Prioritizing Sediment Reduction Strategies in a Large Watershed:
Collaborative for Sediment Source Reduction

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Peter Wilcock and Patrick Belmont, Utah State University
Minnesota River is primary source of sediment and nutrients for Upper Mississippi River.

Lake Pepin Record

“Beating muddy heart” of the Minnesota River
-P. Wilcock

Total Suspended Solids
Average Total Suspended Solid Yield in pounds per acre

TSS Yield (lbs/acre)
- less than 100
- 100-199
- 200-299
- 300-399
- 400-499
- greater than 500

Greater Blue Earth River Basin

State of the Minnesota River: Water Quality Summary
2000-2006
http://mrbdic.mn.gov

MPCA
Disconnected and poorly-drained landscape
Modified from Schottler, 2011 WRC Conf

Novotny and Stefan (2007), Additional data from Sara Kelly
There are also shifts in sediment sources in the past few centuries seen through sediment fingerprinting.

How have erosion rates changed?
Terraces!
“Pre-settlement” sediment load:
Volume of sediment excavated:
50,000 Mg/yr of silt & clay

3-3.5x less than modern valley-derived erosion rates
How do we develop a watershed-scale management plan?

How should we focus management actions?
CSSR
Collaborative for Sediment Source Reduction

**Goal:** To identify a consensus strategy for reducing sediment loading in the Greater Blue Earth watershed using a decision framework that incorporates the best available scientific information, accounts for uncertainty, and provides a model for decision making throughout the Minnesota River Basin.
Stakeholder Group

Thank-you!
Management Option Simulation Model (MOSM)

**Processes**
- Hydrologic Modeling
  - Predict Erosion & Deposition Via Sediment Budget
- Water & Sediment Routing

Management Option Simulation Model (MOSM)

**Part 1**
- Simulation Model
- Part 2: Management Options
  - Extents
  - Rates
  - Costs

**Part 3**

Greater Blue Earth River
Part I. Greater Blue Earth River Basin: Sediment Sources, Sinks, and Delivery
Sediment budget is structured accdg. to subwatershed and geomorphic environments within each watershed.
Above the knick point

Streambanks

Uplands

C. Jennings
Sediment sources and sinks

• Load = erosion rate x extent
  • measuring erosion rates & source extents
  • erosion rate extrapolation methods
• Constrained by gaging records

Sediment Sinks:
Floodplains
Lakes

Uplands
Ravines
Bluffs
Streambanks
Excellent gaging network

GC: Garden City; VC: Vernon City; RJP: Red Jacket Park
Ravines

- **Source Extent:**
  Delineated based on topographic break from uplands
Ravines

- Erosion Rate: calculated from load gauged at outlets of 4 ravines
- Extrapolated based on incised ravine area

![Graph showing sediment yield vs. incised ravine area](Scott Matteson, Laura Triplett)
GBER picture with migration rates, bluff (SSA?), lakes(watersheds), traced channels, ravines, Banks

Erosion Rates
Widening & meandering:
historic air photos, lidar
Incision: terrace dating,
numerical modeling

Source Extent
Lidar, NHD, historic air photos

1 km
Meander migration rates

Higher in zones with lots of bedload

Lower in reaches with bedrock
Bluffs

- **Source Extent:** lidar
Bluffs

- Source Extent: lidar
- Erosion Rates: historic air photos, ground-based lidar

Photo by C. Jennings
Erosion rates and bluff frequency in GBER subwatersheds

Maple Cobb Le Sueur

Le Sueur

Blue Earth Watonwan

bluff frequency (m$^2$/bluff/channel km)

bluff erosion rate, m/a

- 0.05 0.10 0.15 0.20 0.25

- 0.10 0.20 0.30 0.40 0.50

- 0.60 0.70 0.80 0.90 1.00

- 1.10 1.20 1.30 1.40 1.50

- 1.60 1.70 1.80 1.90 2.00

- 2.10 2.20 2.30 2.40 2.50

- 2.60 2.70 2.80 2.90 3.00

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Upland load

- Erosion Rate: Sediment fingerprinting used to determine the % upland sediment at gages
- Turn this into upland yield and apply across watershed by area (i.e. upland % times total load, divide by area)
- Account for storage within lakes
  - Calculate trapping efficiency, the percent of incoming sediment trapped in each lake
Trapping Efficiency in the GBERB

How much upland sediment is trapped?

- \( \sim 0.5 \text{ kg/m}^2 \) of lake area
- 0.3 – 0.9 mm of mud deposited in lakes each year
Sediment sources

Sediment Sinks:
Floodplains
Lakes
Sediment Budget:
Sediment budget is compared both to gage records AND sediment fingerprinting.
Given these sources, how can we reduce sediment loading?
Peak flow events drive bluff and bank erosion in the incised zone within the watershed.

Cho, in prep
While bluff stabilization may help one bluff, water storage may help all of them…

Goal is to reduce flows

And thus reduce near-channel erosion in the incised zone

Cho, in prep
2. Simulation Model to Link Management Choices and Sediment Delivery
Presentation outline

• Research objective and problem definition
• Management options
• Topofilter model
• Hockey stick relation
• Management option simulation model
Research objective

• Develop a comprehensive modeling system to evaluate the widespread sediment pollution and effects of management investment in the Greater Blue Earth River Basin, of south-central Minnesota and north-central Iowa.
Problem definition

- Intensive agriculture and water quality problem
- Widely distributed and shifting dominant sediment sources in the Greater Blue Earth River Basin (GBERB) of the southeast Minnesota.
- Effective mitigation must be watershed-scale solution to control both erosion and runoff.

Ag conservation:
- Conservation tillage
- Grassed waterways
- Buffer strips
- etc.

Hydrologic conservation:
- Wetland restoration
- Two-stage ditches
- Control drainage
- etc.

N-C source protection:
- Toe protection
- Stream restoration
- River contouring
- etc.

MOSM

Z1 = maximize sediment reduction
Z2 = minimize cost of environmental management

MOP I
MOP II
MOP III
MOP IV
<table>
<thead>
<tr>
<th>Management options</th>
<th>Tillage MO</th>
<th>TLMO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reduce soil erosion</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Keep eroded soil out of the stream</td>
<td>Ag Field MO, Buffer MO</td>
<td>AFMO, BFMO</td>
</tr>
<tr>
<td>Reduce ravine erosion</td>
<td>Ravine MO</td>
<td>RAMO</td>
</tr>
<tr>
<td>Reduce bluff erosion</td>
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<td></td>
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<tr>
<td>Toe protection</td>
<td>Near channel MO</td>
<td>NCMO</td>
</tr>
<tr>
<td>Reduce peak river discharge</td>
<td>Water Conservation MO</td>
<td>WCMO, ICMO</td>
</tr>
</tbody>
</table>
Topographic-spatial analysis to identify potential management option sites

- 2011 and 2012 LiDAR
  - NLCD2011
    - cultivated crops
    - barren land
    - hay/pasture
    - herbaceous
  - US Fish and Wildlife Services CONUS wet polygons
  - NCED Conservation Easement polygons
  - Minimum threshold S.A. = 3000 m²

WCMOs

Potential Applicable Conservation Actions:
- Wetland Restoration
- Sediment Basin (for sediment deposition and nutrient cycling)
- Water and Sediment Control Basin
- Constructed Wetlands (not on hydric soil)
- Side inlets (short term ponding near a drainage ditch)

- On hydric soil?
  - Consider WETLAND RESTORATION
- In steeper and undulating land?
  - Consider WASCOB
- Adjacent to drainage ditch?
  - Consider SIDE INLET
- Excessive onfield erosion/nutrients?
  - Consider SEDIMENT BASIN
- Non-hydric soil (general wet area)
  - Consider CONSTRUCTED WETLAND
Spatial analysis overview

Have to determine how much of each MO can be implemented

Locations for on-field reduction in sediment erosion
Rules: Stream Power (Area*Slope)

Locations for water storage
Rules: Topographic Depression
Topographic Index (Area/Slope)

Locations for toe protection
Rules: Bluff height, slope
Hydrologic conservation simulation
- Understanding of sediment loading in the incised zone as a function of discharge
- Identification, classification, and ranking of restorable wetland sites (RWSs)
- Simulation of water conservation and consequent reduction from near-channel source loading

MOSM
- evaluate various management option portfolios (MOPs) in terms of cost of implementation and sediment reduction to support environmental decision-making.
The TopoFilter Concept – Where does sediment come from?

We now routinely have high resolution elevation information for watersheds, represented as a Digital Elevation Model (DEM)

Can we use high resolution DEMs to account for the topographic effect on sediment delivery?

Goal:
- Use USLE to account for local soil erosion rates
- Use DEM to account for the topographic effect on sediment storage
- Use the sediment load record gage data to condition the model parameters

→ Develop a map of the primary sources of eroded sediment that reaches the watershed outlet
→ Evaluate Sediment Delivery Ratio (SDR) at every field and stream raster in the watershed
1. A specific topographic relation for Sediment Delivery Ratio

\[ SDR_{fi} = f \left( \frac{dE_{fi}}{I_{fi}} \right) = \exp \left[ a_1 \left( \frac{dE_{fi}}{I_{fi}} \right)^{b_1} I_{fi} \right] \]

\[ SDR_{si} = f \left( I_{si} * B_{fpi}, \frac{dE_{si}}{I_{si}} \right) = \exp \left[ a_2 \left( \frac{dE_{si}}{I_{si}} \right)^{b_2} I_{si} * B_{fpi} \right] \]

by logic and definition:

\[ a_1 = [-0.001, 0], b_1 = [-1, 0] \]
\[ a_2 = [-0.001, 0], b_2 = [-1, 0] \]

2. Run 10,000 simulations using constant values of \( a_1, a_2, b_1, b_2 \) drawn randomly from a uniform distribution.

3. Narrow the range for each parameter \( a_1, a_2, b_1, b_2 \) by eliminating portions that never produce an adequate fit to the observed total sediment delivery. This is called ‘conditioning’.

4. The Sediment Delivery SD from 10,000 simulations, The mean (3,445 Mg) is close to the observed (3,252 Mg).

5. Do we believe that any of these 10,000 models (combinations of \( a_1, a_2, b_1, b_2 \)) are correct? **Of course not!**

*But we note that some locations just about always contribute the most sediment*

The map below shows locations that contribute to 90% of the sediment delivery in 95% (red), 75% (red + green) and 50% (red + green + blue) of the simulations. This is strong evidence that these are the locations that contribute most of the sediment actually delivered to the watershed outlet.
Understanding the incised zone sediment loading
<table>
<thead>
<tr>
<th>Rivers</th>
<th>Gauge Field Code</th>
<th>Hydra ID</th>
<th>Storet station ID (MPCA)</th>
<th>U/N/D/O</th>
<th>Drainage area (km²)</th>
<th>Incised length (km)</th>
<th>Data</th>
<th>Start date</th>
<th>End date</th>
<th>Sample type</th>
<th>Sample size</th>
<th>Source</th>
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<tbody>
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<td>Little COB</td>
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<td>U</td>
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<td>10/2/2007</td>
<td>10/15/2012</td>
<td>daily</td>
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<td>Seven Mile Creek</td>
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</table>

Note: The table includes information about rivers, their gauge field codes, hydro IDs, storet station IDs (MPCA), U/N/D/O, drainage areas, incised lengths, data types, start dates, end dates, sample types, sample sizes, and sources.
Hydrologic conservation simulation
- Understanding of sediment loading in the incised zone as a function of discharge
- Identification, classification, and ranking of restorable wetland sites (RWSs)
- Simulation of water conservation and consequent reduction from near-channel source loading
Sediment loading prediction with simulated discharge
MOSM overview

• Management Option Simulation Modem (MOSM) consists of a Management Option (MO) allocation algorithm and routing algorithms to move water and sediment through a watershed.

• The evaluation of effectiveness MOs to address sediment storage and input is a part of the sediment routing, and evaluation of effectiveness of water conservation is a part of the water routing.

• The model allows some interaction among MOs.
What makes us think that the model has any bearing on reality?

Because all the pieces have to add up. They are constrained by the sediment budget! Reasonable estimates of reductions are held within bounds.
<table>
<thead>
<tr>
<th>River</th>
<th>LeSueur</th>
<th>Cobb</th>
<th>Maple</th>
<th>LeSueur</th>
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<td>33</td>
<td>33</td>
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<td>190,046</td>
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<td>Reduced till (%)</td>
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<td>Conservation till (%)</td>
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<td>34,997</td>
<td>11,175</td>
<td>46,831</td>
<td>252,346</td>
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<td>Near-Channel Source Management Option (NCMO) ALLOCATION</td>
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</tbody>
</table>

(i) Reduce rate of soil erosion
(ii) Keep more eroded soil on fields and out of streams
(iii) Store water, reducing peak flows in streams in order to reduce bluff and bank erosion
(iv) Reduce erosion from ravines with flow control
(v) Stabilize bluffs and banks to reduce erosion and inputs
<table>
<thead>
<tr>
<th>River</th>
<th>LeSueur</th>
<th>Cobb</th>
<th>Maple</th>
<th>Ga</th>
<th>Simulation output summary</th>
<th>Tillage Management Option (TMO) ALLOCATION</th>
<th>Near-Channel Source Management Option (NCMO) ALLOCATION</th>
<th>Agricultural Field Management Option (AFMO) ALLOCATION</th>
<th>Buffer Strip Management Option (BFMO) ALLOCATION</th>
<th>Water Conservation Management Option (WCMO) ALLOCATION</th>
<th>In-Channel Management Option (ICMO) ALLOCATION</th>
<th>Ravine Management Option (RAMO) ALLOCATION</th>
<th>Near-Channel Source Management Option (NCMO) ALLOCATION</th>
</tr>
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<tbody>
<tr>
<td>Present Sediment Load at Red Jacket (Mg/yr)</td>
<td>186,235</td>
<td></td>
<td></td>
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<td>Present Sediment Load at Red Jacket (Mg/yr)</td>
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<td>Present Sediment Load at Red Jacket (Mg/yr)</td>
<td>Present Sediment Load at Red Jacket (Mg/yr)</td>
<td>Present Sediment Load at Red Jacket (Mg/yr)</td>
<td>Present Sediment Load at Red Jacket (Mg/yr)</td>
</tr>
<tr>
<td>Sediment Load w/ All MO (Mg/yr)</td>
<td>81,762</td>
<td></td>
<td></td>
<td></td>
<td>Sediment Load w/ All MO (Mg/yr)</td>
<td>Sediment Load w/ All MO (Mg/yr)</td>
<td>Sediment Load w/ All MO (Mg/yr)</td>
<td>Sediment Load w/ All MO (Mg/yr)</td>
<td>Sediment Load w/ All MO (Mg/yr)</td>
<td>Sediment Load w/ All MO (Mg/yr)</td>
<td>Sediment Load w/ All MO (Mg/yr)</td>
<td>Sediment Load w/ All MO (Mg/yr)</td>
<td>Sediment Load w/ All MO (Mg/yr)</td>
</tr>
<tr>
<td>Reduction in Sediment Load (Mg/yr)</td>
<td>104,473</td>
<td></td>
<td></td>
<td></td>
<td>Reduction in Sediment Load (Mg/yr)</td>
<td>Reduction in Sediment Load (Mg/yr)</td>
<td>Reduction in Sediment Load (Mg/yr)</td>
<td>Reduction in Sediment Load (Mg/yr)</td>
<td>Reduction in Sediment Load (Mg/yr)</td>
<td>Reduction in Sediment Load (Mg/yr)</td>
<td>Reduction in Sediment Load (Mg/yr)</td>
<td>Reduction in Sediment Load (Mg/yr)</td>
<td>Reduction in Sediment Load (Mg/yr)</td>
</tr>
</tbody>
</table>

(1) Specify extent of the MO
(2) Specify efficiency and cost of Management Options
(3) Find reduction in sediment load and annual cost
Prioritizing Sediment Reduction Strategies in a Large Watershed: Collaborative for Sediment Source Reduction

Karen Gran, University of Minnesota Duluth
Se Jong Cho and Ben Hobbs, Johns Hopkins University
Peter Wilcock and Patrick Belmont, Utah State University

3. Linking Research & Management Choices at the Watershed Scale

Peter Wilcock
First report: 19 October 2011

Strong focus on determining sediment sources, sinks, and delivery because conventional watershed models are unable to predict the largest source.

Models, models, and more models. What am I supposed to use?

What is the best way to forecast *change* in nonpoint sources from conservation actions?

Example management portfolios for reducing sediment delivery from the Blue Earth Basin
CSSR Focus:
Forecast sediment reduction from conservation actions
at the watershed scale

We do not aim to site management options at specific locations.
We do aim to reasonably capture the possible extent of different actions
leading to reduction in sediment loading from the watershed
how much of what types of management actions at what cost?
Spatially Distributed Hydrologic Models
Spatially Lumped Hydrologic Models
Formula-driven Reduced Complexity Models
Data-driven Reduced Complexity Models

GSSHA
HSPF, SWAT
PTMApp
MOSM

Find the best match between data, model, and prediction
We seek a model that
(1) Driven by abundant observations especially those that are spatially comprehensive,
(2) Is well constrained by measured rates and multiple independent sources of information
(3) Is robust, quick to run, transparent

A model should be as simple as possible (and no simpler)
There is nothing worse than a complicated _Reduced Complexity Model_

(1) NRCS Soil Maps (soil type, annual erosion rates)
(2) High resolution topography from LiDAR
(3) Water and TSS at 10+ gages
(4) Historical air photographs
(5) Field observations of erosion and deposition mechanisms
(6) Sediment fingerprinting
(7) History of watershed evolution

**Find the best match between data, model, and prediction**

**Make the observations detailed, keep the model simple**
Collaborative for Sediment Source Reduction

Greater Blue Earth River Basin

Multiple sources of information
Robust, Fast
Compare different portfolios of potential actions in real-time
Account for costs and benefits in transparent, flexible way

Management Options
- Extents
- Rates
- Costs

Processes
- Hydrologic Modeling
- Predict Erosion & Deposition Via Sediment Budget

Water & Sediment Routing

Simulation Model

Minneopa R
Blue Earth R
Collaborative for Sediment Source Reduction

Stakeholder Group
We have a budget. We know the biggest sediment sources. Let’s go!

That does not quite get us to the prioritization solution.  
*How much reduction? For how much cost? What, where, how much?*  
*Can we solve this problem? What will it cost? How can we trade off different options?*

Challenges:

(1) **Sediment Delivery.** Not all sediment supply leaves the watershed.  
In fact, it may be only a small fraction of the sediment supply.  
This *reduces* the *reduction*!  
If only 20% of the sediment introduced to the stream leaves the watershed, 
then reducing that supply by half reduces delivery by only 10%!

(2) **Near-Channel Sources.**  
Biggest sediment sources are near-channel (mostly bluffs).  
Armor the bluff toe or reduce high flows in river?  
High flow reduction – where in the watershed?  
How much will sediment supply be reduced?

(3) What is *cost* and *efficiency* of different management options?

(4) Are there *interactions?* Will doing more of one action make another less efficient?

(5) What about benefits other than sediment reduction?  
*If we want to make well informed planning and priority decisions,*  
we have to estimate: *how much* sediment reduction *at what cost?*  
There is lots of combining to do. And bookkeeping.
Challenges
(1) Sediment Delivery
(2) Near Channel Sources
(3) Management Options
(4) Interactions
Challenges
(1) Sediment Delivery
(2) Near Channel Sources
(3) Management Options
(4) Interactions

How much eroded sediment actually gets delivered to the Minnesota R?

**Sediment Delivery Ratio**: the fraction of eroded sediment delivered from the watershed

We developed a spatially distributed estimate of sediment delivery ratio
*From field to stream* and *Down the stream to the outlet*

Using
High resolution topography
USLE / Sediment Budget to scale sources
Gage observations to constrain magnitude
Stochastic approach to incorporate uncertainty
Challenges
(1) Sediment Delivery
(2) Near Channel Sources
(3) Management Options
(4) Interactions

How much will near channel sediment sources be reduced?
Challenges
(1) Sediment Delivery
(2) Near Channel Sources
(3) Management Options
(4) Interactions

How much will near channel sediment sources be reduced?
Can we capture the many, many management options into a simpler set?

**Challenges**

1. Sediment Delivery
2. Near Channel Sources
3. Management Options
4. Interactions

**Reduce soil erosion**
- Keep eroded soil out of the stream
- Reduce ravine erosion
- Reduce bluff erosion
- Toe protection
- Reduce peak river discharge
Challenges
(1) Sediment Delivery
(2) Near Channel Sources
(3) Management Options
(4) Interactions

We have to account for interactions among management options

Buffer Mapping Project

Lesueurriver.org
What makes us think that the model has any bearing on reality?

→ all the pieces have to add up. They are constrained by the sediment budget!
→ Main contributions are directly measured! Predictions are held within bounds.
For some combinations of cost and efficiency, the least cost solution is
(1) All ravines
(2) Then water conservation

Added Cost for WRAPS Soln

Increased removal for same $
For some combinations of cost and efficiency, the least cost solution is
(1) All ravines
(2) Then water conservation
Data-driven Approach to Nonpoint Source Prediction

Gage. Gage again.
Fingerprint. For sediment and nutrients!

With high-resolution DEM, can allocate delivery ratios at a fine scale. With multiple gages,
- can *measure* contributions from near-channel sources,
- can *measure* storage and uptake
this could well be a *more reliable* approach
relative to predictions from physical relations.
Influences on Lateral Erosion Rates in Three Agriculture-Dominated Minnesota Watersheds

Jen Oknich, Chris Lenhart, Gary Sands, Mikhail Titov, Ben Underhill, and Laura Triplett, University of Minnesota; Mark Ellefson, Minnesota Department of Natural Resources
Funding by

- MN Department of Agriculture
- Clean Water Land & Legacy Amendment
- National Science Foundation

MDA priority setting in watershed restoration
Final report

September 2015
Project Investigator: Chris Lenhart
Co-P.I John Nieber

Project Administration:
Heidi Peterson, Minnesota Department of Agriculture (MDA)

Funding provided from the Clean Water Fund as part of the Clean Water, Land and Legacy Amendment
Understanding Increases In Erosion Rates

- Widespread increases in stream flow across the agricultural regions of Minnesota and the Midwestern U.S contributing to increased rates of stream bank erosion.

- Increased subsurface drainage flow, land-use change and increased precipitation are thought to contribute.

- This study focuses on understanding the hydrologic drivers and processes involved in the increased rates of bank erosion observed in recent decades in many Midwestern streams.

---


MDA Project Goals

• Hydrologic drivers of stream bank erosion

• Mechanics of bank collapse

• TMDL load allocation:
  ✓ Empirical tools to predict sediment, phosphorus from channels
  ✓ Tools focus on channel corridor vs watershed
Methods

- **Natural background rates – lateral migration**
- Field assessment of stream bank erosion rates, processes
- Field assessment of deposition rates
- Decision tool that addresses practicality, logistical issues
- Development of region-specific bank erosion prediction graphs


Methods: Hydrology Field Assessments

Geochemical assessment of sources
- Oxygen and Hydrogen Isotopes $H_2$ or Deuterium (D) and $\delta^{18}O$ (& specific conductivity (SC)) collected from groundwater, subsurface drain tile flow, surface runoff and rainfall
- Plotted isotopic data on Global Meteoric Water Line (GMWL)

Hydrograph separation
- Used geochemistry and stream flow data, separated into base flow, subsurface tile flow and surface runoff
- Used End Member Mixing Analysis with SC as a conservative tracer

Riparian zone hydrology
- Wells in riparian zone, water level-loggers and conductivity probes
- Identification of groundwater input zones and seepage gradients

Watershed hydrology modeling with SWAT
- Developed for Elm Creek to obtain estimates of ground water, surface runoff and sub-surface tile drainage flow

Methods: Stream Erosion

Temporal distribution of bank erosion events
• Monitoring bank erosion events with DNR

Processes of stream bank collapse
• Resurvey of bank monitoring sites and field observations
• Characterization of bank collapse processes and the role of fluvial erosion vs. mass-wasting

The spatial distribution of lateral migration rates across river corridor
• Ellefson GIS lateral migration tool
Buffalo River
• 768,000 acres
• Clay, Becker, Otter Tail and Wilkin co
• Into Red R, L Winnipeg, Nelson R, Hudson Bay

Elm Creek
• 173,000 acres
• Martin and Jackson co
• Into Blue Earth R, Minnesota R, Mississippi R

Whitewater River
• 205,000 acres
• Olmstead, Winona, Wabasha co
• Into Mississippi R
Watersheds: Elm Creek

- 86% corn and soybeans\textsuperscript{1, 2, 3}
- Alluvial silt and clay loams\textsuperscript{3, 4}
- Prairie pothole region
- 3-4 tons per hectare per year eroded\textsuperscript{3}
- One of highest sediment to Blue Earth R, which is largest to Minnesota R\textsuperscript{3, 5}
- Impaired for fish, turbidity, \textit{E. coli}, DO\textsuperscript{6}

\textsuperscript{2} “Turbidity Total Maximum Daily Load Study: Greater Blue Earth River Basin.” Minnesota State University Mankato, Water Resources Center.
\textsuperscript{5} Lenhart, CF, ES Verry, KN Brooks and JA Magner. “Adjustment of prairie pothole streams to land-use, drainage and climate changes and consequences for turbidity impairment.” River Research and Applications (2011) 27: 1609-1619.
\textsuperscript{6} MPCA 2012 EPA TMDL list

https://gisdata.mn.gov/dataset/env-watershed-health-assessment
Watersheds: Buffalo River

- 78% agriculture, 7% forested, 5% urban, 4% grassland, 3% open water, 3% wetland\(^1\)
- Gravel to silt and clay
- Glacial moraines, beach ridge, Lake Agassiz\(^2\)
- Altered hydrology “single most important factor stressing the stream biology”\(^1\)
- Impaired for *E. coli*, aquatic macroinvertebrate, fish, turbidity, and DO\(^2\)

---

https://gisdata.mn.gov/dataset/env-watershed-health-assessment
Watersheds: Whitewater River

- 66% agriculture (58% crops, 8% pasture), 14% wetland and wildlife management area, 13% woodland, 7% other\(^1\)
- Silt loams
- Rolling hills, limestone bluffs/ravines, slough
- In 1920s, 15 feet of soil onto lower farms\(^2\)
- Impaired for turbidity and nitrates

BACKGROUND ON LATERAL EROSION MEASUREMENT METHODS

• FIELD METHODS
  • RE-SURVEY OF CROSS SECTION OR BANK
  • BANK EROSION HAZARD INDEX (BEHI) MEASURED IN FIELD

• AERIAL PHOTO ASSESSMENT
  • CAN MEASURE LATERAL MIGRATION IN MANY STREAMS
  • CAN OBSERVE CHANGE IN WIDTH WHICH IS AN INDICATOR OF DISEQUILIBRIUM

• EMPIRICAL PREDICTION TOOLS
  • BEHI – BANCS
  • OTHERS (?)

• MODELING OF BANK EROSION
  • BSTEM
  • CONCEPTS
  • NEW HEC-RAS / BSTEM LINKAGE
Lateral Erosion: GIS Tools

- Mark Ellefson (DNR)
  - Elm
  - Buffalo
  - Whitewater
- Mikhail Titov (UMN)
  - Buffalo
- Wes Lauer (UMN)
  - Upper Elm

Lateral Erosion: Typical GIS Steps

- Identify variables
- Find orthorectified historical photos
- Digitize centerlines
- Buffer (optional)
- Break by reach
- Run tool
- Populate attribute table
Ellefson Tool

Titov Tool

Lateral Erosion: Elm Creek Results

1991 to 2010

Lateral Erosion: Buffalo River Results

Titov’s Tool

Ellefson’s Tool

1991 to 2010

Titov, M. Average Annual Lateral Bank Erosion Rates. 2015.

Lateral Erosion: Whitewater River Results

1991 to 2011 on hydro breaks

2003 to 2013 on veg breaks

Ellefson, M.  Average Annual Lateral Bank Erosion Rates for the Whitewater River.  Minnesota Department of Natural Resources. 2014.

Erosion Tool Comparison

Difficult to find correlation between erosion and BEHI scores
Regional Bank Erosion Prediction

Using estimates of erodibility (BEHI) and near bank stress, rates of erosion in south-central Minnesota can be predicted for streams similar to Elm Creek.
Erosion Rates Compared To

- Vegetation cover
- NWI
- Eroded area
- Distance along stream
- High bank, low bank and water surface elevations, heights and slopes
- Sinuosity
- Reach length
- Near bank stress (radius of curvature, bankfull)

Whitewater State Park photo courtesy of McGhiever. Licensed under CC BY-SA 3.0 via Commons.
Does vegetation matter?

Vegetation little effect on migration

- Discharge x slope = 48% migration

OR

"Vegetation by itself can cause major changes in channel form and flow dynamics in a braided system"

- Holding discharge and slope constant

Previous Work on Trees v. Grasses

- TREES GOOD
  - BIGGER ROOTS

- TREES BAD
  - FALL IN STREAM

- GRASSES GOOD
  - DENSITY

- GRASSES BAD
  - WEAKER ROOTS

### TABLE 2. Some Significant References to the Influence of Fluvial Processes on Vegetation Dynamics

<table>
<thead>
<tr>
<th>Physical Process</th>
<th>Spatial / Temporal Scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seed dispersal</td>
<td>3 river reaches / 4 years</td>
</tr>
<tr>
<td>Seeds/seed rate</td>
<td>cross section / 2 years</td>
</tr>
<tr>
<td>Seed input</td>
<td>river reach</td>
</tr>
<tr>
<td>Characteristics of riparian plants</td>
<td>river reach / 2 years</td>
</tr>
<tr>
<td>Development of species richness</td>
<td>river reach / 2 years</td>
</tr>
<tr>
<td>Influence of sedimentation and flooding</td>
<td>river reach / 2 years</td>
</tr>
<tr>
<td>Influence of water levels on mortality and root depth</td>
<td>river reach / 2 years</td>
</tr>
<tr>
<td>Root volume ratio and diameter</td>
<td>river reach / 2 years</td>
</tr>
<tr>
<td>Root biomass spatial distribution</td>
<td>5 cross sections / 1 year</td>
</tr>
<tr>
<td>Effect of flooding</td>
<td>river reach / 1 year</td>
</tr>
<tr>
<td>Colonization of sites</td>
<td>river reach / 52 years</td>
</tr>
<tr>
<td>Influence of river flow</td>
<td>25-50 km / 80 years</td>
</tr>
<tr>
<td>Seedings density and influence of shade, position, competition</td>
<td>3 river reaches / 4 years</td>
</tr>
<tr>
<td>Influence of soil texture, elevation, light</td>
<td>river reach / 4 years</td>
</tr>
<tr>
<td>Influence of river discharge</td>
<td>river transect</td>
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<tr>
<td>Influence of river flow</td>
<td>river reach</td>
</tr>
<tr>
<td>Influence of river flow and stage</td>
<td>river reach / 1 year</td>
</tr>
<tr>
<td>Influence of flow and elevation on seedling distribution</td>
<td>river reach / 52 years</td>
</tr>
<tr>
<td>Decays selection by flood</td>
<td>9 cross sections / 100 years</td>
</tr>
<tr>
<td>Growth of riparian plants</td>
<td>9 cross sections / 100 years</td>
</tr>
<tr>
<td>Growth rate, maximum age, and diameter</td>
<td>-</td>
</tr>
<tr>
<td>Growth rate, shade tolerance, and diameter</td>
<td>-</td>
</tr>
<tr>
<td>Growth rate, maximum age, diameter, etc.</td>
<td>-</td>
</tr>
<tr>
<td>Relationship between tree age and dbh</td>
<td>9 cross sections / 100 years</td>
</tr>
<tr>
<td>Ecological succession and biogeography</td>
<td>9 cross sections / 100 years</td>
</tr>
<tr>
<td>Tree cover density and species richness</td>
<td>9 cross sections / 100 years</td>
</tr>
<tr>
<td>Tree distribution</td>
<td>17 cross sections</td>
</tr>
<tr>
<td>Tree density</td>
<td>25-50 km / 80 years</td>
</tr>
<tr>
<td>Vegetation structure</td>
<td>17 cross sections</td>
</tr>
<tr>
<td>Transition of tree species</td>
<td>17 cross sections</td>
</tr>
<tr>
<td>Mass of vegetation</td>
<td>17 cross sections</td>
</tr>
<tr>
<td>Vegetation patterns, species distribution, and tree density</td>
<td>17 cross sections</td>
</tr>
<tr>
<td>Vegetation patterns</td>
<td>17 cross sections</td>
</tr>
<tr>
<td>Relationship between riparian species and stream power</td>
<td>17 cross sections</td>
</tr>
</tbody>
</table>

Effect of vegetation depends on location
• Small watersheds: erosion
• Medium watersheds: stream power
• Large watersheds: mass failure
Why: Roots Play an Important Role in Streambank Stability

- Mechanical Reinforcement
- Dewatering
- Protect from freeze-thaw cycle damage
- Highly variable spatially and seasonally
- Particularly important in highly erodible alluvial soils where bank height exceeds root depth (> 2 ft high)

Differences in Stream and Root Length Density in top 30 cm of soil
Implications for Management: Vegetation

- About 85% root depth in top 30 cm (or less if smaller core increments used)
- Reed canary grass dominance may reduce vegetation benefit both ecologically and functionally
- In certain settings (moderately high banks with erodible soils and short root depth) increased plant growth can help reduce sediment loading
- These conditions are common in Minnesota

Highest Erosion Rate

Oknich study correlated

• Near bank stress, radius of curvature
  ➢ Positive correlation in Elm and Whitewater
  ➢ Negative correlation in Buffalo

• Stream mile
  ➢ Positive correlation in Elm
  ➢ Negative correlation in Whitewater

Underhill study correlated

• Bank height
• Root density


Pointbar Sediment Deposition: Elm Creek

- Assessed balance between deposition and erosion with turf mat squares
- Patterns of vegetation establishment (species, age, location)
- Timing, magnitude, duration of base and peak flow
- Particle size, sediment deposition rate

Reduction of riparian vegetation establishment from:
  - Mod to high flows submerged sand bars all summer

Which may:
  - Reduce deposition and therefore
  - Promote widening and sediment loading

Implications for Management: Hydrology

Largest stream flow events when:
- Rain falls on saturated soils (mostly spring)
- Subsurface flow and rainfall near maximum (May to June)

Sub-surface tile flow drainage contributes to greater frequency of bank erosion-causing events, particularly in the spring
- Flow in Des Moines Till plain dominated by subsurface drain
- Tile less important elsewhere in Minnesota

Fall increasingly large flood events, more climatically-driven

Implications for Management: Hydrology

Separating Flow Sources
- SC useful when inverse relationship with flow
- Salt or pollutants can raise SC in runoff
- O & H isotopes identify water that has undergone evaporation

Bank Collapse
- Driven by fluvial erosion with subsequent mass-wasting
- Groundwater seepage plays a minor role

Erosion Rates
- Maximum in the Whitewater River where high stream power coincided with high, erodible stream banks

Further Reading


Thank You
Sediment Load Reduction Treatments in MN River Valley Streams

Marty Melchior, Inter-Fluve
Ryan Holzer, Scott County
Paul Nelson, Scott County
Overview

- Problem
  - MN River Valley streams
  - The Sand Creek example
- Assessment
- Strategies
- Solutions
- Monitoring
Problem

- MN River Valley Streams
  - Sediment source areas
  - Bluffs, ravines, bank erosion
- Sand Creek
  - Listed as impaired for sediment
  - County had traditionally targeted streambanks for stabilization as requested by landowners
Assessment

- Fluvial geomorphic assessment (2008)
  - Sand Creek mainstem
  - Raven Stream, Porter & Picha Creeks, ditches
  - Included a watershed wide reconnaissance of all streams, tributaries and ditches
  - Examined channel stability
  - Identified potential projects
Assessment

- Geomorphic assessment included project identification
  - Over 200 potential projects identified, including:
    - Natural channel restoration/reclamation
    - Floodplain management
    - Riparian vegetation management
    - Bank stabilization
    - Grade control

Transitional zones, where the channels are steepest, had the most potential for sediment inputs and showed the most bluff and ravine erosion
### Project Priority Matrix

- Rank projects by either one, several or all metrics
- Separates projects also by type

---

**Appendix I: Potential projects on the mainstem of Sand Creek.** Project type codes: B = bank stabilization; G = grade control; C = culvert or other crossing; N = natural channel restoration/relocation; F = floodplain management; I = infrastructure; R = riparian management.

<table>
<thead>
<tr>
<th>Project Number</th>
<th>Station Number</th>
<th>Project Type</th>
<th>Inf. Risk</th>
<th>Channel Stability</th>
<th>Project Complexity</th>
<th>Location</th>
<th>Sed/Nutrient Loading</th>
<th>Cost</th>
<th>Aesthetic Impact</th>
<th>Fish Passage</th>
<th>Public Education</th>
<th>Instream Ecological</th>
<th>Riparian Ecological</th>
<th>Total Score</th>
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<tbody>
<tr>
<td>PP01</td>
<td>9100</td>
<td>I</td>
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<td>5</td>
<td>3</td>
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<td>7</td>
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<td>35200-35500</td>
<td>R</td>
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<td>3</td>
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<td>35</td>
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</tbody>
</table>
Assessment

- **Sand Creek Impaired Waters Diagnostic Study (2010)**
  - Hydrologically resilient landuse has declined significantly (e.g. forest and wetlands)
  - Significant alteration of wetlands and streams
  - Upstream habitat is poor, improving in middle reaches, poor in downstream reaches
  - Greatest TSS loading is during high flows
  - Echoed geomorphic assessment and past erosion assessments pointing to transitional zone as the greatest contributor to TSS loading
Strategies

**MN River Valley Ravine Stabilization Charrettes (2010)**

- Scott WMO and MN River Board
- Brought together concerned watershed managers and technical staff to assess current practice and explore strategies

**Outcomes:**
- A two pronged, concurrent approach involving hydrology and hydraulics
- Start at the headwaters and work downstream
- Reduce rate and volume of runoff
- Control grade in ravines
- Target highest loading bluffs based on cost vs. benefit
Implementation

- **Hydrologic modification**
  - Example: Water and Sediment Control Basins
  - In-gully detention (e.g. Blakely Ravines)
  - Headwater wetlands
  - Riparian buffer establishment

![Typical WASCOB X-Section](image)
Scott WMO & All Other Programs
- 844 Projects Total
- 498 Project since 2006

Practices
- WASCOBs, Rock Inlets, Animal Waste, Grade Stabilization Structures, Well Decommissions, Bioretention - 321
- Waterways, Diversion, Terraces, etc - 142
- Filters, Field Borders, Riparian Forest Buffers - 1075 acres
- Nutrient Management
- Native Grasses/Conservation Cover

Implementation – Hydrologic/WQ
Picha Creek

- Historically a small stream, channelized in 1930s
- Incised up to 8 feet, actively widening
- Grade controlled at upstream driveway crossing
- Planform restoration limited by adjacent agriculture/nursery land use
Picha Creek stabilization

- **Pre-Construction**
Picha Creek stabilization

Construction sequence

- Dewater
- Rough cut channel
- Install bed material, bed morphology
- Fine grade channel
- Install bank protection, plantings
- Fine grade, revegetate upper
- Post construction (6 months)
Picha Creek

- 4 yrs post construction
  - Several above bankfull events
  - 2 x 100yr events
  - Cottonwood recruitment
- Artificial geologic control for bank and tree stabilization
Implementation – bluff stabilization

- Porter Creek
  - 3 bluffs and one bank
  - Preferred option:
    - Stabilize the toe
    - No upper slope grading
    - Passive revegetation of upper slope
Bluff erosion occurs when the stream abuts an older terrace wall or valley wall.
Toe stabilization

Typical Section: Cribwall toe stabilization

EXISTING BANK

SLOPE BACK BANK

NO GRADING NATIVE PLANTINGS

VERTICAL SNAG

PROPOSED GRADE

GENERAL SALVAGED FILL

ROOTWAD PUSH BACK INTO BANK EXCAVATION

Sta.=0+05.98
Elev.=147.901

Sta.=0+43.16
Elev.=123.138

Sta.=0+83.52
Elev.=100.000

Sta.=0+96.22
Elev.=99.603
Porter Creek bluffs

- Analogs – healed over rotational slumps, black willow stabilized segments
- Engineered large wood, floodplain bench
2 years post construction

- Minor slumping
- Vegetation moving upslope
- Large wood rooting
2 years post construction

- Minor slumping
- Vegetation moving upslope
- Large wood rooting
Solutions

- Near-channel Stabilization Feasibility Study (2015)
  - Quantitatively (terrain analysis, aerial photos and ground truthing) examined sediment losses from bluffs, ravines and banks identified in the geomorphic assessment
  - Modified prioritization matrices were developed
  - Priority sites chosen for concept design
  - Select sites chosen for final design and implementation
Solutions

- **Near-channel Stabilization Design – Phase 1**
  - 2 bluff sites, one ravine site
  - Engineered log jams
  - Ravine stabilization (steep channel stone)
  - Phase 1 - Final design Summer 2016
  - Phase 1 - Construction starting Nov 2016
Monitoring

- Contractor warranty for planted materials
- Met Council and Scott County have been monitoring TSS levels since 1989 and will continue
- Scott County will be implementing a maintenance and monitoring plan
Thank you

mmelchior@interfluve.com
608-354-8260
Discharge-TSS Relations Yield Useful Information Regarding Controls on Fine Sediment Production and Transport in Rivers Throughout Minnesota

Angus Vaughan, Patrick Belmont, Peter Wilcock, Chuck Hawkins

MN Water Resources Conference October 19, 2016
Talk Outline

• Background on suspended sediment
• Research Questions
• Methods
• Results
• Key Findings and Implications
Why Care About Suspended Sediment?

A natural component of rivers, but...

How and at what discharges is fine sediment transported?

Is sediment coming from upland or near-channel sources?

- Nutrients and contaminants transported with suspended sediment

Empirical Sediment Rating Curves

- TSS is a non-capacity load
  - Transport = f(capacity & supply)
  - Empirical relations between Q and TSS

- Represent upstream combined effects of erosion, transport and deposition across the range of flows

\[ [TSS] = aQ^b \]
Talk Outline

• Background: suspended sediment and landscape characteristics
• Research Questions
• Methods
• Results
• Key Findings and Implications
Research Questions

• Which landscape or channel characteristics influence the form of Q-TSS relations?
Research Questions

• Which landscape or channel characteristics influence the form of Q-TSS relations?
  – Do Q-TSS relations offer insight into sediment sources and geomorphic processes within a watershed and river system?
Research Questions

• Which landscape or channel characteristics influence the form of Q-TSS relations?
  – Do Q-TSS relations offer insight into sediment sources and geomorphic processes within a watershed and river system?

• Can we develop a better predictive understanding of Q-TSS relations to support decisions related to water quality regulations, water and land management, and restoration practices?
Talk Outline

• Background: suspended sediment and landscape characteristics
• Research Questions
• Methods
  – Q and TSS data
  – Landscape and Environmental Data
  – Statistical Modeling (Random Forest)
• Results
• Implications
Q and TSS Data

- Recent (since 2000) data from 45 gages (36 Rivers) throughout MN
  - DNR/MPCA Cooperative Stream Gaging
  - Watersheds 32 km² – 15,000 km²
Random Forest Models

Predict gage-to-gage variation in rating curve shape using landscape and environmental variables

[TSS] = \(aQ^b\)
Describing/Quantifying Rating Curves

Le Sueur River near Rapidan, MN 66

Chippewa River nr Cyrus, 140th St

Hawk Creek nr Granite Falls, CR52
Describing/Quantifying Rating Curves

- **Power Functions**
  - \([TSS] = aQ^b\)
  - Normalize Q
  - Hysteresis: Separate by rising/falling limb
  - Split data at breakpoint using spline interpolation procedure (Dierckx, 1975)
Landscape and Near-channel Predictor Variables

**Soils**
- SSURGO
- Watershed average soil erodibility
- Near-channel soil erodibility

**Land Use**
- NLCD
- Agriculture percent cover
- Wetlands percent cover
- Forest percent cover
- Lake percent cover
- Lake and wetland area along channel network

**Geology**
- Soller (2009)
- Olson (2012)
- Watershed average rock strength (UCS)
- Surficial geology classification

**3m Lidar Topography**
- PRISM
- NOAA
- Total relief
- Mean elevation
- Mean topographic slope
- Basin area
- Hypsometric integral
- Near-channel local relief and topographic slope
- Stream gradient
- Stream power

**Climate**
- Annual Precip 1000 mm 500 mm
- Avg and extreme temperatures
- Avg precipitation
- Precipitation intensity
- Baseflow index
RF Model Response Variables

- General shape of relation (Classification)

- Exponent of rising + falling limbs combined (Regression)

- Coefficient of rising + falling limbs combined (Regression)

- TSS value at 90% Exceedance Q (Regression)
Random Forest Modeling

• Highly accurate classifier
• Also used for regression of numerical variables
• No distributional assumptions
• Handles complex, non-linear interactions among variables, making no assumptions about the form of the relations between predictor and response variables
Variable Importance

- Scramble values for each observation within each predictor variable
- Important variables decrease model accuracy when scrambled

```
Variable Importance, all Variables Considered

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<th>Score</th>
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<td>ChanKfactRF10km</td>
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</tbody>
</table>
```

![Variable Importance Chart](image)

- Topographic Slope
- Stream Gradient
- Channel Waterbody Area
- Stream Gradient
- Mean Annual Temperature
Talk Outline

• Background: suspended sediment and landscape characteristics
• Research Questions
• Methods
• **Results**
• Key Findings and Implications
Classification, Q-TSS Shape

Le Sueur River near Rapidan, MN 66
Power Function

Chippewa River nr Cyrus, 140th St
Peaked

Hawk Creek nr Granite Falls, CR52
Threshold
Variable Importance

- Percent correctly classified ~ 78%
Regression, Combined Exponent

Le Sueur River near Rapidan, MN 66

Rising Limb: TSS = 186.8*(Q/Qgm)^0.7
Falling Limb: TSS = 78.7*(Q/Qgm)^0.6
Combined: TSS = 114.2*(Q/Qgm)^0.7

[TSS] = aQ^b
Regression, Combined *Exponent*

- Variance explained = 60%

*Variable Importance*

- Stream Gradient
- Channel Waterbody Area
- Relief
- Mean Annual Precipitation
- WS Avg Rock-free K factor

- near-channel metrics strongly influence rate of increase of Q-TSS relations
Regression, Combined Coefficient

\[ [\text{TSS}] = aQ^b \]
Regression, Combined *Coefficient*

- Variance explained = 37%

\[ \text{TSS} = aQ^b \]
Regression, [TSS] at 90% Exceedance Q
Regression, [TSS] at 90% Exceedance Q

- Variance explained = 45%

Land use strongly influences water quality during low flow conditions.
Talk Outline

• Background on suspended sediment
• Research Questions
• Methods
• Results
• **Key Findings and Implications**
Key Findings 1

- Near-channel morphology explains most variation in shape and exponent (steepness) of Q-TSS relations
  - Bluffs, terraces, banks dominate sediment at high Q
  - Steep channels transport more sediment at high Q
  - Lakes along channel network are important sediment sinks, reduce TSS at high Q
Key Findings 2

• Land use explains most variation in vertical offset (i.e., TSS values at low and moderate Q)
  – Land use absent from exponent models
  – may influence TSS at high Q, but not dominant

• Lithology, Soil, Climate, less important
  – (Data issues?)
Management Implications

• Need to focus on near-channel sediment sources and water storage and in certain systems in addition soil conservation measures to reduce TSS concentrations at high Q

• Can this new knowledge be used to improve maps defining regulatory zones?

• Is 10% exceedance criterion best way to manage TMDL, given vastly different Q-TSS shapes?
Acknowledgements

**Funding:**
- REACH
- NSF
- Clean Water Land & Legacy Amendment

**Data:**
- Minnesota Pollution Control Agency
- USGS
- MNDNR
- Metropolitan Council
Questions?
Correlation and Causation

**Golden Gopher Football**

\[ Y = 0.4x - 760 \quad R^2 = 0.36 \]

- Losing %
- 1900 1920 1940 1960 1980 2000

**Fig. 3**

DID AVAS CAUSE THE U.S. HOUSING BUBBLE?

- 1991
- 2009
- Housing price index
- 100
- 193.74
- 15,826
- 281 Avas
- Babies named "Ava"

Vali Chandrasekaran of BusinessWeek

**Fig. 6**

IS THIS MOUNTAIN RANGE AFFECTING THE MURDER RATE?

- 1965
- 2010
- Murders in New York State
- 836
- 866

Sources:
- U.S. NHTSA, DOT HS 810 780
- U.S. Department of Agriculture

Total US Highway Fatality Rate

- 1996
- 1997
- 1998
- 1999
- 2000

- \( R^2 = 0.97 \)

- 15.8
- 15.6
- 15.4
- 15.2
- 15
- 14.8

Fresh Lemons Imported to USA from Mexico (Metric Tons)
Previous Q-TSS Studies

• Syvitski et al. (2000), Global:
  – Rating parameters = f(basin relief, mean annual discharge, long-term sediment yield, latitude, mean annual temperature)
  – Multiple linear regression: $R^2$ 0.51 – 0.70

• Mimikou (1982), Greece:
  – Rating parameters = f(basin relief, watershed area, mean annual precipitation, main channel length, average channel slope)
  – Multiple linear regression: $R^2$ 0.45 – 0.88

Mostly watershed-average metrics
Why near channel morphology might be more predictive than uplands

Near-channel sources (bluffs, banks, terraces) dominate fine sediment supply in tributaries of MRB and Lower Mississippi River

(Belmont et al., 2011)

Root River Watershed, Entire Dataset

Near-channel sources dominate current suspended sediment loads

(Belmont et al., 2016; Stout et al., 2014)
Why Care About Suspended Sediment?

- Suspended load dominant fraction of total load
  - ~ 90% worldwide (Milliman and Meade (1983))

Turowski et al, 2010
Why Care About Suspended Sediment?

- Erosion, transport, deposition impact form and function of rivers
  - Vertical accretion, sediment storage on floodplains
  - Channel narrowing by accretion on channel bars and inset floodplains
  - Channel widening and deepening if transport capacity > sediment supply

Floodplain deposition, Le Sueur River, MN
Watershed Morphology: Does topography explain erosion rates?

Montgomery and Brandon, 2002
Thermochronometry data (long-term, millions of years), Olympic Mountains

Ahnert, 1970
Sediment load data (short-term, years-decades), global mid-latitude basins

Looks good, but...
Watershed Morphology ≠ long-term erosion rates

Radiogenic nuclide data (1000s - 10,000s years) von Blankenburg, 2005

...rates of landscape uplift (or base level fall) actually control long term erosion rates
Watershed Climate ≠ long-term erosion rates

...simple climate metrics don’t translate into long term erosion rates

von Blankenburg, 2005
Regional Trends
Near Channel Relief/Topographic Slope

- Divided network into 500 m long reaches
- Mean relief/slope value within 100 m buffer
- Measured distance upstream from gage to each stream segment
Stream Power

\[ \Omega = \rho g Q S \]

Slope calculated from NHDPlus DEM at 30 m intervals and averaged over 3 km segments.
Unit Stream Power

\[ \Omega = \rho \ g \ Q \ S \]

\[ b = \alpha \ Q^{0.7} \]

\[ \omega = \rho \ g \ Q^{0.3} \ S \]

Hydraulic Geometry
Near Channel Waterbody Area

Area = Overlap between waterbody and 100 m stream buffer
Decay function to weight near channel measurements

- \( M_0 \) = raw measurement
- \( d \) = distance upstream from gage
- \( \lambda \) chosen so function decays to 0 at 10 km and 50 km

Distance-weighted values for all near-channel metrics summed to compute a composite metric
RF: an extension of CART

CART $\rightarrow$ RF:

- Lots of trees (500), average across them
- Each tree trained on bootstrapped sample, predictions onto “out-of-bag” observations
  - Cross-validated predictions (sort of)
RF: an extension of CART

All Data

Topographic Slope, 10 km

Power 16/0/3

> 2.4

Stream Gradient, 10 km

Power 4/0/0

< 2.4

Supply Limited 1/7/0

Threshold 1/3/9
RF Classification Results

<table>
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<th>Supply Limited</th>
<th>Threshold</th>
<th>% Correctly Classified</th>
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<tr>
<td>Supply Limited</td>
<td>1</td>
<td>8</td>
<td>1</td>
<td>80 %</td>
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<tr>
<td>Threshold</td>
<td>5</td>
<td>0</td>
<td>7</td>
<td>58 %</td>
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</table>

• Percent correctly classified ~ 78%
Geomorphic/Modeling Implications

• Our results likely not applicable to every geomorphic setting
  – Use metrics that specifically quantify key aspects of environment controlling sediment dynamics
  – Lidar enhances our ability to do this

• Models only explain 40-65% of variance. What are we missing?
  – Grain size distributions in sediment source and sink areas
  – Bank and soil cohesion
  – Vegetation type and density along the channel
Regression, Combined Exponent

Partial Dependence on Stream Gradient, 10 km

\[ [\text{TSS}] = aQ^b \]
Regression, Combined Exponent

\[ \text{TSS} = aQ^b \]
Regression, Combined Exponent

Partial Dependence on Channel Waterbody Area, 50 km

[TSS] = aQ^b
Regression, Combined Coefficient

\[ [TSS] = aQ^b \]
Regression, Combined Coefficient

\[ TSS = aQ^b \]
Regression, Combined Coefficient

\[ [TSS] = aQ^b \]
Regression, Combined Coefficient

\[ \text{TSS} = aQ^b \]
Regression, Combined Coefficient

\[ [TSS] = aQ^b \]
Regression, Combined Coefficient

\[ [TSS] = aQ^b \]
Regression, Hysteresis

Hysteresis = $\frac{A}{d}$

Red: Rising Limb  
Blue: Falling Limb

$log(TSS) (mg/L)$

$log(Q/Qgm)$
Regression, Hysteresis

Variable Importance

Local Relief, 10 km
Mean Annual Precipitation
Percent Wetland

- Variance explained = 43%
Partial Dependence on Local Relief, 10 km

SRC Hysteresis

0.15  0.25  0.35

Local Relief, 10 km
Partial Dependence on Mean Annual Precipitation

SRC Hysteresis

Mean Annual Precipitation (mm)
Partial Dependence on Percent Wetland
Daily Q vs Instantaneous Q Percent Difference

The graph shows the percent difference in exponent against the drainage area (km^2) for various locations. The data points are labeled as follows:
- Sand Creek
- MF Whitewater
- SF Whitewater
- Vermillion River at Farmington, Ash St.
- Kandiyohi CD27 nr Sunberg
- Snake River
Daily Q vs Instantaneous Q
Absolute Difference
Historical Landslide Inventory for the Twin Cities Metropolitan Area

Carrie Jennings, Mary Presnail, Suzanne Jiwani, Ethan Kurak, Jessica Palazzolo, Foshua Feinberg, Rachel Meier, Craig Schmidt and Eric Waage
Sediment to streams from different sources

Source: MPCA
Landslide-prone areas
Pilot Project
U of M, DNR, FEMA, NWS
Hennepin County Emergency Management

• Historical Records
• Mapped
• Interpreted
• Compared to precipitation
HENNEPIN COUNTY

Significant landslide activity in 2014
Neighboring counties also had landslides
Fatal landslide in 2013 (Ramsey County)
Critical infrastructure threatened in 2014
Single-most expensive event in FEMA DR-4182

Severe Storms, Straight-Line Winds, Flooding, Landslides and Mudslides (11 June 2014 – 11 July 2014)
37 Counties
3 tribal reservations
HISTORICAL RECORDS

9 May 1894 Stillwater, MN
See of Common People

Democracy of Minnesota Calls on the Generous, Loyal and Patriotic People of the State to Aid It

Campaign of Education in Which the Common People Are to Be the Beneficiaries Through a Lower Tax.

Republican Party Has All the Rich Men and the Railroads, All the Corporations and the Monopolies.

on the Common People of the State to Raise a Fund to Pay Railroad Fares and Expenses of Speakers.


History of Democracy's Struggle for the Right Must Be Told at Every Crossroad and Haunted in Minnesota.

A Shot at Canada

President Harrison Issues Proclamation to Enforce Retaliation.

Free Passage of the "Soo" Canal Ordered to Cease September 1.

Two Dollars Per Ton to Be Levied on Every Kind of Freight.

And Five Dollars Per Head on Passengers—Resume of the Incident.

WASHINGTON, Aug. 30.—The great flood of yesterday issued a new warning against the secrets of Canada and the United States against the United States and Canada, and for other purposes.

WASHINGTON, Aug. 30.—The event occurring on the scene of the gristmill at 6:15 A.M., and in its entirety, was the department of the Secretary of State and the Secretary of War.

WASHINGTON, Aug. 30.—The Secretary of the Interior, in charge of the British legation, was called on the occasion of the opening of the British House in London, for a statement of the facts relating to the recent military operations in the province of British Columbia.

WASHINGTON, Aug. 30.—The Secretary of the Interior, in charge of the British legation, was called on the occasion of the opening of the British House in London, for a statement of the facts relating to the recent military operations in the province of British Columbia.

The Globe Bulletin


Crisis Hangs Fire.

The Buffalo Situation a Volcano That May Be Leased in Short Order.

Reports That Firemen Are Determined to Uphold the Holdout.

Grand Master Sweeney's Campaign Is Developing.

It Is Alleged to Contemplate a Series of Successful Strikes.

BUFFALO, Aug. 30.—There were no more startling of events as the fate of the strike workers here than the release which provokes to this of the strike workers here. A fire is imminent in which the workers are undeniably involved. They have it themselves, and we are told that something will yet happen. Their trials are in this business, and the building company is not a small one.

It is asserted on what appears to be a ground that it is only to be the added to the strike workers' strike before many unions.

A strike will be a strike of sympathy, but the firemen can be undeniably involved. They have given in, and we are told that something will yet happen. Their trials are in this business, and the building company is not a small one.

A strike will be a strike of sympathy, but the firemen can be undeniably involved. They have given in, and we are told that something will yet happen. Their trials are in this business, and the building company is not a small one.

A strike will be a strike of sympathy, but the firemen can be undeniably involved. They have given in, and we are told that something will yet happen. Their trials are in this business, and the building company is not a small one.

A strike will be a strike of sympathy, but the firemen can be undeniably involved. They have given in, and we are told that something will yet happen. Their trials are in this business, and the building company is not a small one.

A strike will be a strike of sympathy, but the firemen can be undeniably involved. They have given in, and we are told that something will yet happen. Their trials are in this business, and the building company is not a small one.
MNDOT negative of a 1975 landslide sight along HW 13

1987 landslide due to broken pipe
Current Landslide Inventory

Distribution
Pre-failure slopes extracted at failure site

If LiDAR was taken post-failure, nearby slope recorded

Difficult for very old failure sites
Range of Slopes

Frequency

-70 -60 -50 -40 -30 -20 -10 0 More

Frequency
30% slopes
MPCA-funded
Purgatory Creek, Hennepin County, early June, 2014
Glacial sand on a high terrace being incised by tributary ravine to Purgatory Creek
Outer bend of meandering stream

- Undercutting of toe slope during high water events
- Residential storm water
LiDAR hillshade of Purgatory Creek
Stephanie Day: Hennepin Bluff Hazard Areas

Purgatory Creek
Landslides in glacial sediment, Shorewood, Lake Minnetonka, June 19, 2014
Wetland perched on fine-grained glacial sediment was filled and overflowing after rains.
History of failures on west slope

Roadway along toe of already vulnerable slope.
To assess landslide susceptibility

1. Distribution of failures
   Product = slide distribution map and database

2. Understanding of causative factors
   • Dominant slide type
   • Geology, hydrogeology, geomorphology
   Product = landslide domain map
   • Other causative factors
     ✓ Precipitation
     ✓ Human modification
Failure locations and inches of rain in June
“...the recent record is changing because of a lack of low values and not so much because the high values are getting higher.”
Hennepin Data
Late spring to summer
Correspond to convective storms (thunderstorms)
Slightly wet unconsolidated materials exhibit a very high angle of repose because surface tension between the water and the grains tends to hold the grains in place.

Surface tension of thin film of water holds grains together.
How does precipitation cause landslides?

- Increases porewater pressure
- Shallow storm flow
- Increases overland flow
- Erosion of new ravines
Figure 2a. Preliminary graph showing estimates of 3-day and prior 15-day cumulative precipitation associated with historical landslides that were part of events with 3 or more landslides in a 3-day period, in Seattle (filled triangles). The solid red line is a lower-bound threshold (visually identified) for the initiation of landslides when the 15-day cumulative is 3.0 inches or less. The dashed horizontal line is a lower-bound threshold, that was tentatively proposed, for conditions of 15-day antecedent precipitation exceeding 3 inches. (Chleborad, 2000).
Figure 9a. Scatter plot showing antecedent precipitation associated with landslides that occurred during the 2001 - 2002 wet season in Seattle and surrounding areas in relation to the 3-day and prior 15-day threshold (red line). Plot includes all landslides in Tables 1 & 2 with sufficient information to estimate 3-day and prior 15-day antecedent precipitation. Seattle landslides that could be shown to be part of events with 3 or more landslides in a 3-day (72 hr) period are differentiated and discussed in a later section of the report.
Develop awareness to change policy
How to predict future failures and reduce sediment loading?

Document historical failures to develop susceptibility map

Interpret local geology and hydrology

Develop model of precipitation threshold

Provide education to landowners and local governments to

Control slope modifications in vulnerable areas
Landslide Mitigation Strategies

Landslides are an unfortunate reality for Hennepin County, the metropolitan area and other regions in the State of Minnesota. In 2015, a deadly landslide occurred in St. Paul’s Vasa Regional Park. Heavy rains in the spring of 2014 were responsible for several landslides that closed roads, including the slide on the West Bank at the University of Minnesota’s Fairview Medical Center. This landslide closed West River Parkway for over a year and resulted in a $6 million stabilization project.

Landslides in Minnesota could potentially be more common over the next 100 years due to the impacts of climate change and development that does not take the hazard into account. Climate change in Minnesota is expected to result in an overall increase in precipitation of 3-4 inches per year and an increase in the frequency and intensity of precipitation events. These mean additional flooding, ground saturation, and runoff. In addition to steep slopes, the most important factors contributing to landslides are extreme precipitation events, groundwater discharge (springs) and stormwater handling. Even though some of these contributors may be beyond our control, there are steps that communities can take to make their properties safer.

The sections below introduce several assessment, planning, and protection strategies that county officials may consider to mitigate landslide hazards. Example ordinances and codes have been provided to demonstrate potential land-use planning solutions for reducing risk related to landslides. Also included are education and outreach tools addressing slope stabilization that can be shared with affected homeowners.

2. 2014 National Climate Assessment. U.S. Global Change Research Program

Prepared for:
MNDNR

Prepared by:
Stantec
Model ordinance language

Landslide Hazard Overlay Zone or Landslide Hazard Area Development Ordinance

Counties and municipalities can enact landslide-specific regulations in the form of an overlay zone or development ordinance. These types of regulation can fill gaps left by municipality-specific versions and can reinforce practices called for in the Minnesota Department of Natural Resources’ Mississippi River Critical Area program. New landslide-related regulations should build on existing policy and may include the following:

- Development restrictions and moratoriums;
- Minimum setbacks – Including permit reviews and approvals with geotechnical assessment;
- Vegetation standards (native plants with strong, deep root systems);
- Open space designations;
- Real estate disclosure requirement;
- Storm water management and impervious surface restrictions;
- Landslide maintenance easements & deed restrictions; and
- Landslide hazard area building code with minimum foundation, grading, and drainage requirements
3. Olmsted County Decorah Edge Overlay District

Section 9.20 Decorah Edge Overlay District

9.21 Intent and Application
Intent: The intent of the Decorah Edge Overlay Zone (DEOZ) regulations is to guide development in the vicinity of the Decorah Edge in order to protect discharge, interflow, and infiltration and recharge processes taking place in the vicinity of the Decorah Edge; to protect water quality and quantity recharging the aquifers relied on for potable water supply; to prevent extraordinary public expenditure for remediation of damage to public infrastructure; and to protect the environmental quality of Decorah Edge wetlands and related natural habitats; all of which promote the public health, safety and general welfare.

4. Pittsburgh, Pennsylvania Landslide-Prone Overlay District


906.04.A Purpose

The LS-O, Landslide-Prone Overlay District regulations require subsurface investigations by a registered professional and approval of construction plans by the Chief of the Bureau of Building Inspection prior to issuance of a Certificate of Occupancy for any development in the LS-O District. The purpose of these regulations is to reduce the risk of damage or hazards of life that may occur as a result of construction and land operations on lands susceptible to movement or sliding of earth.

906.04.A.1 Warning and Disclaimer

The mapped delineations of land that may be subject to sliding or subsidence do not necessarily include all land that is subject to those hazards. While it is the purpose of the regulations contained in this section to afford reasonable protection against damages caused by construction on or use of hazard-prone land, neither the mapped delineations nor any regulations contained in this section shall create any liability on the part of the City, its officers or employees for damages that may occur.
Mall of America
Filling gaps in spring mapping

Working with Greg Brick, DNR
Spring Inventory
Then we can just step back and enjoy the view
Modeling the Influences of Riverine Hydrology on Near-Channel Turtle Nesting Habitat

Jason Naber - Biologist
Jason Ulrich - Hydrologist
Wood Turtle- State Threatened

Threats-
• Nest Site Predation
• Nest Site Habitat Loss
• Adult Mortality
• Pet Trade
Smooth Softshell - Special Concern

Threats:
- Nest Site Predation
- Nest Site Habitat Loss
- Nest Site Disturbance
- Commercial Harvest

Smooth Softshell

Spiny Softshell

© Jeff LeClere
Field Surveys- Softshell Turtle
Field Surveys
Data Collection

Male

Female
Physical Marking
High Flow Deposition
Below Bankfull Point Bar Nesting Site
Article

Impacts of Hydrologic Change on Sandbar Nesting Availability for Riverine Turtles in Eastern Minnesota, USA

Christian F. Lenhart 1*, Jason R. Naber 2 and John L. Nieber 1

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   E-Mail: nieber@umn.edu

2 Emmons and Olivier Resources, Inc., Hale Ave. N., Oakdale, MN 55128, USA;
   E-Mail: jnaber@eorinc.com

* Author to whom correspondence should be addressed; E-Mail: lenh0010@umn.edu;
   Tel.: +1-612-269-8475; Fax: +1-612-624-3005.

Received: 12 June 2013; in revised form: 16 August 2013 / Accepted: 20 August 2013 / Published: 28 August 2013
Hydrologic Analysis Results:

mean annual flow

Change in mean annual flow as % change from the pre-1980 time period.

Lower % Change in Mean Flow for Northern Rivers

Date of sandbar availability for nesting

Southern rivers show much later sandbar emergence post 1980 compared to northern rivers (Kettle & St. Louis).

Date of earliest nesting opportunity

Julian calendar date

02 June

22 June

02 July

Cannon

Kettle

Minnesota

Root

St. Louis

Pre-1980

Post 1980
2014-16 MN DNR Riverine Turtle Project

- DNR Project Funded through a State Wildlife Grant (SWG) from the US Fish & Wildlife Service
- Habitat Assessment and Cross Sections
  - wood turtle habitat
  - smooth softshell habitat
- Hydrologic Modeling and Analysis
- Spring Nesting Site and Population Survey
- Tasks by Others; DNR, UMD/NRRI, USFS, Fond du Lac Tribe
  - Abundance/Population Surveys
  - Habitat Use Assessment- Telemetry/GPS Tracking
  - Nest Site Monitoring and Enhancement
  - Mortality Assessment
Needed to establish the flood frequency and duration at known and potential nest sites during nesting season (June-August)

Question:
- In an average summer, what nest sites are likely inundated for at least a day?
- Where are suitable nest site restorations/creations

Challenges:
- Standard bankfull indicators not effective references: most flood flows occur prior to nesting season
- 1 to 2 days of inundation result in 100% mortality
- Remote reaches are ungauged: both hydrologic & hydraulic data missing
- Need extended record of summer elevations to establish defensible probabilities
Hydrologic & Hydraulic Modeling

General Methodology

Wood Turtle Rivers:
- Use existing HSPF model (MPCA) to simulate hydrology
- Build hydraulic models to predict flow elevations using surveyed cross-sections and LiDAR

Smooth Softshell- Mississippi River:
- Lock & Dam flow elevation data (USACE)

Smooth Softshell- Minnesota River:
- Existing HEC-RAS hydraulic model (USACE) & gauged flow elevations (USGS Jordan)

Build frequency/duration analysis and output framework in R
Minnesota River Methods

Water surface elevations from USACE HEC-RAS & USGS Jordan gage (1972-2014)
Nest site predicted to be inundated in the summer for at least a day about every 5 to 10 years.
In an average summer, nest site predicted to be inundated for less than a day.
Minnesota River Outputs: Flood Inundation Map
Mississippi River Methods

Water surface elevations and discharge from Lock and Dams (1972-2014)
Mississippi River Outputs:
Nesting Period Flood Elevation Frequency

Nesting Season Return Period Flows at Mississippi River

Nest locations
Rarely if ever flooded
Mississippi River Outputs: Flood Inundation Map
Wood Turtle Rivers

General Methodology

- No discharge
  (downstream USGS gages too far)

- No water surface elevation data

What we did:

• Get local discharge from existing HSPF model (1993-2012)
• Model water surface elevations using PC-SWMM
• Use surveyed cross-sections for near-channel
• “Stitch in” LiDAR data for floodplain and cut-off meander geometry
• Write lots of R code
River Cross sections
Nest Site Example
Example Outputs:
Nesting Site Flood Elevation Frequency

Nest site predicted to be inundated in the summer for at least a day about every 2 to 5 years.
Nest Site
Outputs:
Nesting Period Flood Elevation Frequency

Nesting Season Period Flows (Looking Downstream) at XS09

Potential Nest locations
 Outputs: Nesting Period Flood Elevation Frequency
Recommendations:

- Nice potential nest site
- Gravel bar at new cut off
Recommendations:

- Canoe stop planted pine, good resto site on hill
- Needs clearing, egg shells found near water's edge
- Great restoration site, 2 painted turtles sighted

Legend:
- Purple: 1 year
- Yellow: 10 year
- Blue: 2 year
- Orange: 25 year
- Green: 5 year
- Red: 50 year
Thank You!

Jason Naber - Biologist
Jason Ulrich - Hydrologist

Minnesota Water Resources Conference

By Joel T. Groten, Christopher A. Ellison, David L. Lorenz, and Karl S. Koller

October 19, 2016
Sediment Impacts in Minnesota
Importance of Sediment Data

- Monitoring, river restoration, sediment budgets, effectiveness of sediment reduction strategies
- High costs to collect sediment and gaps in the data mandate alternative methods
- Simple and dependable methods are needed to generate sediment data for areas where no data are available
Background

- DSRC models were developed using data from Rivers near Pagosa Springs, CO by Dave Rosgen (2010)

- Rivers were delineated according to Pfankuch stability rating

- Normalization

- Close agreement between the DSRC model and observed SRC was observed at 16 rivers with

U.S. Department of the Interior
U.S. Geological Survey

Figure 2 Predicted bedload and suspended sediment rating curves derived from the dimensionless model compared to observed values for eight diverse river systems: 1) Bell River (Frenette & Julien, 1987); 2) Senatobia Creek, MS (Simon et al., 2004); 3) Elkhorn Creek, KY (Singh & Durgunoglu, 1991); 4) Salamonie River, IN (Singh & Durgunoglu, 1991); 5) Etobicoke Creek, Canada; 6) Harmony Creek, Canada; 7) Redhill Creek, Canada; and 8) Stoney Creek, Canada.
What is a Dimensionless Sediment Rating Curve?

- Sediment and streamflow are scaled to dimensionless values by developing a ratio between regional samples and a reference index.

- Reference index is the value of SSC and bedload at bankfull streamflow.

- For streamflow, the reference index is bankfull streamflow.

- Dimensionless values of SSC and bedload are plotted against dimensionless streamflow to create predictive equations.
Why develop a Dimensionless Sediment Rating Curve Model?

- DSRC can be used to estimate SSC and bedload for streams where no data are available.
- Reduces costs by minimizing extensive sediment data collection.
- Supports decision-making for stream restoration prioritization, planning, and design.
Objectives

1. Describe SSC, bedload, and streamflow for selected rivers in Minnesota

2. Evaluate and develop relations among streamflow, SSC, and bedload for selected rivers

3. Evaluate if Pagosa Springs DSRCs or Minnesota DSRCs can produce estimates of SSC and bedload within acceptable limits
Data Collection

- high flows
- SSC
- streamflow
- bedload
- high flows
Figure 7.—Discharge-weighted concentration of suspended sediment for different particle-size groups at a sampling vertical in the Missouri River at Kansas City, Mo.
Methods Used to Sample Suspended Sediment and Bedload

**SEDIMENT-SAMPLING TECHNIQUES**

- **Width of Increments**
  \[ W_{i1} = W_{i2} = \cdots = W_{in} = \frac{W_T}{n} \]

- **Time on Bottom**
  \[ t_1 = t_2 = \cdots = t_n \]

- **Stations**
  \[ S_1, S_2, S_3, S_4, S_5, S_{n-1}, S_n \]

- **Number of Verticals**
  \[ n = 20 \]

1 Sample Per Vertical Per Cross Section
2 Cross Sections
Minnesota DSRC Models

1. Data compilation
2. Determine SSC and bedload at bankfull
3. Model requirements and assumptions
4. Model construction

U.S. Department of the Interior
U.S. Geological Survey
Determining SSC and bedload at bankfull streamflow
Determining SSC and bedload at bankfull
### SSC relation to streamflow

<table>
<thead>
<tr>
<th>Site Description</th>
<th>Streamflow, in cubic feet per second</th>
<th>Silt concentration, in milligrams per liter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Knife River near Two Harbors, Minn.</td>
<td><img src="image1" alt="Graph" /></td>
<td><img src="image1" alt="Graph" /></td>
</tr>
<tr>
<td>Sucker River near Palmers, Minn.</td>
<td><img src="image2" alt="Graph" /></td>
<td><img src="image2" alt="Graph" /></td>
</tr>
<tr>
<td>Swan River near Toivola, Minn.</td>
<td><img src="image3" alt="Graph" /></td>
<td><img src="image3" alt="Graph" /></td>
</tr>
<tr>
<td>Wild Rice River at Twin Valley, Minn.</td>
<td><img src="image4" alt="Graph" /></td>
<td><img src="image4" alt="Graph" /></td>
</tr>
<tr>
<td>Wild Rice River near Ada, Minn.</td>
<td><img src="image5" alt="Graph" /></td>
<td><img src="image5" alt="Graph" /></td>
</tr>
<tr>
<td>Little Fork River at Littlefork, Minn.</td>
<td><img src="image6" alt="Graph" /></td>
<td><img src="image6" alt="Graph" /></td>
</tr>
<tr>
<td>Big Fork River near Craigsville, Minn.</td>
<td><img src="image7" alt="Graph" /></td>
<td><img src="image7" alt="Graph" /></td>
</tr>
<tr>
<td>Long Prairie River at Long Prairie, Minn.</td>
<td><img src="image8" alt="Graph" /></td>
<td><img src="image8" alt="Graph" /></td>
</tr>
<tr>
<td>Buffalo Creek near Glencoe, Minn.</td>
<td><img src="image9" alt="Graph" /></td>
<td><img src="image9" alt="Graph" /></td>
</tr>
<tr>
<td>South Fork Crow River at Delano, Minn.</td>
<td><img src="image10" alt="Graph" /></td>
<td><img src="image10" alt="Graph" /></td>
</tr>
</tbody>
</table>

**EXPLANATION**

- **(1)** Site number (table 1)
- **(2)** Best-fit regression line
- **(3)** Suspended-sediment concentration
- **tau**: Kendall’s tau correlation coefficient

U.S. Department of the Interior
U.S. Geological Survey
Pagosa Springs and Minnesota DSRC model equations

Pagosa Springs SSC models:

- good/fair stability: $SSC = 0.0636 + 0.9326Q^{2.4085}$
- poor stability: $SSC = 0.0989 + 0.9213Q^{3.659}$

Minnesota SSC models:

- good/fair stability: $SSC = 0.026 + 0.974Q^{0.951}$
- poor stability: $SSC = 0.066 + 0.934Q^{1.066}$

U.S. Department of the Interior
U.S. Geological Survey
Model Evaluation and Interpretation

1. Proximity of the models fitted line to measured data’s best fit line
2. Nash-Sutcliffe Efficiency
3. Model bias
4. Deviation of the models annual loads
Nash-Sutcliffe Efficiency Index

- Values range from $-\infty$ to 1
- A value of 1 indicates a perfect match of modeled data to the observed data
- A value of 0 indicates that the model predictions are as accurate as the mean of the observed data
- A value less than 0 occurs when the observed mean is a better predictor than the model
SSC for poor stability sites

Sucker River near Palmers, Minn.
Wild Rice River near Ada, Minn.
South Fork Crow River at Delano, Minn.
LeSueur River near Rapidan, Minn.
Minnesota River at Mankato, Minn.
Minnesota River near Jordan, Minn.
Cascade Creek at 45th Ave NW in Rochester, Minn.
Cascade Creek at 35th Ave NW in Rochester, Minn.
Zumbro River at Kellogg, Minn.
Whitewater River near Beaver, Minn.

Nash-Sutcliffe Efficiency Index

EXPLANATION
- Pagosa Springs model
- Minnesota model
- Site model

U.S. Department of the Interior
U.S. Geological Survey
Model Bias (Rb)

Pagosa Springs SSC Model = 37%
Minnesota SSC Model = 30%

Pagosa Springs Bedload Model = 29%
Minnesota Bedload Model = 20%
Annual Loads

A. Good/Fair stability sites for 2012

Knife River near Two Harbors, Minn. (site 1)

Wild Rice River at Twin Valley, Minn. (site 4)

Little Fork River at Littlefork, Minn. (site 6)

Big Fork River near Craigs ville, Minn. (site 7)
Annual Loads

- Minnesota River at Mankato, Minn. (site 13)
- Minnesota River near Jordan, Minn. (site 14)
- Zumbro River at Kellogg, Minn. (site 18)
- Whitewater River near Beaver, Minn. (site 20)

EXPLANATION

(70200, 93600, 122000)  Lower 95% confidence interval; annual load, in tons; upper 95% confidence interval

-- Suspended-sediment load, in tons
The Minnesota DSRC model more closely matched the measured data for nearly every site.

Pagosa Springs DSRC overestimated SSC, bedload, and loads at streamflows equal to and exceeding bankfull.

For SSC, the Pagosa Springs model was a poor predictor of SSC for half of the sites samples.

Minnesota DSRC had positive NSE values for nearly every site and closely matched site-specific NSE values and had overall smaller model bias.

U.S. Department of the Interior
U.S. Geological Survey
Southeast Minnesota sites significantly deviated from DSRC model, indicating regional DSRC should be developed.

Annual loads are not significantly different among models for most sites except for southeast Minnesota sites.

Results support development of regionally-based DSRCs for uses such as stream restoration prioritization, planning and design, and estimating annual sediment loads.
Application of Dimensionless Sediment Rating Curves to Predict Suspended-Sediment Concentrations, Bedload, and Annual Sediment Loads for Rivers in Minnesota

Scientific Investigations Report 2016–5146
Questions
Shattuck-St. Mary’s School: Indicators for Altered Hydrologic Influences on Fluvial Geomorphology and Sediment Loading

Ravine Stabilization and BMP Feasibility Study
Indicators for Altered Hydrologic Influences on Fluvial Geomorphology and Sediment Loading

Greg Bowles, PE – Houston Engineering
Alex Schmidt, PE – Houston Engineering
Drew Kessler, PhD – Houston Engineering
BACKGROUND
OBJECTIVES
ANALYSIS
SOLUTION

CASE STUDY: ALTERED HYDROLOGY
BACKGROUND
OBJECTIVES
ANALYSIS
SOLUTION

CASE STUDY:
ALTERED HYDROLOGY
517 acres

LOCATION

City of Faribault

Cannon River

Straight River

I-35

517 acres
TERRAIN
PROBLEM
OBJECTIVES

- Quantify erosion and pollutant loading
- Prioritize pollutant sources
- Recommend BMPs
  - Implementation plan
  - Cost-benefit analysis
GOAL: LAKE PEPIN TMDL

- Cannon River is a known contributor to Lake Pepin TSS
- Lake Pepin Excess Nutrient TMDL proposes a 20% TSS reduction goal
- Quantify TP

ANALYSIS

Straight River

WATERSHED LOAD

RAVINE LOAD
Watershed Load

- P8 Model (water quality)
  - Generates pollutant loads
  - Simulates treatment
  - “Delivered Load”
ANALYSIS

- Ravine Load – Erosion
  - HydroCAD Model (water quantity)
    - Estimate discharge through ravines
  - Ravine Assessment
    - Ravine Restoration Toolkit
    - Quantify Erosion
RAVINE ASSESSMENT
Ravine Restoration Toolkit
ANALYSIS: FINDINGS

- Quantify erosion and pollutant loading
  - 28 tons TSS/yr from watershed
  - 383 tons TSS/yr from ravine erosion
- Prioritize pollutant sources
  - Target areas with highest yield?
  - $/lb?
  - Threat to infrastructure?
- Recommend BMPs
  - Implementation plan
  - Cost-benefit analysis
ANALYSIS: ANNUAL TSS LOAD

Straight River

WATERSHED LOAD: 28 TONS

RAVINE LOAD: 383 TONS
SOLUTION: WATERSHED

Watershed Load

Target Structural BMP’s
- Bioretention
- Infiltration/filtration
- Underground treatment
SOLUTION: WATERSHED

Watershed Load

Target Structural BMP’s
- Bioretention
- Infiltration/filtration
- Underground treatment

Typical Cross Section:

The gravel blanket area may be used to achieve several different functions when the underdrain pipe discharge elevation is set higher.

Typical Cross Section:
- Inflow
- Overflow
- Washed stone
- 48” perforated pipe
- Topsoil & grass
TARGETING: LOAD EXISTING
SOLUTION: RAVINES

Flow Reduction
- Upstream
- Retention Basin
- Utilize existing gullies

Sedimentation Basin
- Downstream
- In floodplain

Ravine Load
SOLUTION: FLOW

Typical Cross Section:

- Road
- Overflow structure
- Bulkhead
- Live storage during rain event
- Existing culvert
- Restricted outflow
- Sump & Manhole
- Existing ravine
SOLUTION: SEDIMENTATION BASINS
SOLUTION: SEDIMENTATION BASINS

Sediment Basin
SOLUTION: SEDIMENTATION BASINS

CONCEPTUAL BMP DESIGN

BMP 10 – RAVINE 4 POND

WATERSHED: SSM4
LOCATION: Outlet of ‘Ravine 4’ (northwest of the main Shattuck campus)
BMP TYPE: Sedimentation Pond

Legend:
- Existing Sanitary Sewer
- Proposed Storm Sewer
- Proposed Storm Structure
- Drainage Area
- Parcel Lines

Direct outflow from ravine into the pond and protect channel

Embankment

Outflow pipe, structure, and emergency overflow weir

BMP 10

Drains to box culvert at BMP 22

Shattuck Property

Ravine 4

Notes: The pond is designed to be a sedimentation basin (wet pond) to reduce the sediment load discharging to the Straight River from the upstream ravine erosion or other watershed loadings. Additional benefits include discharge reduction and nutrient treatment. The pond would discharge to the railroad ditch to the south, ultimately flowing through a box culvert and into the Straight River. A dirt access road from the north is available for pond construction and maintenance.

Limitations/Cautions: Utilities shown are approximate, locate prior to final design. Maintain appropriate cover over the sanitary sewer. Also, maintain or provide an access path in this area from north to south.

Typical Cross Section:

BMP Alternatives:
- Dry Pond (temporary storage)
- Filtration Basin w/underdrain
- Locate south of ravine on MSAD property

Estimated BMP Construction Cost: $63,000
BACKGROUND
OBJECTIVES
ANALYSIS
SOLUTION

CASE STUDY:
ALTERED HYDROLOGY
RAVINE 5: CASE STUDY
ALTERED HYDROLOGY

- Despite the construction of a peak flow reducing pond...
- The downstream ravine is experiencing major, active erosion.
- The pond isn’t cutting it.
Ravine 5: 10-year Hydrographs

Pre-Settlement:
- Flow: 0.26 ac-ft

Existing:
- Flow: 1.10 ac-ft

2-yr Pre-Settlement Channel Forming Flow
This case may indicate that...

1. A reduction in peak discharge alone did not prevent substantial erosion.
2. An increase in depth and *duration* of hydrologic loading to the ravine above the 2-year event may also cause erosion.

Other possible contributors to erosion?
GEOMORPHIC STABILITY

Ravine 6: 2-year Hydrographs

Existing

Proposed

2-yr Pre-Settlement Channel Forming Flow
Conclusion

- As we devote resources to improving water quality, we must be cognizant of the load from erosion.
- When protecting downstream resources against erosion, should we look at other metrics in addition to peak flow?
THANK YOU!
GEOMORPHIC STABILITY

1-year Hydrograph

Existing

2-yr Pre-Settlement Channel Forming Flow
2.5” event (1-year return period) weeks before our site visit.

No rain events over 3” in 2015 (no abnormal events to skew our erosion observation)

Other possible influences:
Hei’s solution was a three fold approach

- Treatment BMPs
- Downstream sedimentation
- Upstream discharge reduction
THANK YOU!
Flow-related dynamics in suspended algal biomass and its contribution to suspended particulate matter in an agricultural river network of the Minnesota River Basin, USA

Christy Dolph, Amy Hansen & Jacques Finlay
Acknowledgements

Finlay Lab
Sandra Brovold  Anika Bratt
Shelly Rorer  Anna Baker
Katie Kemmit  Winnie Winikoff
Erika Senyk  Evelyn Boardman
Andrea Keeler  Ben Janke
Wendy Hughes  Claire Griffin
Nick Omodt  Tessa Belo
Rachel Van Allen  Shannon Pappas
Cathleen Nyugen
Sally Donovan
Alex Bahr
Why suspended algal biomass?

- Organic matter cycling - not well studied in ag systems
- BOD (fish kills)
- Toxic algae blooms
- Food source
Le Sueur River Basin
Most site types **eutrophic**, on average.

- **Eutrophic lakes** have the highest CHLa (μg/L) among the site types, indicating a higher level of nutrient enrichment.
Suspended algae important to stream and river carbon budgets in the Le Sueur Basin

Compare to other systems in late summer...

<table>
<thead>
<tr>
<th>System</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Le Sueur Streams &amp; Rivers</td>
<td>20% (4% - 54%)</td>
</tr>
<tr>
<td>Upper Miss, MO, OH Mainstem Rivers</td>
<td>28%</td>
</tr>
<tr>
<td>Reservoirs (KY, OH)</td>
<td>61%</td>
</tr>
<tr>
<td>Lakes</td>
<td>39%</td>
</tr>
</tbody>
</table>

Bukaveckas et al. 2011
Flow Effects – Stability vs Mobilization

Fig. 4. Relation between chlorophyll $a$ concentration and discharge in the Hungarian Danube (1988–1992).
• Suspended algae plays important role in organic matter and nutrient cycling in ag streams and rivers

• Suspended algae peaks at intermediate flows, rather than at low flows

• Lakes and wetlands connected to the network may act to increase suspended algae concentrations in downstream channels
Flow-related dynamics in suspended algal biomass and its contribution to suspended particulate matter in an agricultural river network of the Minnesota River Basin, USA

Christine L. Dolph · Amy T. Hansen · Jacques C. Finlay
Nitrogen Limitation?
September 2015 (late summer)