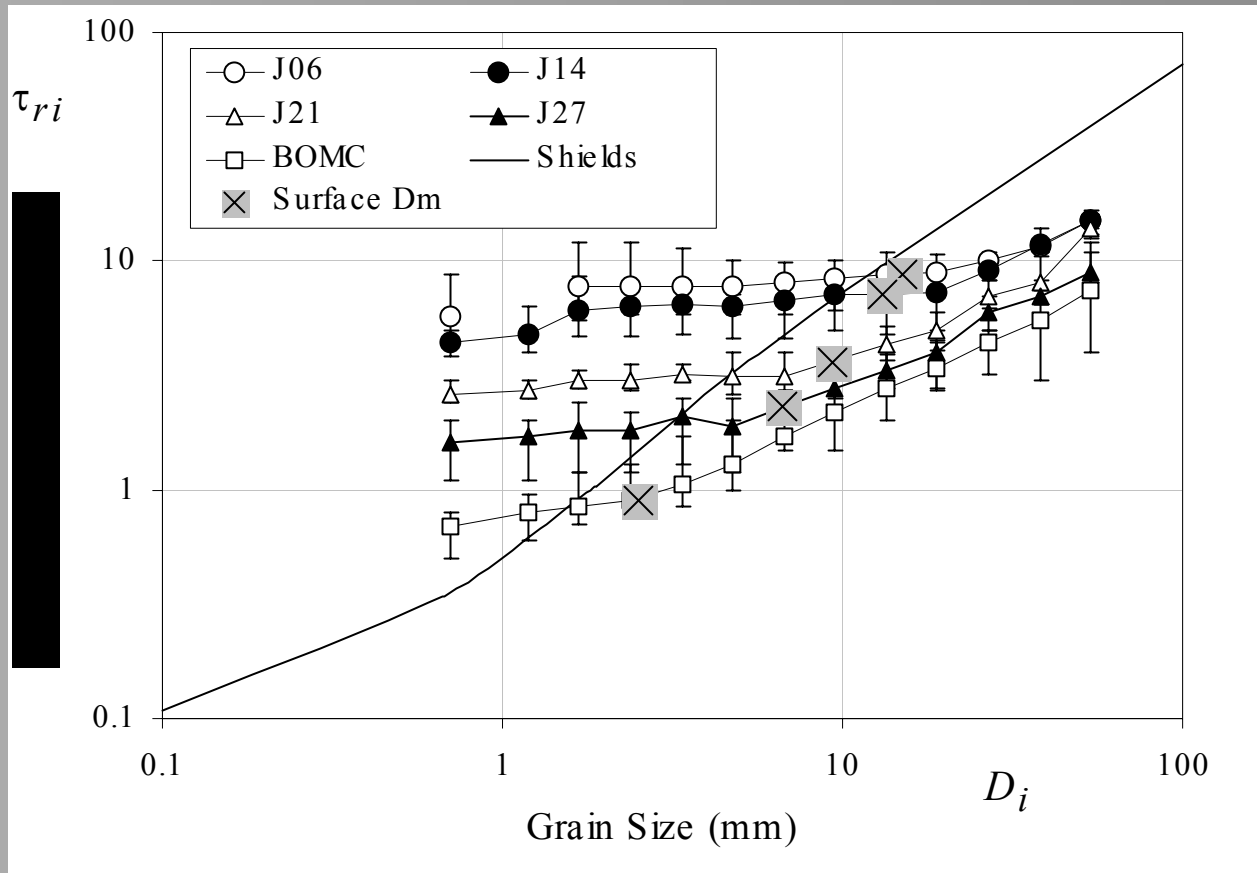
Surface-Based Transport Model

All sizes,
All runs,
All sediments

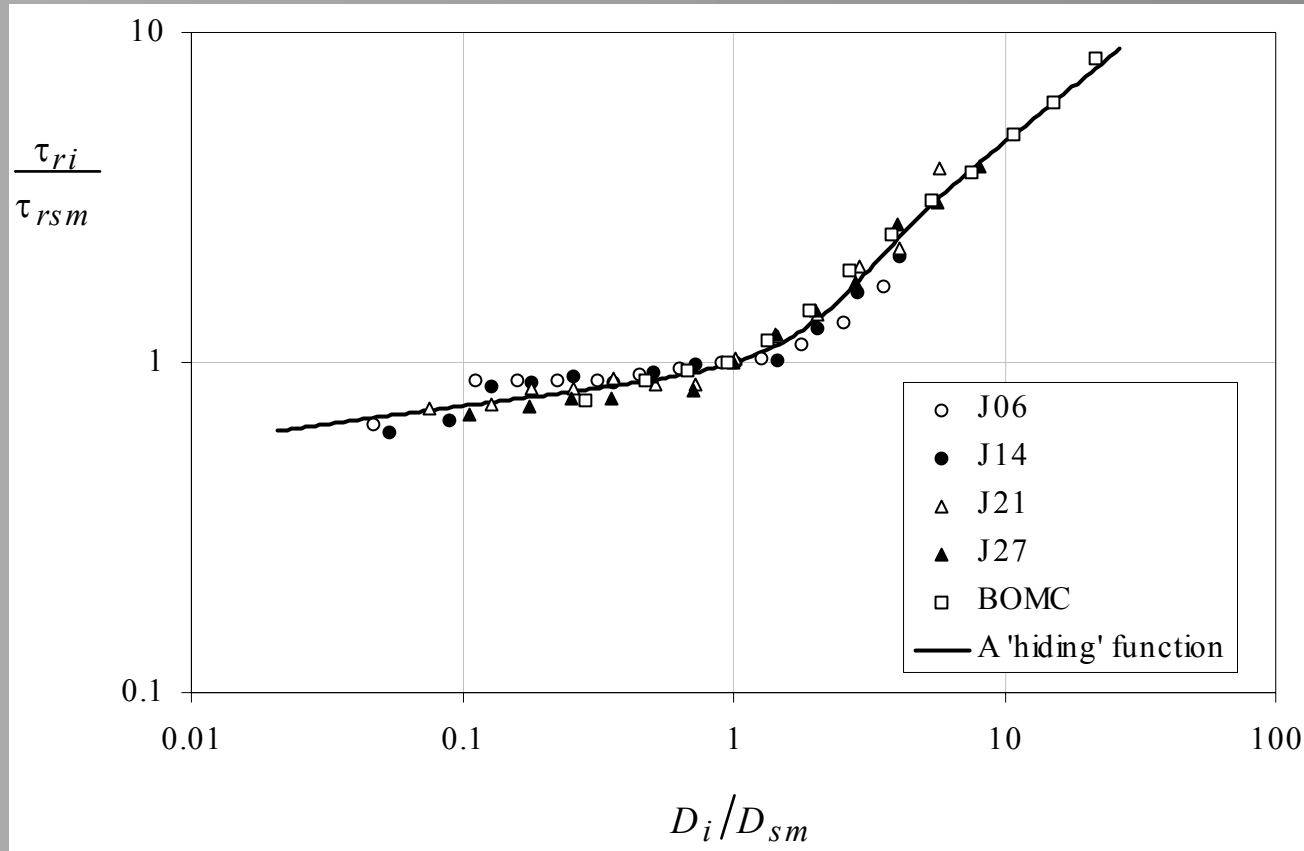
W_i^*



Values of τ_{ri} for all sizes and all sediments



Values of τ_{ri} collapse nicely when divided by values at the mean size D_{sm}



The resulting “hiding function” completes the surface-based transport model

Surface-based transport model can be used in both forward & inverse forms

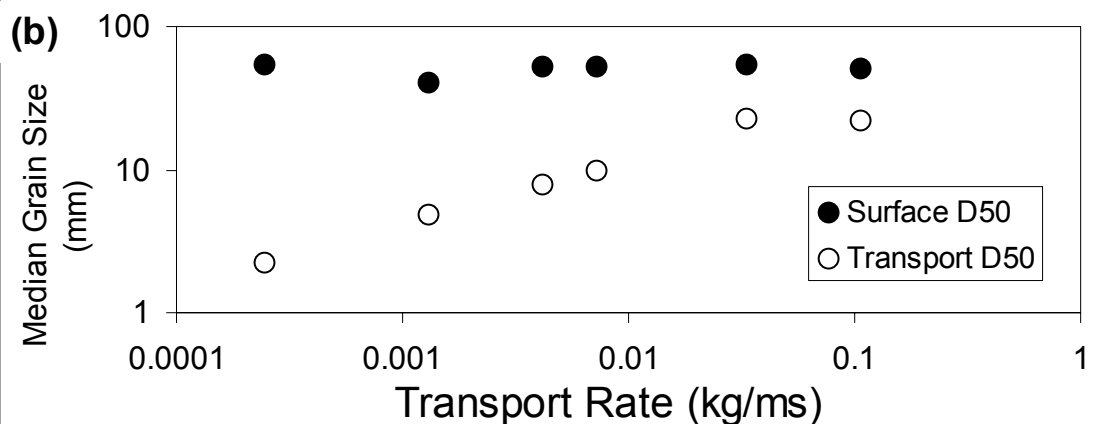
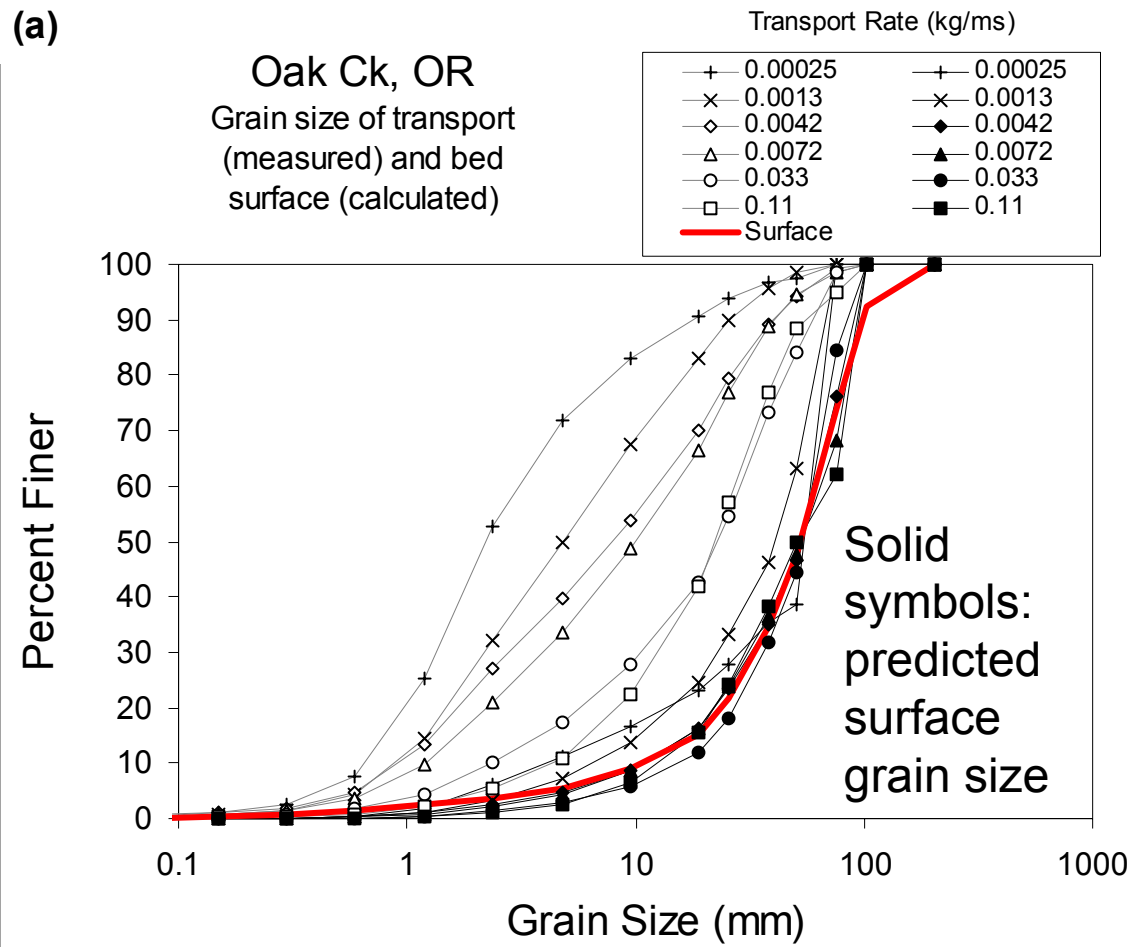
- **Forward:** predict transport rate & grain size as function of τ and bed surface grain size
- **Inverse:** predict τ and bed surface grain size as function of transport rate & grain size

Don't try this with a subsurface –based model!

The **inverse** model provides a useful tool for considering **armor persistence** – because we do have good transport data from the field

Transport grain size increases with flow!

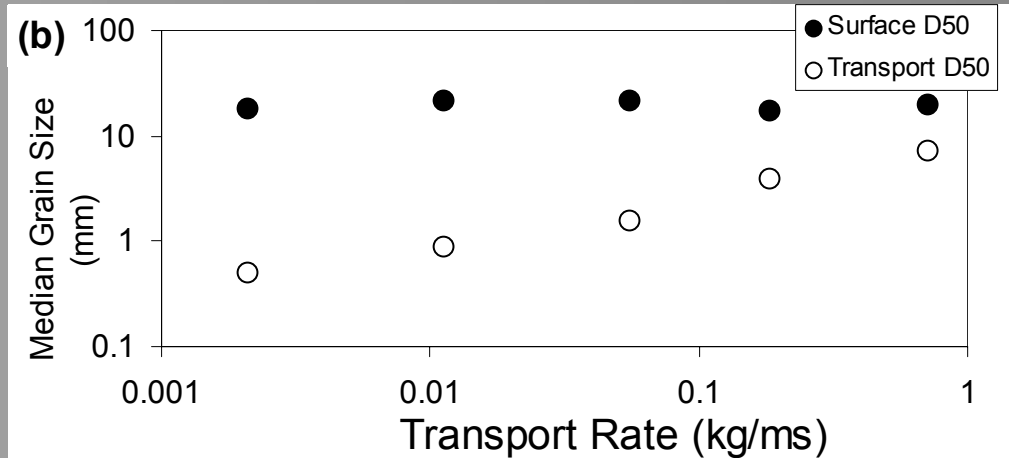
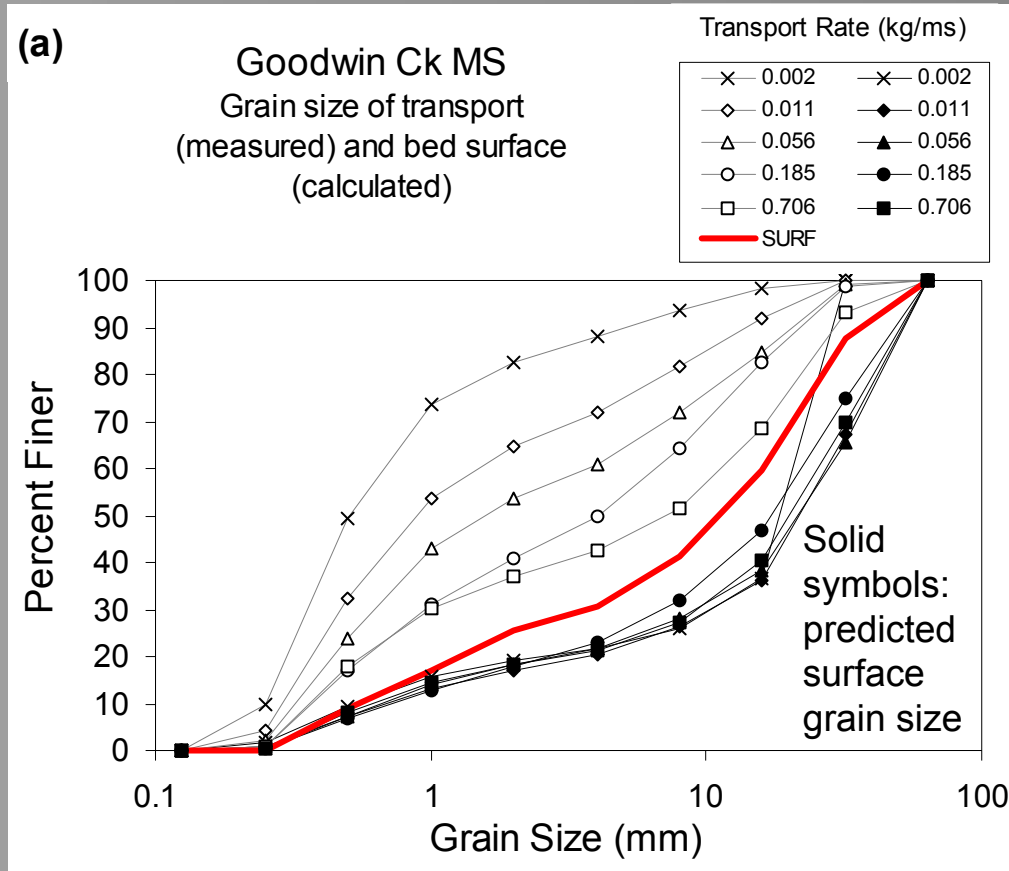
iSBTM not only predicts a persistent armor layer, it also predicts the surface grain size observed in the field!



Again,
transport grain
size increases
with flow!

Again, iSBTM
predicts a persistent
armor layer. This
time it overpredicts
the surface grain size
observed in the field!

Reason: *dunes*!



At “reach” and “storm” scales of space and time

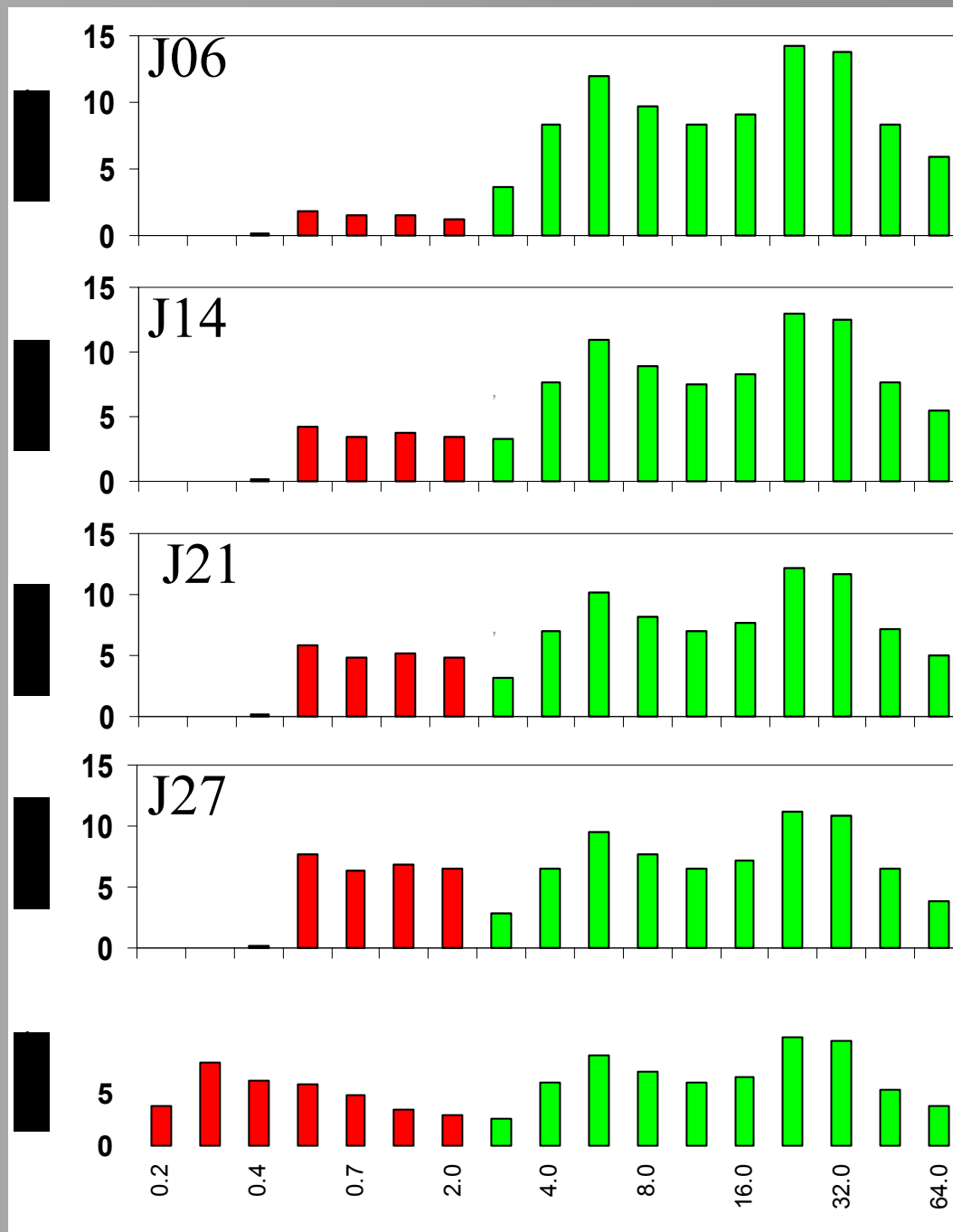
- Armor layer grain size appears to be persistent – a real advantage for predicting roughness & transport during floods:
a low flow measurement of bed composition may suffice (unless dunes develop)
- Increasing transport grain size balances change in grain mobility to produce a constant bed surface
- A SBTM needed to model transients

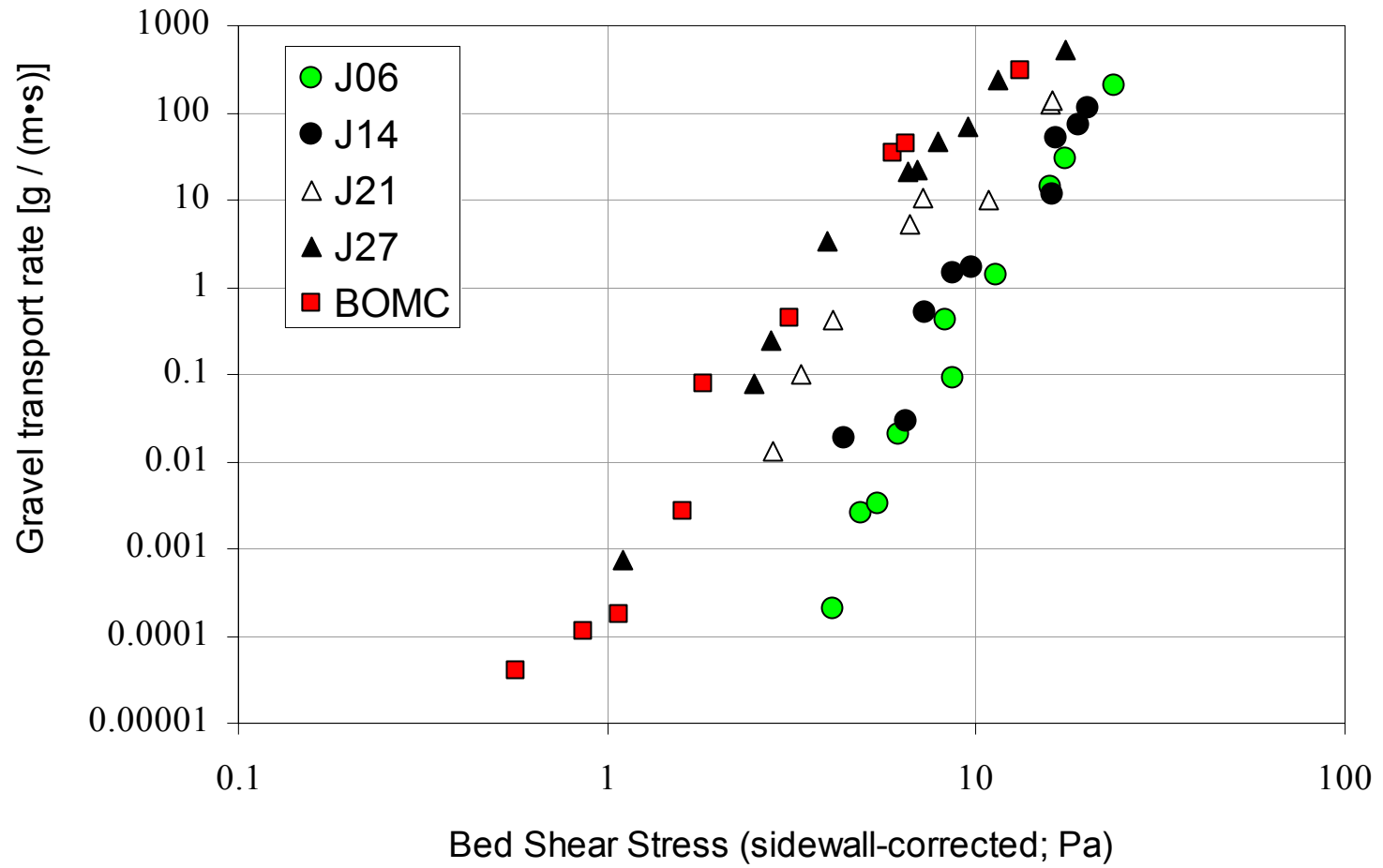
3. How does increasing the supply of fines (sand) affect the gravel transport?

Previous Experiments

- Jackson & Beschta (1984)
- Ikeda & Iseya (1988)

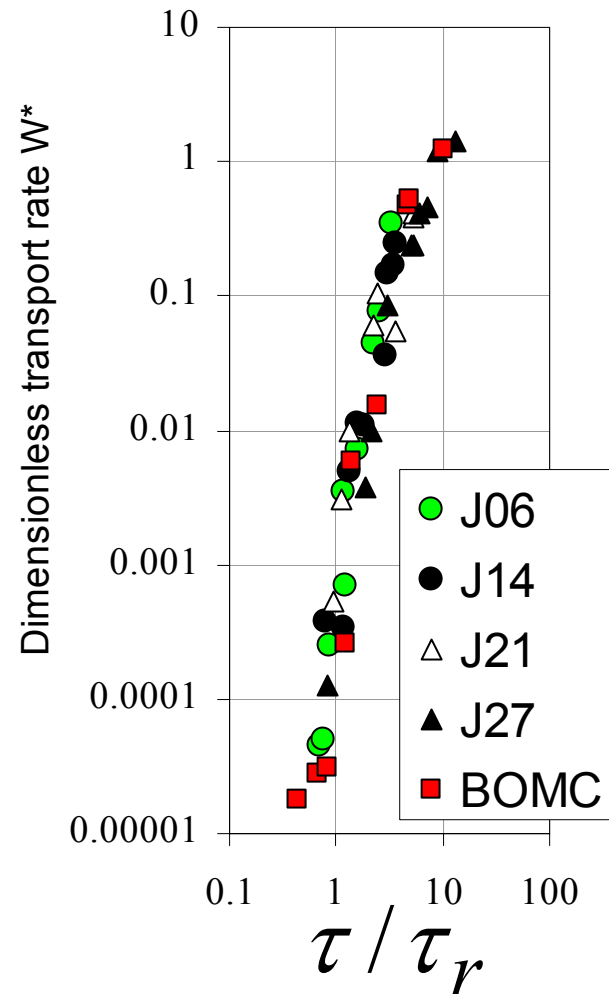
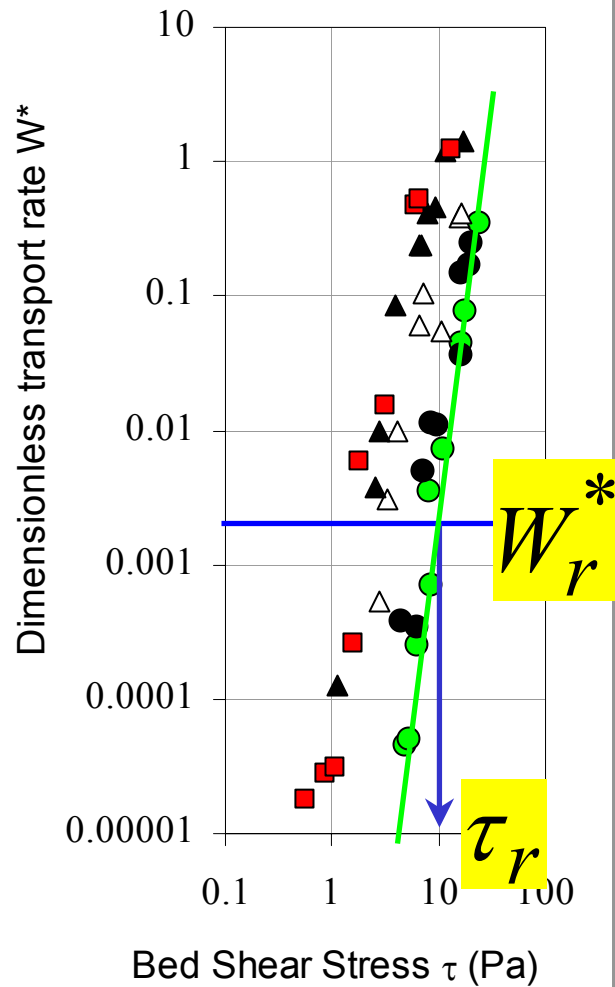
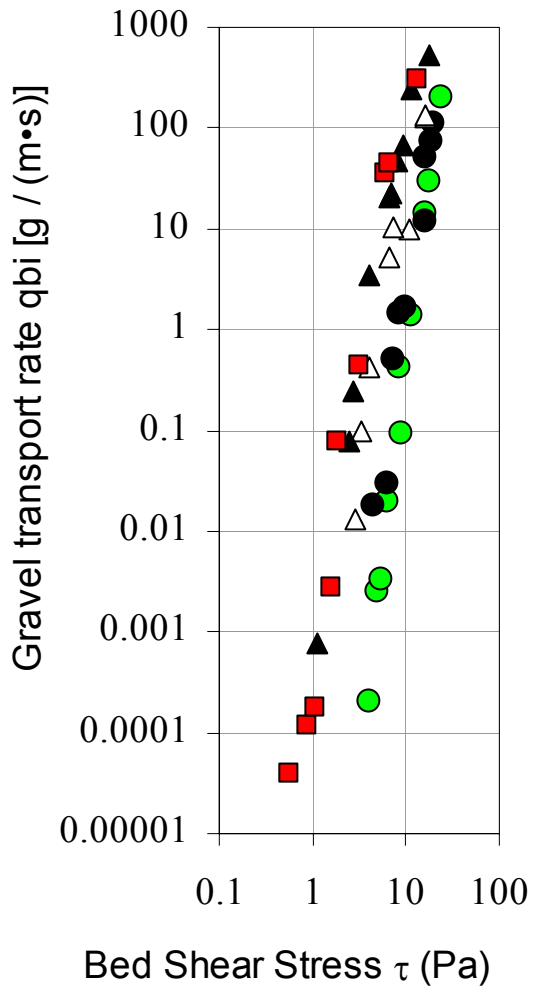
→ *Adding sand increases gavel mobility.*





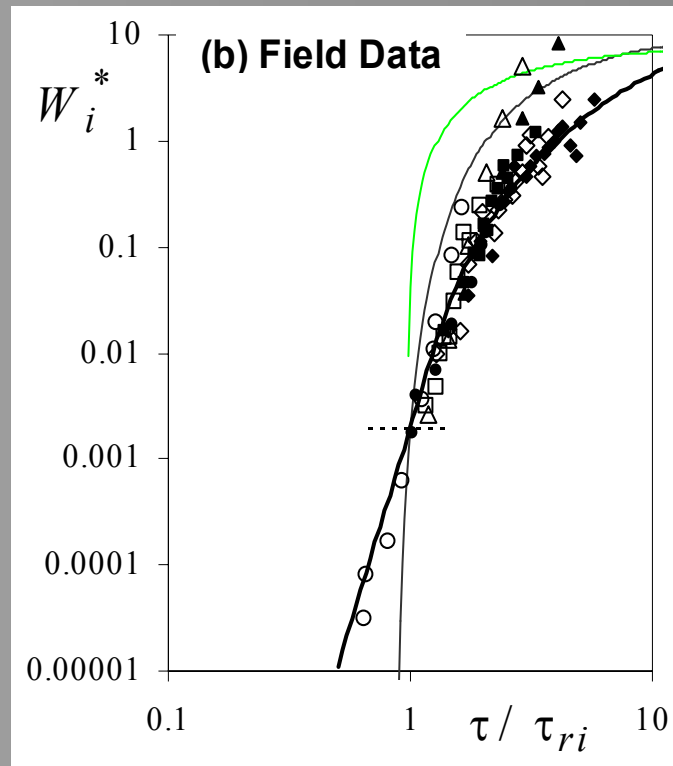
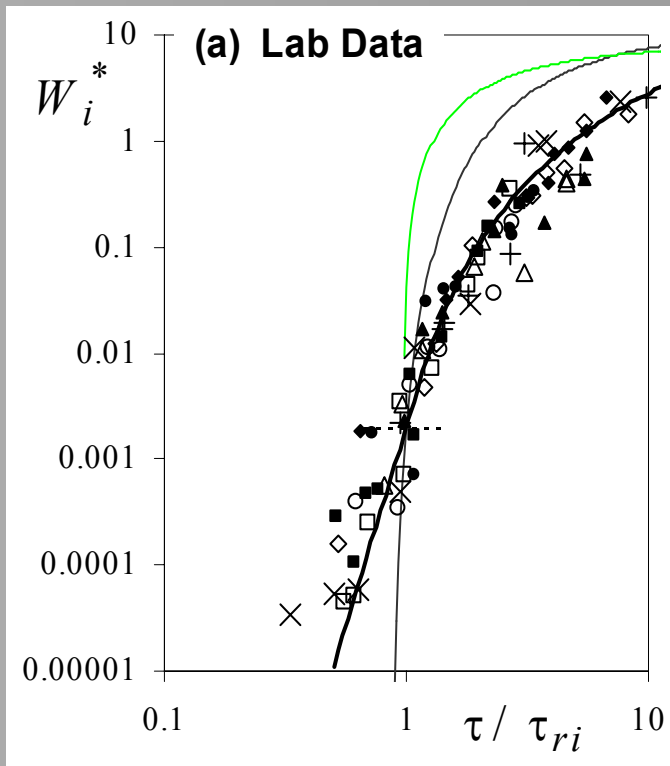
Sand content has a huge effect
on gravel transport rates –
How to generalize?

- Model two fractions: Sand & Gravel
 - Use a similarity collapse
 - Use one scaling parameter, the reference shear stress τ_r (a surrogate for the critical shear stress for incipient motion)
- $$W^* = \frac{(s-1)gq_{bi}}{(\tau_o / \rho)^{1.5}}$$
- $$\tau / \tau_r$$



Include field data to broaden model basis

- Oak Creek, Or (Milhous, Parker et al.)
- Goodwin Creek MS (Kuhnle)
- East Fork River WY (Emmett & Leopold)
- Jacoby Creek CA (Lisle)



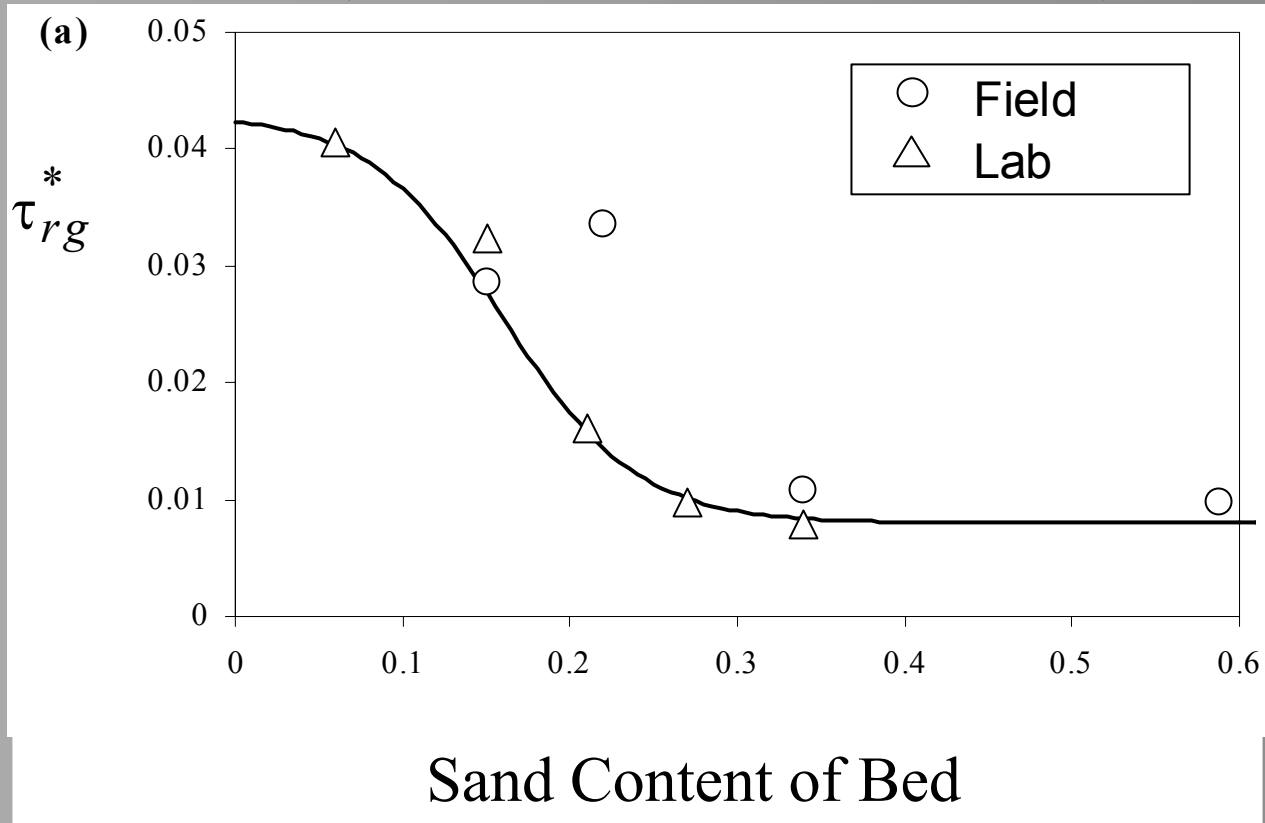
Both sand & gravel fractions plotted

Model collapse reasonably good; leaving a single similarity parameter to explain: the reference shear stress, τ_r

It provides a clean description – and prediction – of the effect of sand on gravel transport

Framework
Supported

Matrix
Supported



$$\tau_{rg}^* = \frac{\tau_{rg}}{(s-1)\rho g D}$$

Wilcock, P.R. and Kenworthy, S.T., 2002, A two fraction model for the transport of sand/gravel mixtures, Water Resources Research, 38(10).

Wilcock, P.R., Kenworthy, S.T. and Crowe, J.C., 2001. Experimental study of the transport of mixed sand and gravel, Water Resources Research

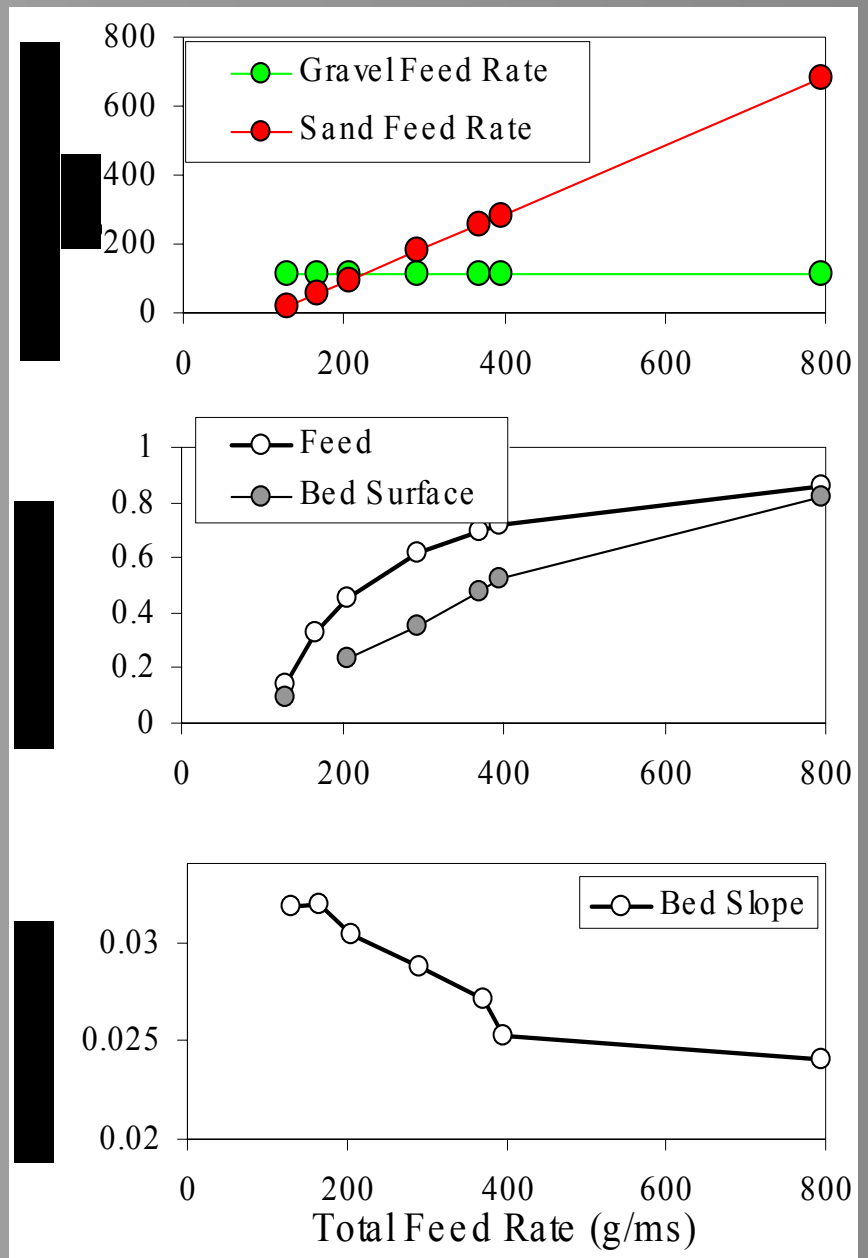
Wilcock, P.R., 1998. Two-fraction model of initial sediment motion in gravel-bed rivers, Science 280:410-412

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 is required to carry same gravel load and 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

fire, urbanization, reservoir flushing, dam removal

& 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!*

*Some essential
acknowledgements*

Alan (partial transport) Barta

Brian (Mr. BOMC) McArdell

Steve (buginflume) Kenworthy

Joanna (million pts of color) Curran

Brendan (iSBTM) DeTemple



Summary

Armor layers persist

May be only partially active in a typical flood

↑ sand supply ↑ ↑ mobility of coarse grains

Surface-based model available for predicting transient transport

2-fraction model available as a robust alternative

