Can Subsurface Flow Erode Streambanks?

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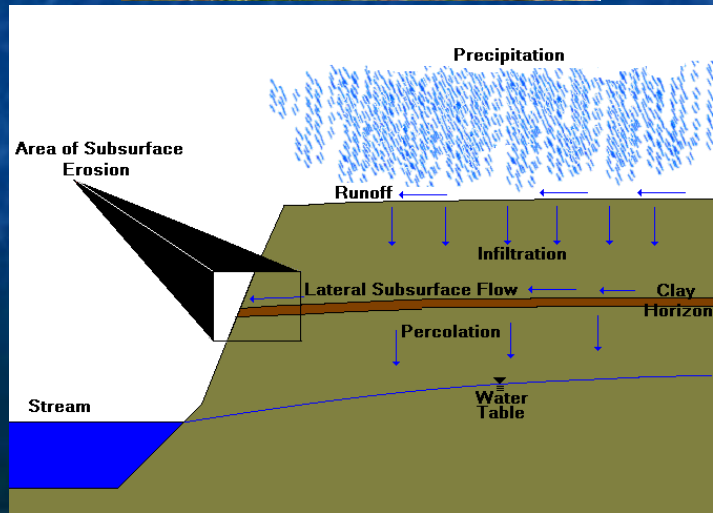
Introduction

- Excessive sediment is one of the most widespread causes of water quality degradation in the US
- Sources of sediment:
  - Upland areas & streambank
- Uplands now in conservation practices
- As much as 85% of sediment load is from the streambank in some watersheds

Introduction

- Erosion primarily considered by fluvial mechanisms
- Streambank stability models
  - CONCEPTS
  - Research on riparian vegetation
- What potential role does subsurface flow play in this erosion?
  - Considerable research on interaction of surface erosion and ground water (Lobkovsky et al., 2004)
  - Seepage force analysis for hillslope failure (Howard and McLane, 1988)
  - Lack of a sediment flux model



Objectives

- Quantify soil/hydraulic properties at field site: Little Topashaw Creek
  - In-situ sampling and characterization
  - Seepage erosion measurements

Little Topashaw Creek at XS 11, January 23, 2001

Objectives

- Construct two-dimensional soil lysimeter to simulate seepage erosion and bank collapse
  - Lysimeter - 100 cm x 100 cm x 15 cm
- Determine the soil and hydraulic controls on failure
- Investigate formation of tension cracks
- Derive sediment transport model for seepage erosion

LTC Soil Characterization

Silt loam (SiL) topsoil overlying alluvial material with alternating layers of unconsolidated sand (LS) and clay loam (CL)

Depth	Texture	B.D.	Ks	?s	?r	a	n
cm		g/cm^3	cm/d	cm^3/cm^3	cm^3/cm^3	1/cm	
0-160	Si L	1.36	10.8	0.45	0.07	0.015	1.4
215-250	LS	1.50	345.6	0.40	0.03	0.012	2.0
250-270	CL	1.61	0.4	0.44	0.05	0.009	1.7

Seepage Erosion along LTC

Three seeps were selected for study

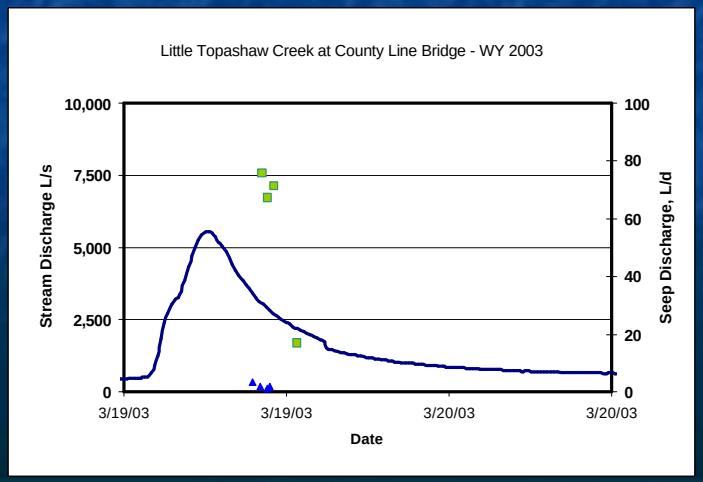
Consolidated slump material

Bank failures from seepage erosion

Seepage erosion

Seep Measurements

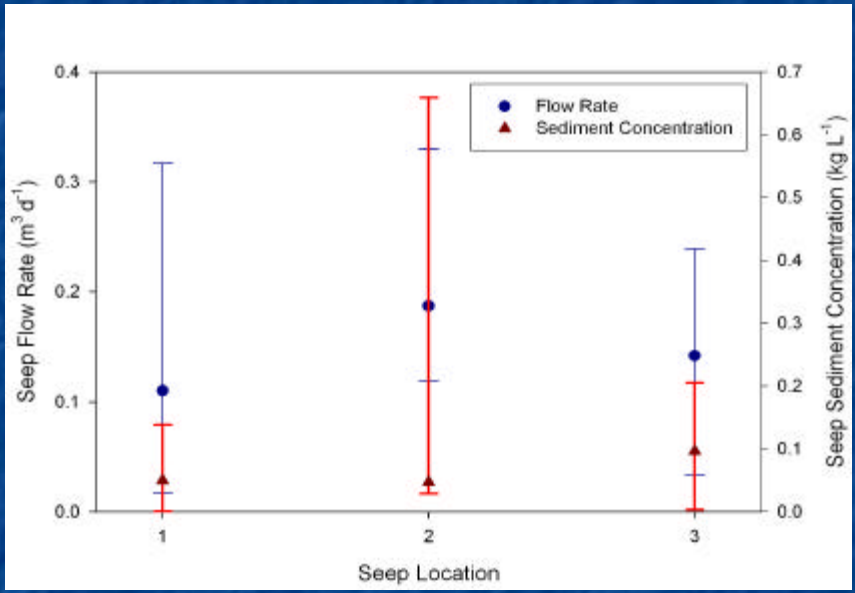
50 cm wide pans were temporarily pressed into bank face to measure subsurface flow rate and sediment loss at a discrete time following a storm flow event.



Seepage Erosion along LTC

Seepage/Sediment Flux

- Seeps measured intermittently between February and July 2003
  - Seep 1 – 5 Sampling Events
  - Seep 2 – 7 Sampling Events
  - Seep 3 – 4 Sampling Events



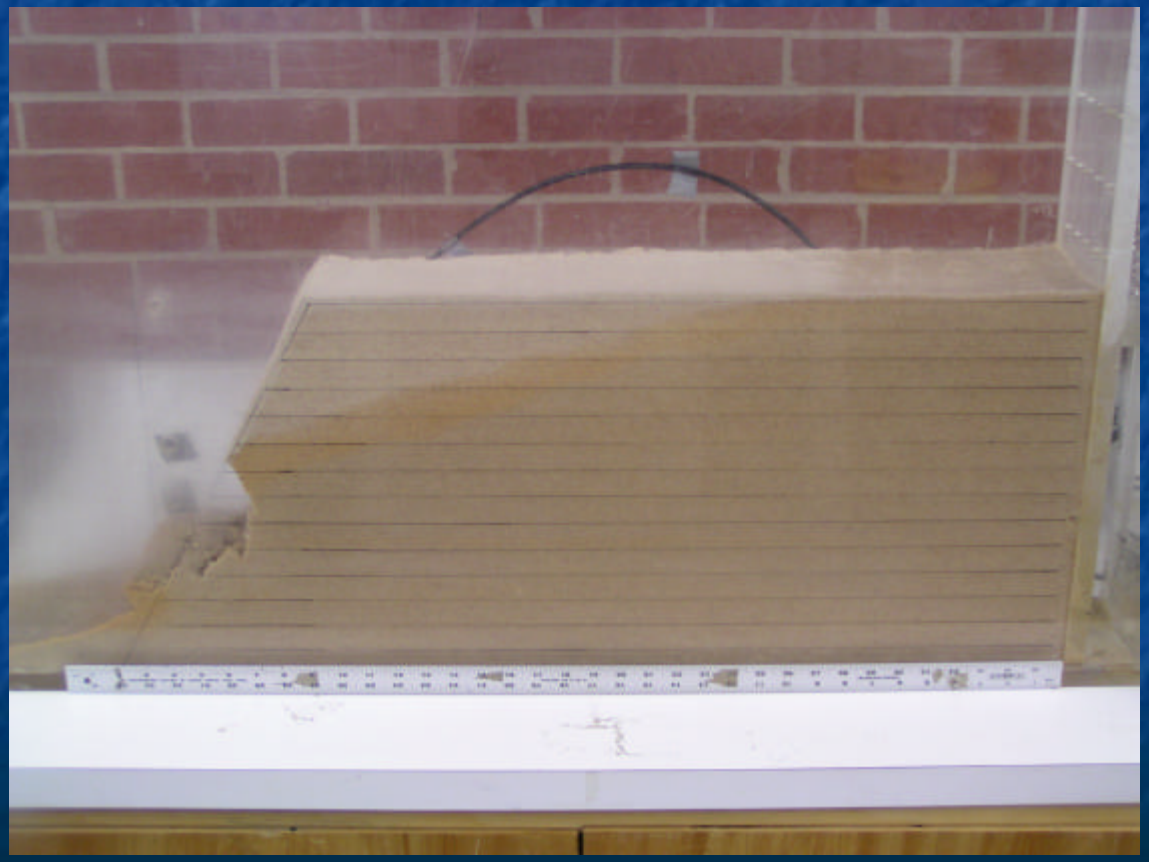
- Sediment concentration correlated to seepage flow
  - Power Law with r^2=0.68
  - Seepage flow averaged 0.15 $m^3\ d^{-1}$ (CV = 62%)
  - Sediment concentrations averaged 0.25 kg L^{-1} (CV = 93%)

Lysimeter Experiments

Lysimeter Experimental Setup

- Packed to field bulk densities:
  - ✓ Single-Layer Sand
  - ✓ Layered Profiles
- Bank Angles – 30-90°
- Water Inflow Reservoir - 30, 60, 90 cm head
- Slope – 0%, 5%, 10%

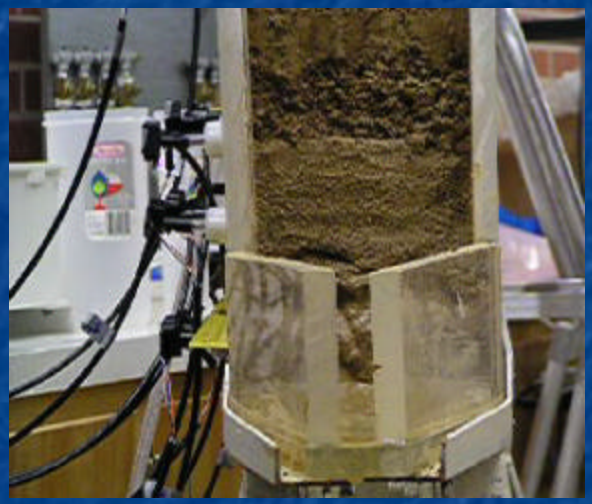
Seepage Erosion – Single Layer Sand



Seepage Erosion – Single Layer Sand

Seepage Erosion and Bank Collapse

Seepage Erosion – Sapping/Undermining Zones



Lysimeter Results - LTC

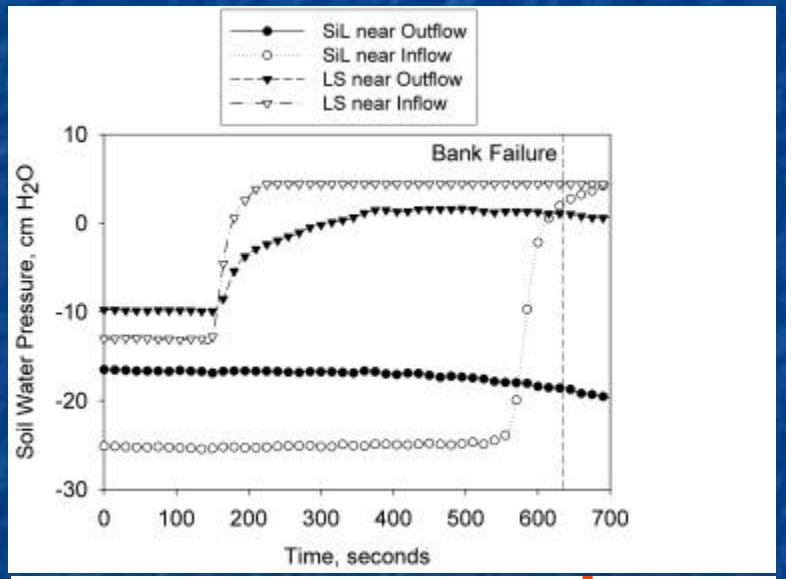
Boundary Conditions			Lysimeter Measurements					
Bank Height (cm)	Water Head (cm)	Slope (%)	Time to failure (s)	Seepage Erosion (kg)	Tension Crack (cm)	Bank Erosion (kg)	Undercut (cm)	Soil-Water Pressure* (cm H2O)
80	30	0	660	0.53	35.5	24.3	9	-28
80	60	0	570	1.07	21.5	23.1	14	-37
80	90	0	300	0.19	12.4	23.5	4	-33
80	60	5	600	2.20	11.5	7.5	14	-36
80	60	10	645	1.42	32.0	56.3	10	-19
50	60	0	840	3.17	9.0	4.7	13	-29
50	60	5	900	2.00	28.5	33.6	15	-44
50	60	10	1050	3.76	35.0	36.8	28	-22

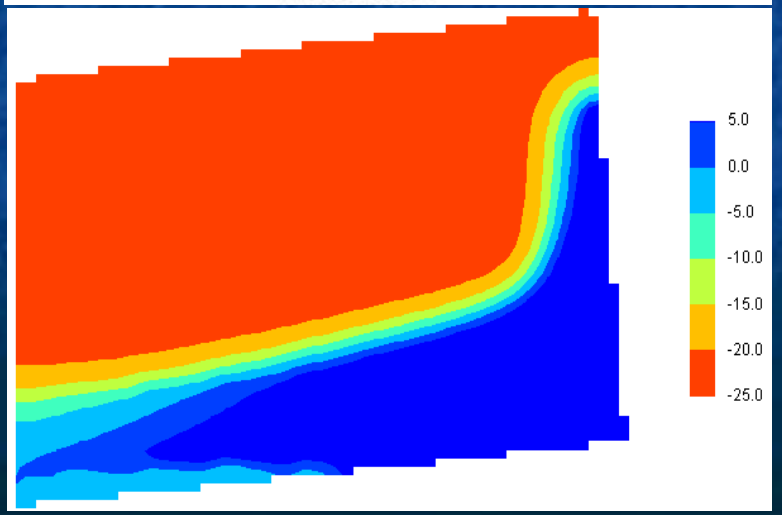
* Soil-water pressure refers to the pressure reading at Tensiometer 1 (15 cm from streambank face and 30 cm from the bottom of the lysimeter in the SiL) at the end of the experiment (i.e., bank failure time).

- Seepage flow averaged 0.12 $m^3\ d^{-1}$ (CV = 62%)
- Sediment concentrations averaged 1.87 kg L^{-1} (CV = 16%)

Bank Failure Mechanisms

- Soil-water pressures remained negative at formation of tension cracks and subsequent failure
  - Saturation of bank profile may not be required for bank failure
  - Undercutting approximately 10-30 cm in loamy sand prior to tension crack formation



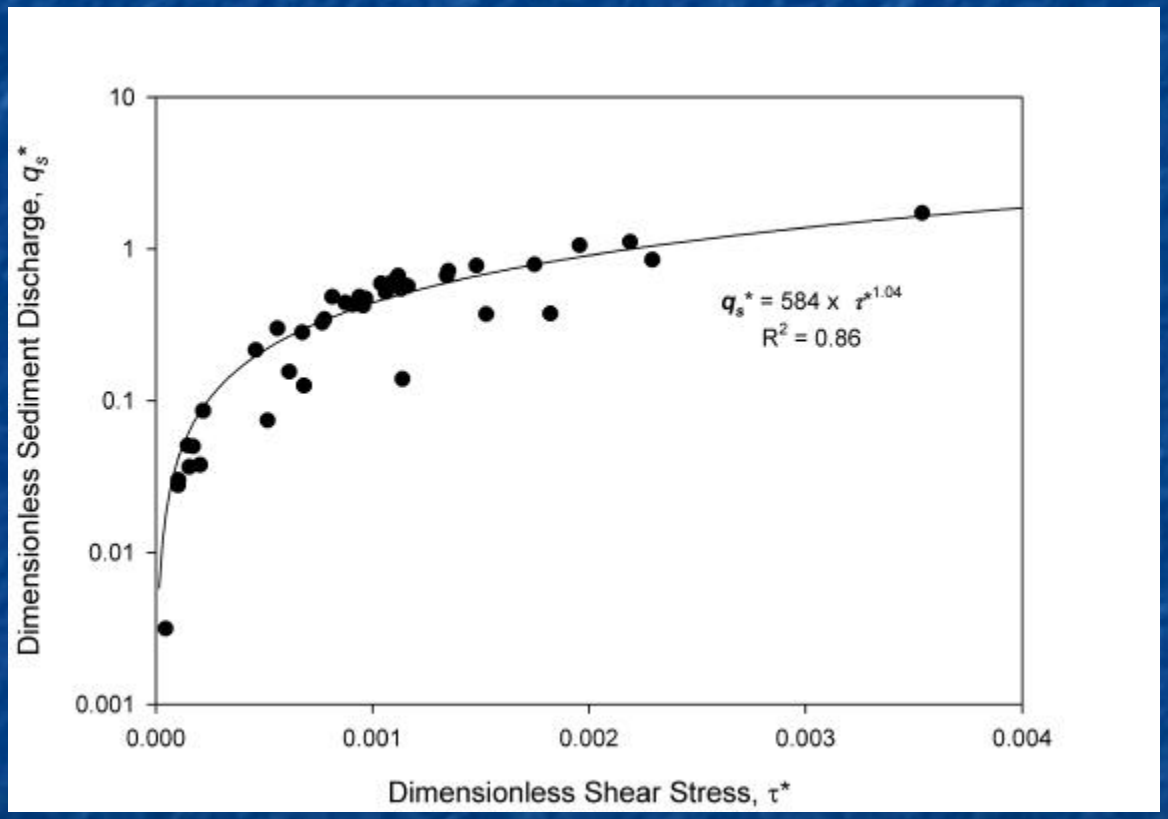


Seepage Erosion Sediment Transport Model

$$q_s^* = a\ \tau^{*\,b}$$

$$q_s^* = \frac{q_s}{\sqrt{(s-1)gd^3}}$$

$$\tau^* = \frac{C_2'' q \sin(\theta)}{(s-1)nK}$$



- Dimensionless shear stress based on ground water seepage force

Conclusions

- Seepage erosion initiated within minutes of water table development
  - Rapidly undercut the bank
- Bank failure occurred prior to removal of negative pore-water pressures
  - Usually occurred with 10-30 cm of undercutting
- Bank failure time significantly correlated to water level head but not to slope
- Seepage erosion transport model capable of predicting sediment flux based on discharge

Future Research

- Evaluate sediment transport model using field data
  - Sample greater number of seeps at multiple locations
- Characterize soil, hydraulic, and geotechnical bank properties at two field sites
  - Little Topashaw Creek and Goodwin Creek
- Expand lysimeter experiments
  - Layered profiles at Goodwin Creek
  - Rapid-drawdown/Reverse bank storage
- Incorporate seepage erosion transport model into channel evolution model (CONCEPTS)
  - Importance of sapping relative to fluvial erosion

Questions?

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