THE SCIENCE AND PRACTICE OF EROSION THRESHOLD THEORY

in Applied Geomorphology

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Western

Mitacs

Erosion Threshold Awareness

The Science

- Boundary types and sediment **mixtures**
- The good ol' **Shields** parameter
- Don't be scared of **selective** mobility

The Practice

What **sometimes** works, sort of, maybe…)

- Threshold versus **alluvial** channel beds
- Factors of **safety**
- **Uncertainty**, does it matter?
- Field **verification** of erosion thresholds

CONTINUUM OF CHANNEL BOUNDARY TYPES

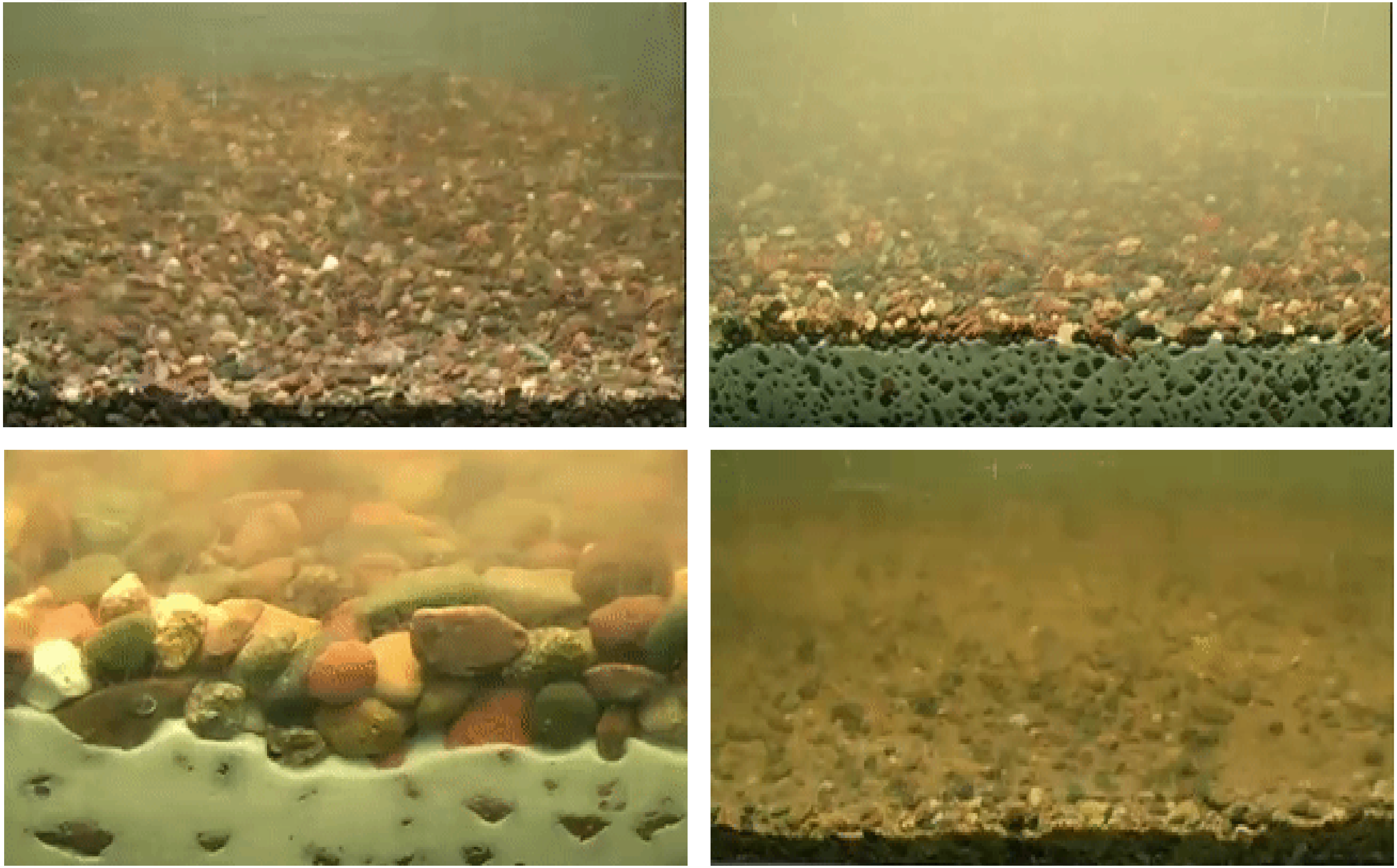
SAND

GRAVEL

CLAY

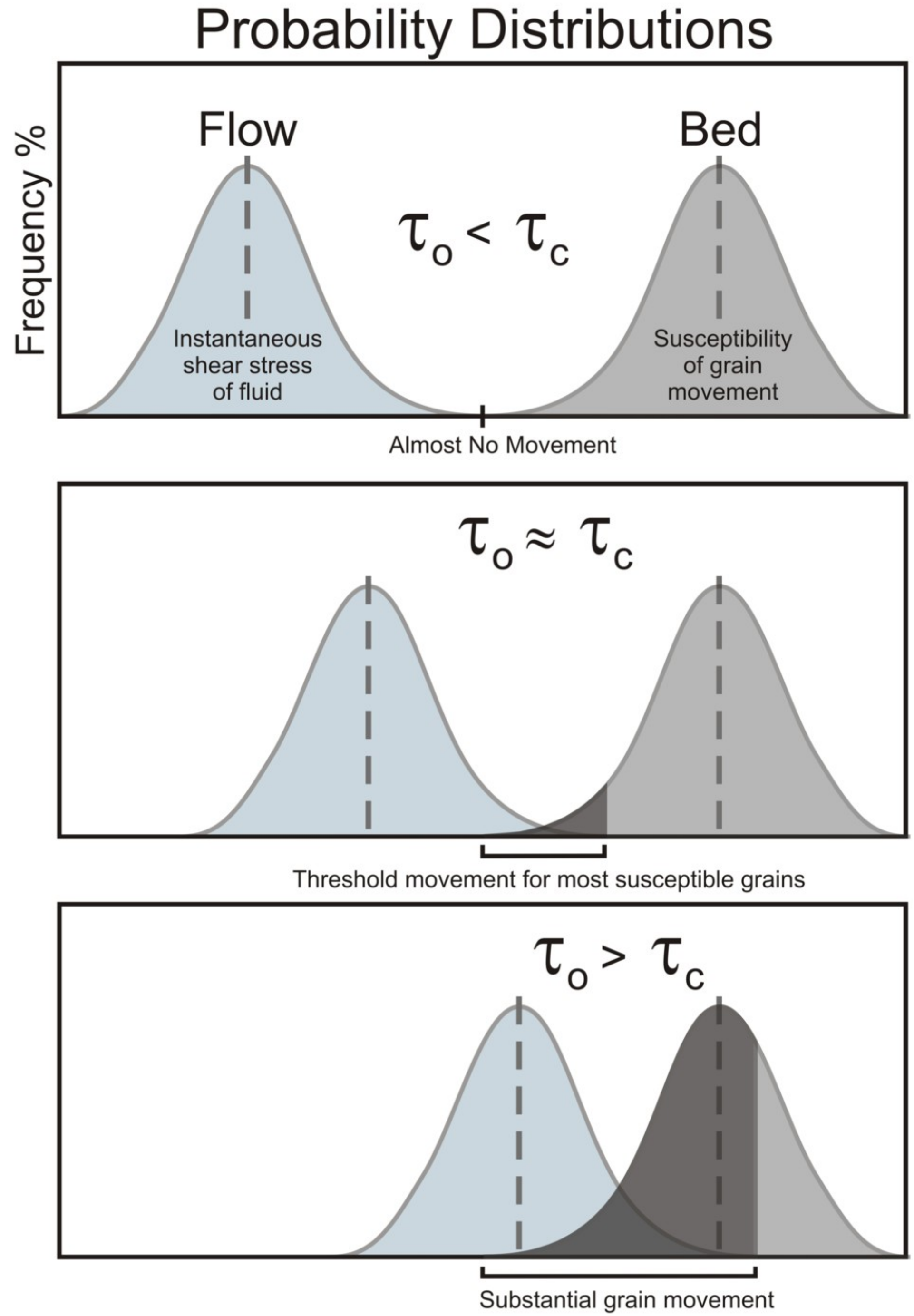
COBBLE

Bedload Transport of Sediment Mixtures



Credit: John Gaffney (2009) University of Minnesota Department of Civil Engineering St. Anthony Falls Lab

EROSION THRESHOLDS
SEDIMENT MOTION



STATISTICAL PROBLEM

Fluid Shear Stress = τ_o

Critical Shear Stress = τ_c

Dimensionless Shields Number

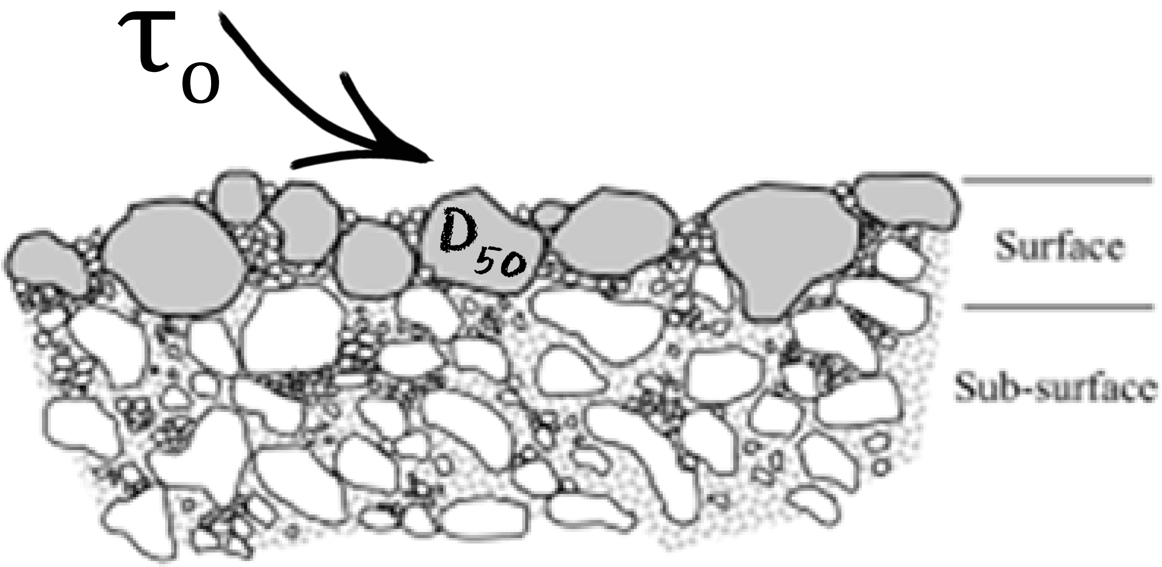
Erosion Thresholds of Motion (Sheilds, 1936)

$$\theta_c = \frac{\tau_c}{(\rho_s - \rho) g D_{50}}$$

Average $\theta_c = 0.045$

0.03 – 0.06

Range 0.01 to >0.1



Miller et al. 1977

Buffington and Montgomery 1997

Also θ_c **varies** with:

Bed-State: Church 1978

Slope: Lamb et al. 2008

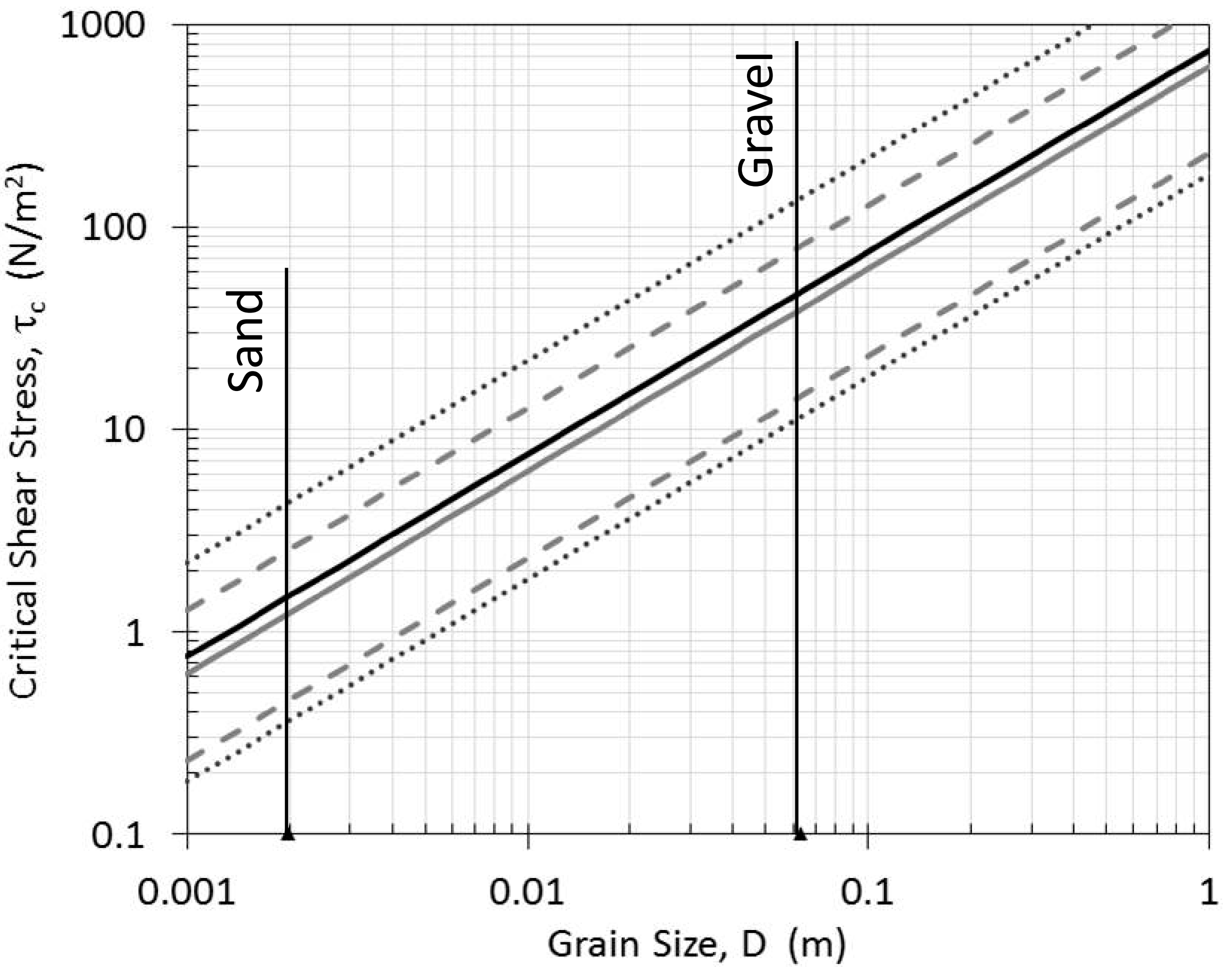
Field-Measurements: Petit et al. 2015

Monte Carlo Simulation

Adapted from Stewardson and Rutherford (2008), based on data from Buffington and Montgomery (1997)

θ_c treated as a **random** variable with log-normal distribution

mean = **0.045**, standard deviation = **0.03**, n = 1000 (per size, D)



$$\tau_c = \theta_c\,(\rho_s - \rho)gD$$

Gravel = 6.4 cm

Average τ_c = **48.2** N/m^2

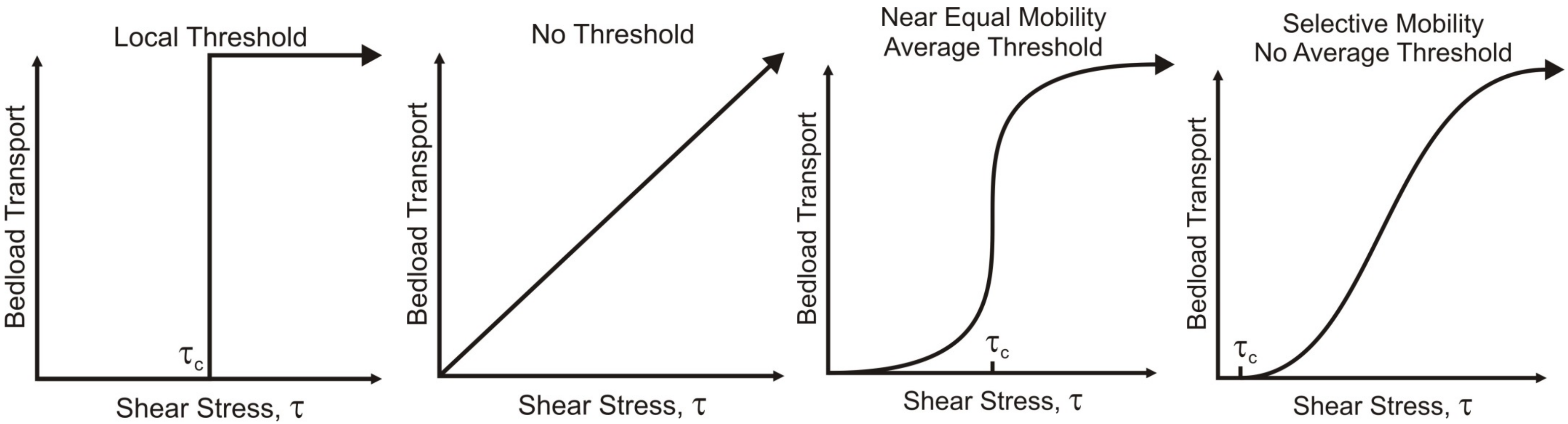
Mean's 95% Confidence Interval: 46.2 – 50.3 N/m^2

± 4.5%

± 1 Standard Deviation
14.8 – 81.6 N/m^2

95% of Data
11.7 – 140.4 N/m^2

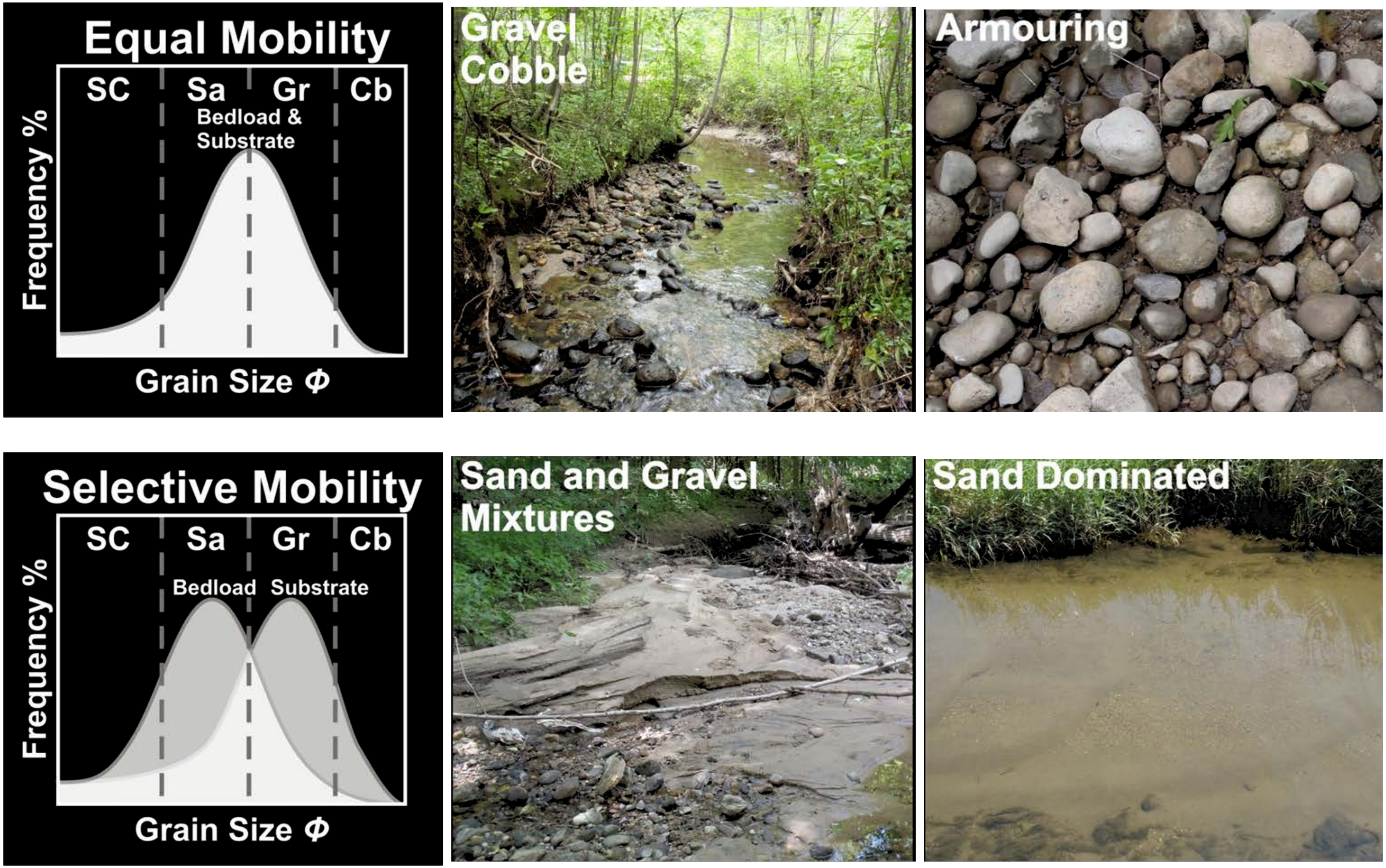
Erosion Thresholds and Scale



Single particle or uniform grain-size scale

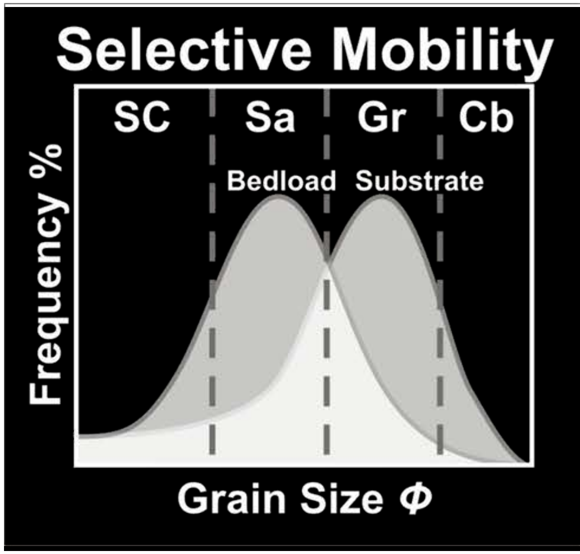
Average Channel Scale

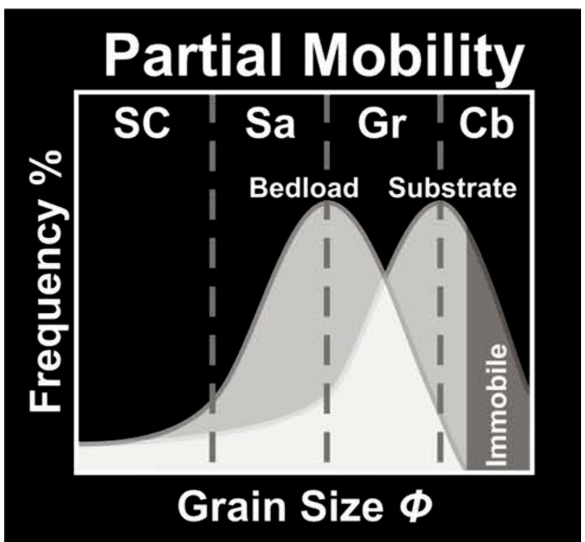
Sediment Mobility Theory

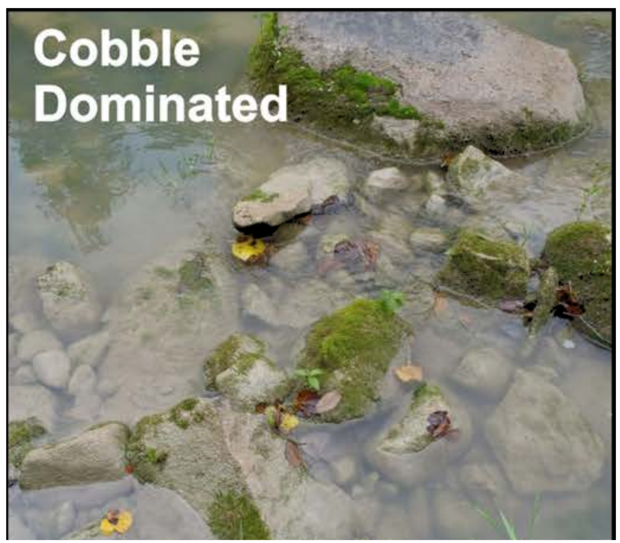


(Distribution graphs adapted from Venditti et al., In Press)

Sediment Mobility Theory







(Distribution graphs adapted from Venditti et al., In Press)

SELECTIVE MOBILITY

KOMAR (1987, 1996)

HIDING FUNCTIONS

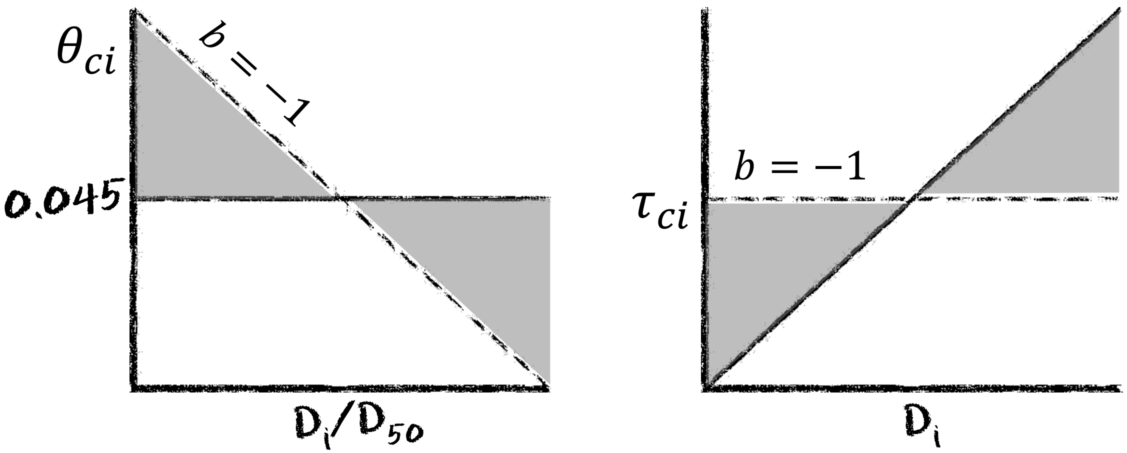
$$\theta_{ci} = a\left(\frac{D_i}{D_{50}}\right)^b$$

$a = \theta_{c50} \approx 0.045$

$b = -1$ Equal Mobility

$-1 < b < 0$ Selective Mobility

$b \approx -0.6$ Average



Example:

$$\theta_{ci} = 0.0375\left(\frac{D_i}{D_{50}}\right)^{-0.872}$$

SELECT REFERENCES

- PARKER (1990)

  http://hydrolab.illinois.edu/people/parkerg/default.asp
- WILCOCK and CROWE (2003)

  http://www.stream.fs.fed.us/publications/bags.html

SELECTIVE MOBILITY

HIDING FUNCTIONS

WILCOCK and CROWE (2003)

$$\theta_{ci} = \theta_{c50}\left(\frac{D_i}{D_{50}}\right)^b$$

$$b = \frac{0.67}{1 + e^{(1.5 - D_i/D_{50})}}$$

$$\theta_{c50} = 0.021 + e^{(-20F_s)}$$

WHERE:
F_s IS THE FRACTION OF SAND

Fractional (selective) sediment transport of sediment mixtures

- Non-linear effect of sand on gravel transport rates
- Two-part hiding function for more sandy and less sandy gravel mixtures
- Increases θ_c for fine fractions (reducing sediment transport rates)
- Decreases θ_c for course fractions (increasing sediment transport rates)
- As sand content increases, sediment transport rate increases for all grain sizes

Two Different Applications

Engineered **Threshold** Channel

Entrainment **threshold** (force/area)
Forced riffles-pools and/or runs
Armouring (**equal mobility** or immobility)
Factors of **safety** for design stone sizing

<u>River engineering:</u>

"Most" channel designs, including stream restoration and **rehabilitation** in Ontario

'Natural' **Alluvial** Channel

Sediment **load** (mass/time)
Dynamic bed morphology
Fractional sediment transport (**selective mobility**)
Sediment **mixture** gain-size distributions

<u>River assessment and channel design:</u>

"Some" **natural** channel designs in Ontario
Watershed impacts, sediment **yield**
Stormwater erosion control targets

E.g., USDA

Chapter 8:
Threshold Channel Design

Allowable shear stress techniques ($\theta_c = 0.045$)

Factors of **safety**
x 1.2–1.3 (Fischenich)

Notes:
Adjustments for **mixtures**

$$\theta_{ci} = 0.0834\left(\frac{D_i}{D_{50}}\right)^{-0.872}$$

Chapter 9:
Alluvial Channel Design

United States
Department of
Agriculture

Natural
Resources
Conservation
Service

Part 654
National Engineering Handbook

Stream Restoration Design

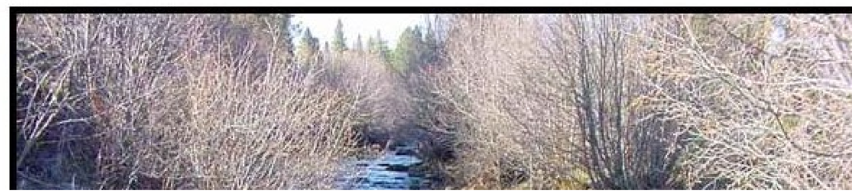


Table 8–1 General guidance for selecting the most appropriate channel design technique

Technique	Significant sediment load and movable channel boundaries	Boundary material smaller than sand size	Boundary material larger than sand size	Boundary material does not act as discrete particles	No baseflow in channel. Climate can support permanent vegetation
Allowable velocity		X			
Allowable shear stress			X		
Tractive power				X	
Grass lined/tractive stress					X
Alluvial channel design techniques	X				

http://www.nrcs.usda.gov/wps/portal/nrcs/detail/national/water/manage/restoration/

Factor of Safety and Uncertainty

Stone Sizes for River Engineering

- References (e.g., **USDA**, NCHRP, AASHTO)
- Factor of **Safety** = 1.1 to 1.5
- **Common** recommendation is 1.2

Erosion Threshold Uncertainty (does it matter?)

- Threshold channel design – **depends…**
- Natural channels, alluvial channel design – **yes!**

'Natural' Alluvial Channels

- Equal mobility (threshold) assumptions need to be **justified**.
- **Selective** mobility to estimate sediment load
- Sediment **yield**, connectivity, land use **impact**

Field Verification of Thresholds

Field Bedload Measurements

- Tagging, tracing
- Trapping, detention
- Impact, acoustics
- Sediment budgets

Need Standard Definitions

- What measurement **technique**?
- **Threshold** stone sizes versus sediment load estimates?
- Length of **monitoring** period, quality of **hydrographs**?

Project Expectations

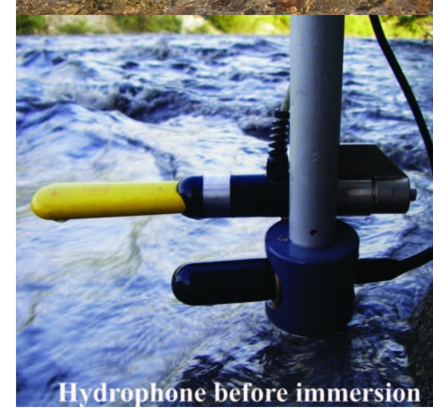
- **Not** standard practice, cost and schedule limitations
- Practitioners that **do** "field truthing" should be:
  - Clear about scope and **limitations**
  - Open to **Publication** and peer-review

Reliable field **truthing** is easier said then done!

Lamarre et al., 2005

Schneider et al., 2014

www.fs.fed.us



Belleudy et al. 2010

Erosion Threshold Awareness

The Science and Practice

- Understand **limitations** of Shields number
- Don't be scared of **selective** mobility
- Threshold versus **alluvial** channels
- Factors of safety and **uncertainty**
- **Expectations** for Field Verification

Selective Mobility Applications

- **Sediment** load, yield, budgets, monitoring
- Stormwater management **erosion criteria**

Thank You!

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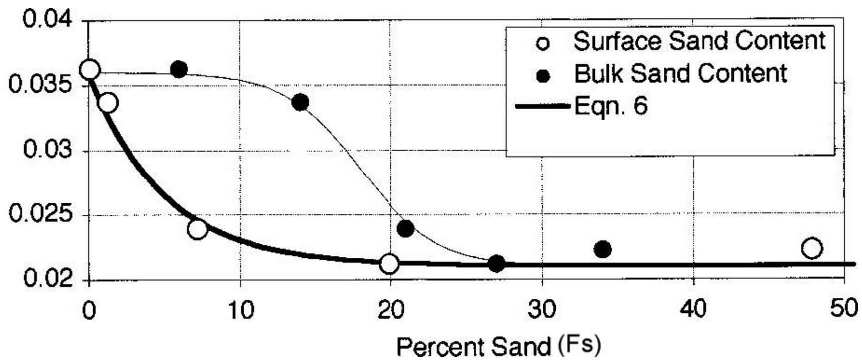
More Wilcock and Crowe (2003)

θ^*_{r50}



Uses **reference** shear stress (τ_r) and **Shields** number (θ^*_{r50})

Non-linear relation between sand content and sediment transport rates

As $F_s \uparrow$, θ^*_{r50} and $\tau_r \downarrow$ thus **increasing** sediment transport rates for all sizes

Two-part trend in hiding function relative to τ_r for single-sized sediment (1:1 line)

Hiding function acts to:

Finer fractions:

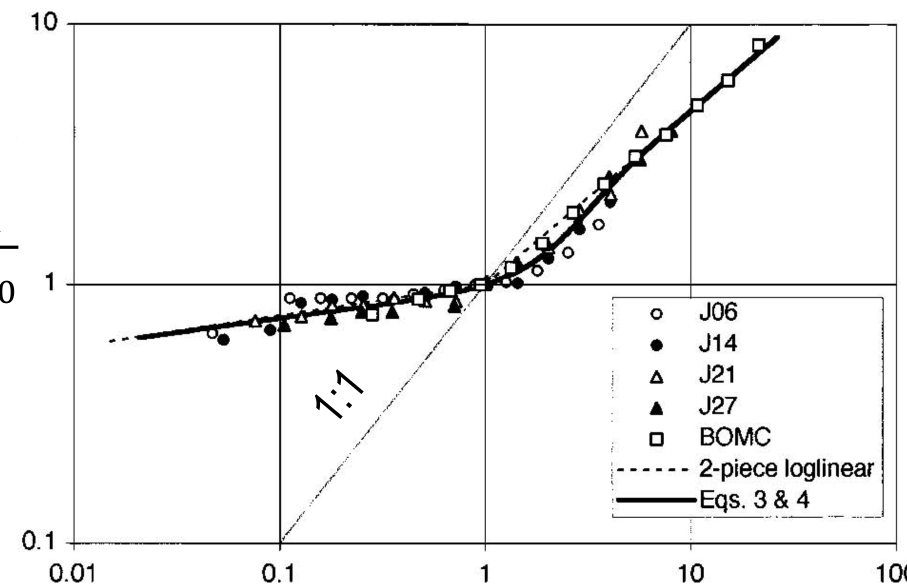
$\tau_r \uparrow$ ($\downarrow$ sediment transport)

Coarser fractions:

$\tau_r \downarrow$ ($\uparrow$ sediment transport)

*Sand **changes** gravel sediment transport

$\frac{\tau_{ri}}{\tau_{r50}}$



D_i/D_{50}

List of References

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