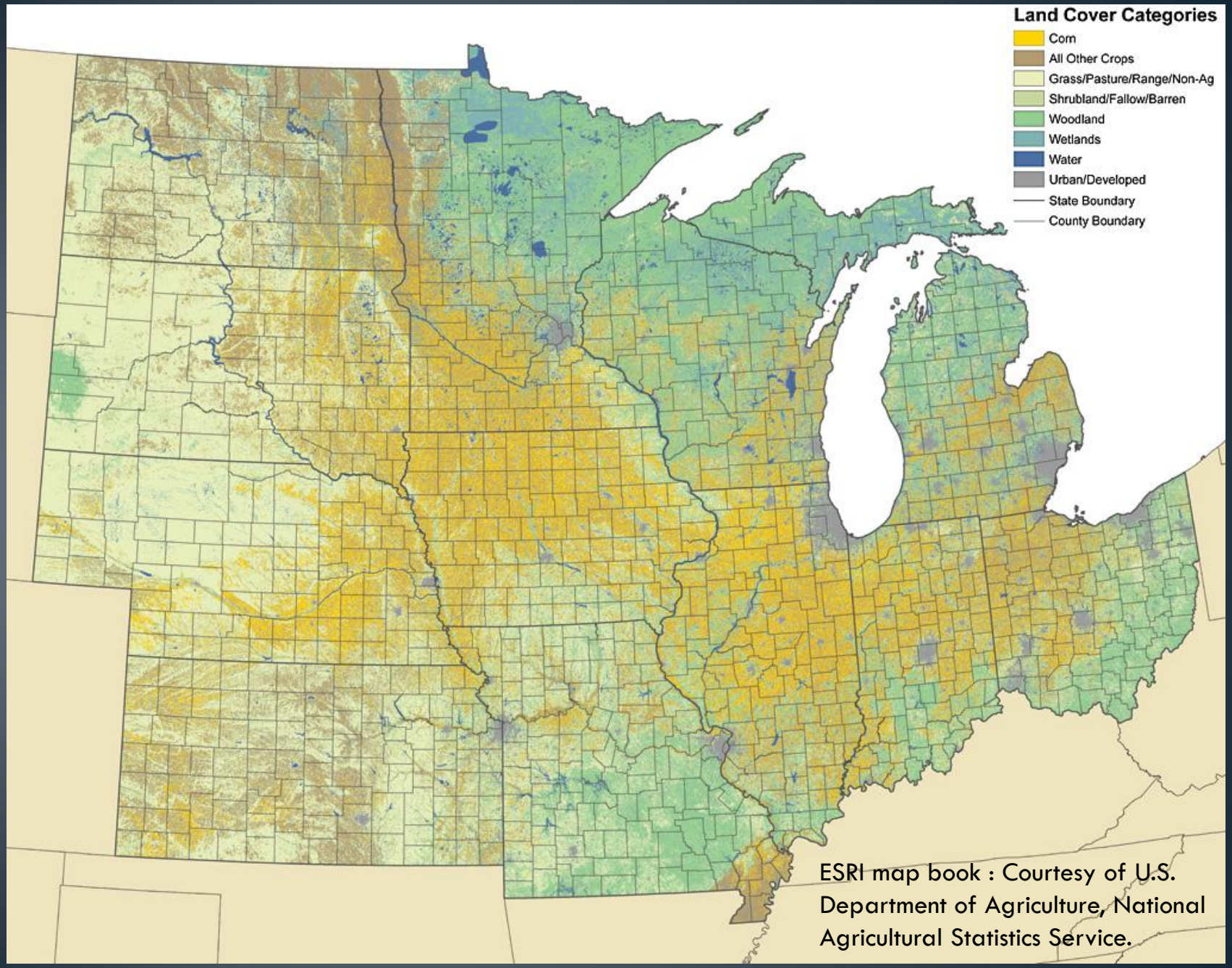
Understanding Ravine Growth Using Physical Experiments

Stephanie S. Day

North Dakota State University



ESRI map book : Courtesy of U.S. Department of Agriculture, National Agricultural Statistics Service.

http://www.esri.com/mapmuseum/mapbook_gallery/volume24/images/agriculture2_lg.jpg

The Big Question

How have changes to the hydrograph, including increased flow rates and flow volumes, impacted erosion?

Approach

- Utilized small physical experiments to effects of changing the delivery rate of a fixed volume of water to an incising ravine.
- Performed experiment using two substrates representing cohesive and non-cohesive sediments.
- Compared experimental results with results calculated using sediment transport equations.

Experimental Set Up

D50 = 90 µm

Basin size = 2 m x 3 m

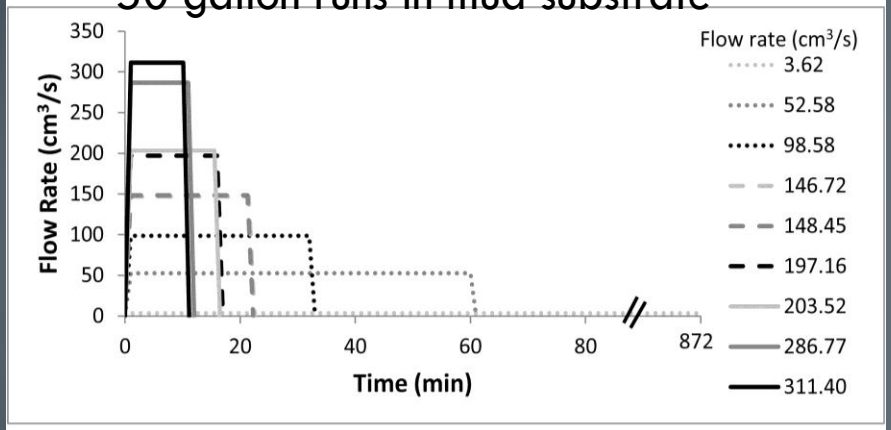
D50 = 18 µm

Basin size = 1 m x 1 m

Range of Flows

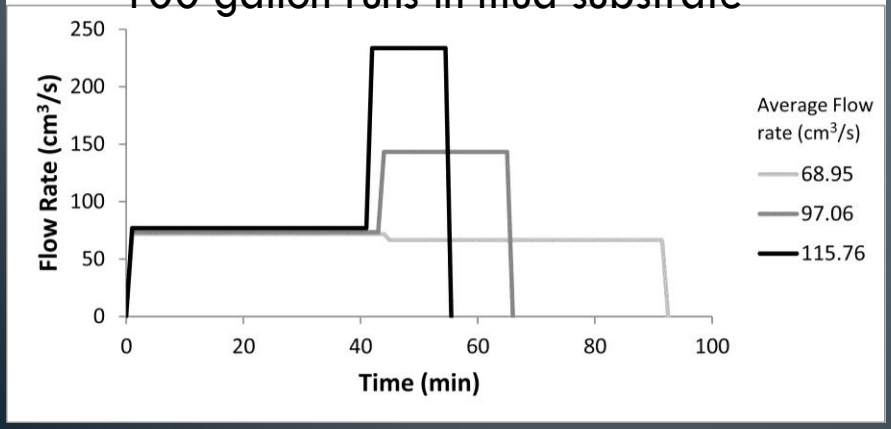
A)

50 gallon runs in mud substrate



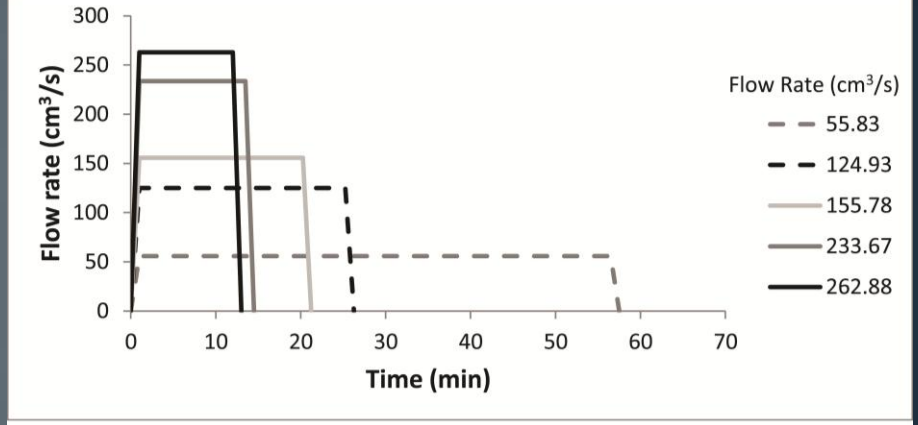
B)

100 gallon runs in mud substrate



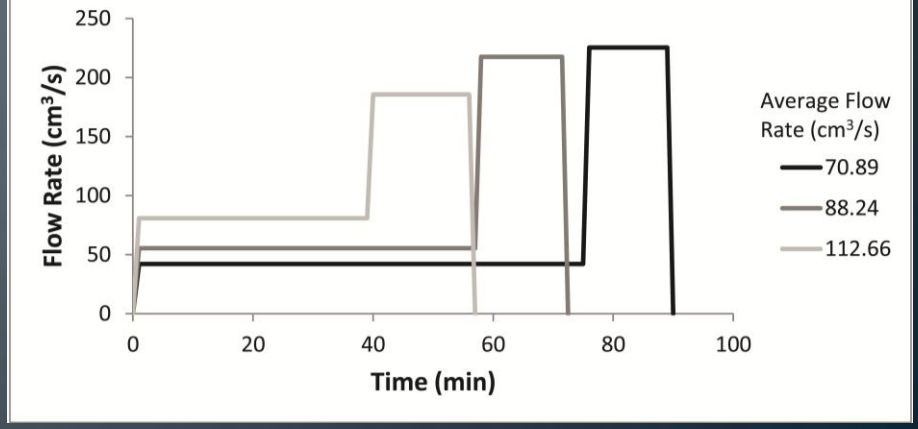
C)

50 gallon runs in sand substrate



D)

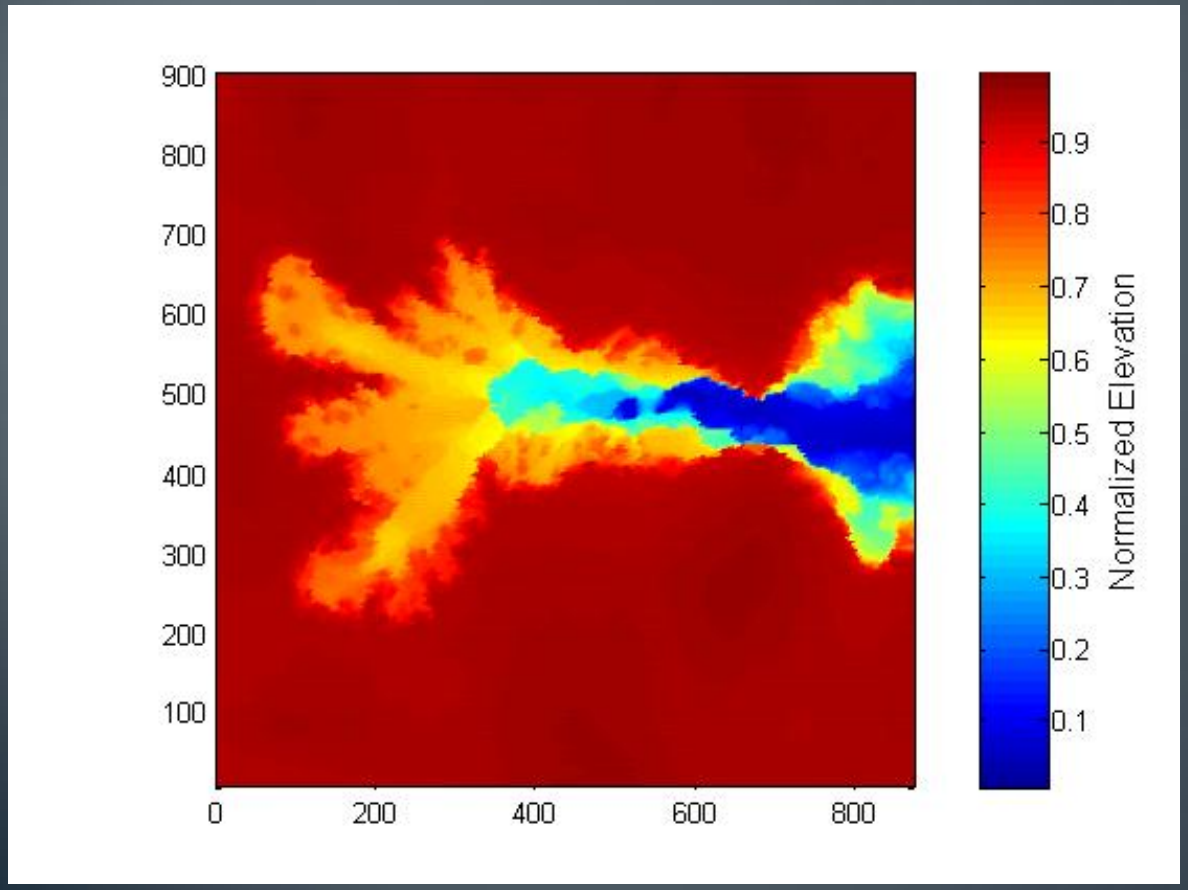
100 gallon runs in sand substrate



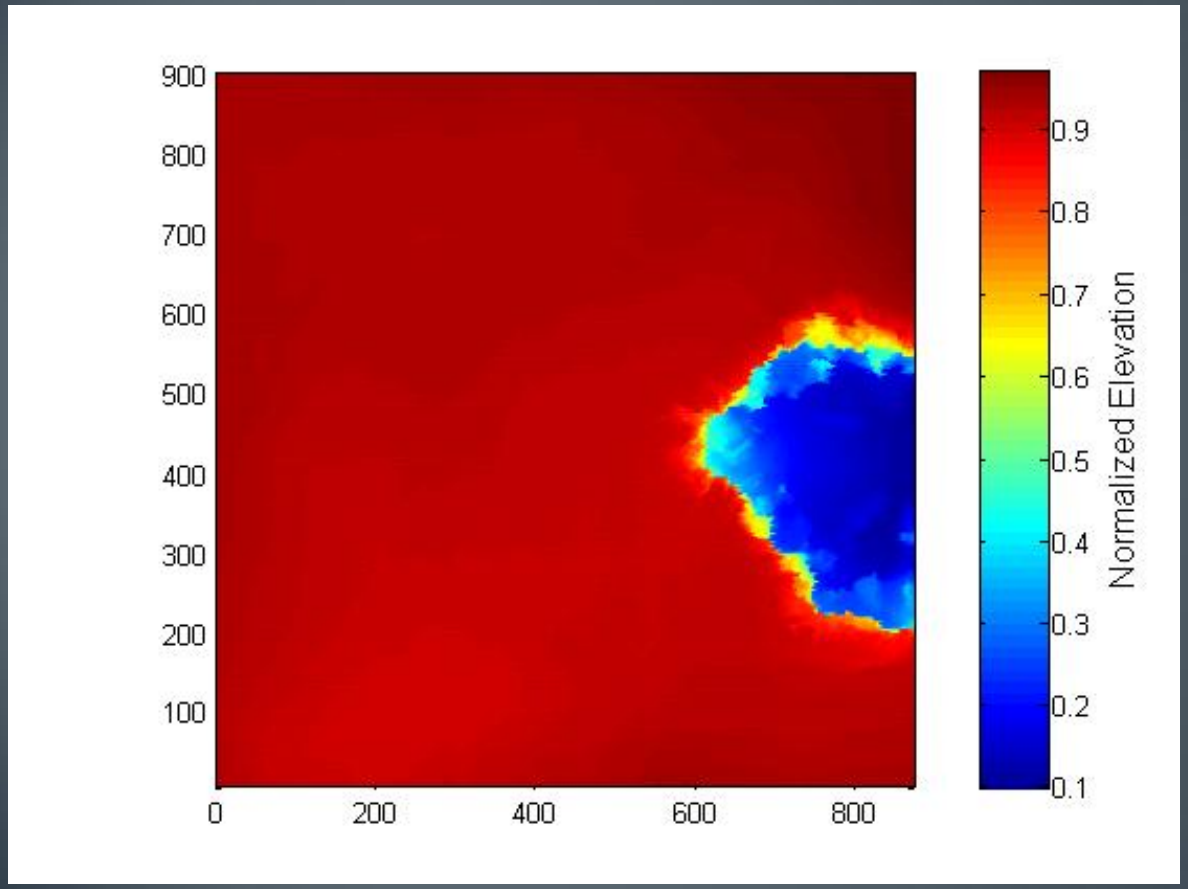
Ravine Growth in Mud Substrate

Time Complete

100%



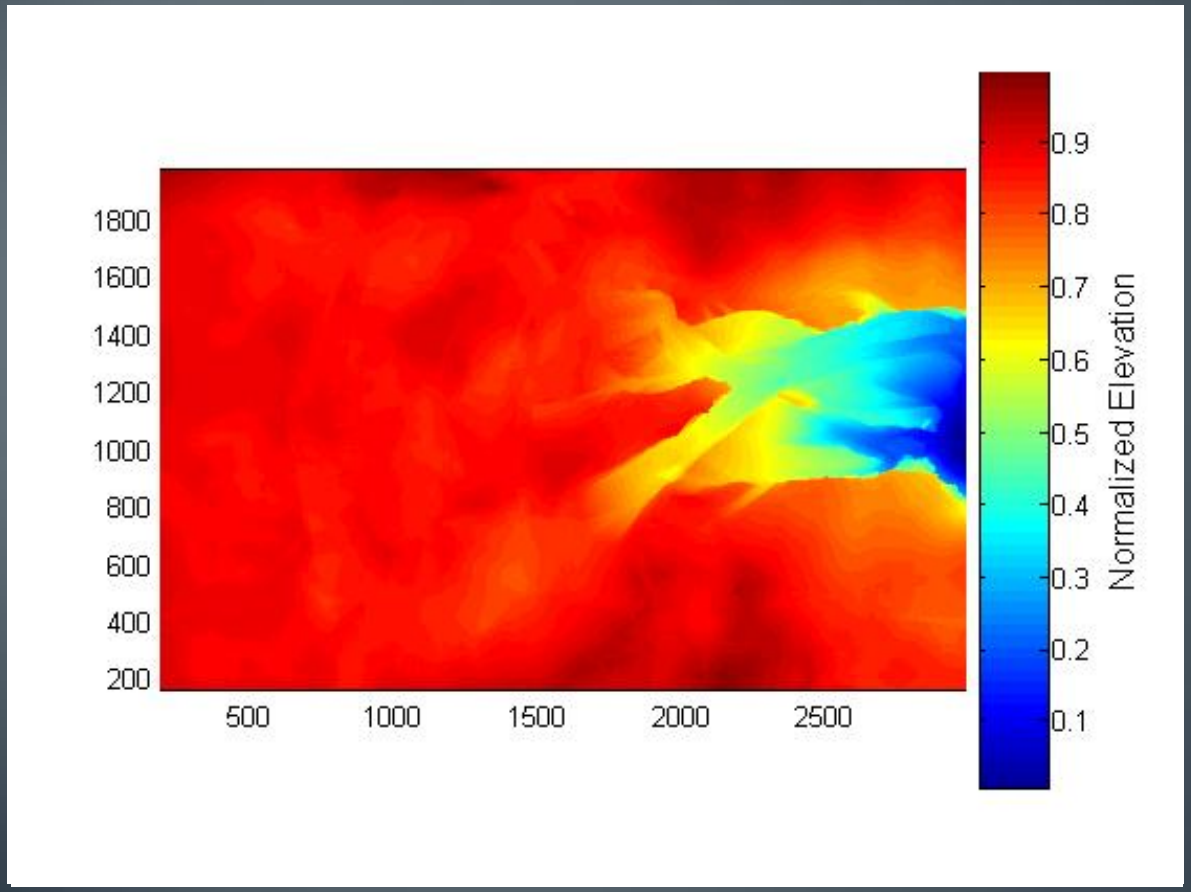
Experiment Results in Mud Substrate



Flow Rate (ml/sec)

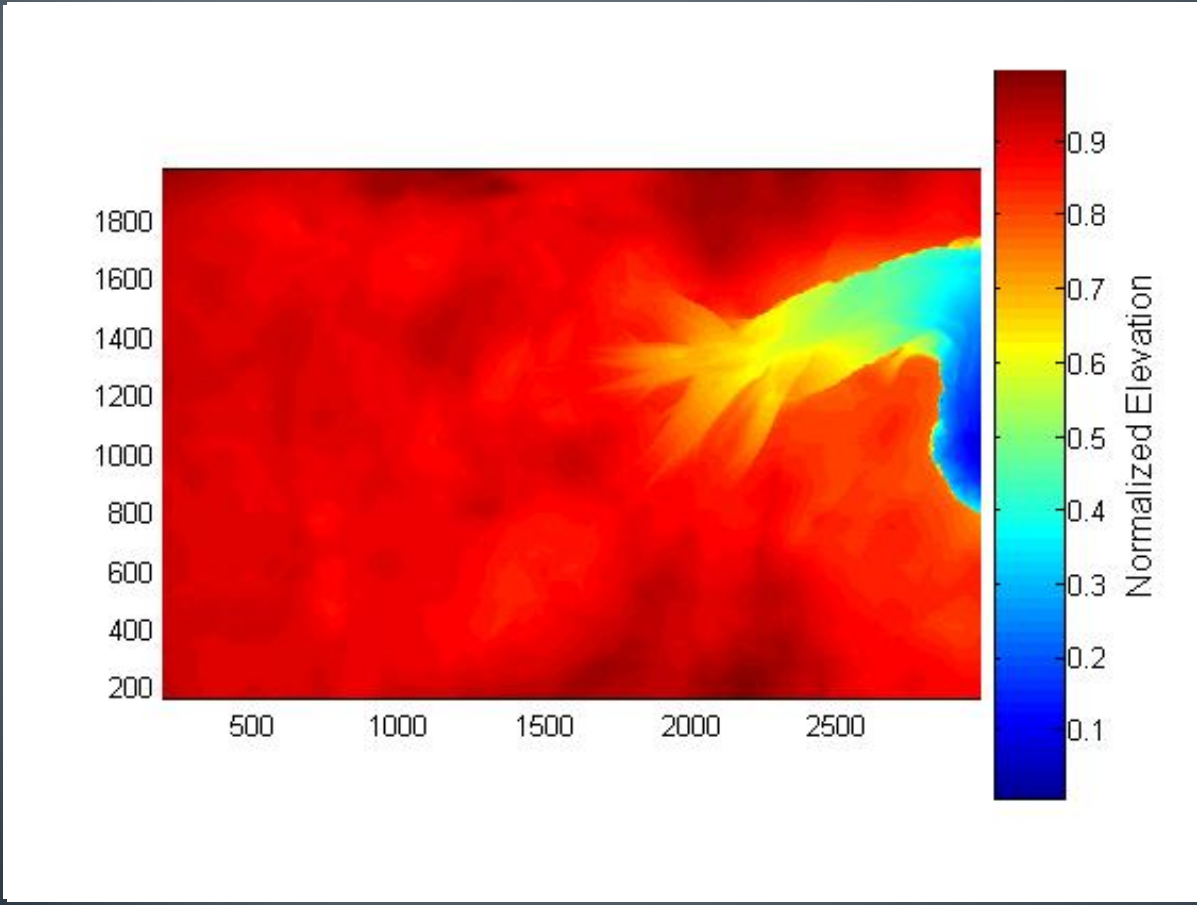
3.62
52.58
98.58
146.72
148.45
197.16
203.52
286.77
311.40

Ravine Growth in Sand Substrate



100%

Experiment Results in Sand Substrate

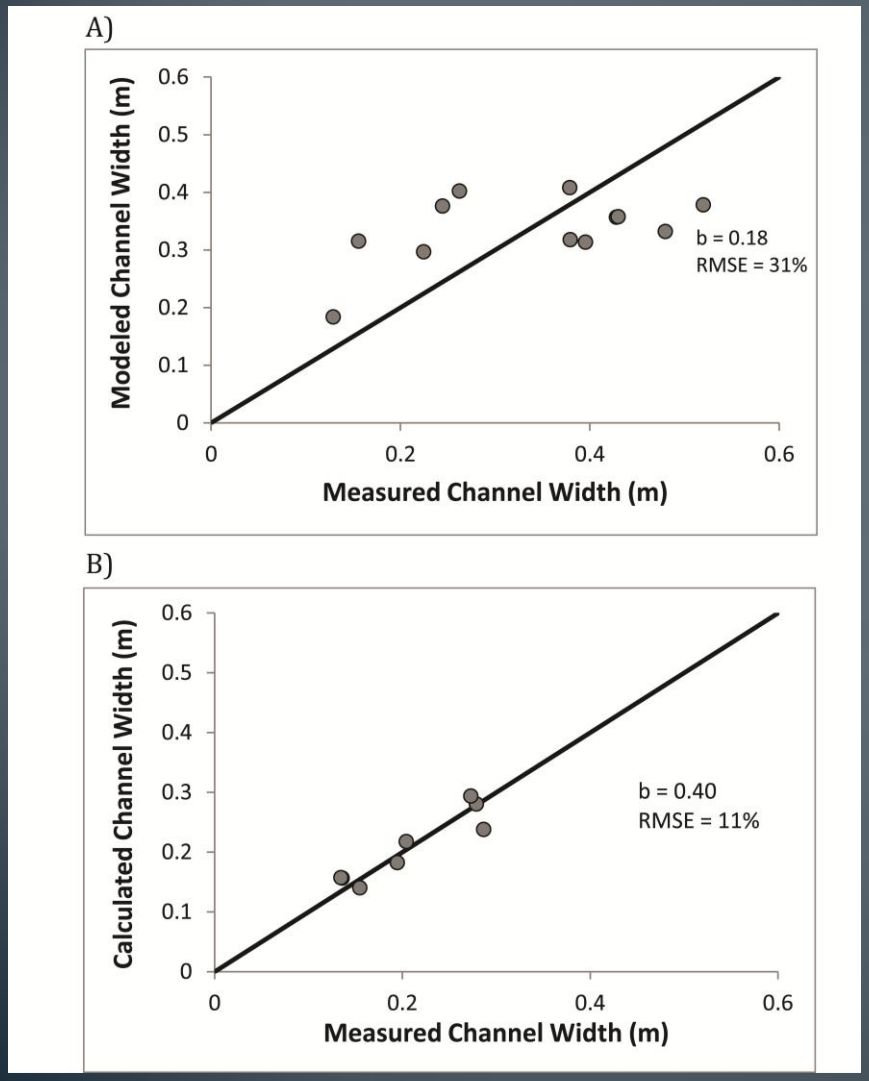


Flow Rate (ml/sec)

- 55.83
- 124.93
- 155.78
- 233.67
- 262.88

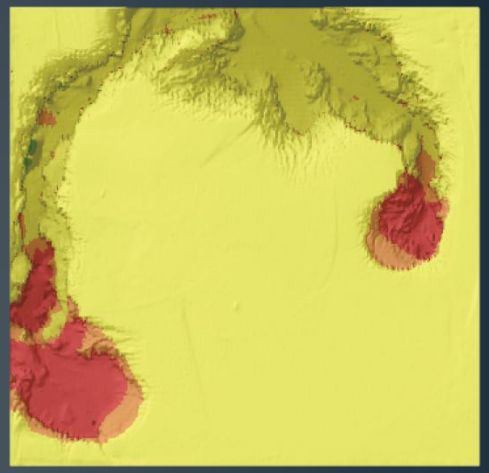
Ravine Width in response to discharge

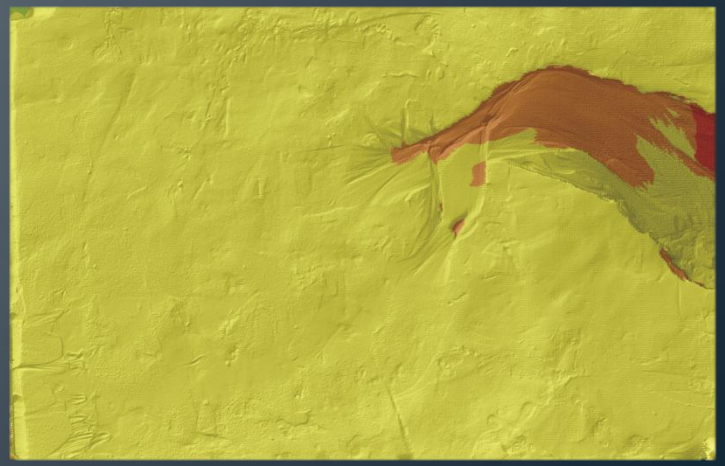
$$W = aQ^b$$



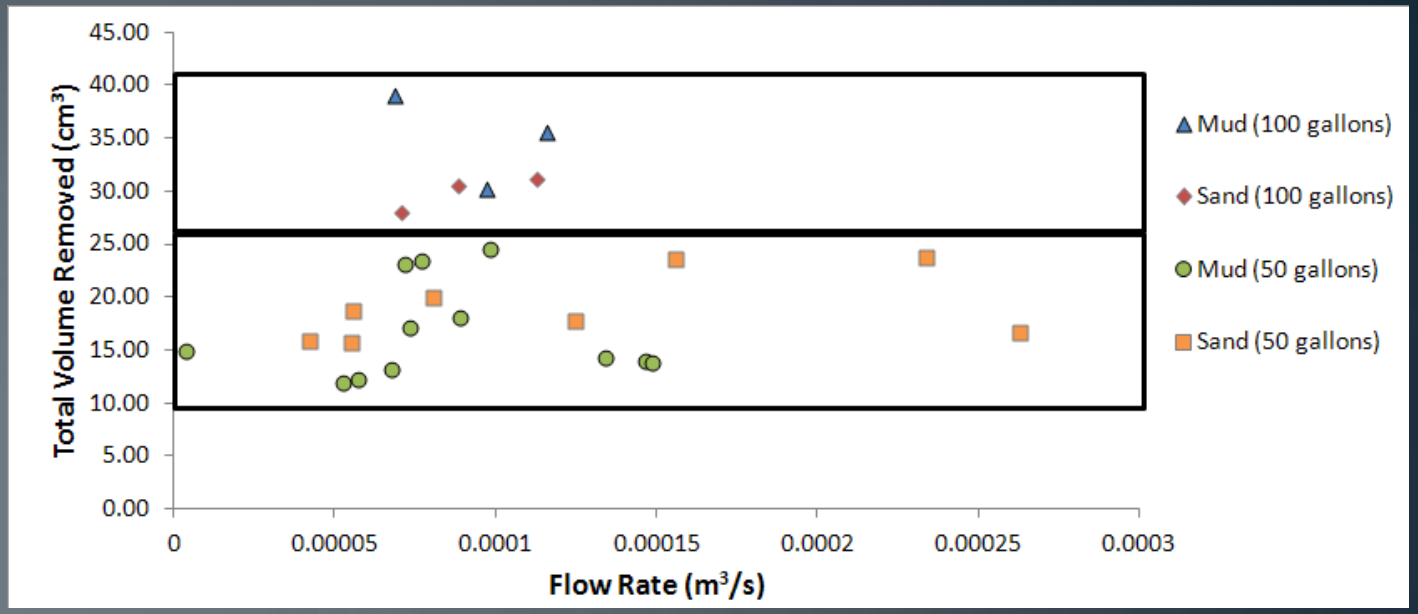
Change after flow increase (mm)

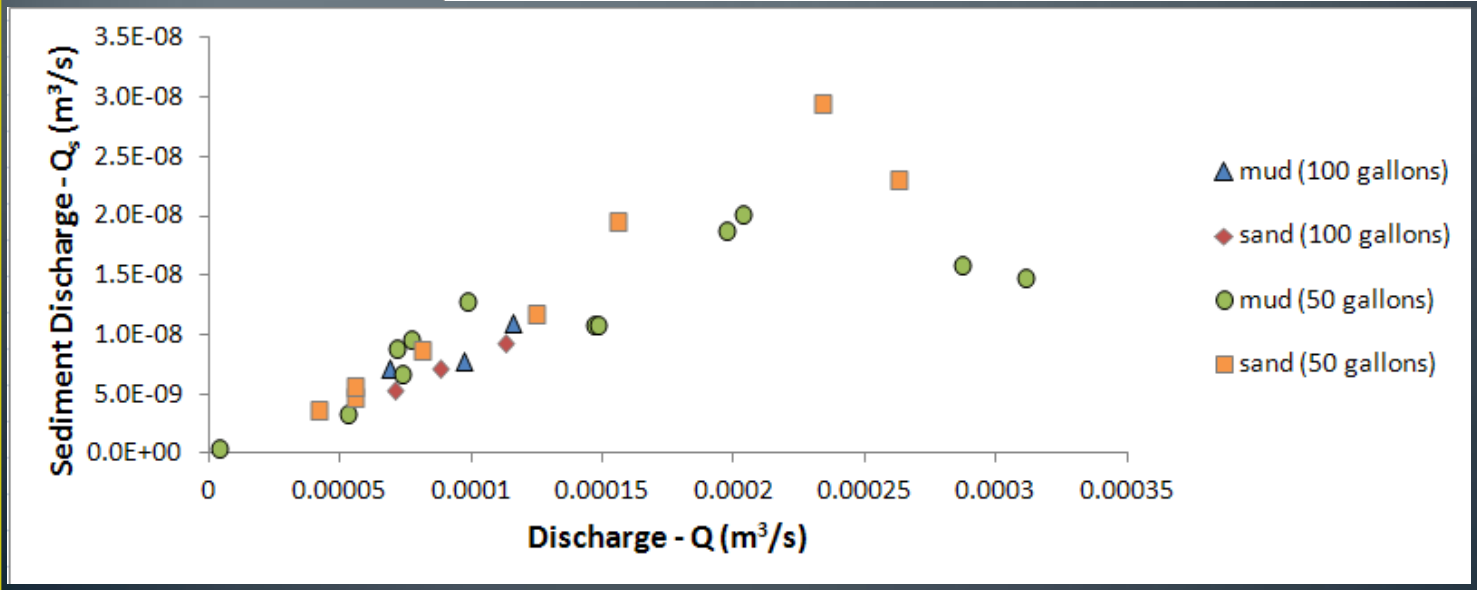
-101 – -39
-39 – -15
-15 – 15
15 – 50
50 – 170





Sediment and discharge relationships





Relating Results to from Mud Substrate to Stream Power Incision Model

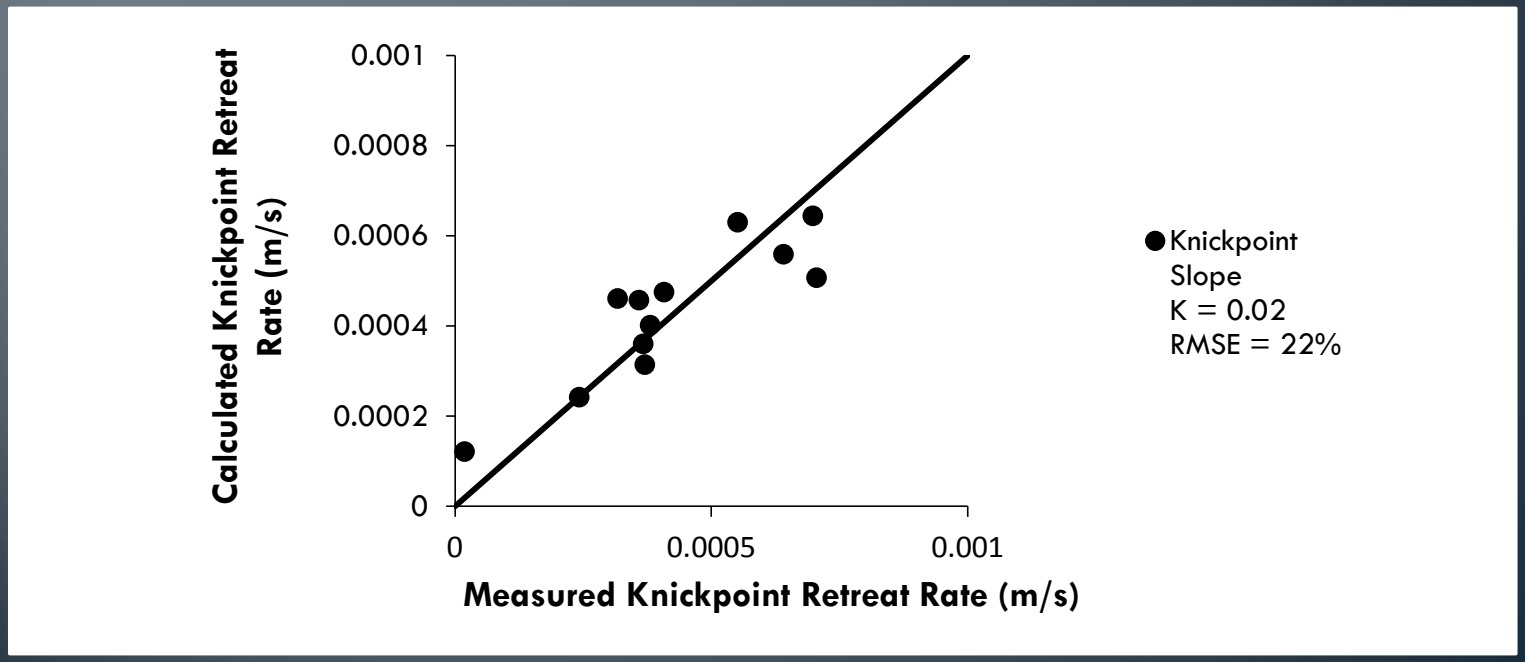
$$\frac{dz}{dt} = kQ^{m_d} S_k^{n_d}$$

From Howard and Kirby, 1983

$$U \cdot S_k = \frac{dz}{dt}$$

$$U = kQ^{m_d} S_k^{n_d - 1}$$

dz/dt = vertical erosion rate
Q = discharge
S_k = knickpoint slope=tan θ
k, m_d, n_d = coefficients
(m_d = 4/9 and n_d = 2/3)
U = knickpoint retreat rate

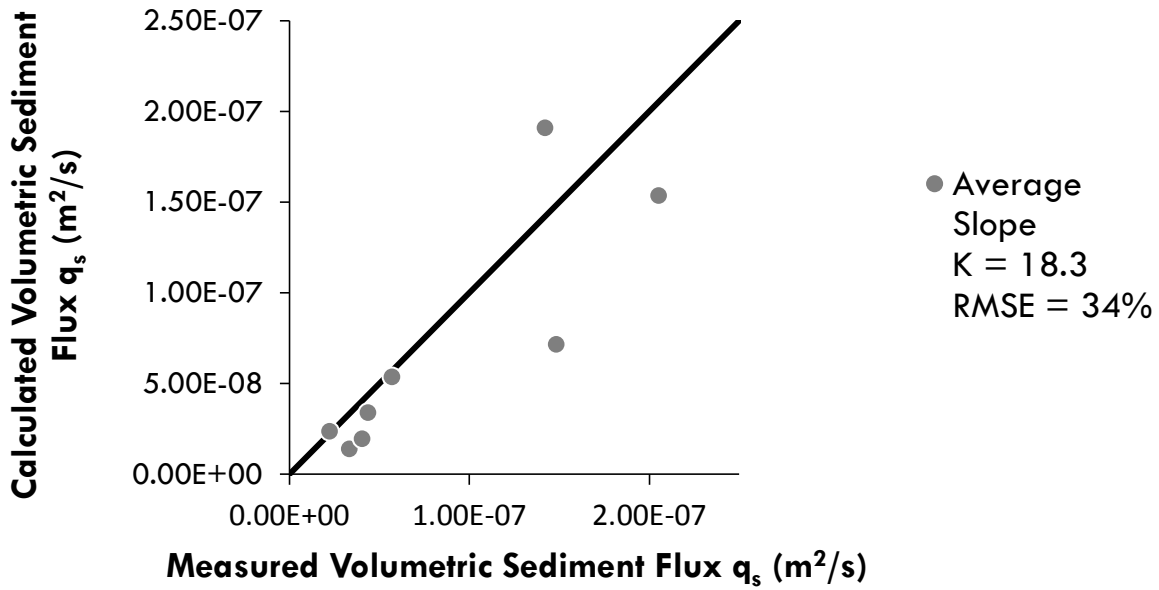


Relating Results to from Sand Substrate to Transport Limited Erosion Model

$$q_s = kQ^{m_t}S^{n_t}$$

Modified Engelund and Hansen (1967)
From Pelletier, 2011

q_s = volumetric sediment flux
Q = discharge
S = Bed slope
k, m_t, n_t = coefficients
($m_t = 5/3$ and $n_t = 5/3$)

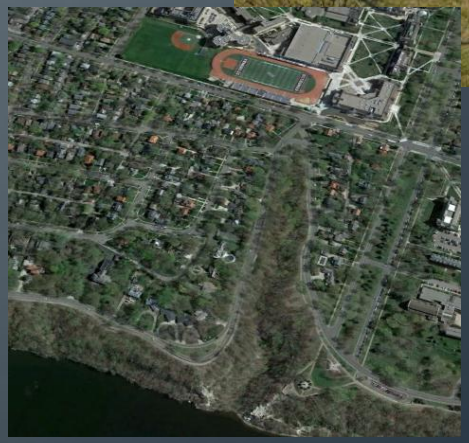


Summery of Results

- Flow rate does not determine total eroded ravine volume in either cohesive or non-cohesive sediment.
- Flow volume does determine total eroded ravine volume in both cohesive and non-cohesive sediment.
- Results can be explained with traditional sediment transport equations.
- Ravine width might be determined by flow rate

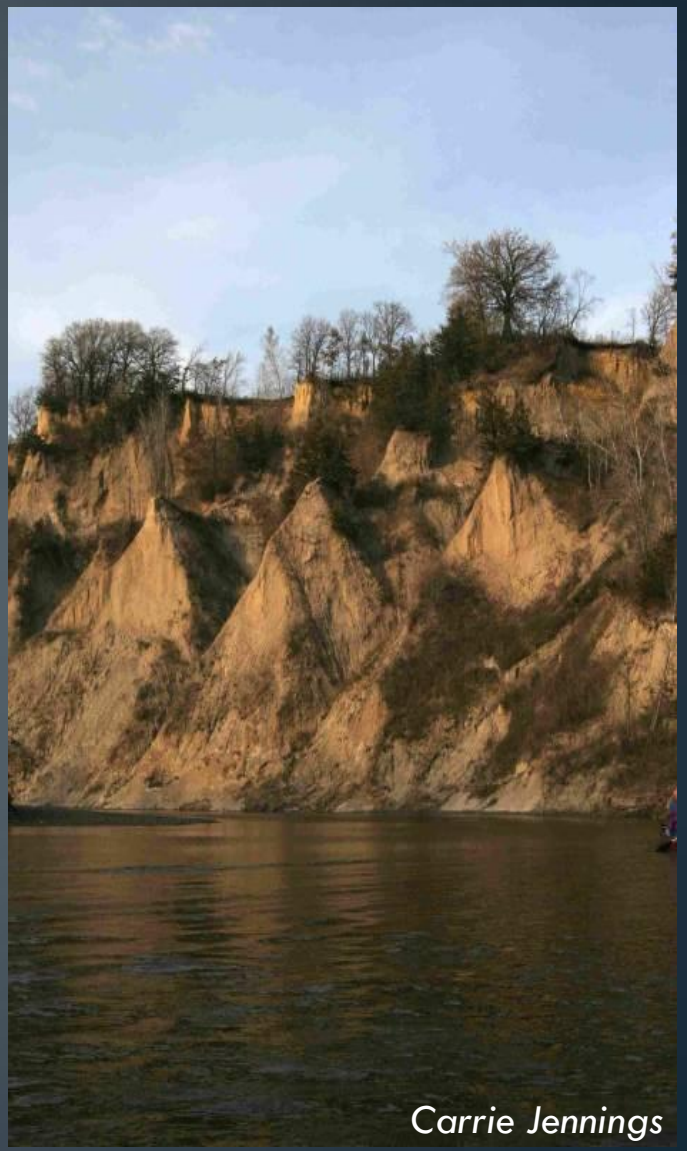
Effects of Anthropogenic Alteration

- Tile drains and storm sewers reduce overland flow volume – this likely reduces ravine growth.
- Fields are bare in the late fall, winter and early spring potentially resulting in overland flow– this likely makes ravine growth seasonal.
- Impervious surfaces lead to increased overland flow volumes – this likely increases ravine growth



More Research is needed

This work focused on ravine growth, but might provided some insight on what happens in pre-existing streams. Generally wider streams formed in runs with higher flow rates. This may suggest that higher flow rates do result in increased bank erosion.



Questions?