Predicting Erosion Rates of Cohesive Streambanks

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The plan...

1. Why we care about streambank erosion
2. The processes: What's really going on?
3. Vocabulary: Singing from the same page
4. Measuring bank retreat
5. Predicting the "if and how much" of streambank retreat
6. New information

Why is bank erosion important?

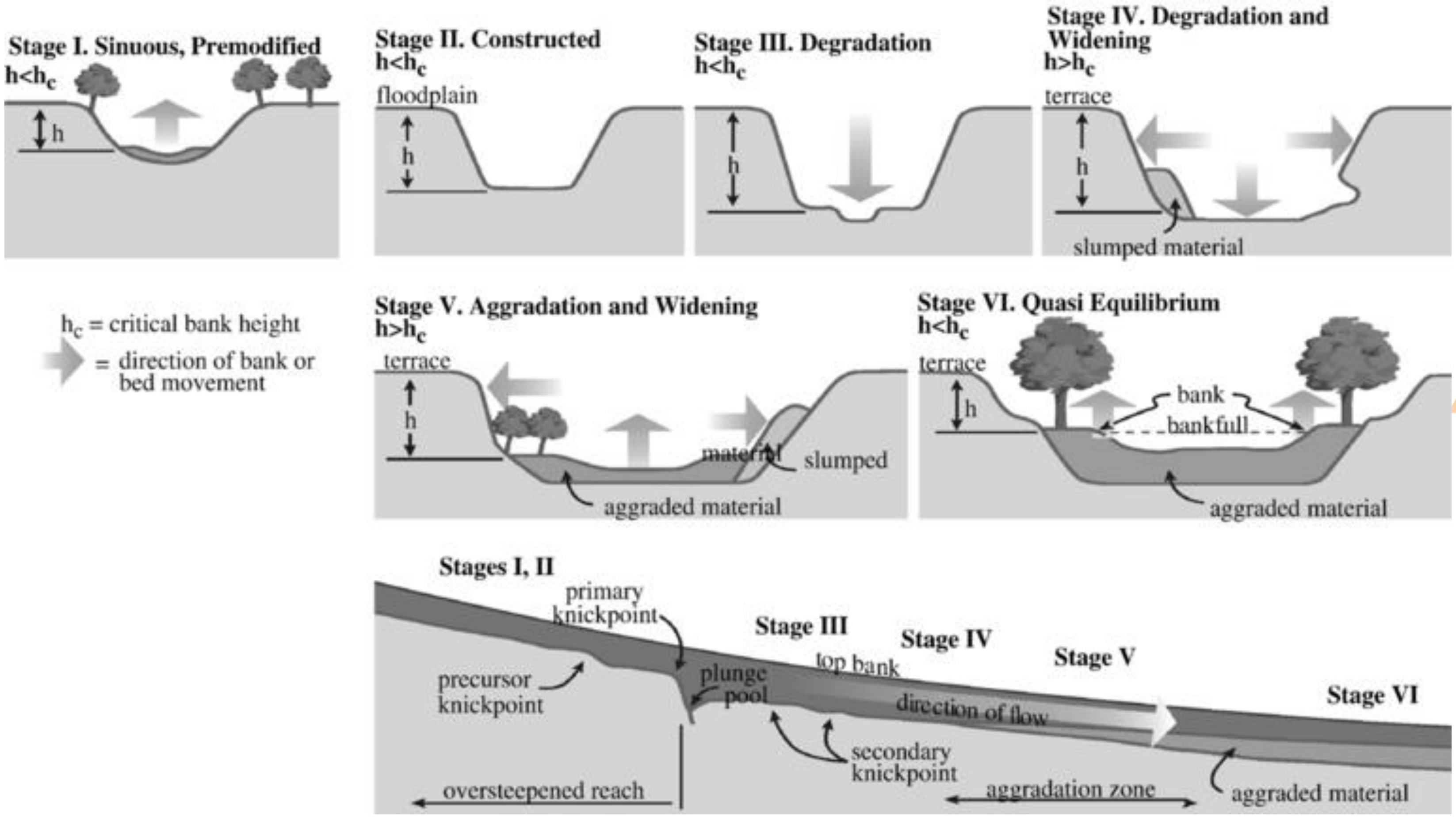
1. Required for channel meandering
2. Critical part of recovery of incised channels
3. Threatens buildings, roads, bridges, pipelines
4. Net bank sediment yields constitute 70% of Piedmont watershed sediment yields in Chesapeake Bay watershed*


Chesapeake Bay, USA (NASA)

* Donovan M, A Miller, M Baker, A Gellis. 2015. Sediment contributions from floodplains and legacy sediments to Piedmont streams of Baltimore County, Maryland. Geomorphology 235: 88-105.

Legacy sediments are now stored in the floodplains of headwater streams

Channel incision frequently initiates bank retreat



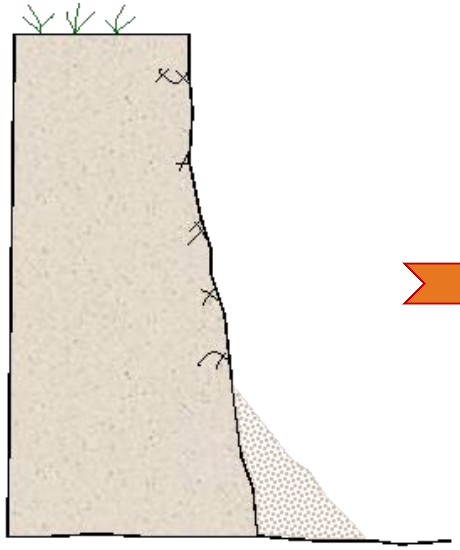
Channel incision frequently initiates bank retreat

In eastern US streams, channel incision is frequently limited by bedrock and/or culverts

…so channel widening is common

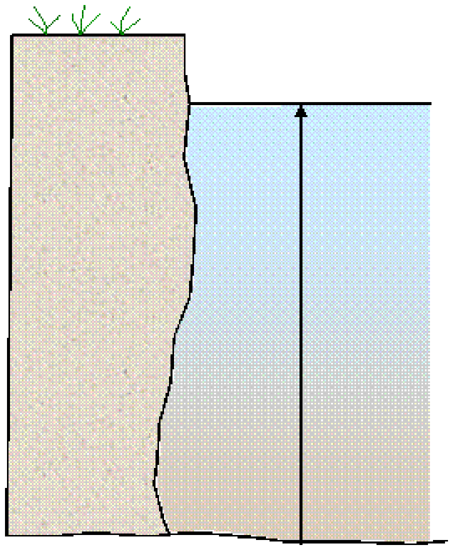
How does bank retreat (typically) occur?

Subaerial Processes/ Erosion



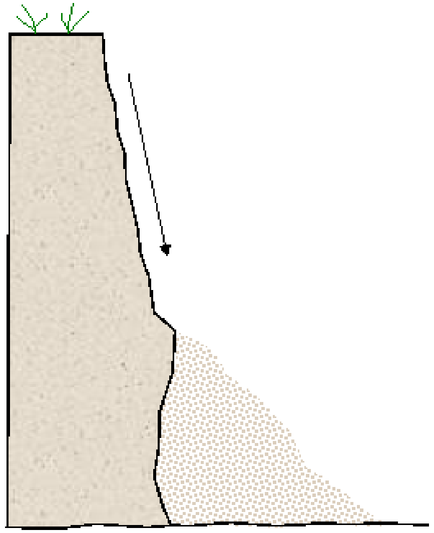
Freeze-thaw and wet-dry cycling weaken soil

Fluvial Entrainment



Soil entrained during high flows

Bank Failure



Mass failure from slope instability

Box 6.1 Definition of terms

Bank erosion

Detachment, entrainment and removal of bank material as individual grains or aggregates by fluvial and subaerial processes

Bank failure

Collapse of all or part of the bank *en masse*, in response to geotechnical instability processes

Bank retreat

Net linear recession of bank as a result of erosion and/or failure

Bank advance

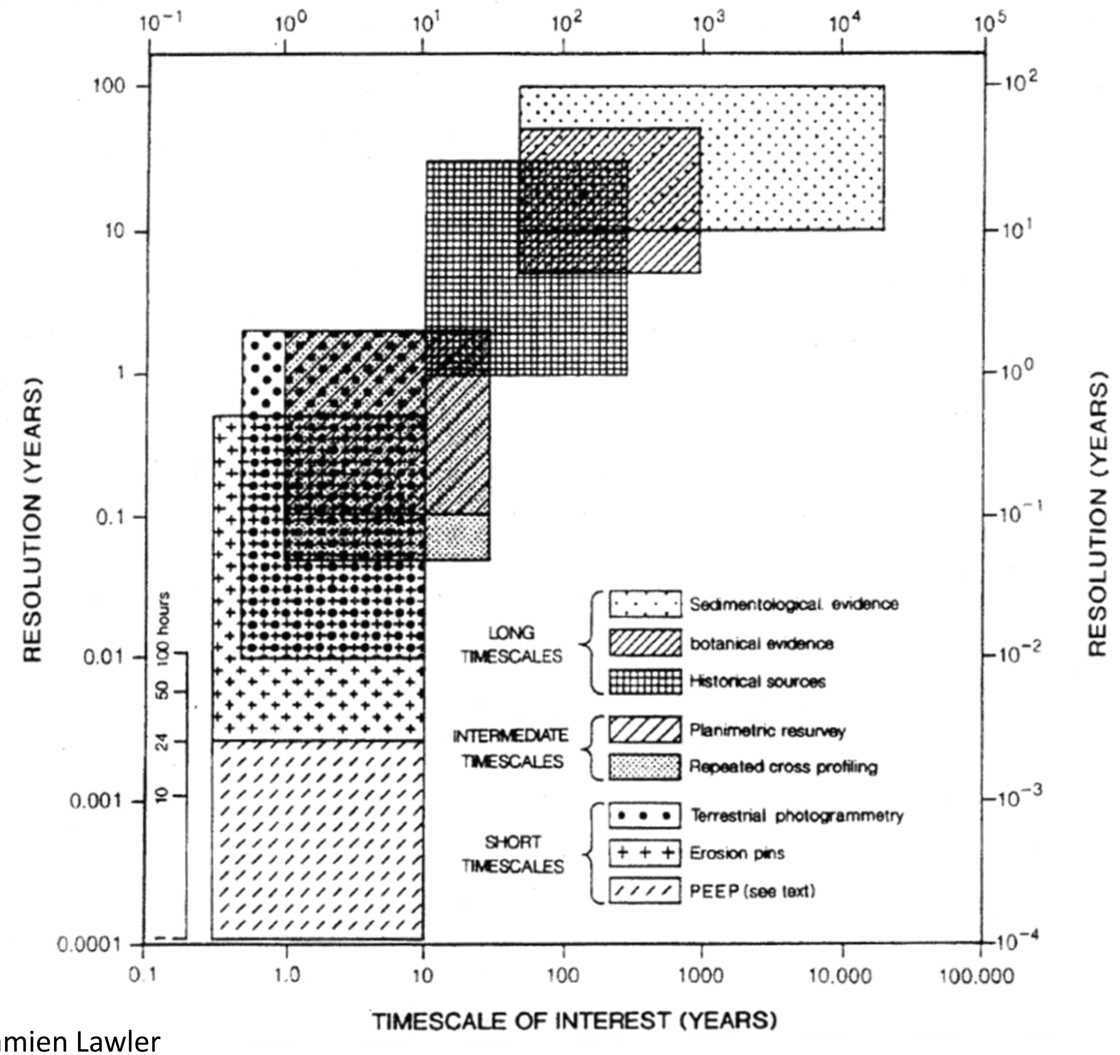
The opposite of bank retreat, i.e. net linear streamwise change in bank surface position, as a result of deposition of sediment or *in situ* swelling of bank materials

Bank erodibility

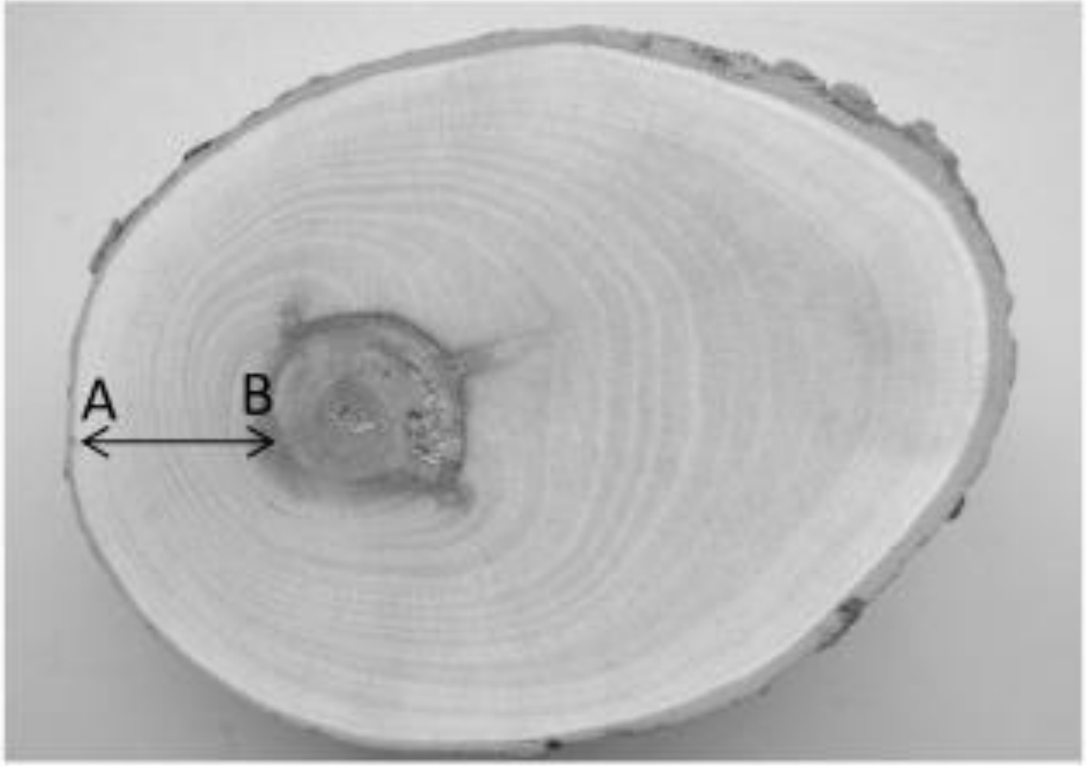
The ease with which bank material particles and aggregates can be detached, entrained and removed (normally by flow processes)

Lawler D., Thorne C., and Hooke J. 1997. Bank erosion and instability. In: Applied Fluvial Geomorphology for River Engineering and Management

How do we measure bank retreat?



Damien Lawler



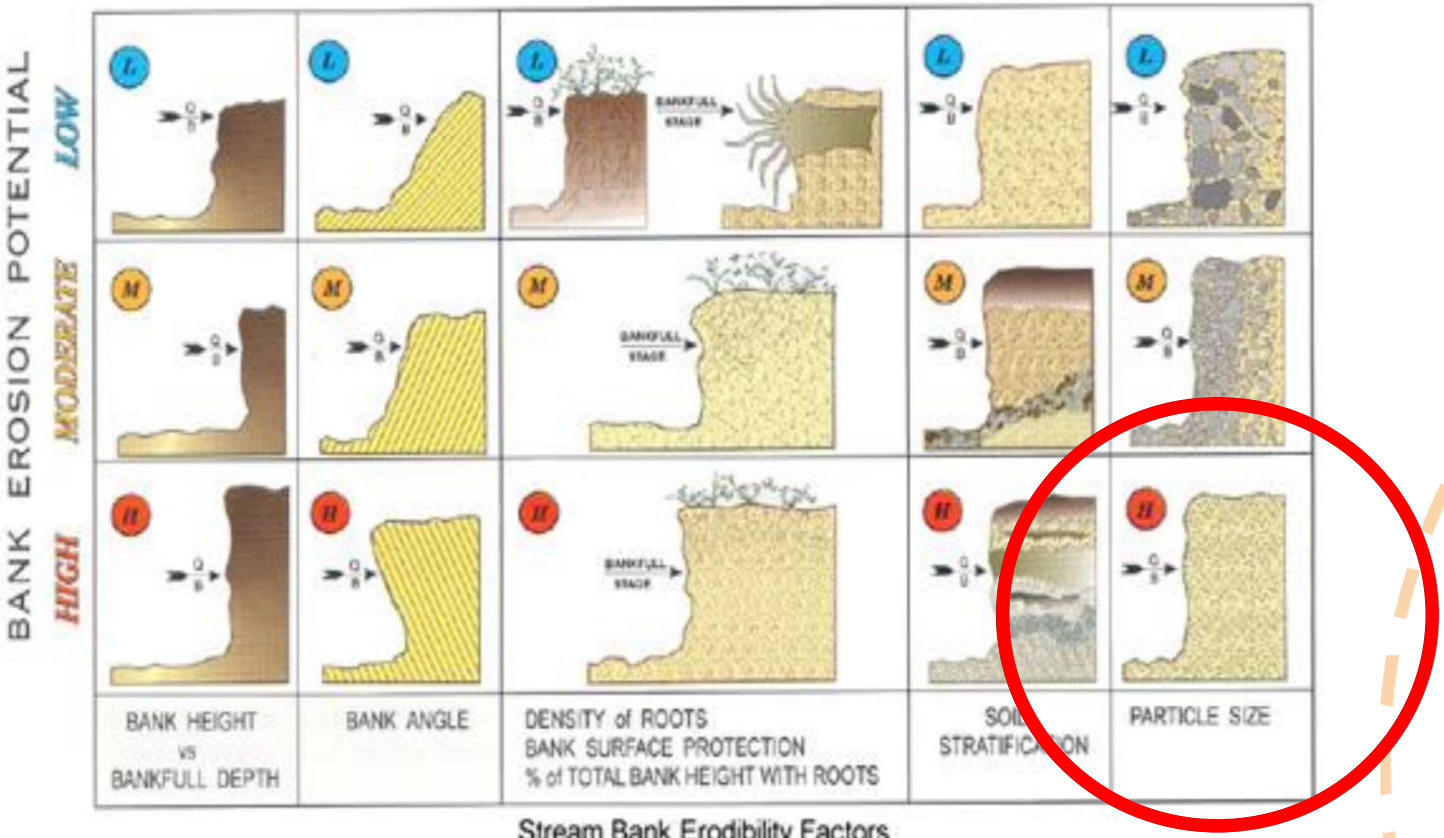
Stephanie Stotts, Michael O'Neal, James Pizzuto, Cliff Hupp. 2014. Exposed tree root analysis as a dendrogeomorphic approach to estimating bank retreat at the South River, Virginia. Geomorphology 223: 10-18.

Measured bank retreat rates are highly dependent on the duration and timing of measurement

https://media.spokesman.com/photos/2018/05/29/Maryland_Flash_Flooding.JPG_t1170.jpg?e2225bc5c1a75a1036ca3021fecba2b47792abfe

The problem isn't the accuracy of our measurement techniques. The problem is weather varies over time scales much greater than human lifespans!

Predicting the "if and how much" of streambank retreat - BANCS



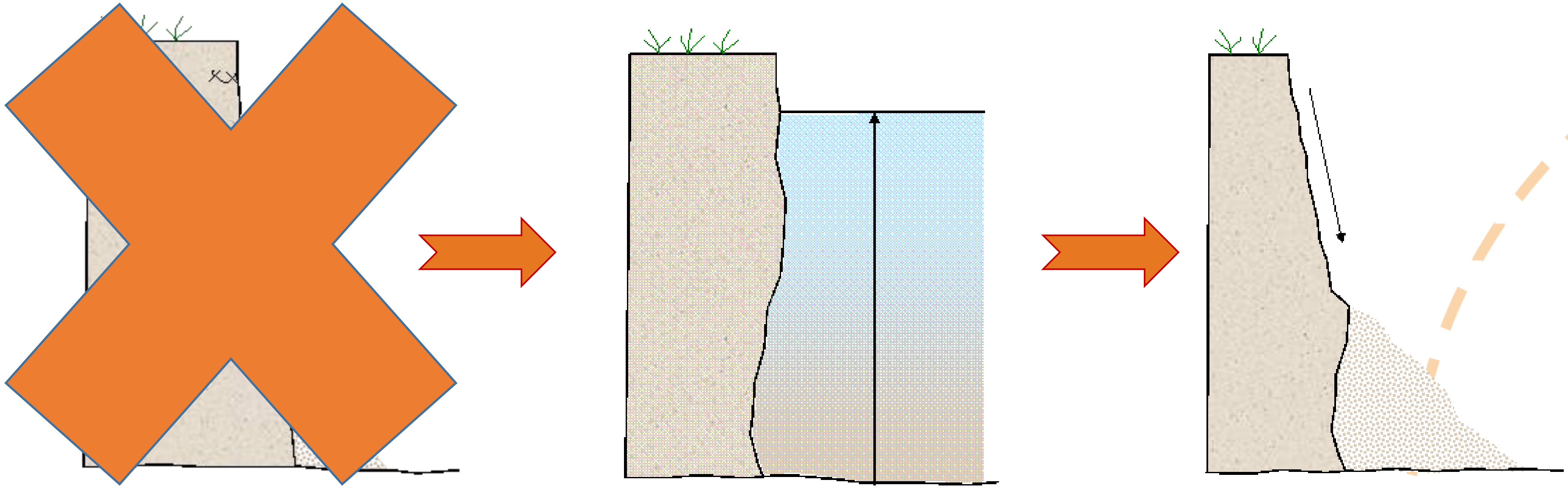
Stream Bank Erodibility Factors
(Rosgen 1993d)

Predicting the "if and how much" of streambank retreat - process models

Subaerial Processes/ Erosion

Fluvial Entrainment

Bank Failure



$$E_r = K_d(\tau_a - \tau_c)^a$$

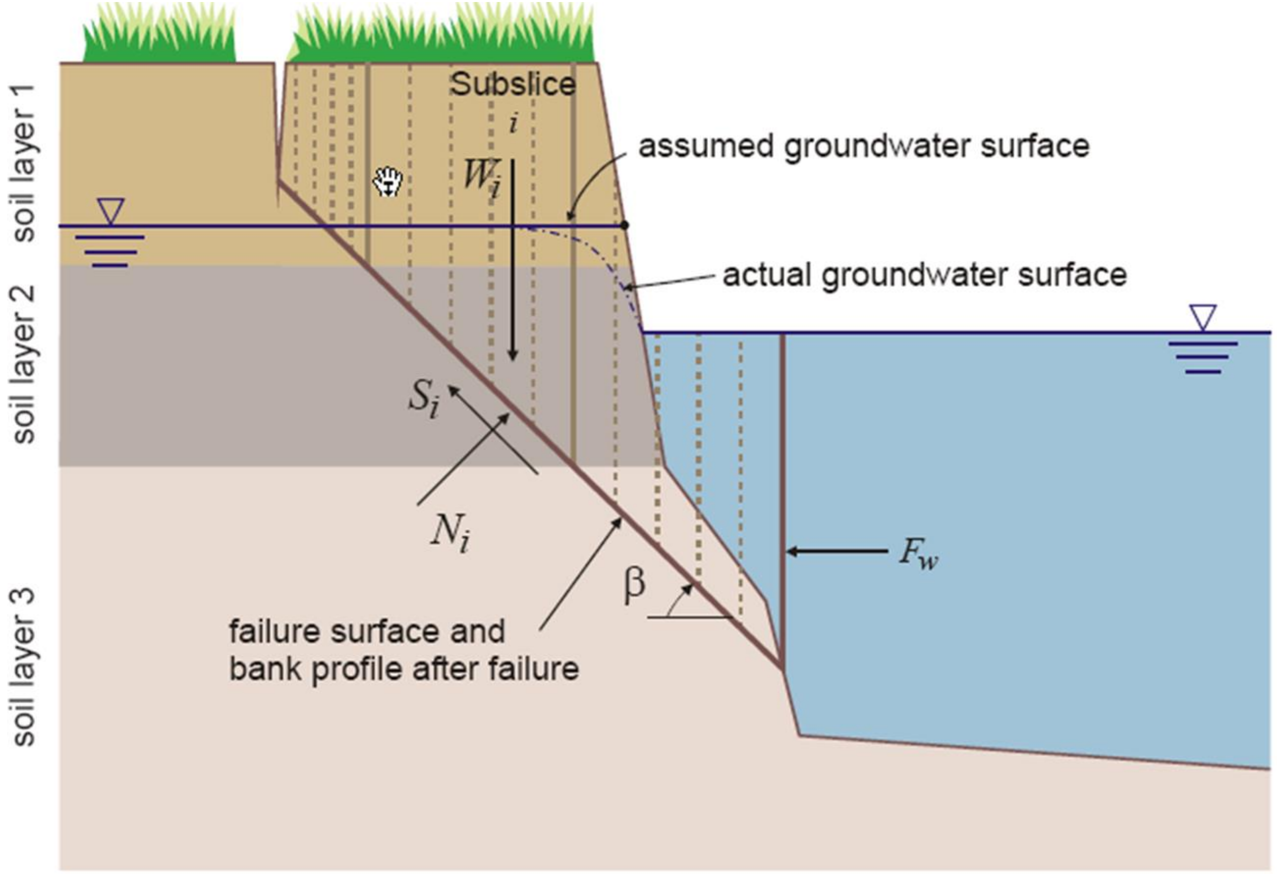
$$\tau_f = c' + (\sigma - \mu_w) \tan \phi'$$

Excess shear stress equation models the fluvial erosion rate of fine grain soils

$$E_r = K_d(\tau_a - \tau_c)^a$$

E_r = Erosion rate (L/T)
K_d = Erodibility coefficient ($L^2 \cdot T/M$)
τ_a = Actual shear stress ($M/L \cdot T^2$)
τ_c = Critical shear stress ($M/L \cdot T^2$)
a = Exponent, assumed equal to 1

Bank stability calculations perform a force balance on a slice of soil

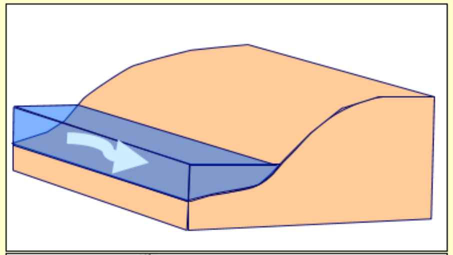


Predicting the "if and how much" of streambank retreat - BSTEM

Bank Stability and Toe Erosion Model

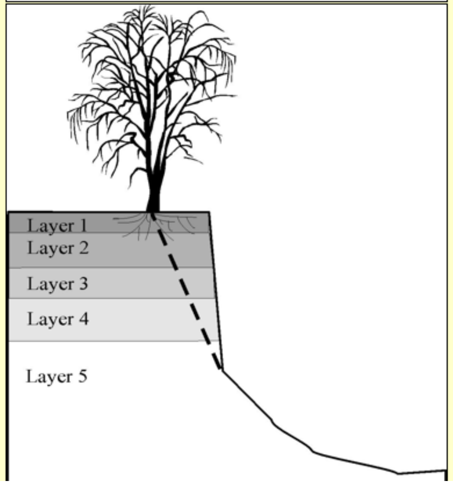
Static Version 5.4

Bank Stability Model



The Bank Stability Model combines three limit equilibrium-method models that calculate Factor of Safety (*Fs*) for multi-layer streambanks. The methods simulated are horizontal layers (Simon *et al*., 2000), vertical slices with tension crack (Langendoen and Simon, 2008) and cantilever failures (Thorne and Tovey, 1981). The model can easily be adapted to incorporate the effects of geotextiles or other bank stabilization measures that affect soil strength.

The model accounts for the strength of up to five soil layers, the effect of pore-water pressure (both positive and negative (matric suction)), confining pressure due to streamflow and soil reinforcement and surcharge due to vegetation.



Input the bank coordinates (**Input Geometry**) and run the geometry macro to set up the bank profile, then input your soil types, vegetation cover and water table or pore-water pressures (**Bank Material**, **Bank Vegetation and Protection** and **Bank Model Output**) to find *Fs*.

The bank is said to be 'stable' if *Fs* is greater than 1.3, to provide a safety margin for uncertain or variable data. Banks with a *Fs* value between 1.0 and 1.3 are said to be 'conditionally stable', i.e. stable but with little safety margin. Slopes with an *Fs* value less than 1.0 are unstable.

This version of the model assumes hydrostatic conditions below the water table, and a linear interpolation of matric suction above the water table (unless

https://www.ars.usda.gov/southeast-area/oxford-ms/national-sedimentation-laboratory/watershed-physical-processes-research/research/bstem/overview/

New Stuff!

Changes in Fluvial Erosion with Stream Chemistry

of Cohesive Streambank Soils

TESS WYNN-THOMPSON, AKINROTIMI AKINOLA, SIAVASH HOOMEHR, WAVERLY GARNAND, MATT EICK

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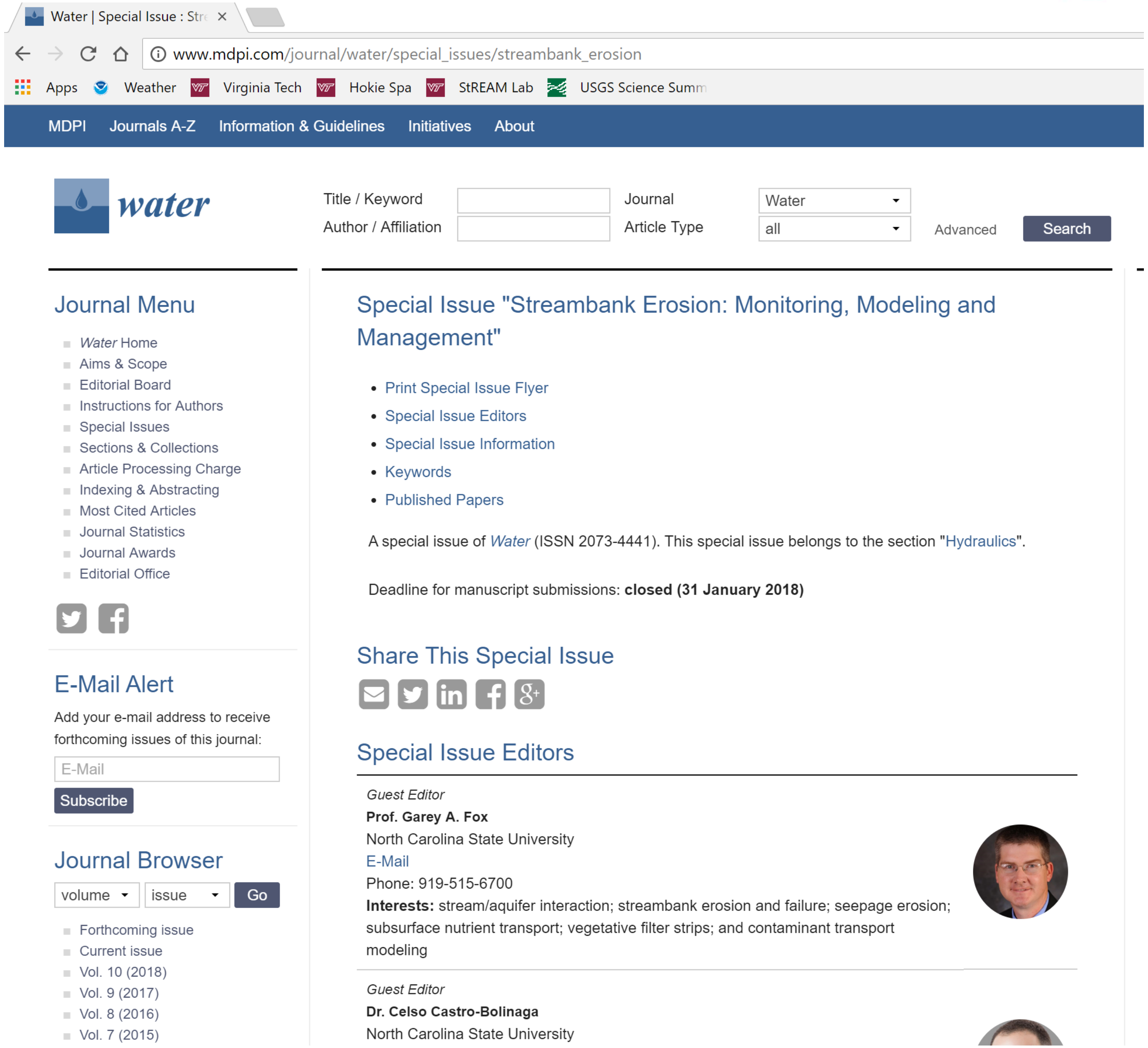
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www.mdpi.com/journal/water/special_issues/streambank_erosion

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Special Issue "Streambank Erosion: Monitoring, Modeling and Management"

- Print Special Issue Flyer
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- Special Issue Information
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A special issue of *Water* (ISSN 2073-4441). This special issue belongs to the section "Hydraulics".

Deadline for manuscript submissions: **closed (31 January 2018)**

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Special Issue Editors

Guest Editor
Prof. Garey A. Fox
North Carolina State University
E-Mail
Phone: 919-515-6700
Interests: stream/aquifer interaction; streambank erosion and failure; seepage erosion; subsurface nutrient transport; vegetative filter strips; and contaminant transport modeling

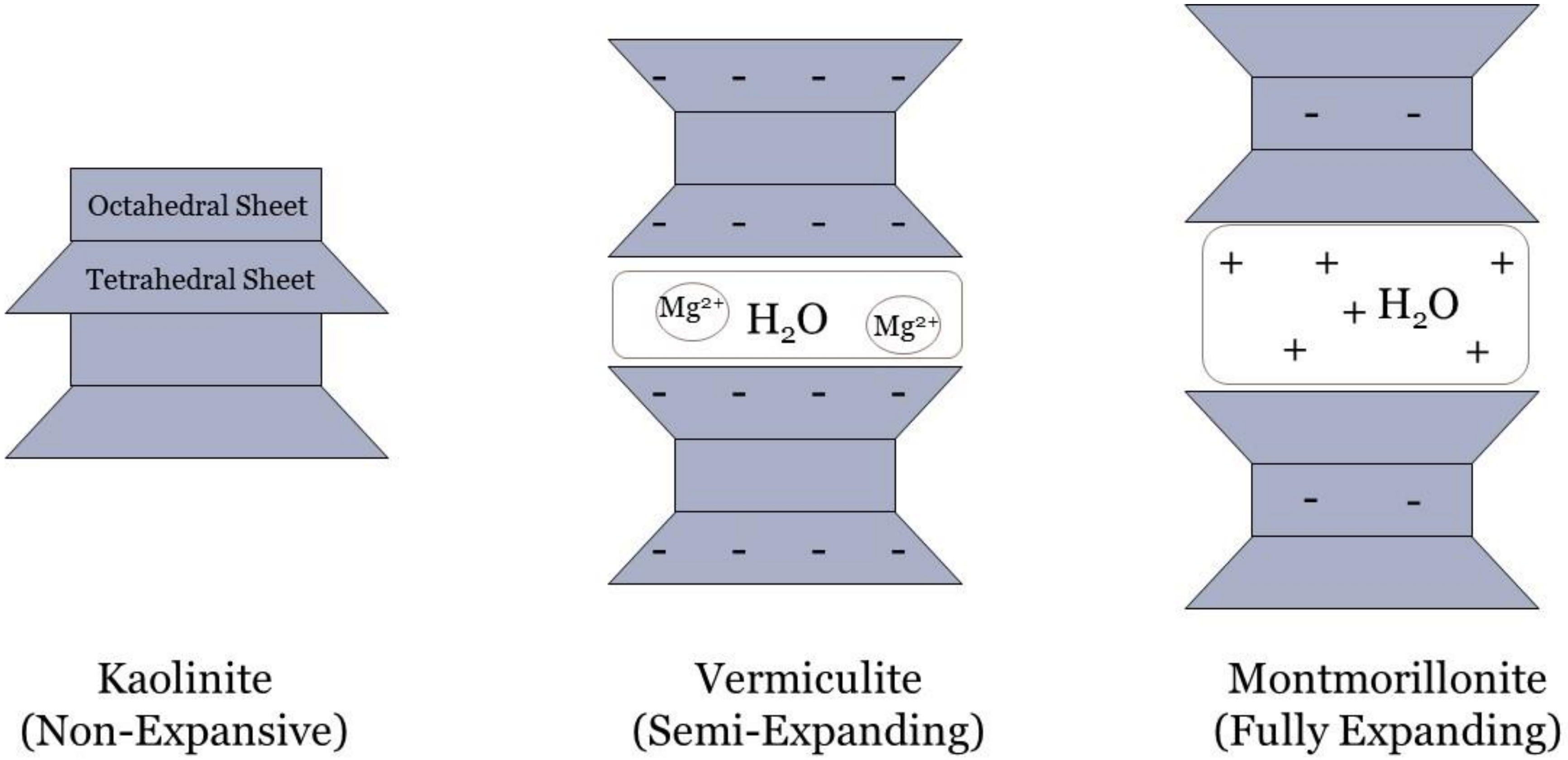
Guest Editor
Dr. Celso Castro-Bolinaga
North Carolina State University

The goal of this study was to quantify changes in fluvial erosion rates with changes in stream chemistry

- Temperature
- pH
- Deicing salt

My long-term goal is to develop models of cohesive soil fluvial entrainment to allow assessment of landuse and climate change on bank retreat.

Cohesive soils are dominated by inter-particle attraction

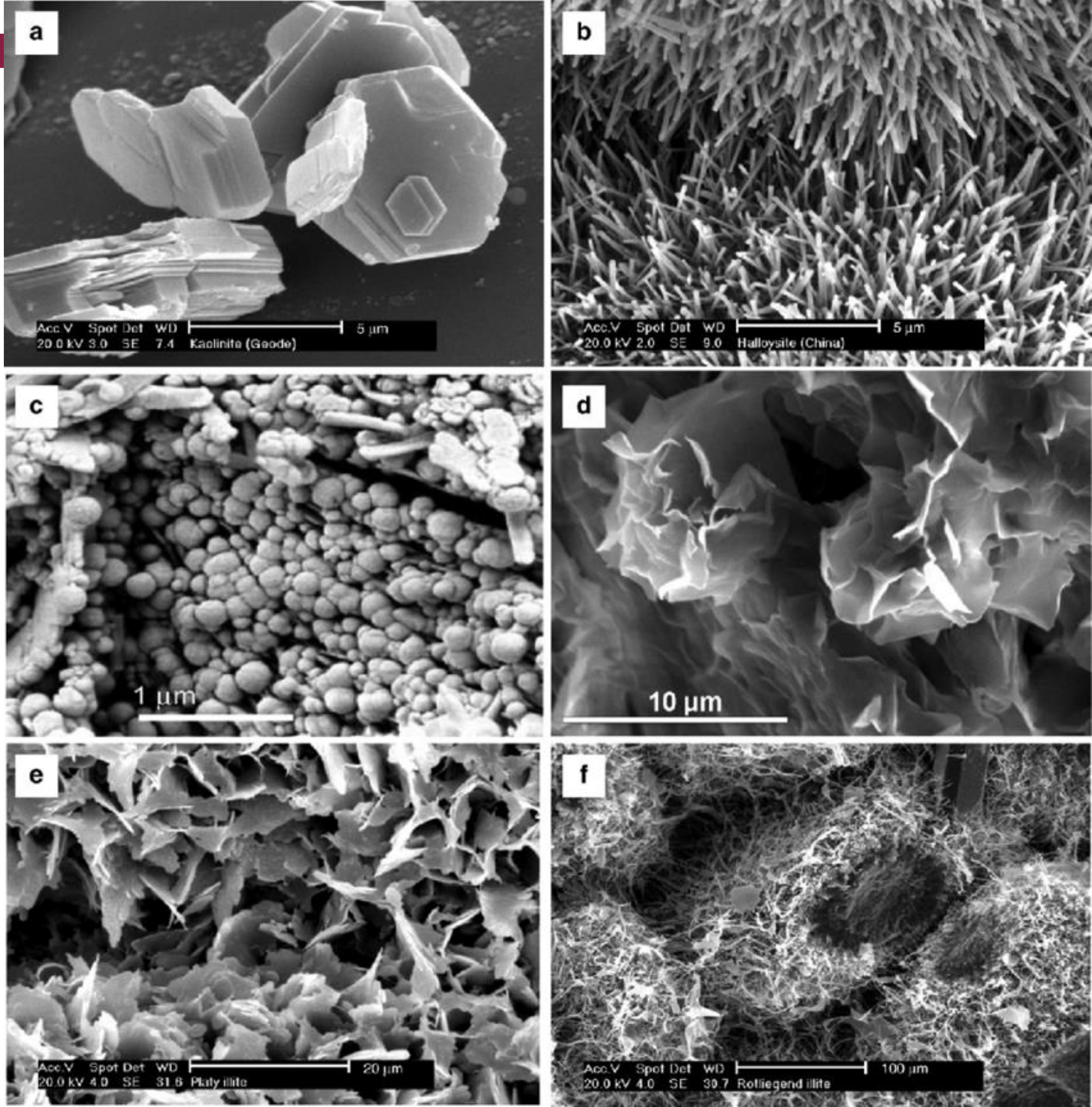


The type of clay in a soil plays a major role in erosion

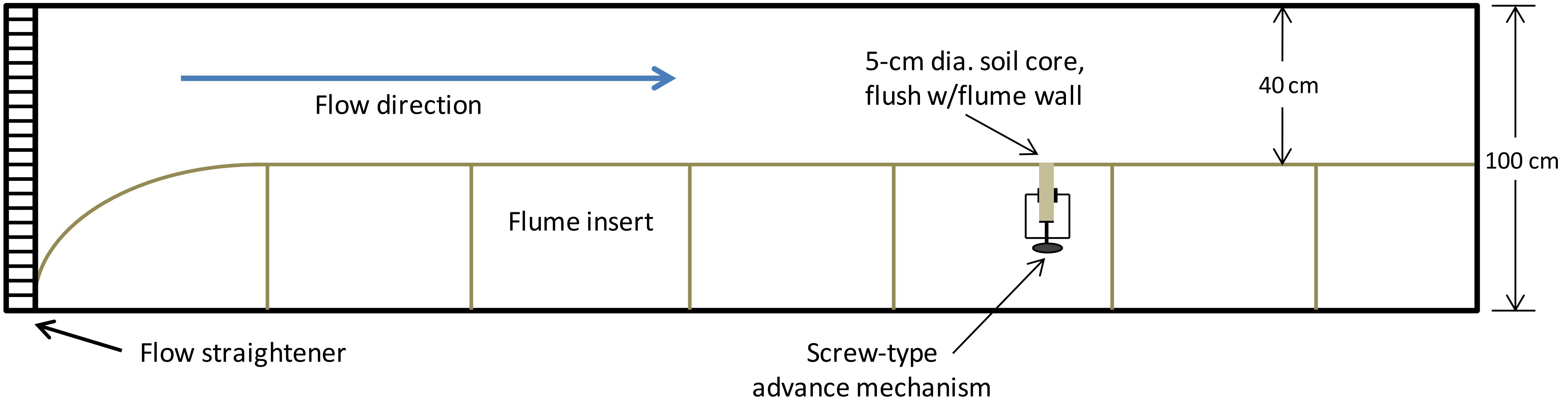
(a) Kaolinite
(b) Tubular crystals of halloysite
(c) Spheroidal crystals of halloysite
(d) Montmorillonite
(e) Flaky illite
(f) Fibrous illite

Images courtesy of The Clay Minerals Society and the Clay Minerals Group of the Mineralogical Society (Images of Clay Gallery, available at www.minersoc.org/pages/gallery/claypix/index.html).

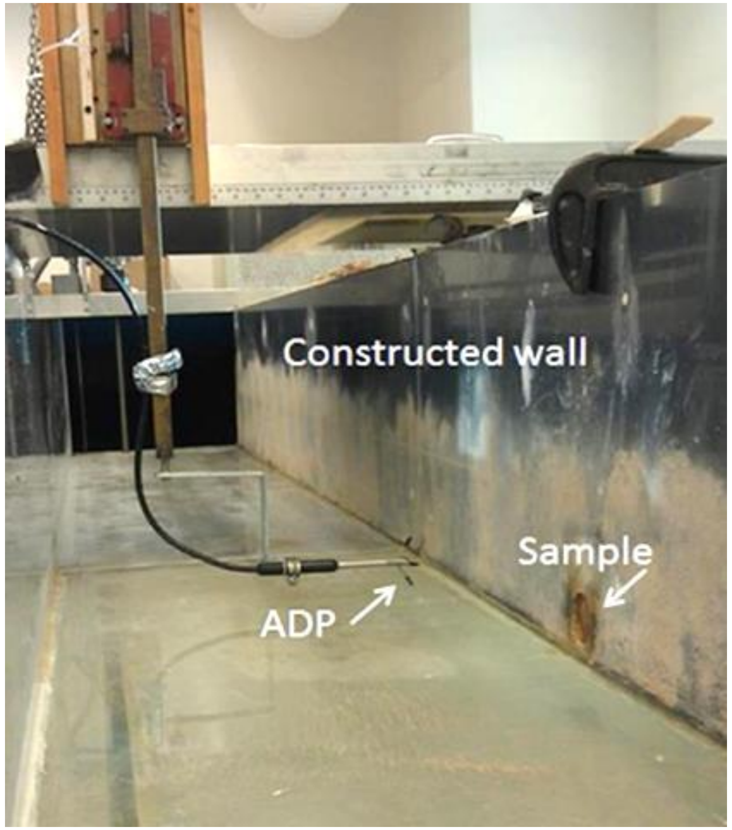
Industrial Clays - Scientific Figure on ResearchGate. Available from: https://www.researchgate.net/SEM-images-of-clay-minerals-a-pseudohexagonal-crystals-of-kaolinite-b-tubular_fig4_311583515 [accessed 30 May, 2018]



Remolded, 5-cm diameter cores of two natural soils were tested in an 8-m recirculating hydraulic flume



Water temperature, pH, and salt concentration were varied



- Water temperatures of 10, 20, and 30˚C
- pH of 6 and 8
- NaCl concentrations of 0 and 5000 mg/l
- 3 replicates for each soil-T-pH-salt combination

- Velocity profiles and distance to sample measured with a Vectrino II ADCP
- Sample advanced after every 1 mm of erosion
- Shear velocity determined using rough law of wall ($u^* = \sqrt{\tau/\rho}$)
- Shear stress ranged from 0.2—6.5 Pa (0.004 – 0.135 psf)

Two natural soils were tested

Vermiculite-dominated

- 40% sand, 40% silt, 20% clay
  - 35% hydroxyl interlayered vermiculite
  - 10% vermiculite
  - 10% mica
  - 15% kaolinite
  - 13% quartz
  - 10% chlorite
  - 6% smectite

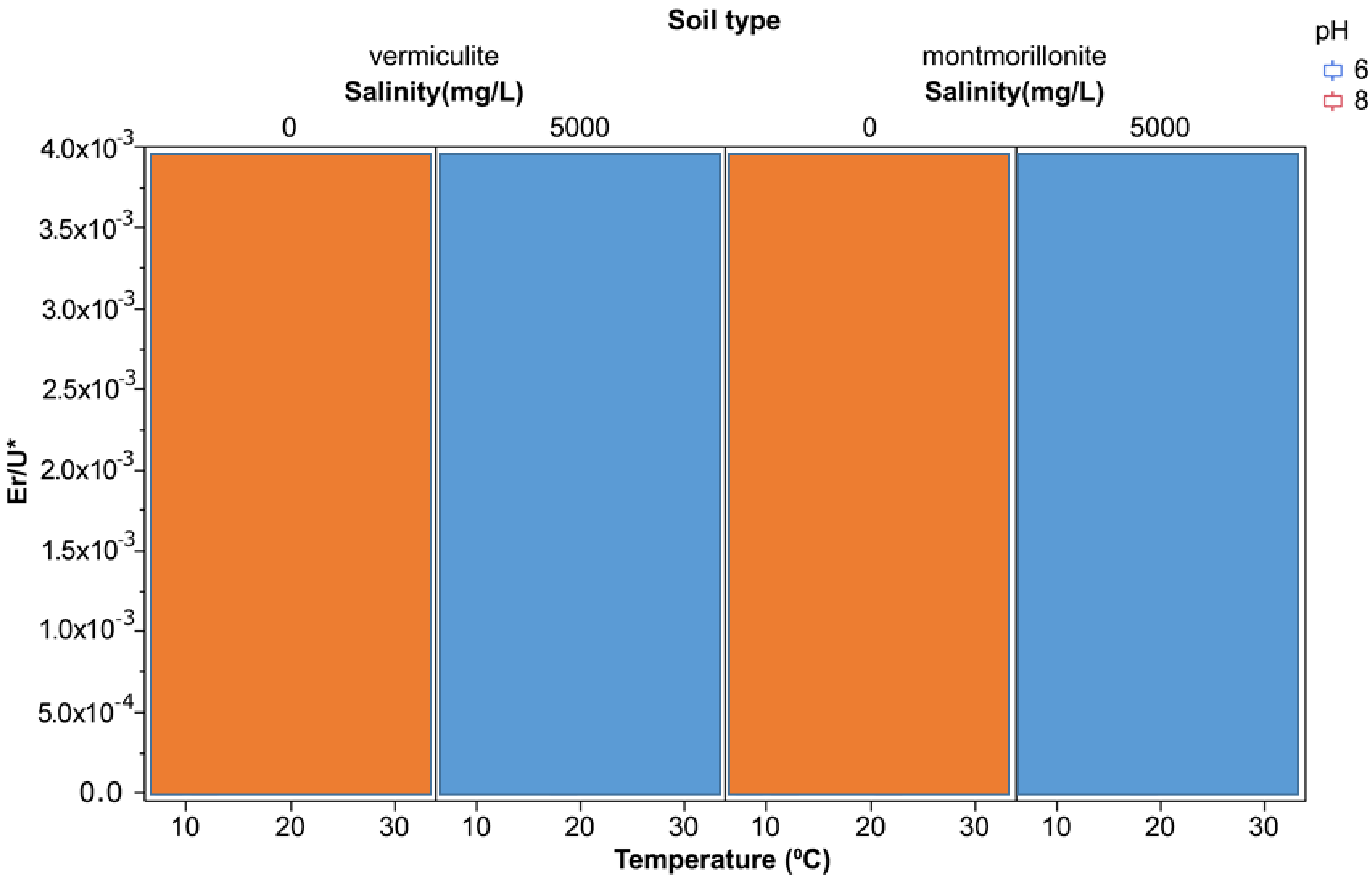
Montmorillonite-dominated

- 47% sand, 42% silt, 11% clay
  - 35% kaolinite
  - 25% montmorillonite
  - 20% mica/illite
  - 15% hydroxyl-interlayered vermiculite
  - 3% chlorite
  - 2% quartz

Soil sample preparation

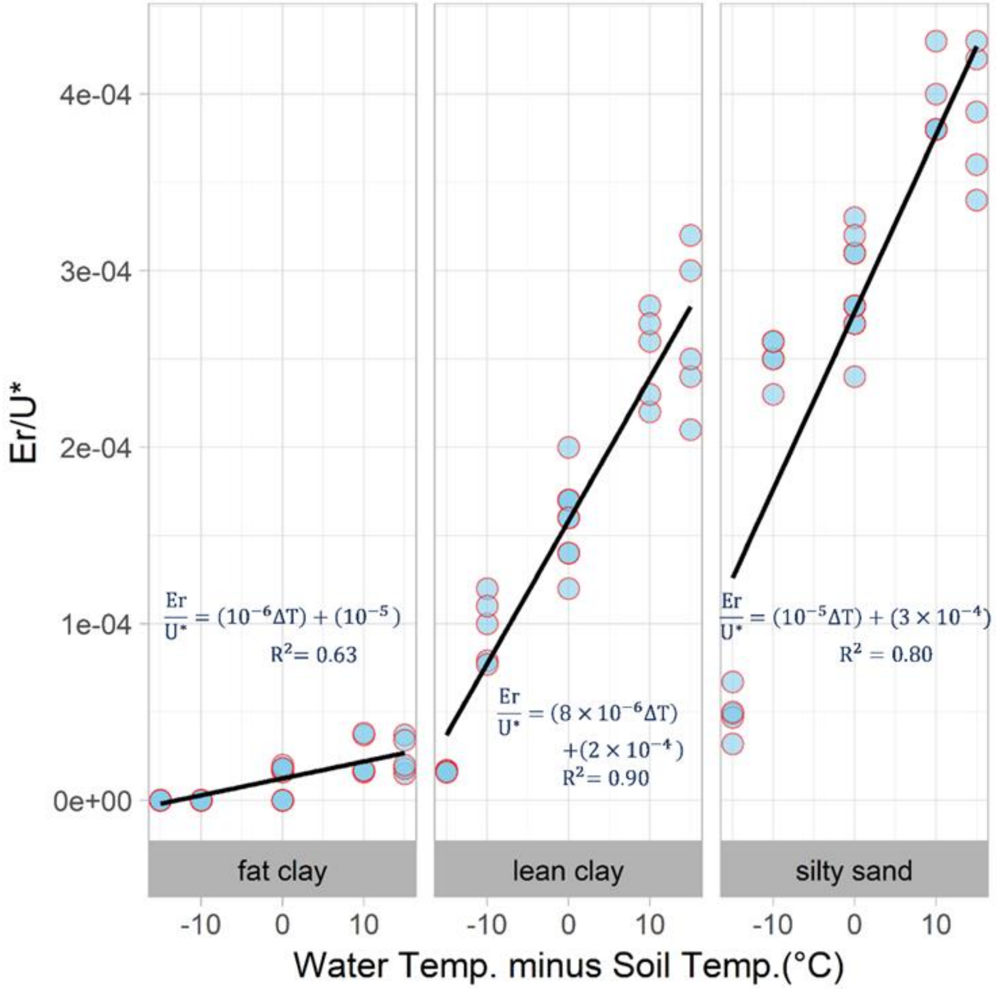
1. Air-dried soils crushed and sieved (2-mm)
2. Dionized water added to bring to test moisture content
3. Compacted into 5-cm x 5 cm aluminum cylinders with a slide hammer
4. Saturated overnight
5. Placed in a pressure plate chamber to bring samples to field capacity (-1/3 bar)
6. Tested within 8 hours of removing from pressure chamber

Clay Type	Bulk Density (g/cm^3)	Soil Moisture Content at Compaction (%)	Hammer Blows Per Layer
Vermiculite	1.5	7.5	4
Montmorillonite	1.3	4.7	3


Soil type
vermiculite
Salinity(mg/L)
0
5000
montmorillonite
Salinity(mg/L)
0
5000
pH
6
8
Er/U*
4.0x10^-3
3.5x10^-3
3.0x10^-3
2.5x10^-3
2.0x10^-3
1.5x10^-3
1.0x10^-3
5.0x10^-4
0.0
10 20 30 10 20 30 10 20 30 10 20 30
Temperature (ºC)

Actually, the heat exchange between the water and the soil affects erosion rates

New research by Akin Akinola



Wrapping it up…

1. Streambank retreat occurs primarily due to three processes: subaerial erosion/processes, fluvial erosion, bank failure
2. An accurate “sample” of streambank erosion rate requires similar time spans as precipitation and stream discharge measurement (20-30 years)
3. BSTEM provides a process-based estimate of bank retreat
4. Fluvial erosion rates of cohesive streambanks vary with stream and soil temperature, pH, and salt concentration

Questions??

https://en.wikipedia.org/wiki/Carnac_the_Magnificent