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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.
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

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

3. Erosion thresholds and sediment transport:
   Shields parameter

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

Probability Distributions

Flow

\[ \tau_o < \tau_c \]

Instantaneous shear stress of fluid

Bed

Susceptibility of grain movement

Almost No Movement

\[ \tau_o \approx \tau_c \]

Threshold movement for most susceptible grains

\[ \tau_o > \tau_c \]

Substantial grain movement

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 - $\theta_C$

$Re_p = \frac{D}{\delta_0}$

- **Smooth**
- **Transitional**
- **Rough**

- **Sand**
- **Gravel**

$\theta_C$ ranges from 0.03 to 1.0.

$Re_p$ ranges from 1 to 1000.
Field-based dimensionless critical shear stress

(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

Hiding Functions

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

**Example:**

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

**KOMAR (1987, 1996)**

\[ a = \theta_{c50} \approx 0.045 \]

\[ b = -1 \] Equal Mobility

\[ -1 < b < 0 \] Selective Mobility

\[ b \approx -0.6 \] Average

**Select References**

* Parker (1990)*
  
  [http://hydrolab.illinois.edu/people/parkerg/default.asp](http://hydrolab.illinois.edu/people/parkerg/default.asp)

* Wilcock and Crowe (2003)*
  
**Selective Mobility**

**Hiding Functions**

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

\[ \theta_{c50} = 0.021 + e^{(-2 \, \phi_s)} \]

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

**WHERE:**

- \( F_s \) is the fraction of sand

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**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 \( \theta_c \) for fine fractions (reducing sediment transport rates)
- Decreases \( \theta_c \) 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...

\( \theta_c \) 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)

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

\( \text{NOT} \quad \sqrt{V_{\text{constant}}} \)

✓ 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

Assume: $\tau_{BF} = \tau_{C50}$

$\theta_{C50} =$ coefficient of proportionality for mobility of average grain size at the bankfull discharge
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?

- How valid is the \textit{threshold critical discharge (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


Uses reference shear stress ($\tau_r$) and Shields number ($\theta_{r50}^*$)

Non-linear relation between sand content and sediment transport rates

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

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

Hiding function acts to:

Finer fractions:
$\tau_r \uparrow$ (↓ sediment transport)

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

*Sand changes gravel sediment transport

\[ \frac{\tau_{ri}}{\tau_{r50}} \]
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
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List of References


Thank You!

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