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REGIONAL GLACIAL LEGACY EFFECTS ON STREAM BOUNDARY TYPES

and the implications for erosion threshold and sediment transport models




Dr. Roger T.J. Phillips, P.Geo.

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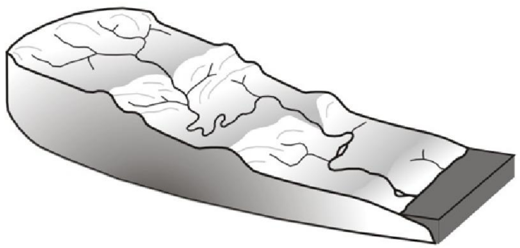
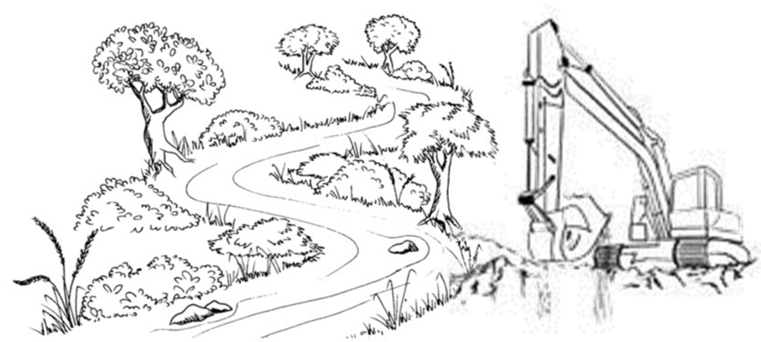
REGIONAL GLACIAL LEGACY EFFECTS ON STREAM BOUNDARY TYPES

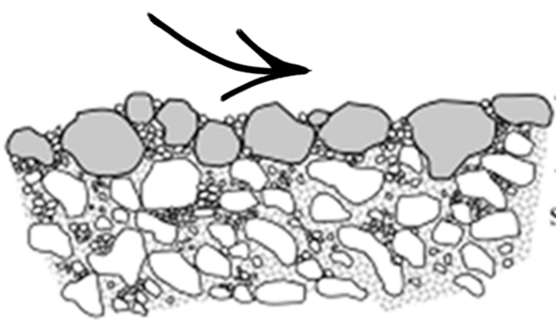
and the implications for erosion threshold and sediment transport models



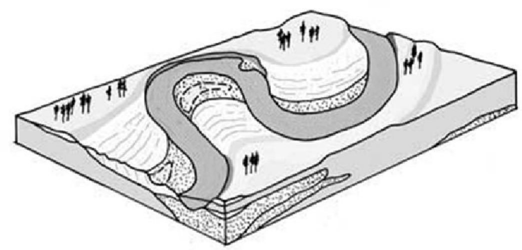
1. Glacial legacy effects:
Stream power and sediment sources



4. Applied geomorphology:
Make the case for better science in practice

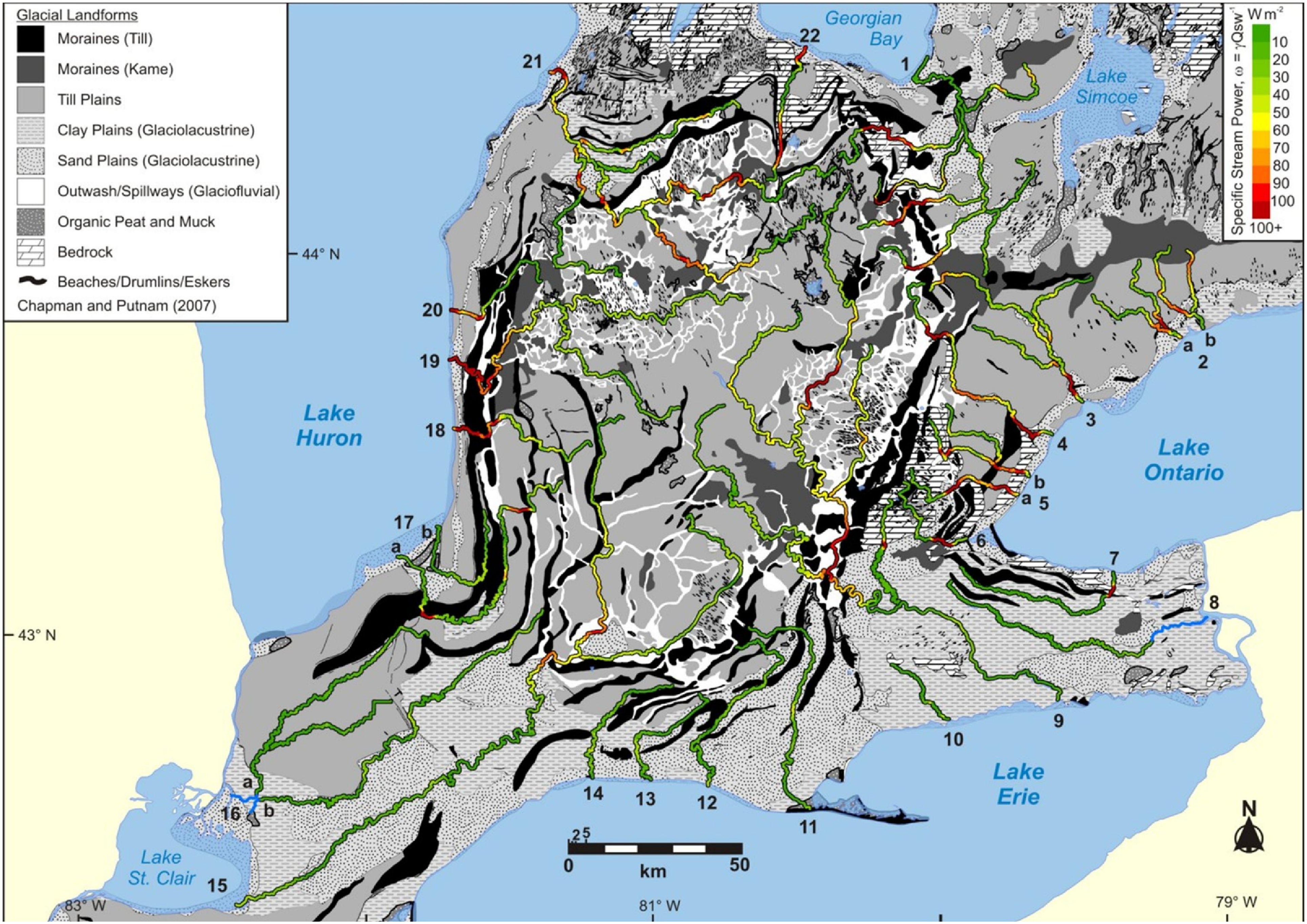


3. Erosion thresholds and sediment transport:
Shields parameter

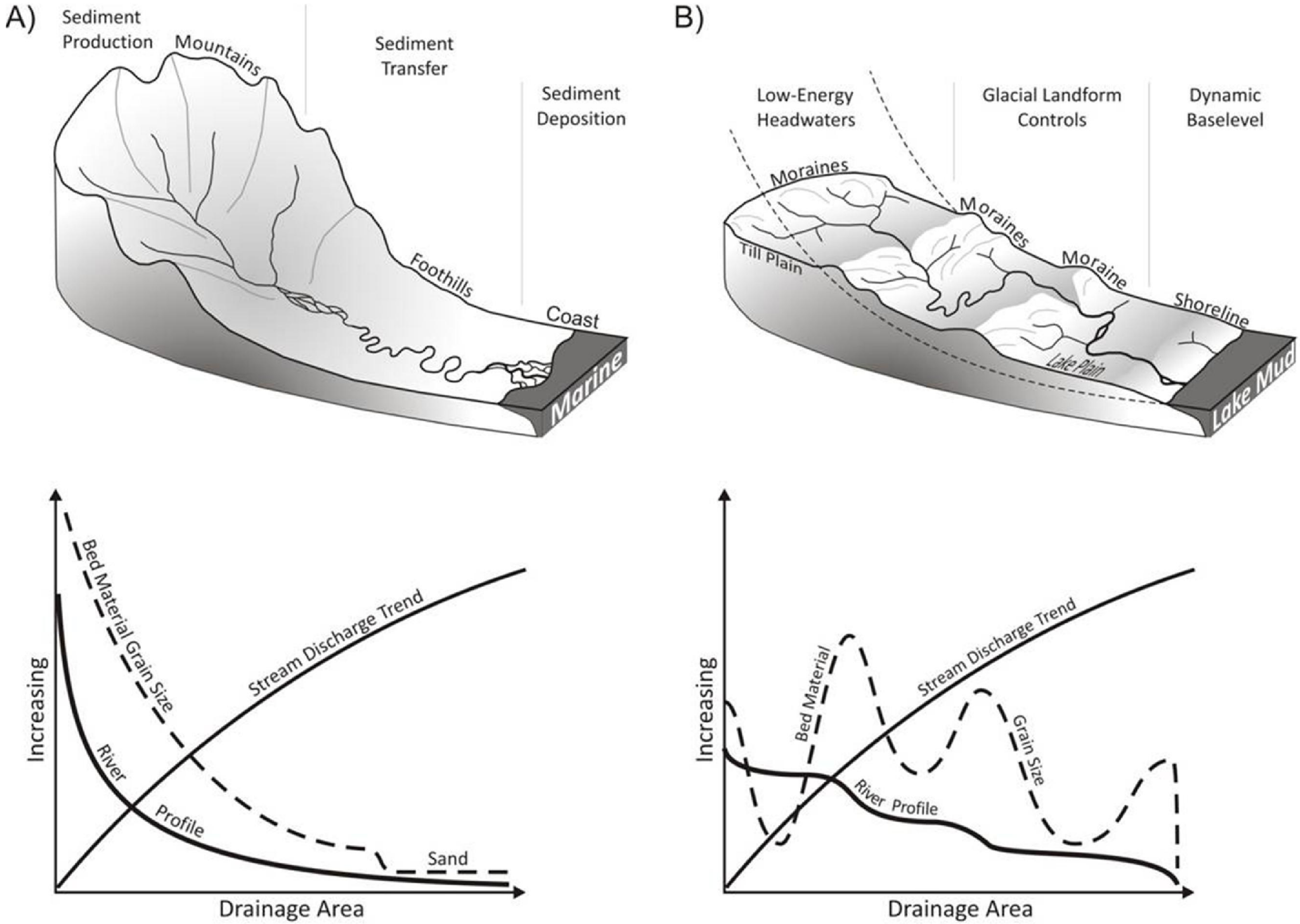


2. Stream boundary types:
Sand, cobble, and glacial till

Glacial landforms and stream power in southern Ontario (Phillips and Desloges, 2014)

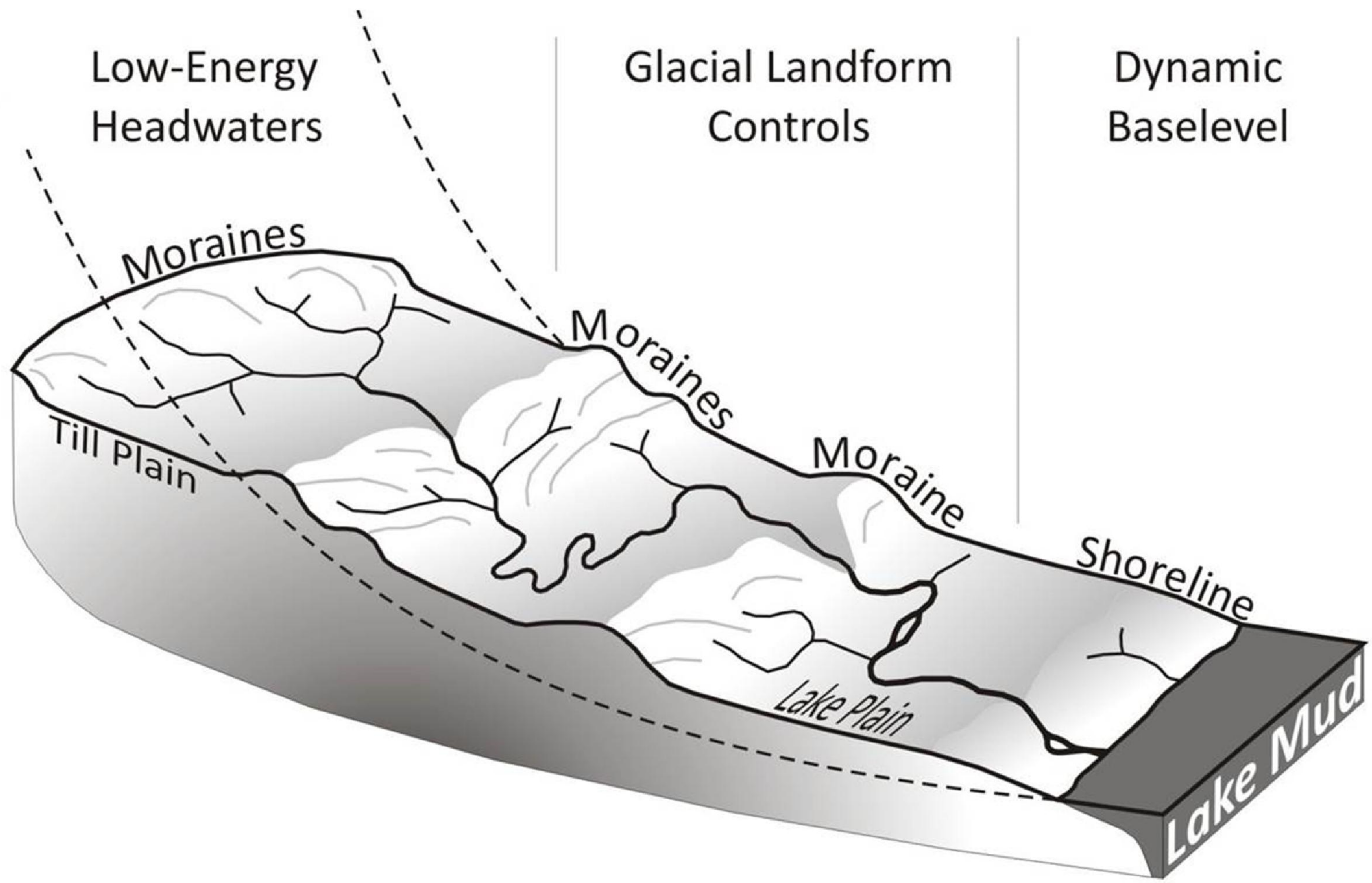


Landscape watershed models



(Phillips and Desloges, 2015)

Low-relief glacial landscape watershed model



(Phillips and Desloges, 2015)

CONTINUUM OF CHANNEL BOUNDARY TYPES

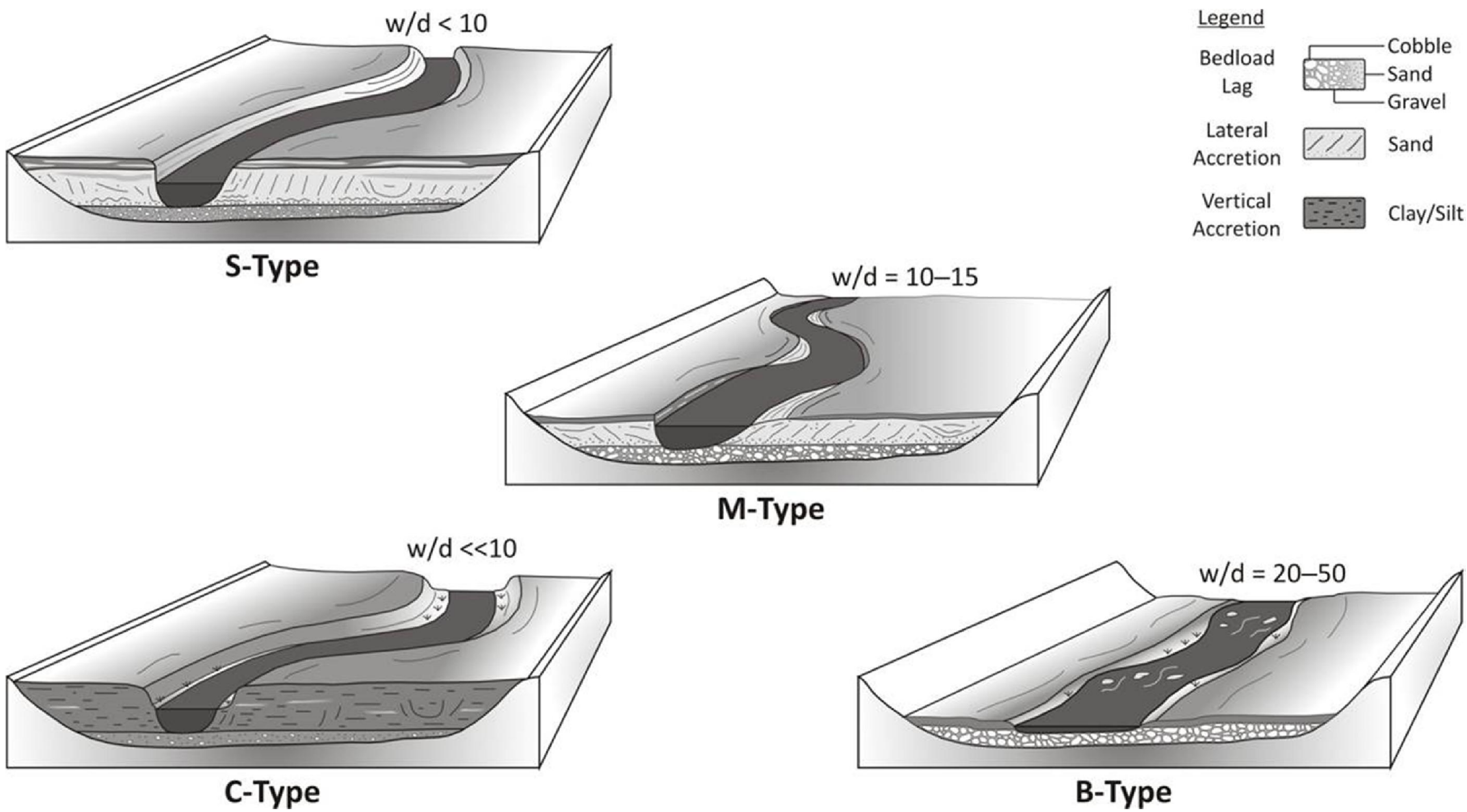
SAND

GRAVEL

CLAY

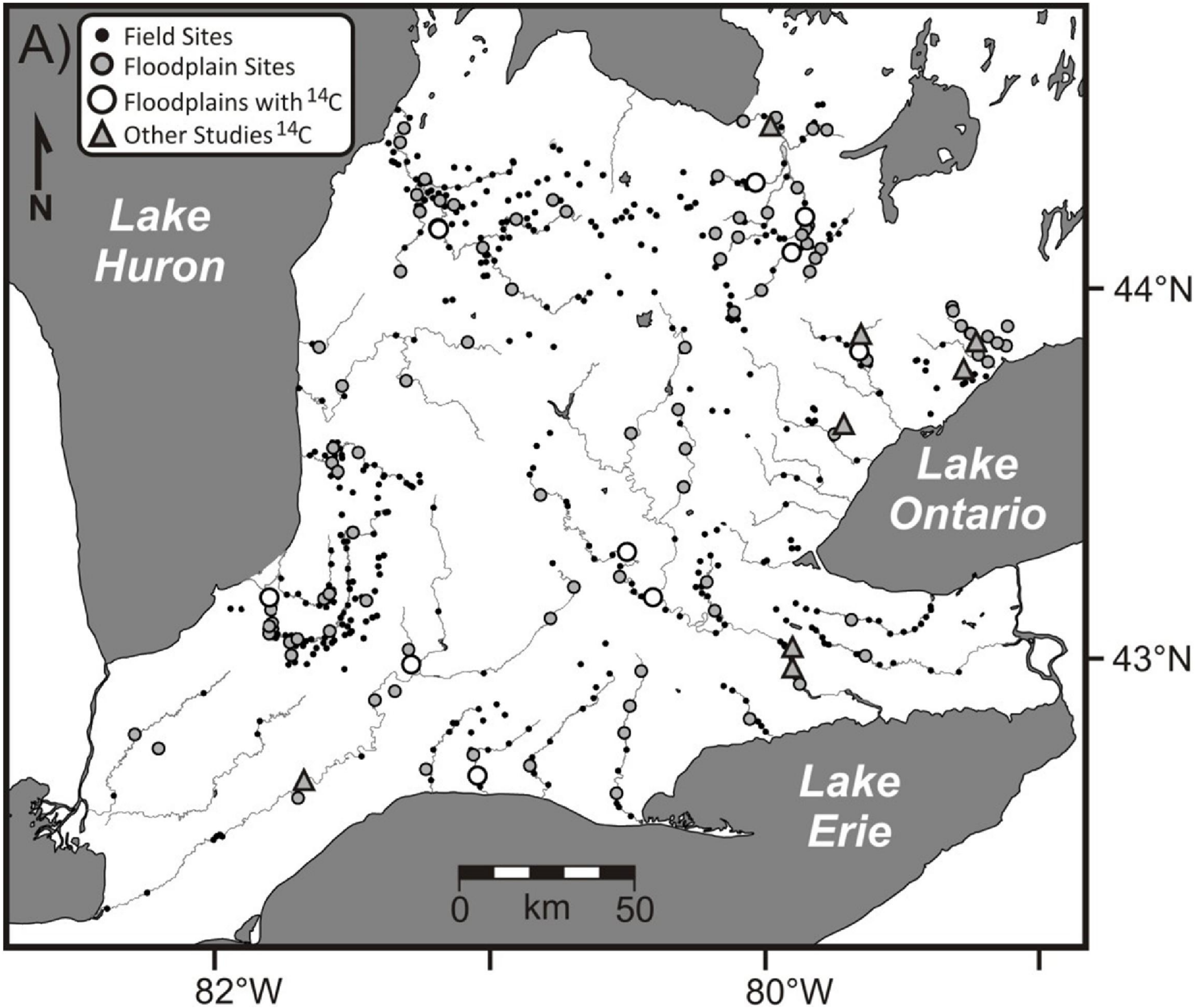
COBBLE

Continuum of alluvial floodplains



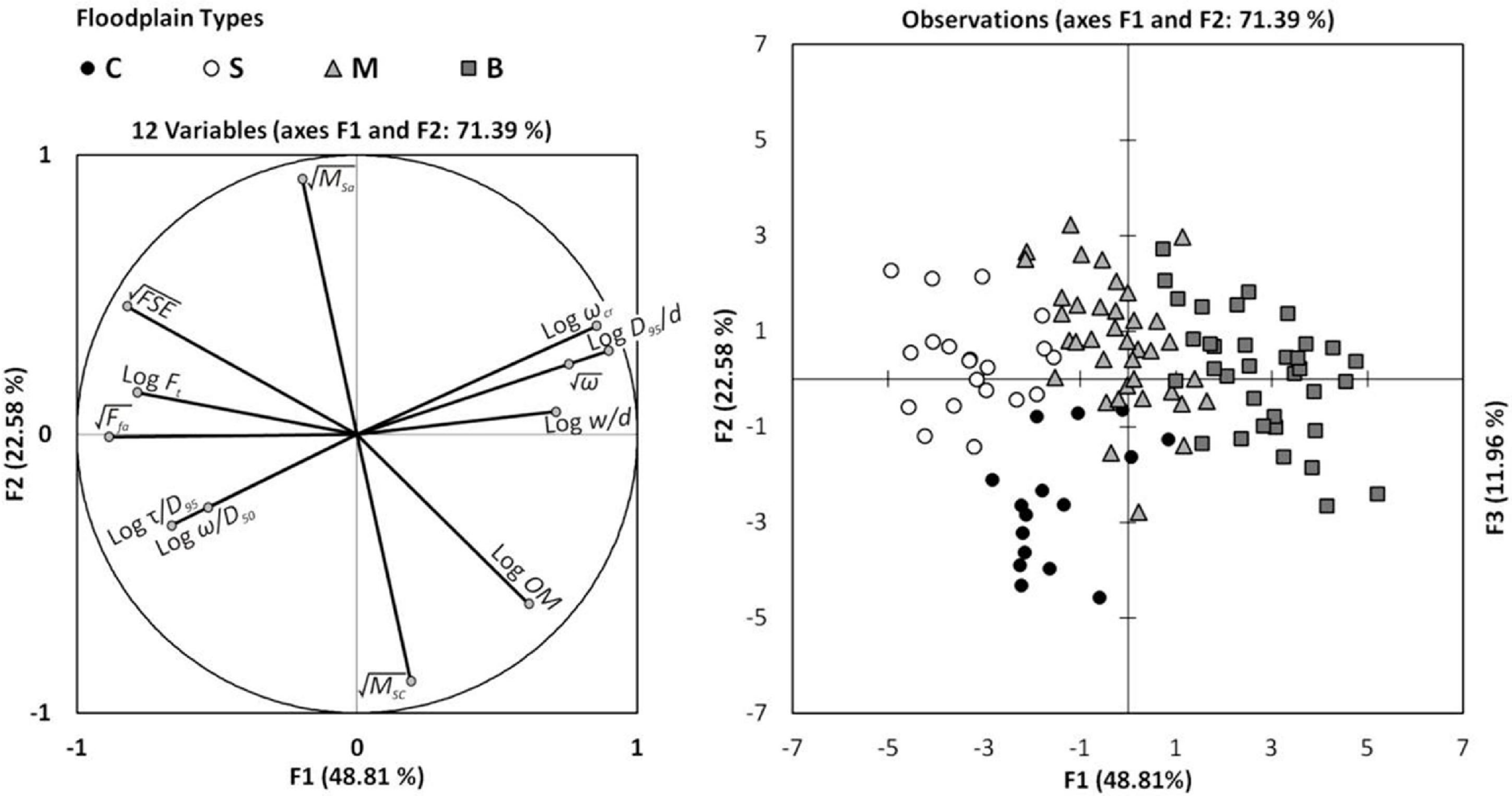
(Phillips and Desloges, 2015)

Field sites in southern Ontario region



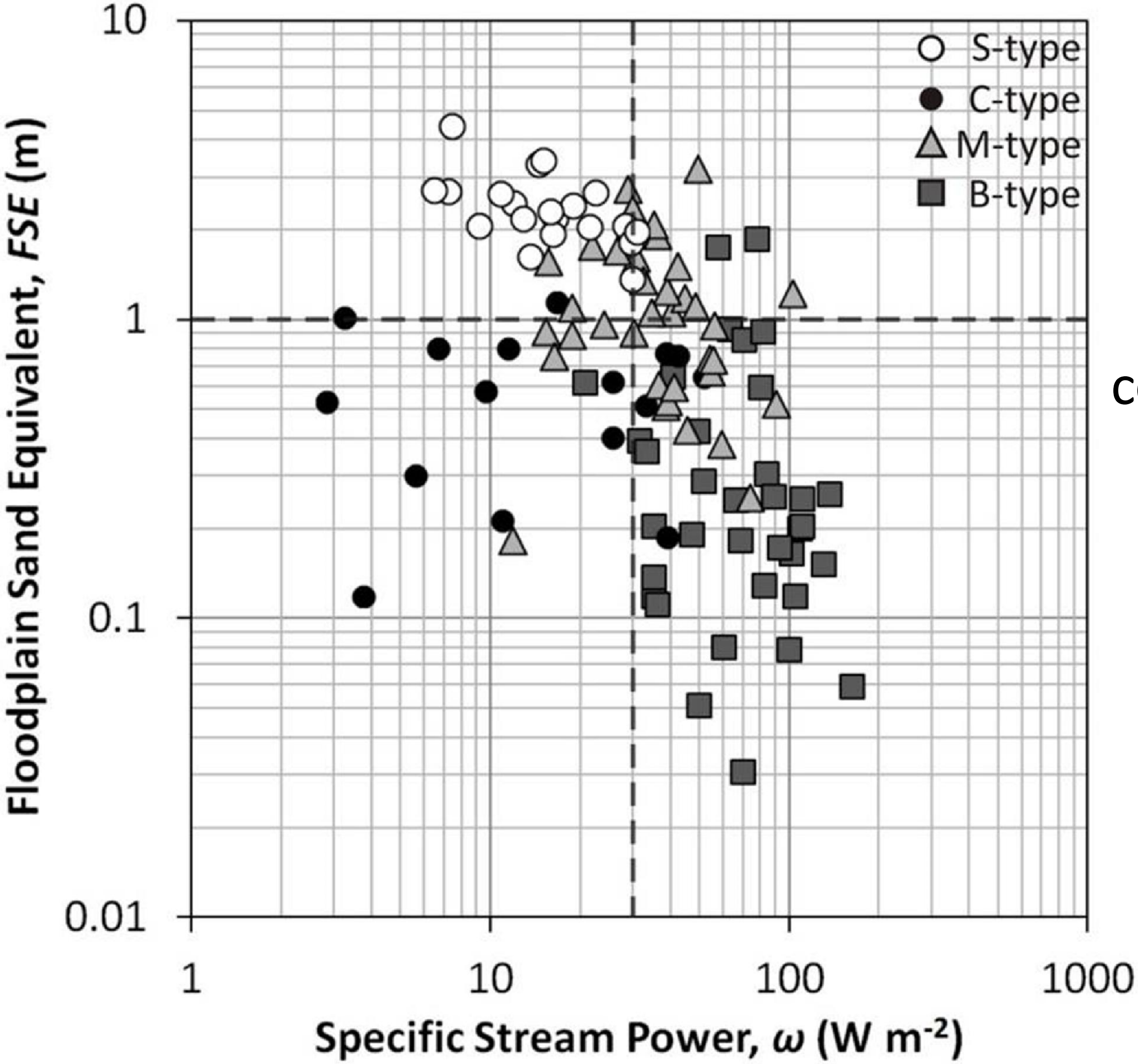
(Phillips and Desloges, 2015)

Principal component analysis (PCA) of alluvial floodplain sites
12 variable PCA and K-means clustering



(Phillips and Desloges, 2015)

Continuum of stream power and alluvial sand



Glacial legacy sources of cobble and sand

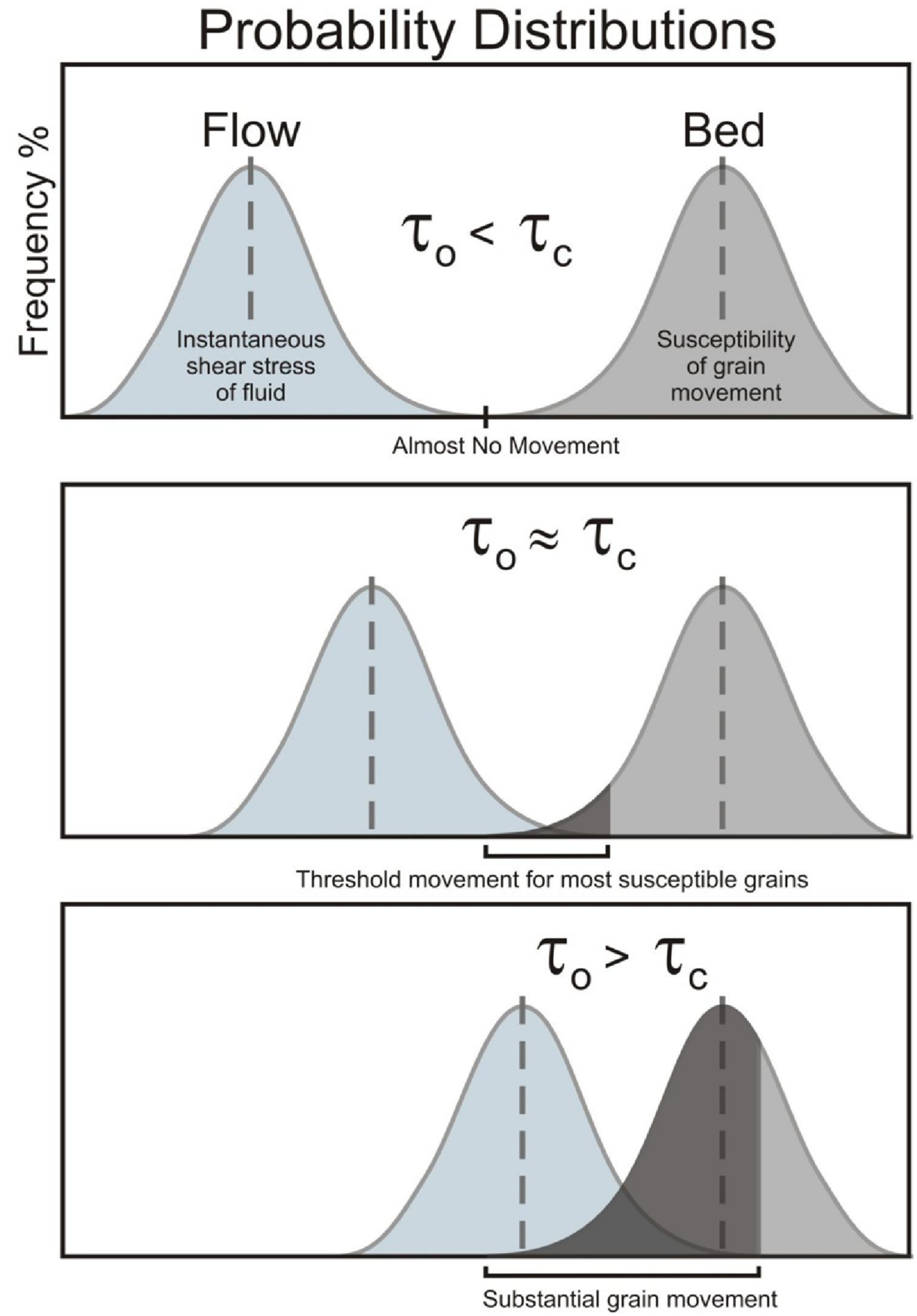
(Phillips and Desloges, 2015)

EROSION THRESHOLDS AND SEDIMENT TRANSPORT

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

Erosion thresholds of motion

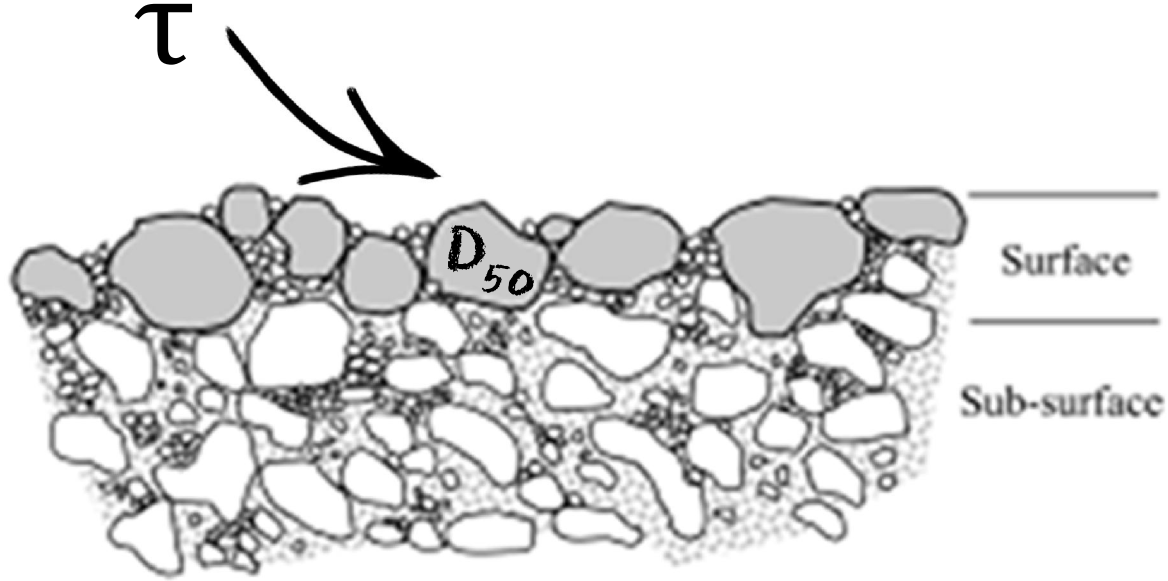
STATISTICAL PROBLEM



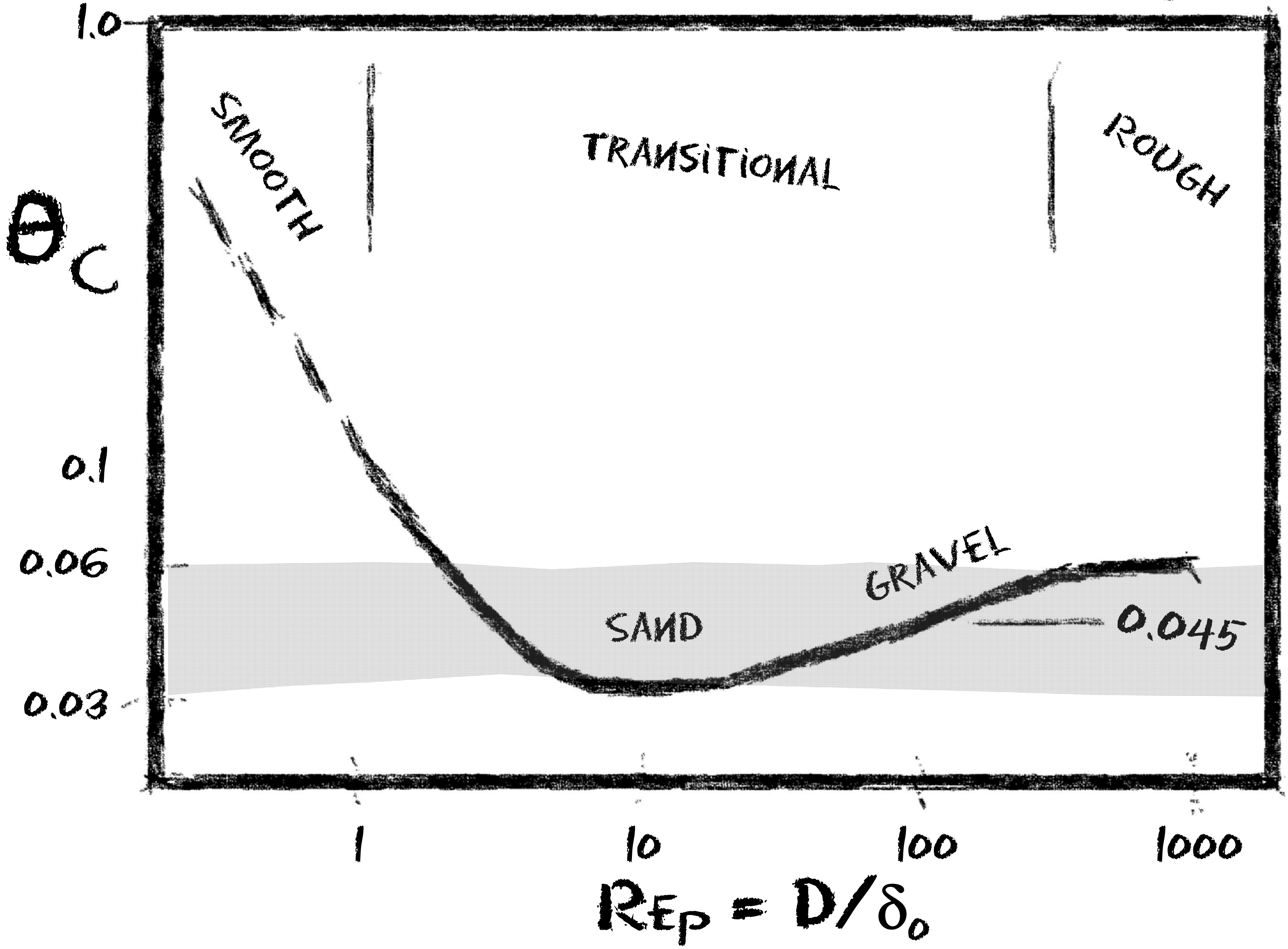
EROSION THRESHOLDS OF MOTION

DIMENSIONLESS SHEILDS NUMBER (SHEILDS, 1936)

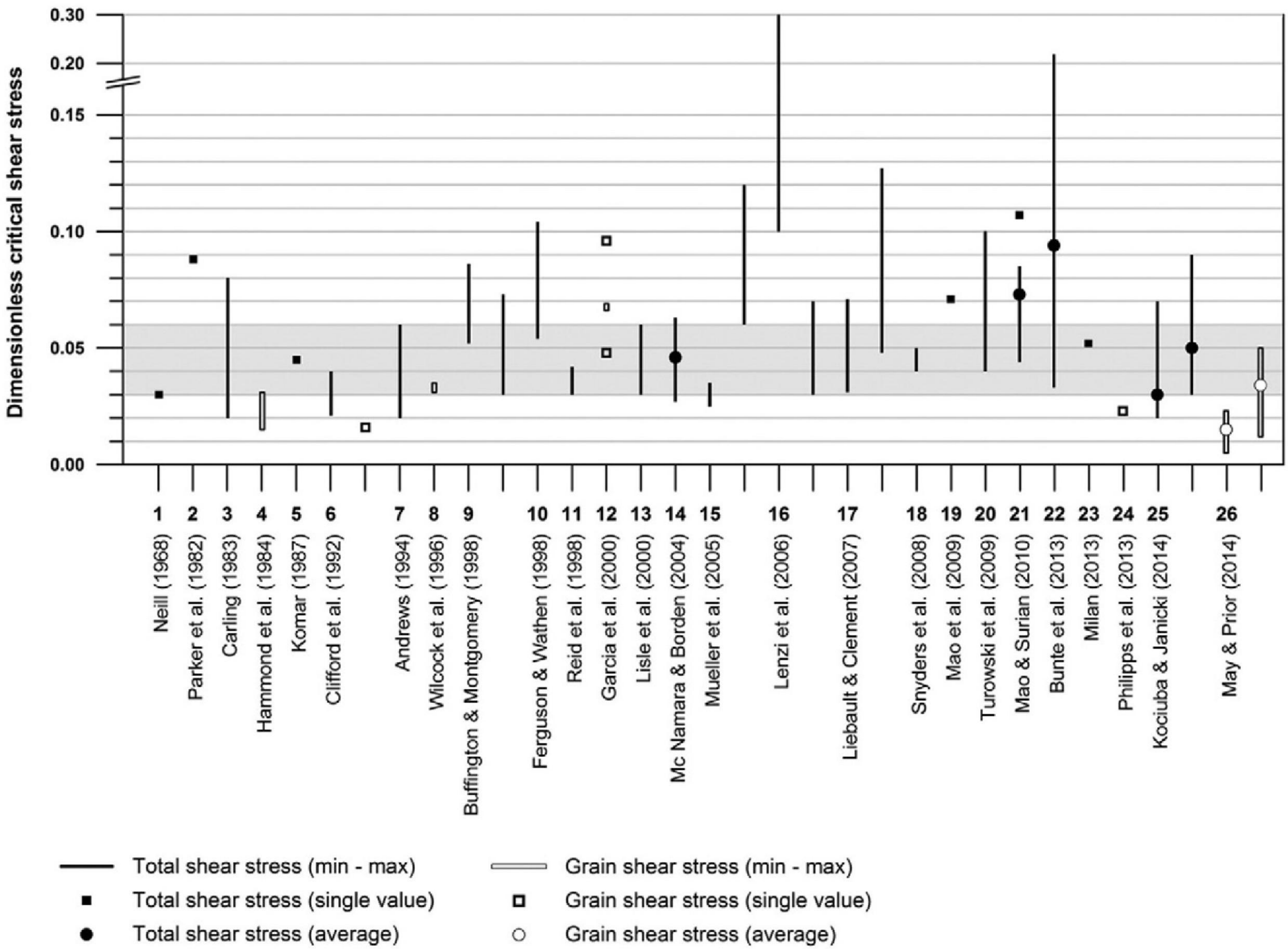
$$\theta_c = \frac{\tau_c}{(\rho_s - \rho)gD_{50}} = \text{CONSTANT ?}$$



DIMENSIONLESS SHEILDS - θ_C



Field-based dimensionless critical shear stress

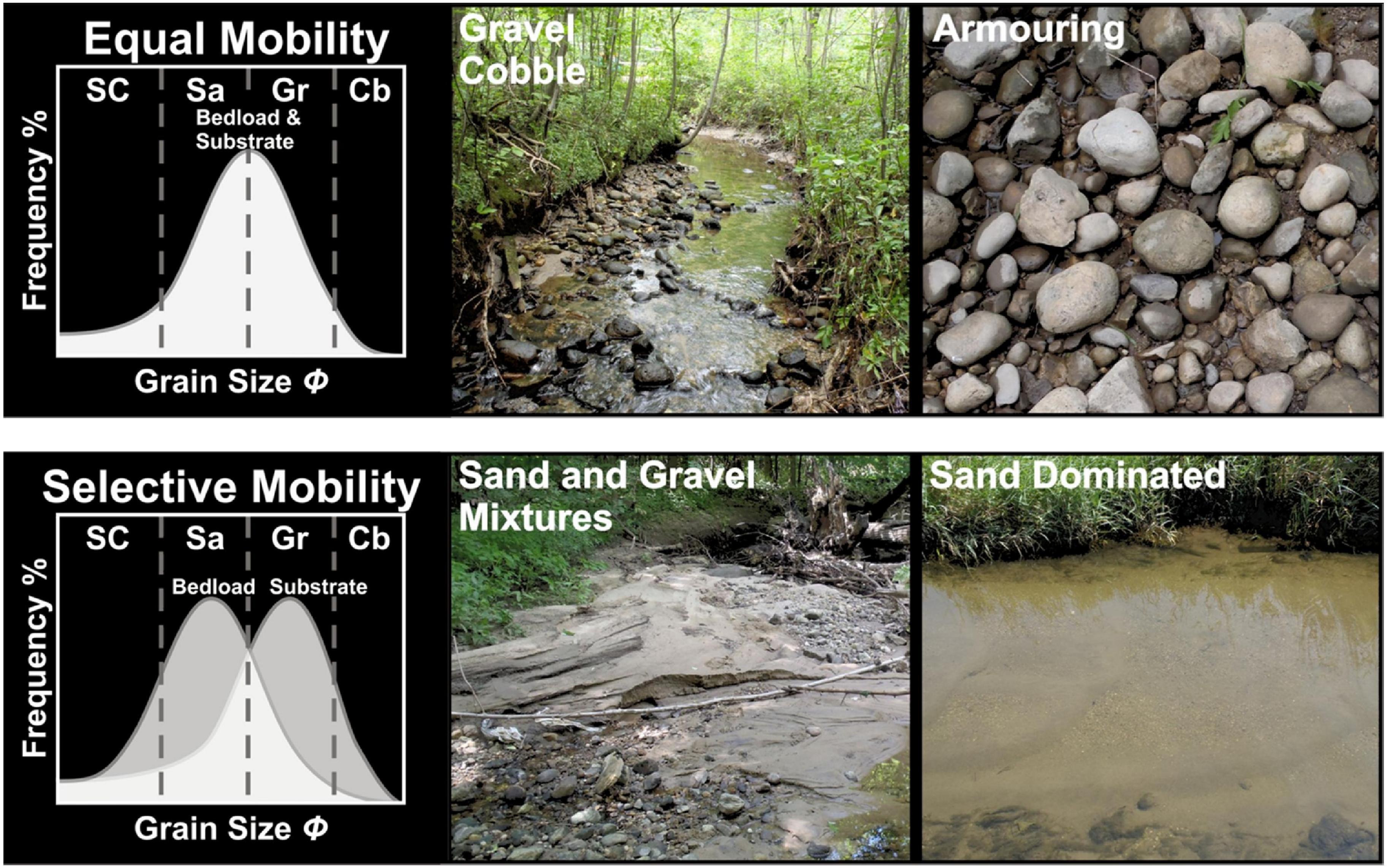


Full mobility

Partial transport

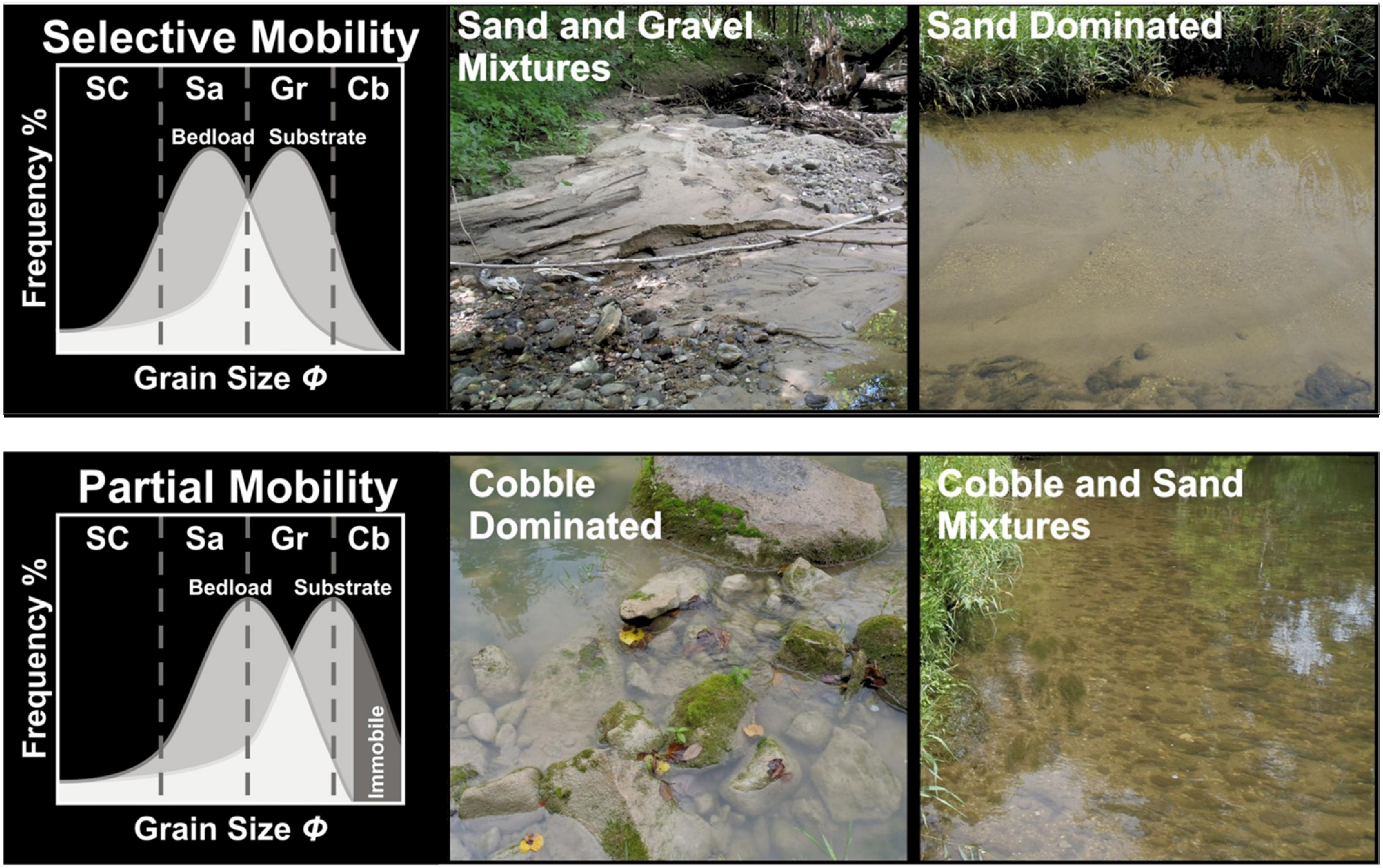
(Petit et al., 2015)

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

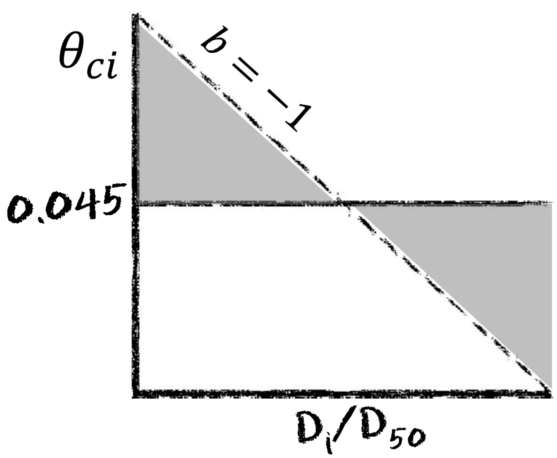
$$\theta_{ci} = a\left(\frac{D_i}{D_{50}}\right)^b$$

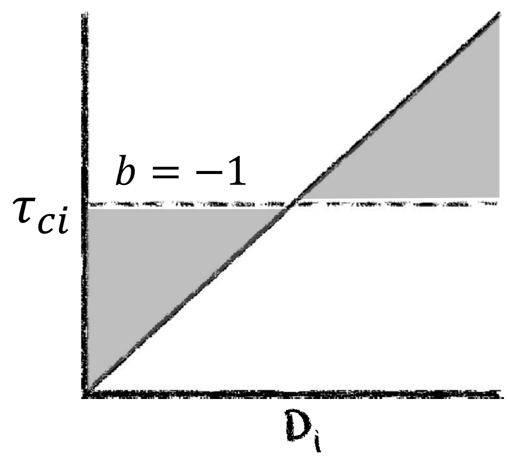
$a = \theta_{c50} \approx 0.045$

$b = -1$ 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)

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

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

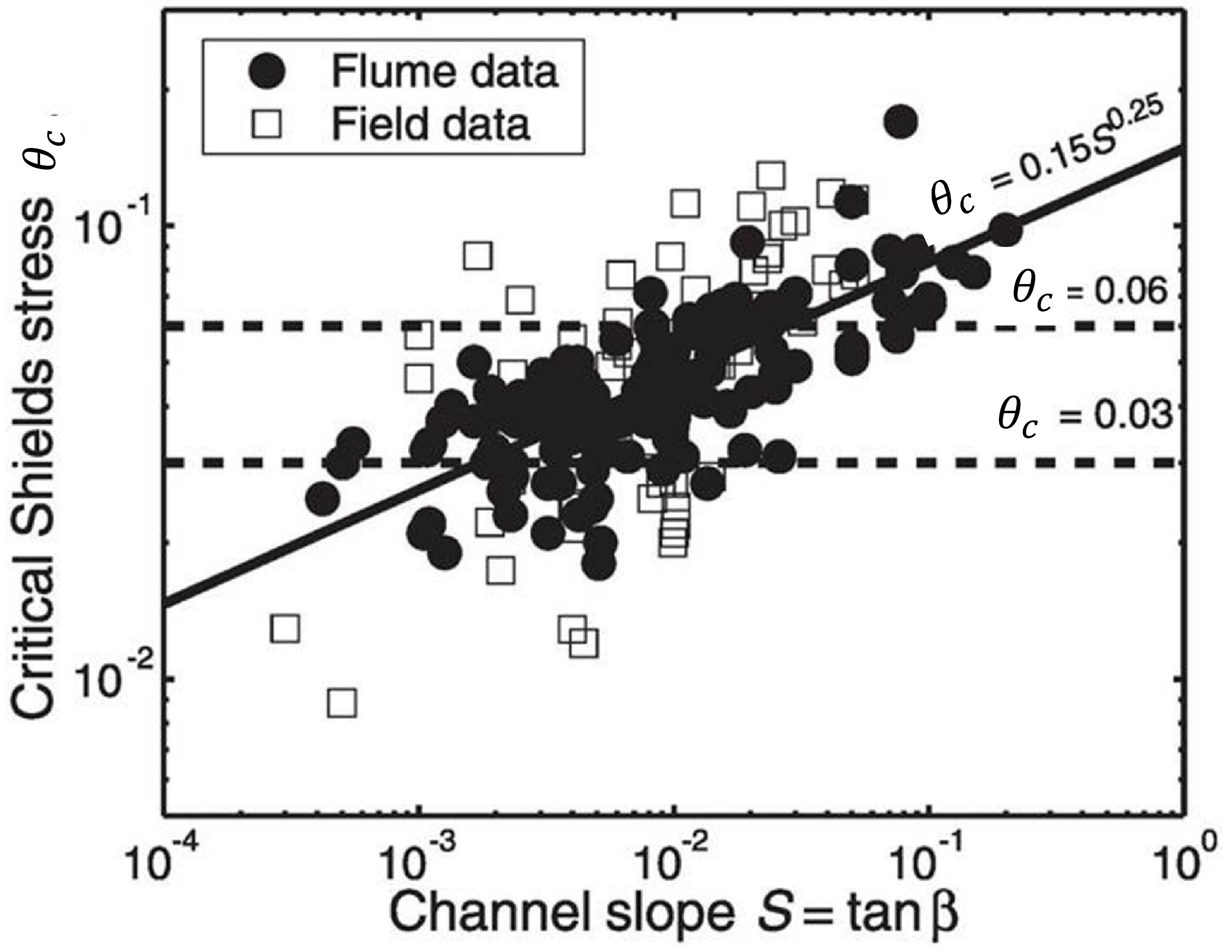
$$\theta_{c50} = 0.021 + e^{(-20F_s)}$$

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

Field and flume data for dimensionless critical shear stress variations with channel slope



$\theta_c = 0.045$
S = 0.01

$\theta_c = 0.03 - 0.06$
S = 0.002 – 0.02

So…
θ_c is averaged
in terms of both:

1. “bed-state”
(grain size, structure)

and

2. channel slope

(Lamb et al., 2008)

EROSION THRESHOLDS OF MOTION

DIMENSIONLESS SHEILDS NUMBER (SHEILDS, 1936)

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

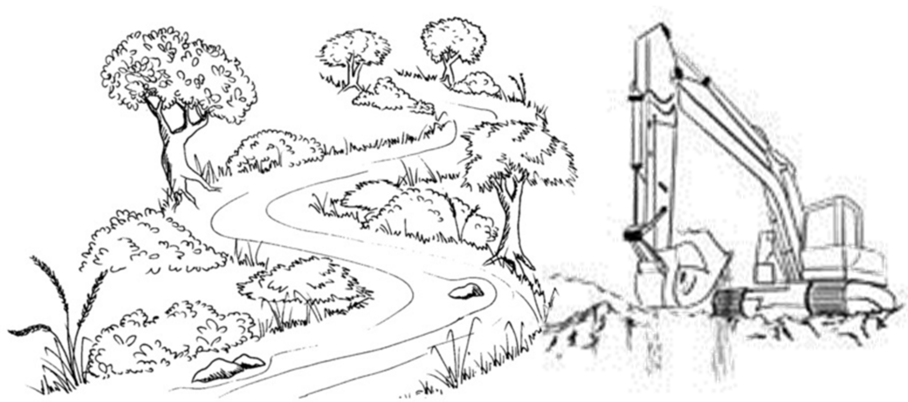
= NOT CONSTANT ?

✓ COEFFICIENT OF PROPORTIONALITY

✓ ADJUSTABLE "BED STATE" PARAMETER


EQUAL MOBILITY
Assumptions
Good Enough

Making the case for better science in practice for Applied Geomorphology



TWO SELECTED LINES OF REASONING

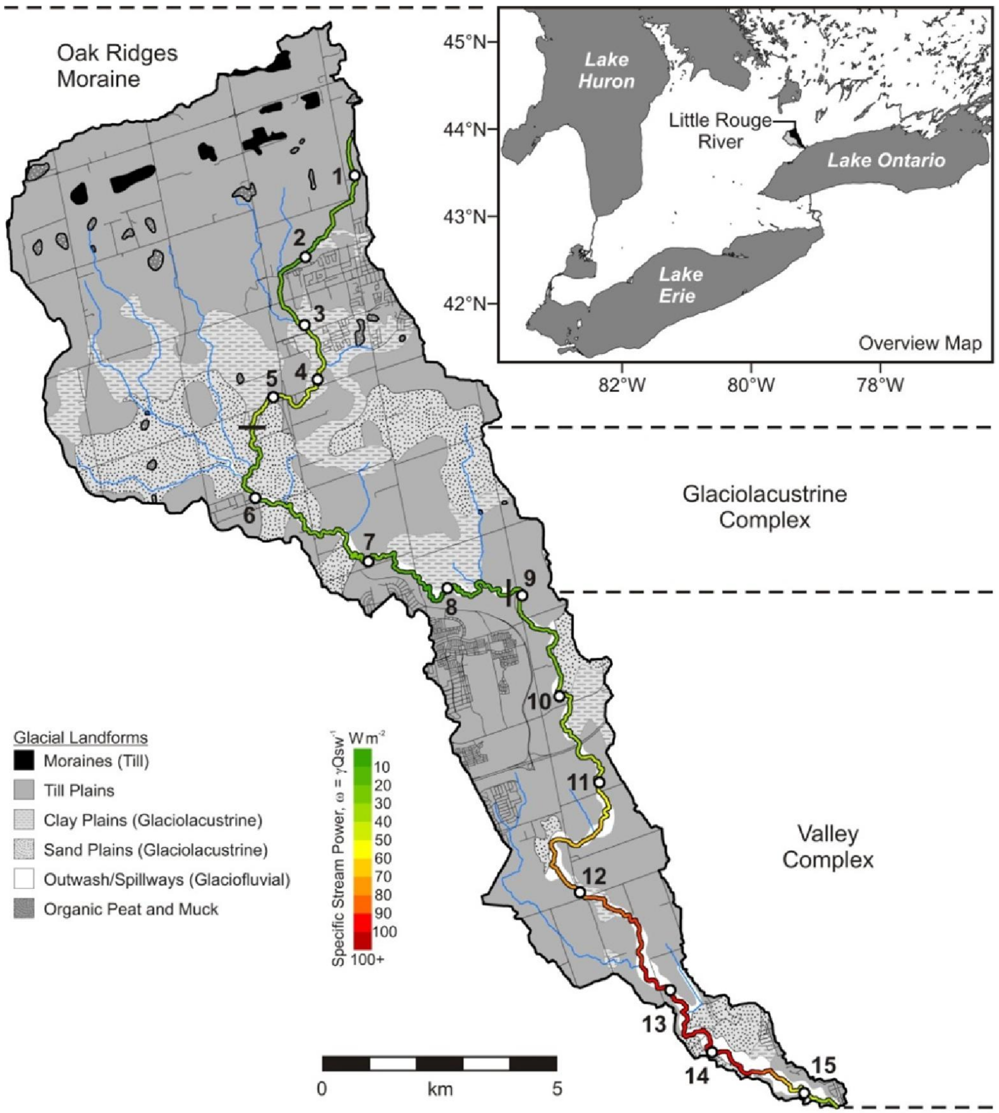
A. GLACIAL LEGACY:

- Downstream bankfull adjustment and substrate mobility

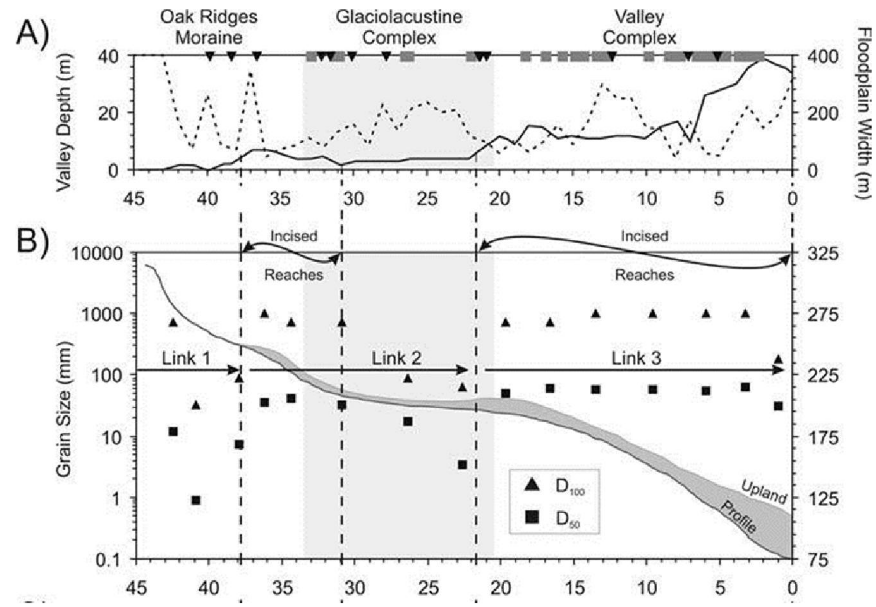
B. STORMWATER MANAGEMENT:

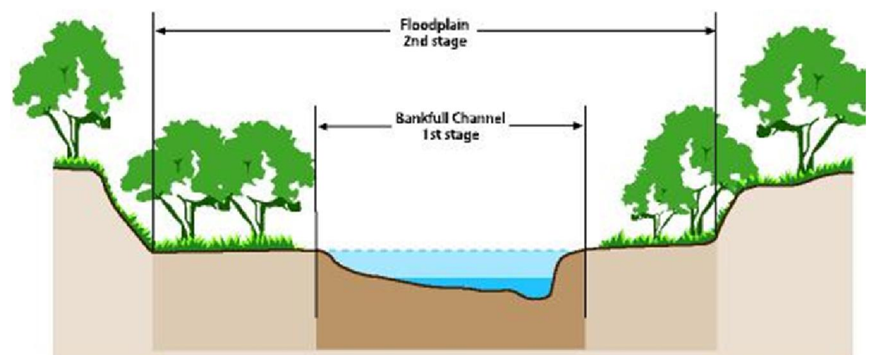
- Threshold critical discharge for erosion criteria

A. Little Rouge River downstream bankfull adjustment



(Thayer, Phillips, Desloges, In Press)

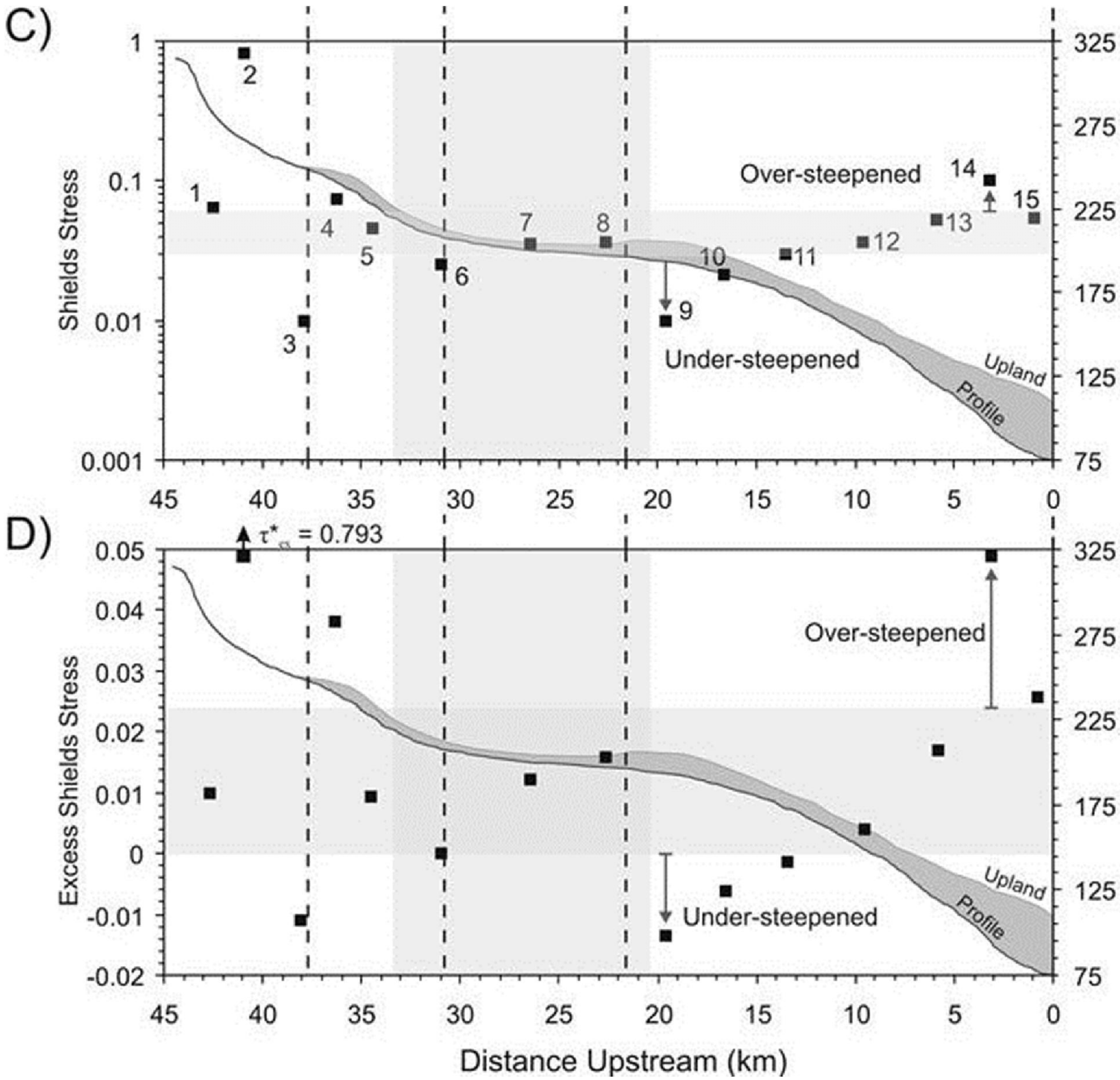




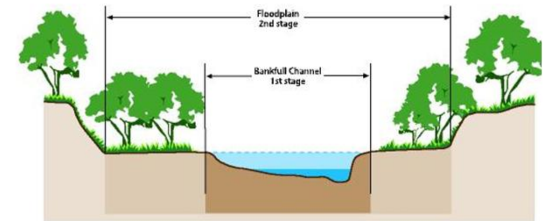
Assume: $\tau_{BF} = \tau_{c50}$

θ_{c50} = coefficient of proportionality for mobility of average grain size at the bankfull discharge

A. Little Rouge River bankfull Shields stress



(Thayer, Phillips, Desloges, In Press)



Conclusions

Longitudinally substrate mobility is not uniform;

Bankfull channels are not consistently adjusted morphologically to transport the substrate;

and/or

Constant "bed-state" and average Shields stress assumptions are not valid.

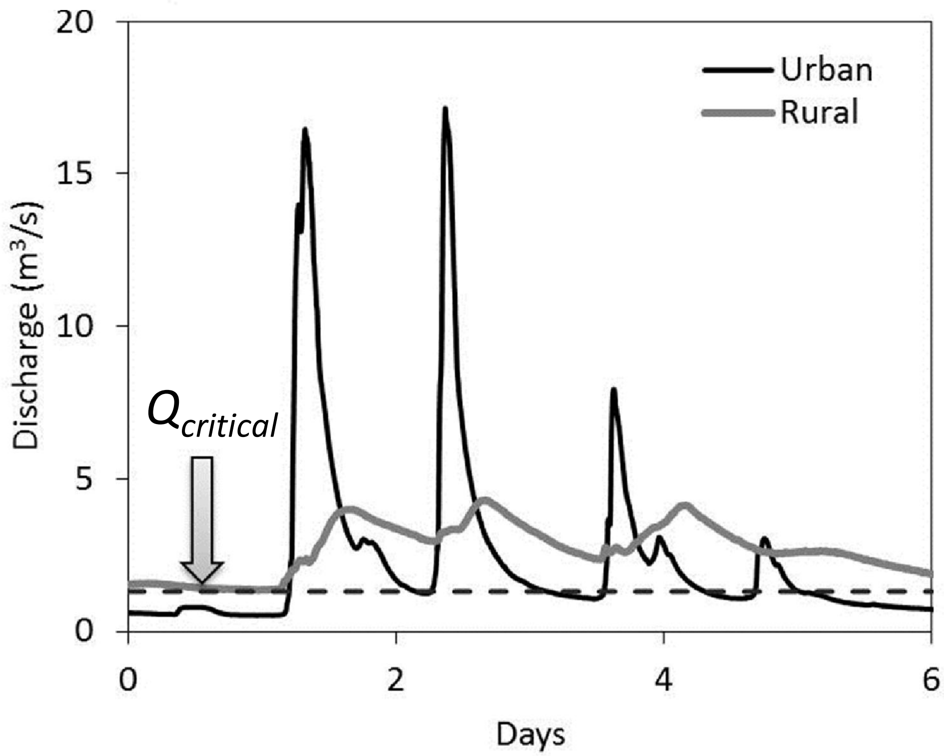
B. Stormwater management critical discharge criteria

$\theta_c \rightarrow \tau_{cr} \rightarrow Q_{critical}$

Selective mobility cases?

Cumulative Effective Work Index (Rowney and MacRae, 1992);

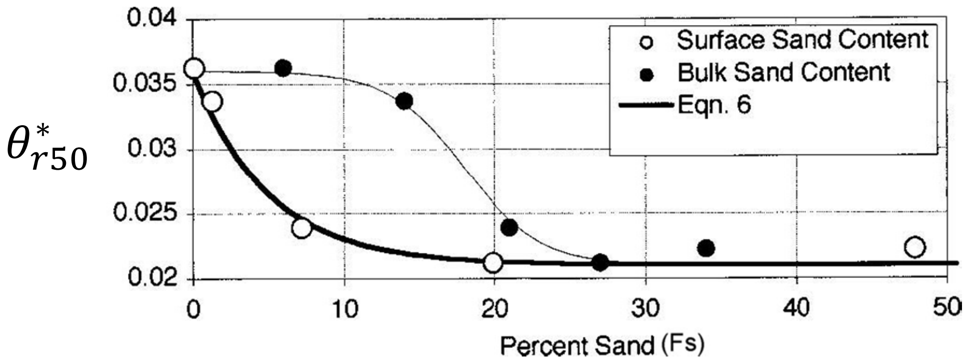
$$PWR = \sum (\tau_o - \tau_{thr}) V \Delta t$$



- How valid is the <u>threshold critical discharge</u> ($Q_{critical}$) approach when selective mobility is a significant share of sediment transport?
- Conservatively low $Q_{critical}$ to account for sand sediment transport?
- Better to calculate sediment transport for mixed sand-gravel substrates

B. Stormwater management critical discharge criteria

Wilcock and Crowe (2003)



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

Non-linear relation between sand content and sediment transport rates

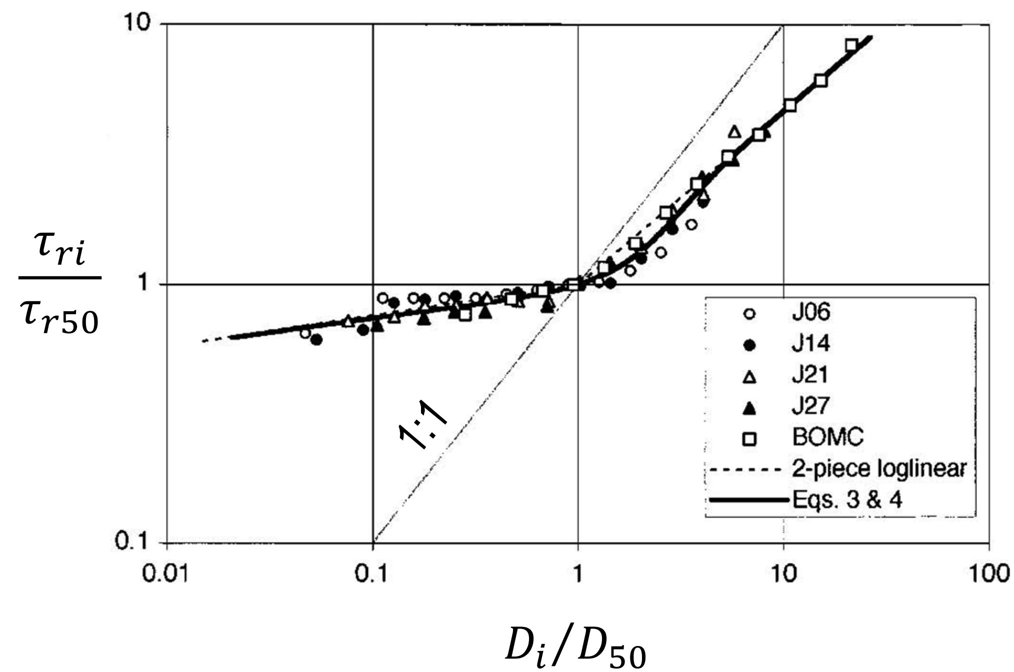
As $F_s \uparrow$ θ^*_{r50} and $\tau_r \downarrow$ thus increasing sediment transport rates for all sizes

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

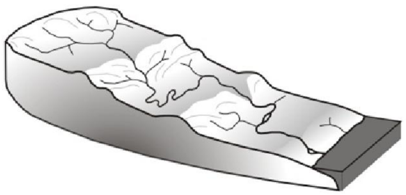
Hiding function acts to:
Finer fractions:
$\tau_r \uparrow$ ($\downarrow$ sediment transport)

Coarser fractions:
$\tau_r \downarrow$ ($\uparrow$ sediment transport)

*Sand changes gravel sediment transport

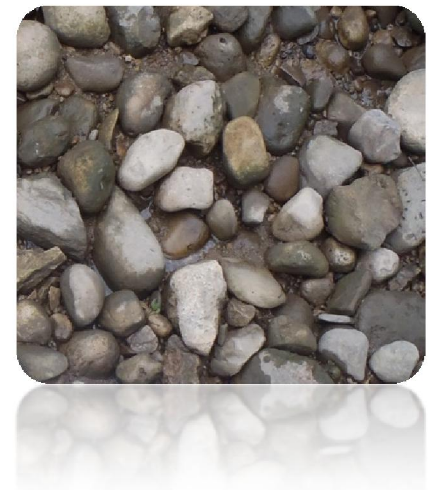


SUMMARY



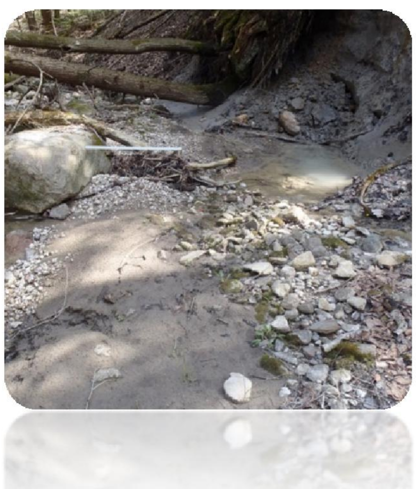
The glacial legacy in southern Ontario imparts an diverse range of channel boundary conditions and thus variable "bed-states"

- Inherited sources of sand and cobble



Shields shear stress is an adjustable "bed-state" parameter

- Average $\theta_c = 0.045$ best for equal mobility gravel



Selective transport is important for sand-gravel mixtures

- Hiding functions (e.g., Wilcock and Crowe, 2003)
- Sand content changes transport rate of larger sediment sizes

We rely on theory because geomorphic outcomes are naturally revealed over long time-scales and collection of empirical field data for sediment transport is expensive

REGIONAL GLACIAL LEGACY EFFECTS ON STREAM BOUNDARY TYPES

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Thank You!

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