Goundwater Seepage Mechanisms of Streambank Erosion and Failure

Taber L. Midgley – M.S. Student

Garey A. Fox – Associate Professor

Abdulsahib Al-Madhhachi – Ph.D. Student

Rachel Carson – M.S. Student

Biosystems Engineering | Oklahoma State University

Glenn V. Wilson – Research Hydrologist/Soil Physicist

USDA Agricultural Research Service | National Sedimentation Laboratory

Introduction

- Sediment loadings in streams cause
  - Degradation of downstream lakes
  - Phosphorus loadings
  - Destruction of aquatic habitat
  - Impairment of water for domestic use
- Streambank erosion may be significant
  - Geotechnical
  - Fluvial

Erosion Mechanisms

- Fluvial Erosion
  - Critical shear stress (t_c) and erodibility coefficient (k_d)

$$E_r = k_d\,(\tau_o - \tau_c)^a$$

  - Numerous studies have measured t_c and k_d
  - A submerged jet test device (JET – Jet Erosion Test)

JET – Jet Erosion Test

Erosion Mechanisms

- Streambank Erosion by Groundwater Flow
  - Often neglected
  - Can cause erosion in three specific mechanisms
    - Soil Pore-Water pressure
    - Seepage Gradient Forces
    - Seepage Particle Mobilization

Soil Pore Water Pressure

$$s = [c' + (\sigma_n - u_w)tan\varphi'] + [(u_a - u_w)tan\varphi^b]$$

- Negative pore water pressure (suction) increase the 2nd bracketed term
  - Apparent Cohesion
- Saturation of soil profile results in loss of this apparent cohesion
- Also increases soil weight

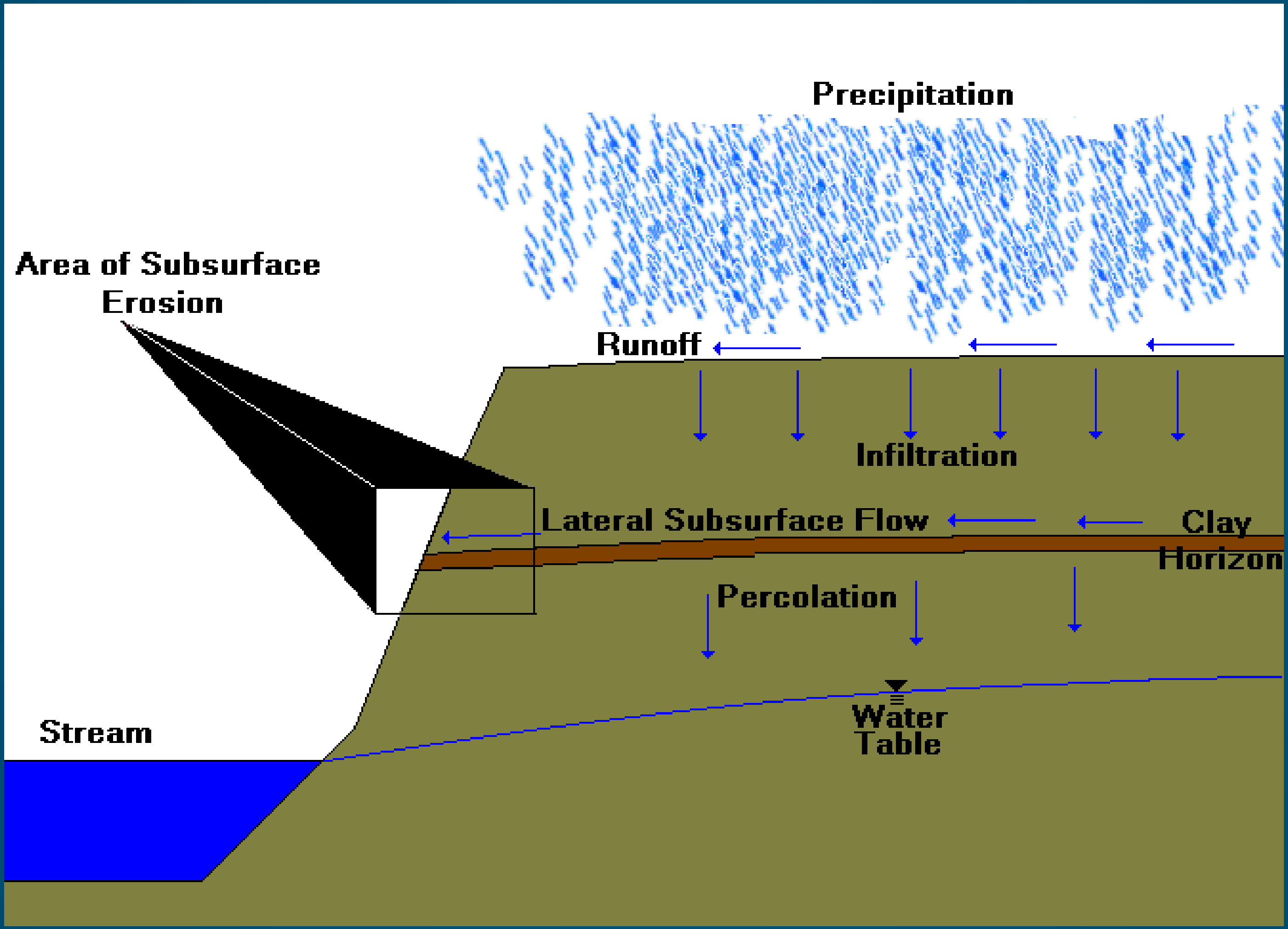
Seepage Gradient Forces

- Three factors
  - Ratio of seepage forces magnitude to gravitational force magnitude
  - Bank angle
  - Seepage vector angle
  - Soil's internal angle of friction

$$SF = \rho g \frac{\partial h}{\partial y}$$

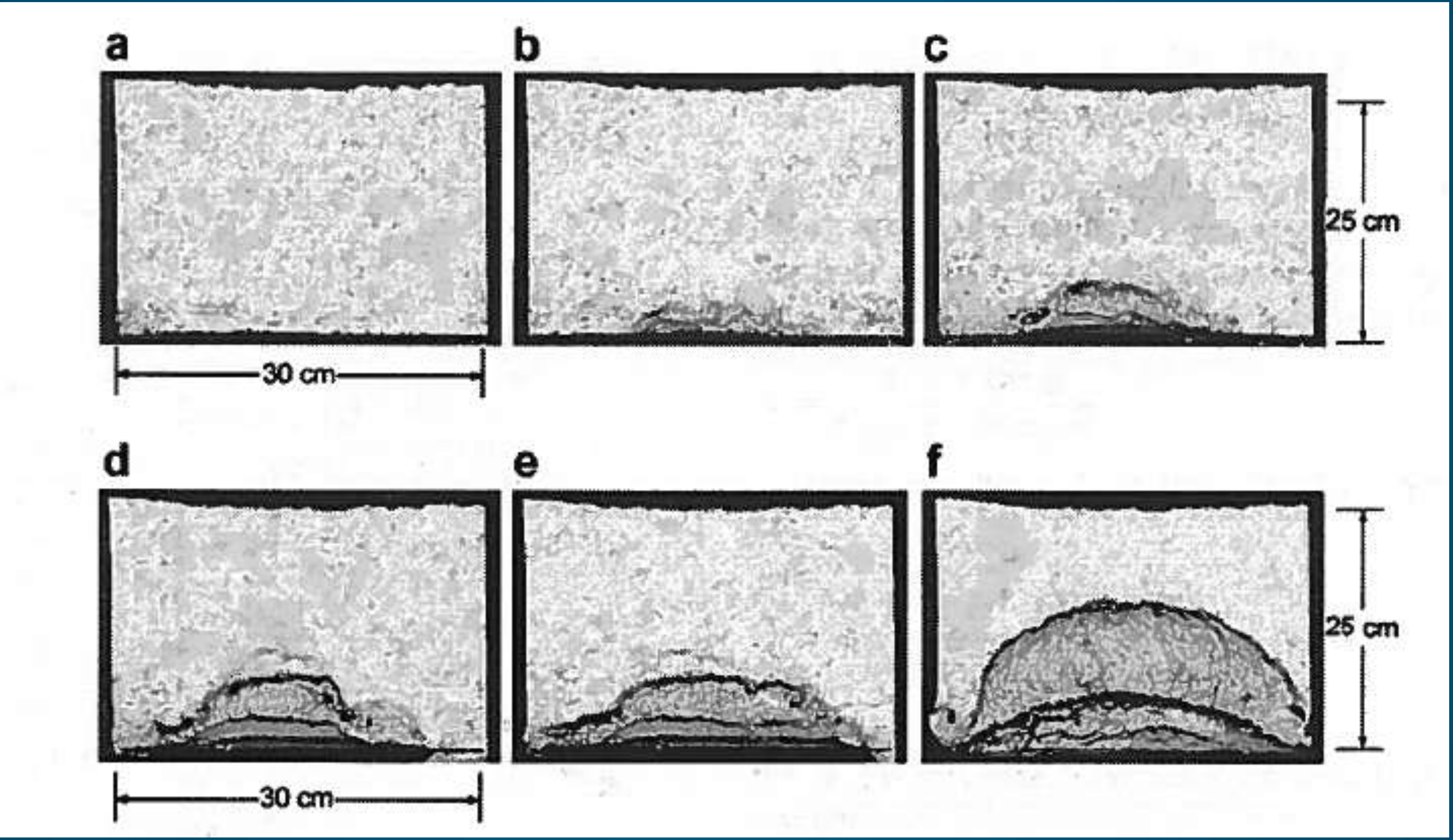
- Pop-out or Tension Failures
- Chu-Agor et al. (2008)
  - When soil resistive forces **cannot** withstand the seepage gradient force, a pop-out failure occurs
  - When soil resistive forces **can** withstand the seepage gradient force, the possibility of concentrated seepage with particle mobilization occurs

Seepage Particle Mobilization



Seepage Particle Mobilization

Chu-Agor et al. (2008)



Failure Mechanisms

- Pop-out Failure (1.45 g/cm^3, 15 cm head)

- Undercutting (1.7 g/cm^3, 15 cm head)

Lab Conclusions

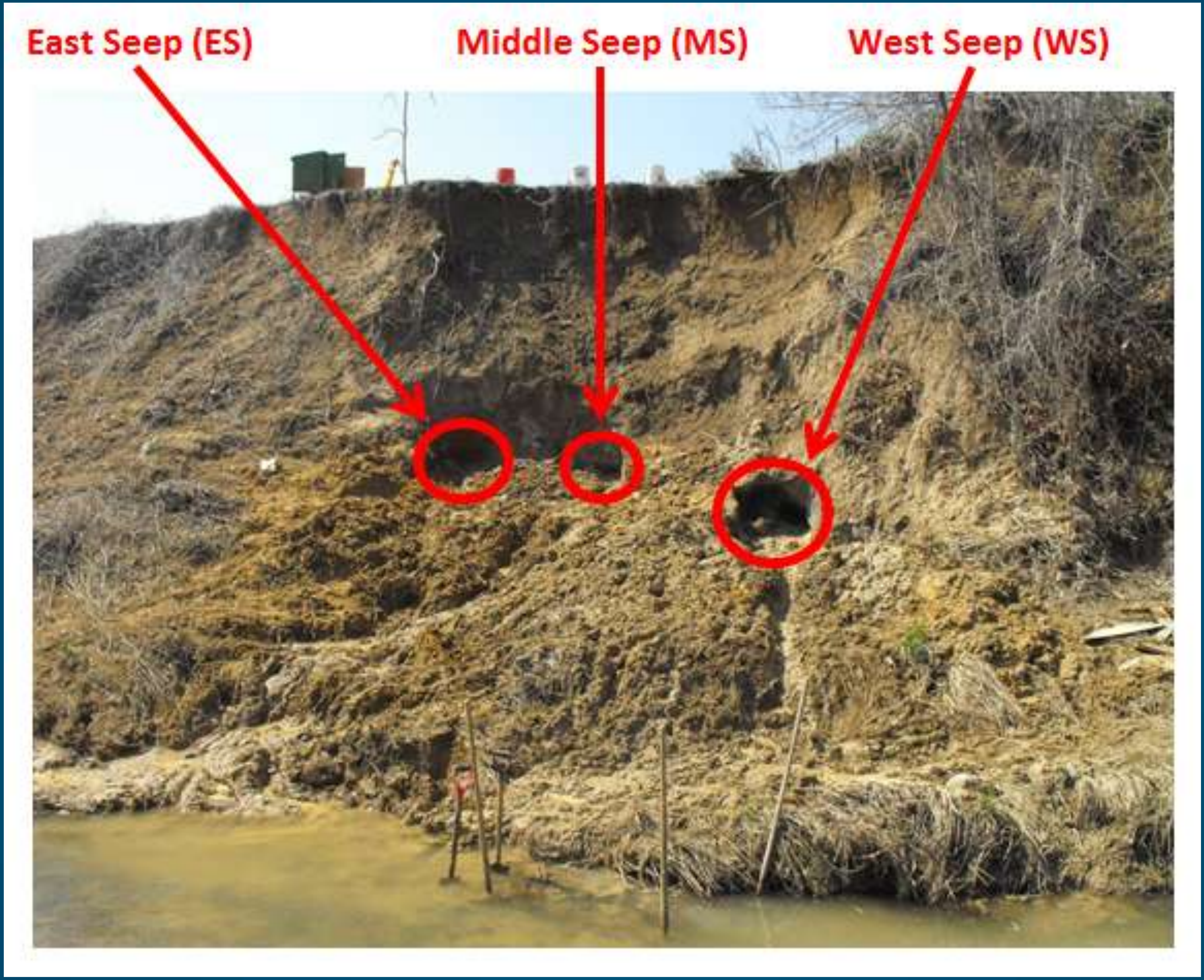
- Experiments continue…
- Critical density distinguishes mechanism of failure
  - Sandy Soil – 1.3 g/cm^3 Chu Agor et al. (2008)
  - Loamy Sand – 1.5 g/cm^3 Chu Agor et al. (2008)
  - Sandy Loam – 1.6 g/cm^3
  - Pop out below / Particle mobilization above
- More cohesive soils
  - Significantly increased time to failure
  - Decreased failure volume

Dry Creek, Mississippi

- Chickasaw County
- Tributary to Little Topashaw Creek

Site Setup

Seepage Collection


East Seep (ES)
Middle Seep (MS)
West Seep (WS)

East Seep

Flowrate

- Avg: <0.01 L/min
- Max: <0.01 L/min

Erosion Rate

- Avg: 0.06 g/min
- Max: 0.13 g/min

Middle Seep

Flowrate

- Avg: 0.29 L/min
- Max: 0.43 L/min

Erosion Rate

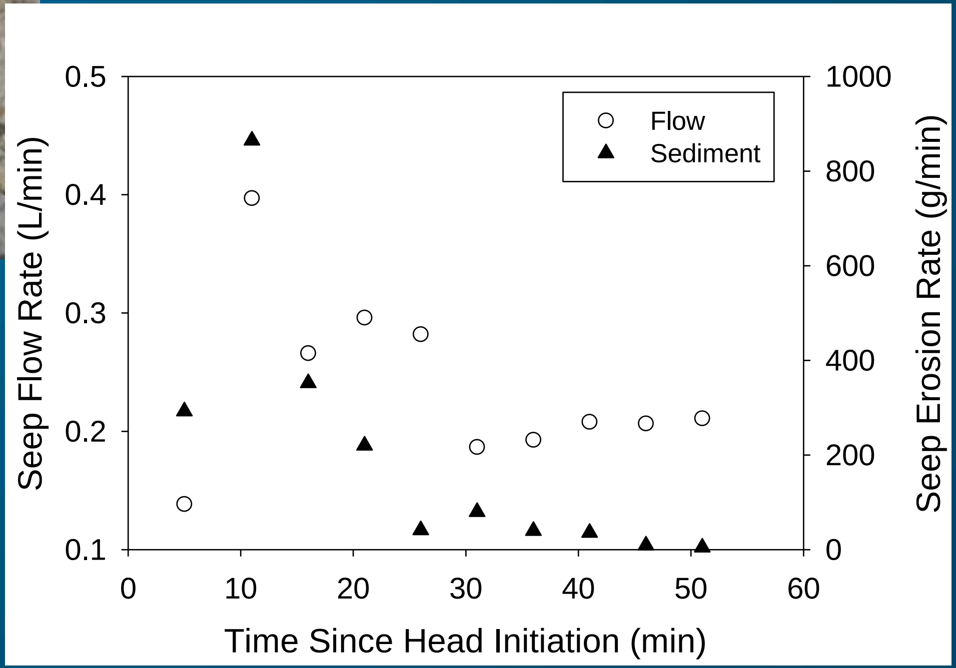
- Avg: 1.78 g/min
- Max: 7.85 g/min

30 cm depth initially followed by 10 cm over next 8 hours

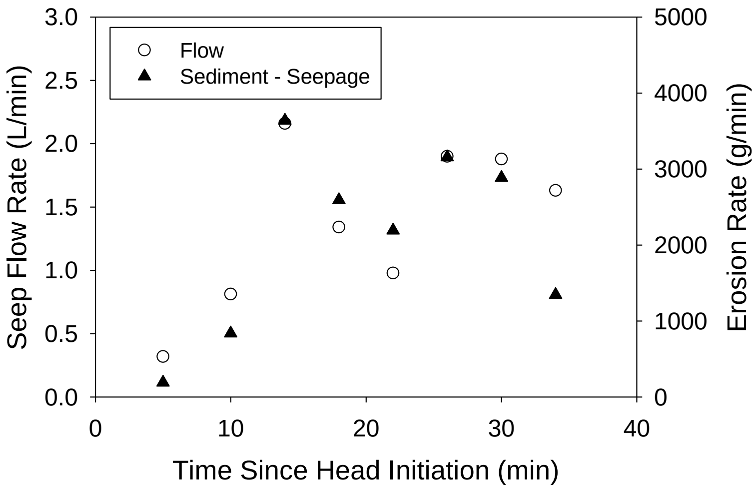
West Seep One

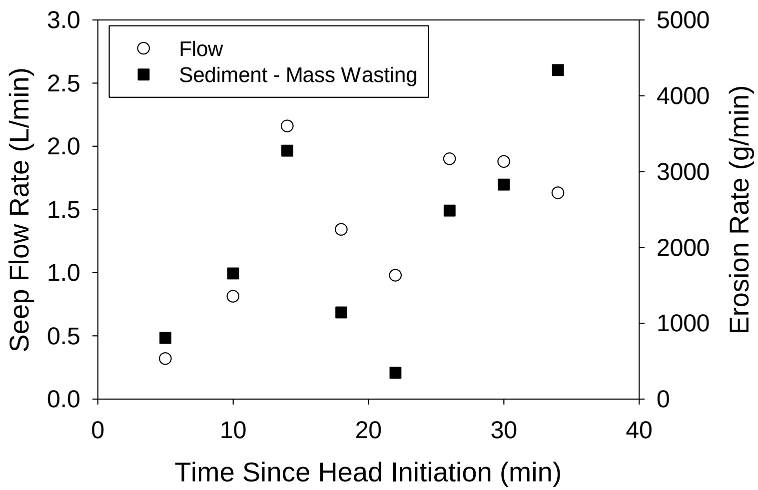
Self Healing Process

38 cm in depth over 51 minutes



West Seep Two





91 cm in 40 minutes

Field Conclusions

- Seepage rapidly mobilized particles from the sand layer
- Undercutting resulted in unstable upper cohesive banks which b/c of increased soil weight and lack of support
- As this material failed, it would have to be mobilized to clear the way for further particle mobilization
- This soil was resistant to mobilization, so it would further block mobilization – **Self Healing Process**

Field Conclusions

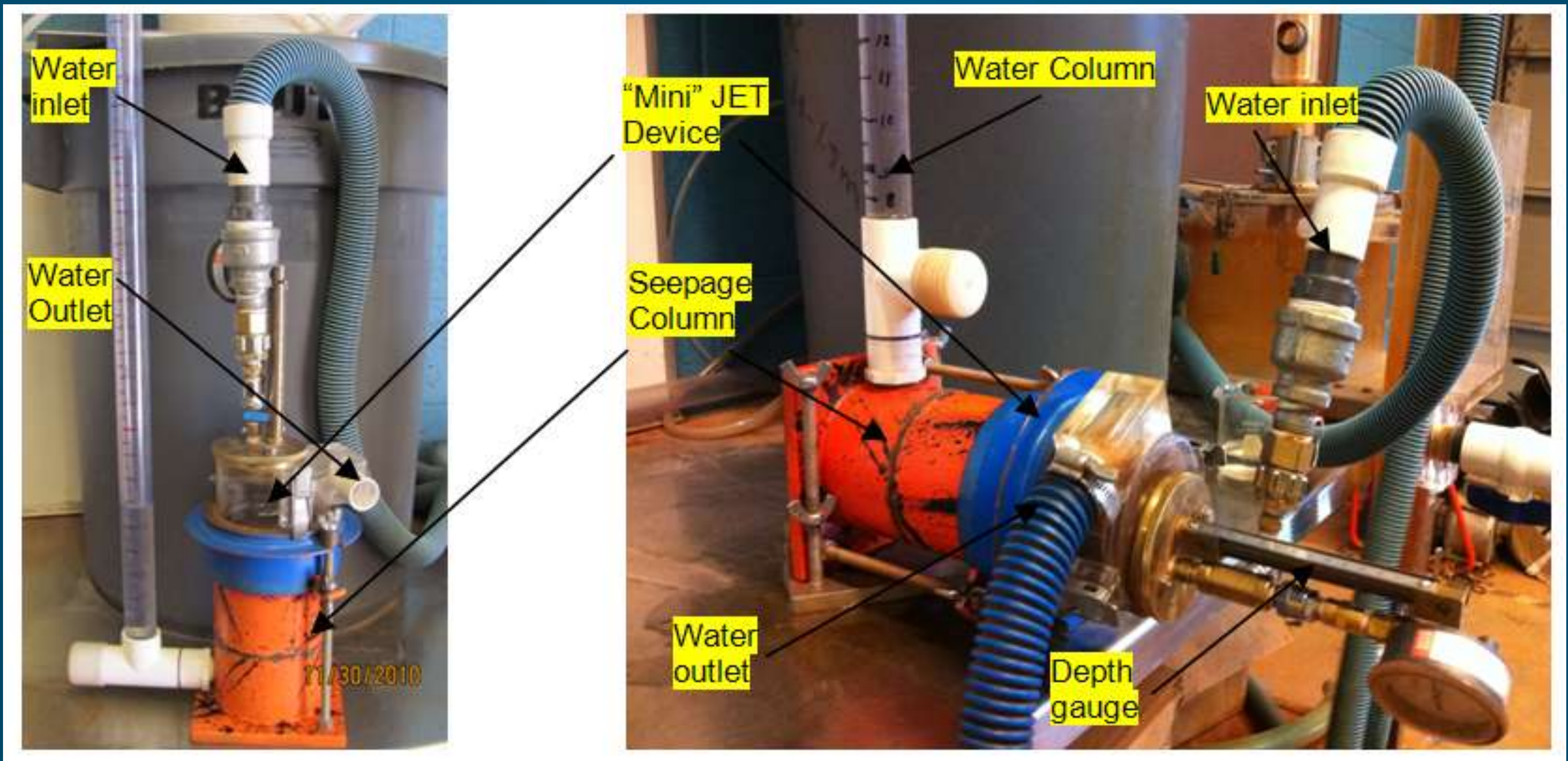
- If linked with fluvial erosion, seepage erosion can be a dominate factor in streambank erosion
- Future work is need studying the effects of seepage combined with fluvial processes…

JET Device

- First developed by Hanson in 1990 to measure t_c & k_d
- A laboratory version of the submerged jet (Hanson and Hunt, 2007)
- A new miniature version of the device ("Mini" JET) (2009)

JET Device

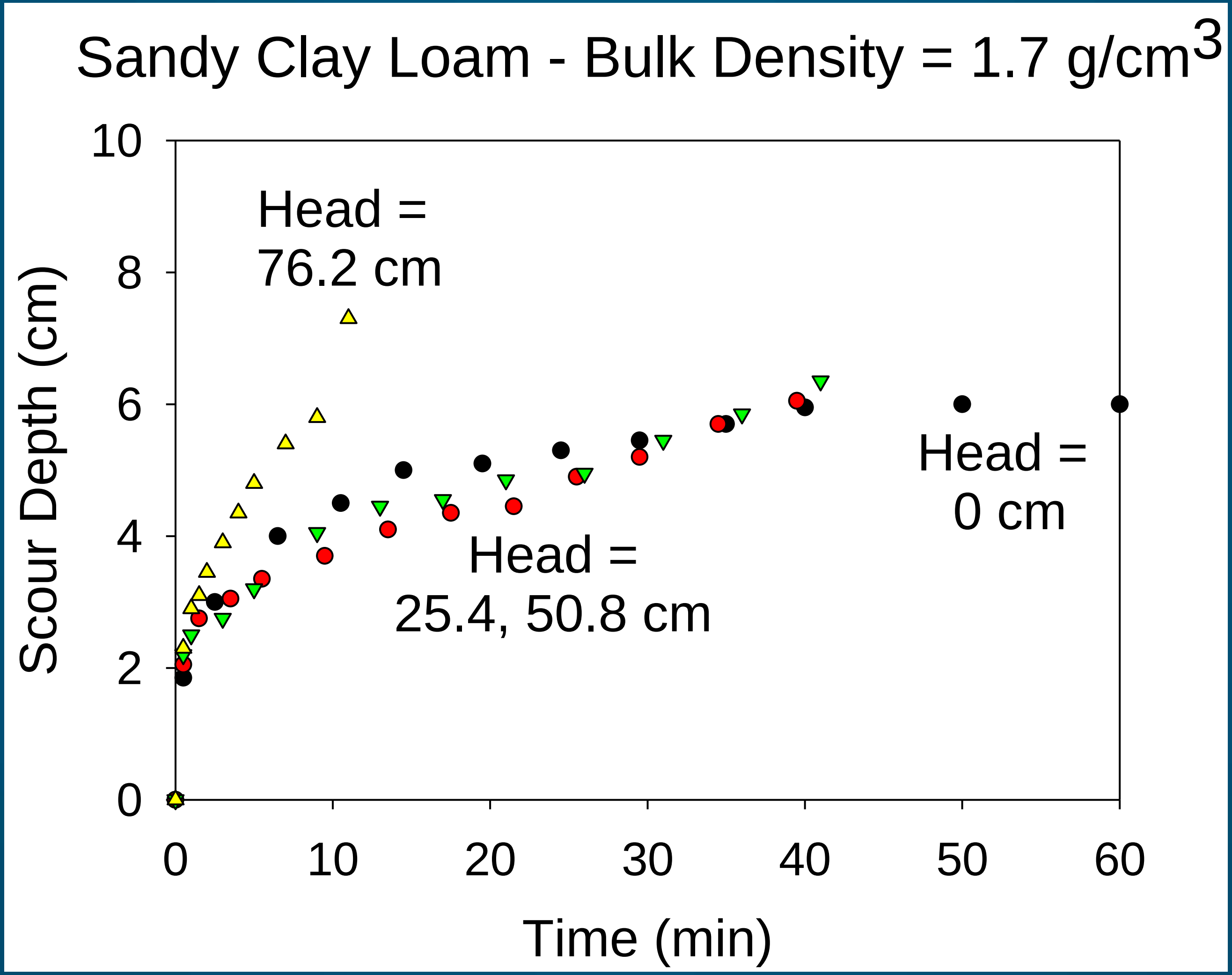
- Experimental Setup
  - Vertical (Streambed) & Horizontal (Streambank)



Experimental Procedure

- Soil samples prepared in the same manner at same time…
  - Sample tested without seepage (seepage head = 0 cm)
  - Other tested with a constant, imposed seepage head (up to 100 cm head on the 12-cm soil mold)
- Equivalent head for JET used in all experiments (61 cm)
- Depth gauge acquired readings of scour over time
- Experimental data analyzed using Blaisdell method

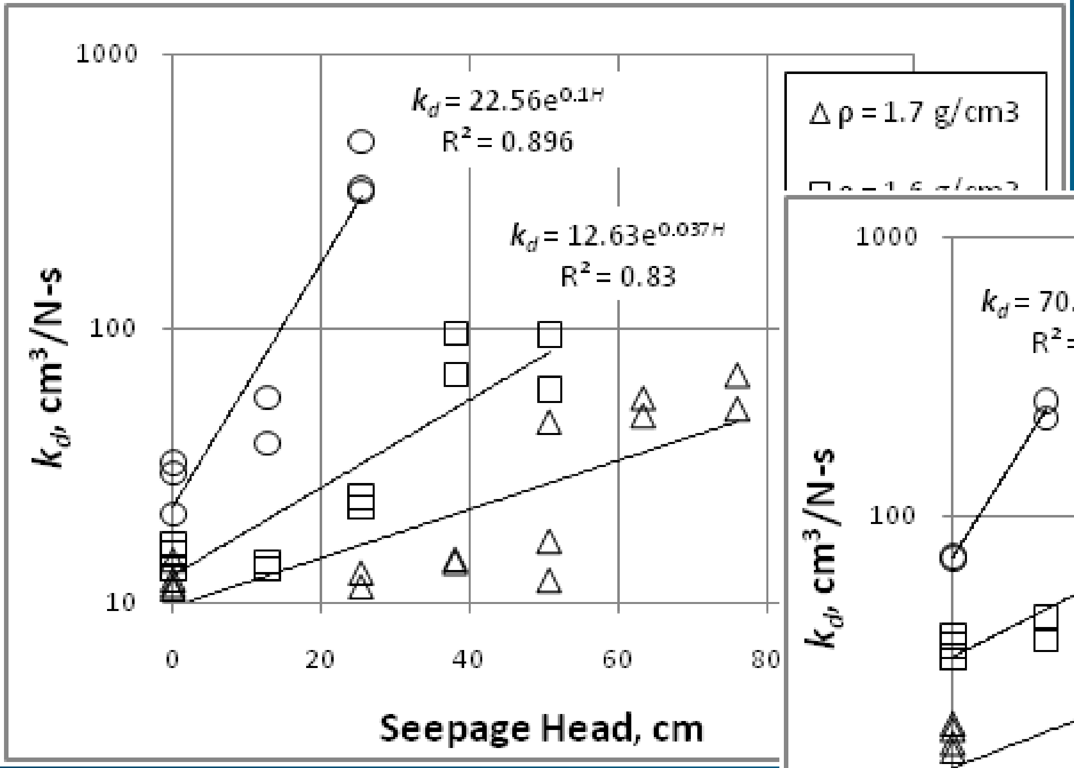
Results

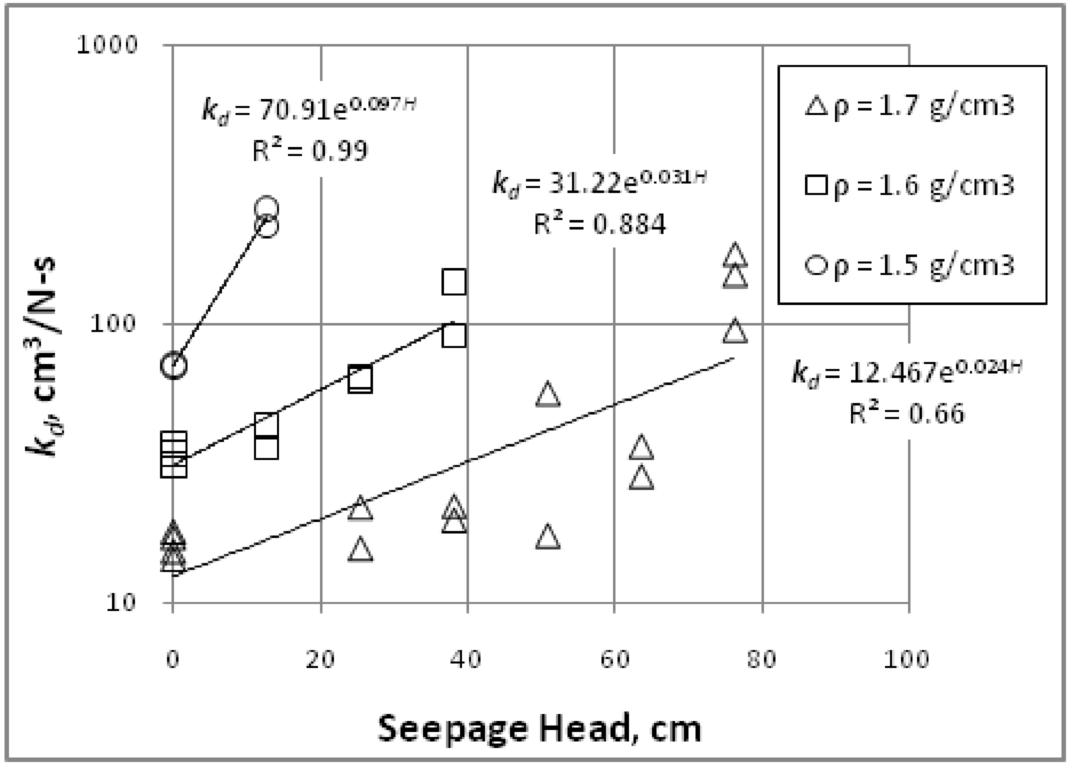


Sandy Clay Loam - Bulk Density = 1.7 g/cm3
Head = 76.2 cm
Head = 25.4, 50.8 cm
Head = 0 cm
Scour Depth (cm)
Time (min)
0
2
4
6
8
10
0
10
20
30
40
50
60

Results

Clay Loam Soil – Vertical





Clay Loam Soil – Horizontal

Conclusions

- Erodibility of cohesive soils exponentially increased with higher seepage forces, especially for lower bulk density soils
- Higher erodibility observed with horizontal setup
- Influence of seepage on erodibility soil specific
  - Mechanistic equations are being derived to estimate erosion under the influence of seepage

Acknowledgments

- Support staff of the USDA National Sedimentation Lab and the USDA Hydraulics Lab for assistance with instrumentation and data collection
- Funded by a National Science Foundation Grant (No. 0943491)