River channel responses
to large increases
in flows and sediment supply

How do we assess, protect, and restore rivers when flow and sediment are systematically changing?

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None of our work would be possible without the tireless and meticulous work of innumerable local and state agency staff and the interest and support of south central Minnesotans.
In the next 30 min...

For the flows, they are a changin’

“Come gather ‘round people, wherever you roam
and admit that the waters around you have grown”

Different rivers, different responses

Determining sediment sources and sinks to inform restoration
Flows have gone waayyy up

Schottler et al., 2014; Foufoula-Georgiou et al., 2015; Belmont et al., 2016; Kelly et al., 2017
Relationships between flow and sediment
Sediment Rating Curves

- Persistent, distinguishing characteristics of a river’s sediment regime that integrate sediment supply and transport capacity across the range of flows.

- Separate rising/falling limb samples

Vaughan et al., 2017
Distinct relations between $Q$ and suspended sediment concentration.

- What controls the shape and other characteristics of Sediment Rating Curves?
- Role of land use versus geomorphic setting/history?
Predict gage-to-gage variation in SRC characteristics using landscape and environmental variables.

\[ [\text{TSS}] = aQ^b \]

Random Forest Models

Variable Importance
- Stream Gradient
- Local Relief
- Channel Waterbody Area
  - Mean Watershed Slope
  - WS Avg Rock-free K factor

% Increase MSE

Partial Dependence on Stream Gradient
- SRG Rising Limb Exponent

Vaughan et al., 2017
What controls Q/TSS relations throughout Minnesota?

What controls the SHAPE of the curves?
...geologic setting/history

What controls how STEEP the curves are?
...geologic setting/history

What controls sediment concentrations at moderate to low flow conditions?
...land use

Vaughan et al., 2017
In the next 22 min...

For the flows, they are a changin’

Different rivers, different responses

• Flows have dramatically increased in many parts of Minnesota
• Flow-sediment relationships vary considerably throughout the state
• Near-channel morphological features dominated explanatory power for predicting SRC shape and steepness
• Land use dominated explanatory power for predicting sediment concentrations at low- and moderate-flows

Determining sediment sources and sinks to inform restoration
Sediment, nutrient problems in the upper Mississippi River

Minnesota River Basin: 964 impairments for sediment, nutrients, aquatic life

MRB is primary source of sediment and nutrients for the upper Mississippi

Where is all that mud coming from?
How much is natural and how much is pollution?
Impacts on ecosystem? Economic costs?
(How) can we clean these rivers up?

Belmont et al., 2011; Gran et al., 2011; Belmont and Foufoula-Georgiou, 2017
The cause of the problem is obvious, right?
Past and future investments in water quality...
Lots of money invested, but no reduction in sediment?

Lots more to be invested...
- need to get the right answers for the right reasons
- how to get the best ‘bang for the buck’?

11,000+ projects!
How to quantify sediment sources?

Semi-quantitative models

Factorial Scoring Model (FSM)
Verstraeten et al., 2003

$$SSY = 4139 \times A^{-0.44} + 7.77 \times FSMIndex - 310.99$$

Must be calibrated to a particular landscape

Common critique: these evaluations may be more likely to reinforce pre-conceptions than provide new, objective insight
Comparable hydro-erosion models may give you very different answers.

Complex hydro-erosion models accommodate lots of ag input data... inherently biased to ag problems and solutions... Hundreds of parameters... limited by equifinality.
Geologic history made this a very sensitive landscape

Belmont, 2011; Gran et al., 2013
Geologic history makes this a very sensitive landscape.

River profiles tend toward this shape.
Le Sueur River Watershed Sediment Budget

Many tools employed...

- Sediment fingerprinting
- Aerial Lidar analysis
- 50+ Field surveys
- 70 years of bluff erosion rates
- 70 years of river migration & widening
- Modeled Soil erosion rates
- 4 years of terrestrial lidar
- Gages galore!
- 14C & OSL-Dates for incision history

Belmont et al., 2011
Upland soil erosion is a moderate contributor. Erosion of geologically-sensitive bluffs has been amplified by high flows.

### Sources
- U: Uplands
- Fp: Floodplain
- Bl: Bluffs
- Ba: Banks
- C: Channel incision
- R: Ravines

### Constraints
1. Gaging data
2. Geochemical tracers
3. Aerial lidar analysis
4. Terrestrial lidar scans
5. Air photo analysis
6. Numerical modeling
7. Field surveys
8. Optically Stimulated Luminescence and $^{14}$C dating

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U: Uplands
Fp: Floodplain
Bl: Bluffs
Ba: Banks
C: Channel incision
R: Ravines
Corroborations of Le Sueur sediment budget in the geochemical profile of Lake Pepin sediments

Soil erosion from farm fields used to be a bigger part of the problem. Increases in streamflow are amplifying near-channel erosion.

Need to manage water runoff better!

Belmont et al. 2011 ES&T
How can we reduce runoff, keep soil erosion low and maintain this as a productive ag landscape?

Drain management

Wetland restoration

Ditch management

Buffer strips

Soil organic matter

Water retention

Cover crops

Bank stabilization
Collaborative for Sediment Source Reduction (CSSR)

Processes
Hydrologic Modeling
Predict Erosion & Deposition
Water & Sediment Routing

Management
Options
Extents
Rates
Costs

Simulation Model

Evaluating tradeoffs:
How much of which actions, at what cost, in which areas, should be done to meet sediment reduction targets?

Wilcock et al., 2016; Cho et al., 2018; Cho et al., in review
How do we get the most ‘bang for the buck’?

[Graph showing relationship between Sediment Reduction (Mg/yr) and Cost ($/yr) for Buffers.

CSSR MOSM Model Results for Le Sueur watershed, for demonstration]
How do we get the most ‘bang for the buck’?

CSSR MOSM Model Results for Le Sueur watershed, for demonstration
Wetlands also decrease nitrogen concentrations in ditches during most critical season

- Reduces N during highest flows
- Apr-June flux sets size of Gulf Hypoxic Zone (Turner et al. 2012)

June Nitrate-N
94 sites (3 to 5800 km²) sampled same week

A. Hansen, J. Finlay
Consensus!

General agreement on the facts and how to fix the problem...

The Collaborative for Sediment Source Reduction (CSSR) was a five-year effort to evaluate strategies for sediment source reduction in the Greater Blue Earth River Basin. With support from local, state, agribusiness, and environmental organizations, a diverse stakeholder group met nine times to evaluate watershed strategies for reducing sediment loading to the Minnesota River and beyond.

**CSSR Goal:** To identify a 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. We hope that the strategy developed will be effective, cost-efficient, fair, and supported by all stakeholders.

There are numerous sources of sediment loading from the Minnesota River and many tributaries of the Blue Earth, known as Blue Earth County. Sediment, a major contributor of solids, causes problems for the user of the water. In addition, sediment loading causes deposition problems in the waterways that are part of the Minnesota River drainage. Most of the sediment that is delivered into the Mississippi River comes from more than two-thirds of the area of the basin. By reducing the amount of sediment loading in the Minnesota River, we reduce the amount of sediment loading to the Mississippi River, which includes the watersheds of seven major rivers.

The citizens of Minnesota are increasingly concerned with the quality of our drinking water in the Minnesota River, particularly with the effects of phosphorus and other nutrients on waterways. The Collaborative for Sediment Source Reduction (CSSR) was established by several agencies to work on the problem of reducing sediment loading in the Greater Blue Earth River Basin. The CSSR has been working for five years to develop a strategy for reducing sediment loading in the basin. The CSSR has been working with local, state, and federal agencies to develop a plan for reducing sediment loading in the basin.

**CSSR Participants**

The people listed below attended the final meeting of the CSSR workgroup, or reviewed the meeting materials and outcomes, and indicate that this report is an accurate account of the findings of the workgroup.

<table>
<thead>
<tr>
<th>Name</th>
<th>Affiliation</th>
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<tbody>
<tr>
<td>David Ward</td>
<td>Farmer, Mapleton, MN</td>
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<tr>
<td>Steve Sodeman</td>
<td>Farmer, Consultant, St James, MN</td>
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<tr>
<td>Dave Bucklin</td>
<td>GBERBA, Cottonwood SWCD</td>
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<tr>
<td>Eric Gulbransen</td>
<td>Waseca SWCD</td>
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<td>Wayne Cords</td>
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<td>Leann Cords</td>
<td>MN Association of SWCD</td>
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<td>Julie Conrad</td>
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<td>Heidi Peterson</td>
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<td>Shaina Keseley</td>
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<td>Al Kean</td>
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<td>Jill Sackett Eberhart</td>
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<td>Paul Davis</td>
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<td>Les Everett</td>
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<td>Ann Lewandowski</td>
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<tr>
<td>Scott Sparlin</td>
<td>Coalition for a Clean MN River</td>
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<tr>
<td>Duane Ninneman</td>
<td>Clean Up the River Environment</td>
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<tr>
<td>Carrie Jennings</td>
<td>Freshwater Society</td>
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<tr>
<td>Rebecca Seal Soileau</td>
<td>US Army Corps of Engineers</td>
</tr>
<tr>
<td>Kimberly Musser</td>
<td>MNSU Water Resources Center</td>
</tr>
</tbody>
</table>

CHO et al., in review
Not done yet, but close!

For the flows, they are a changin’

Different rivers, different responses

Determining sediment sources and sinks to inform restoration

- Semi-quantitative assessments and hydro-erosion watershed models can be useful...external checks needed for them to be reliable
- Sediment budgets using multiple, redundant measurements for each sediment source provide the most robust approach to quantify sediment source and sinks
- **NEED TO SLOW THE FLOW!** Temporary water storage is the most effective practice to reduce sediment loading in the Le Sueur watershed
Coarse sediment sources and transport: A closer look at bluff erosion
Monitoring bluff erosion

20 cameras x 600+ days = 12,000+ photos
Total Erosion Events  n = 2705
Large Erosion Events  n = 347

3 years of high resolution TS, SfM surveys

4 years of terrestrial lidar surveys

7 years between repeat aerial lidar surveys

Day et al., 2013; Kelly and Belmont, 2018; Schaffrath et al., 2015
When and why do bluffs erode?

BUT... Considering Frequency x Magnitude: 1.2 year flood does the most erosion over 3 years!

What does increased coarse sediment supply mean for the mainstem Minnesota River?
Striking differences in form and behavior along the lower 175 km of the Minnesota River
Very different behavior in the two river reaches
Lots of data to constrain a sediment budget

- Grain size samples
- 234 km of MNR bathymetry
- Historical aerial photos: 1937-2017
- USGS/DNR/MPCA flow & sediment data

Lots of data to constrain a sediment budget.
Sediment budgets for mainstem Minnesota River

**Mixed bedload and suspended load**
- Bedload at Mankato: 19%
- Bedload at Jordan: <0.5%
- Bedload at Fort Snelling: 0%

Migration (30%) and widening (23%) dominate supply
Channel migration contributes more than widening

**Suspended load dominated**
- Material already in transport dominates supply
- Channel widening (19%) contributes more than migration (7%)
Almost there...

For the flows, they are a changin’

Different rivers, different responses

Determining sediment sources and sinks to inform restoration

- Large (and increased!) supply of coarse sediment causes very different form and dynamics in the mainstem Minnesota River

- Bedload supply exerts strong control over river morphology and dynamics...needs to be incorporated explicitly in assessment and design
Sediment Transport in Stream Assessment and Design Short-course in Logan, UT

- Sediment source/sink analysis
- Sediment transport calculations
- Field measurement of sediment transport
- Use of hydraulic and transport models in design
- Design project: threshold & alluvial design, with uncertainty
None of our work would be possible without the tireless and meticulous work of innumerable local and state agency staff and the interest and support of south central Minnesotans.

**Funding provided by:**

- Clean Water Land & Legacy Amendment
- NSF
- USDA
- Department of Natural Resources
- Minnesota Pollution Control Agency
- MAWRC
- Minnesota Department of Agriculture
- Minnesota Corn Research & Promotion Council

**UCI**
- Efi Foufoula
  - Hydrology

**UMN-D**
- Karen Gran
  - Geology

**UMN**
- Jacques Finlay
  - Ecology

**USU**
- Peter Wilcock
  - Sed. Transport

**USU**
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- Shawn Schottler
- J. Wesley Lauer
- Chris Lenhart

**Students:**
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- Jon Czuba
- Se Jong Cho
- Sara Kelly
- Bruce Call
- Zeinab Takbiri
- Martin Bevis
- Nate Mitchell
- Tim Beach
- Shayler Levine
- Patrick Adams
- Adam Fisher
Some take-away points

1. **Geologic history** makes the MRB a very sensitive system.

2. **Slow the flow!** Store more water in the landscape.
   - Make better use of existing water storage sites
   - Install new water retention basins
   - Multipurpose drainage
   - Cover crops and improved soil health

3. Continue to maintain and **improve field practices**.

4. Minnesota has excellent **monitoring and planning framework**.
   - Coordinate efforts...the collective, downstream impacts matter.
   - Key players have to engage.
   - Provide incentives with minimal red tape.
Channel form – **slope**, bed grain size, and bar topography

Slope break upstream of Jordan near river km 85

Slope Mankato to Jordan: 0.0002

Slope Jordan to Fort Snelling: 0.0001
Channel form – slope, bed grain size, and bar topography

Significant downstream fining, coarsening at tributary junctions

$D_{50}$ Mankato to Jordan: 1 mm

$D_{50}$ Jordan to Fort Snelling: 0.25 mm

No trends between bars and bed (thalweg)
Channel form – slope, bed grain size, and bar topography

Bars taller downstream

Bars Mankato to Jordan: broad, alternate and point bars

Bars Jordan to Fort Snelling: narrow, forced point bars

No trend for pools
Upper 100 km is very different than lower 65 km
Sediment supply and transport – sediment budgets

Mixed bedload and suspended load

Migration and widening (53%)

Channel migration (30%) > widening (23%)

Suspended load dominated

Material already in transport (74%)

Channel widening (19%) > migration (7%)
How does artificial drainage affect streamflow?

At the field scale:
- Tiles help more rain penetrate into the soil (and therefore less run off the surface)
- But it gets into and moves through tiles quickly!

Sooo...

At the watershed scale:
- More water is getting to the stream faster (so high/peak flows go up)

Kelly et al., 2017

Kumarasamy & Belmont, in prep

Discovered Farms monitoring

SWAT model results
When and why do bluffs erode?

20 cameras x 600+ days = >12,000 photos
Total Erosion Events n = 2705
Large Erosion Events n = 347

Kelly and Belmont, in prep
When and why do bluffs erode?

I. Acquire Photos

II. Build Model

III. Model Validation

Kelly and Belmont, in prep

2 sites monitored for 3 years

RMSE = 0.285 m
When and why do bluffs erode?

- 20-year flood: 1,500 Mg erosion (10%)
- 2,000 Mg erosion (17%)
When and why do bluffs erode?

Kelly and Belmont, in prep
These two events accounted for:

88% + 10% = 98% !!
What controls Q/TSS relations throughout Minnesota?
Pollutant reduction targets for Minnesota River

**Nitrogen**
- Baseline Period (1980–1996): 0%
- 2014: 0%
- 2025: 20%
- 2040: 45%
- Milestone
- Progress strategy focus
- Goal enabled by future research

**Phosphorus**
- Baseline Period (1980–1996): 0%
- 2014: 33%
- 2025: 45%
- Reduction from baseline load

**Sediment**
- Baseline Period (1993 – 2005): 0%
- 2014: 0%
- 2025: 20%
- 2040: 90%
- Milestone
- Progress strategy focus
- Goal enabled by future research

50% by 2030
What controls Q/TSS relations?

**Geomorph setting dominates**

**Exponent**
- Stream Slope, 10 km
- Local Relief, 10 km
- Channel Waterbody Area, 50 km
- Mean Watershed Slope
- WS Avg Rock-free K factor

**Shape**
- Slope, 10 km
- Stream Slope, 50 km
- Channel Waterbody Area, 50 km
- Mean Annual Temperature

**Coefficient**
- Percent Agriculture
- 5 Yr Recurrence, 10 Min Precip Frequency
- Percent Forest
- Local Relief, 10 km
- Unit Stream Power, 50 km

**Near-channel metrics in bold**

---

**Simple Power Function**

- Rising Limb: $TSS = 9.9 \cdot (Q/Qgm)^{-0.2}$
- Falling Limb: $TSS = 9.0 \cdot (Q/Qgm)^{-0.5}$
- Combined: $TSS = 9.3 \cdot (Q/Qgm)^{-0.4}$
- Low Flow: $TSS = 8.3 \cdot (Q/Qgm)^{1.1}$

**Peak**

- Rising Limb: $TSS = 186.8 \cdot (Q/Qgm)^{0.7}$
- Falling Limb: $TSS = 78.7 \cdot (Q/Qgm)^{0.8}$
- Combined: $TSS = 114.2 \cdot (Q/Qgm)^{0.7}$

**Threshold**

- Rising Limb: $TSS = 40.0 \cdot (Q/Qgm)^{0.6}$
- Falling Limb: $TSS = 17.5 \cdot (Q/Qgm)^{0.6}$
- Combined: $TSS = 21.5 \cdot (Q/Qgm)^{0.8}$
- Low Flow: $TSS = 20.7 \cdot (Q/Qgm)^{0.0}$

---
In the last 14 min...

The current situation

What we have learned from the past

Some new data and insights

How to proceed from here?
Water storage in Credit River watershed

Credit River runoff ratio

[Graph showing the Credit River runoff ratio from 1990 to 2012 with data points indicating a trend over time.]

Number of Water Retention Structures

[Bar chart showing the number of water retention structures from 1937 to 2016, with a significant increase from 2003 to 2016.]
A metaphor…

…and a few words about the buffer bill

“I don’t think this is how you do it.”
Minnesota has some of the best, targeted monitoring in the world

Heart disease?
Do you want the stethoscope or the ECG?
Minnesota has an excellent framework for watershed planning

One Watershed One Plan

Locally developed & implemented

Facilitates targeting & prioritization

Coordinates efforts

Engages broad range of stakeholders

Formal agreements, but adaptable
Consider **all types of capital** (i.e., accumulated wealth)

**Natural capital**

**Social capital**

**Political capital**

- Sense of Belonging
- Networks Bonding Bridging
- Feelings of Trust & Safety
- Reciprocity
- Participation
Integrated modeling of Minnesota River System

Drivers
- Energy
- Food
- Climate

Socio-economic modeling

Land and water management actions

Social and economic impacts

Changes in valued attributes

Biophysical modeling

Terrestrial sediment and nutrient dynamics

River network sources, sinks and transformations

Alternative Futures
- AF1: 2020 ----> 2050
- AF2: 2020 ----> 2050
- AF3: 2020 ----> 2050
- AFn: ...

Policy, market or institutional change

Cost-benefit assessments and value articulation frameworks

uncertainty, dynamics, thresholds
Random Forest Modeling

Machine learning technique based on boot-strapped classification and regression trees

Advantages of RF models:
• Fully non-parametric, no distributional assumptions
• resistant to over-fitting
• identify and accommodate complex, non-linear interactions among variables
• do not require independence of predictor variables
• make no assumptions about the form of relationships between predictor and response variables

Cutler et al., 2007
### Predictor variable importance

#### Variable Importance, all Variables Considered

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean Decrease Accuracy</th>
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<td>Slope10km</td>
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<td>ChanWaterbodyArea50km</td>
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<td>ChanKfactRF10km</td>
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</tbody>
</table>

**Bold are near-channel metrics, Non-bold are watershed-avg metrics**
Human-amplified hydrologic change

The debate: increases in streamflow are due to a) increased precipitation b) artificial drainage c) combination of these factors

If,
- streamflows have been amplified by agricultural drainage
- sediment problems in the Minnesota River Basin are exacerbated by streamflow increases

Then gains in water quality will likely require cooperation with agriculture
Quantify flow trends in 4 large agricultural watersheds

Quantify climate and land use change

Build a water budget to determine relative importance of climate vs drainage mgmt

Similar glacial histories:
Watersheds underlain by glacial till

Similar land use:
Corn and soybean agriculture with surface and subsurface drainage

Similar climate:
Humid, temperate climate with local differences in dominant air masses and degree of climate change
Data

PRISM Precipitation

Modeled Evapotranspiration from Livneh et al. 2013

USGS Daily Streamflow

US Census of Agriculture (NASS)

Methods

Normalized streamflow time series

Student’s t-test

Kolmogorov–Smirnov test

Wavelet analysis

Piecewise linear regression

Water budget

\[ P - ET - Q = \frac{dS}{dt} \]

\[ P = \text{precipitation} \]
\[ ET = \text{evapotranspiration} \]
\[ Q = \text{streamflow} \]
\[ \frac{dS}{dt} = \text{change in soil moisture, groundwater, and/or lake/reservoir storage} \]
Tile Drainage Extent

*Tile drainage increasing over small areas in Red River of the North basin*

*Drainage most extensive and increasing in Illinois and Minnesota River basins*

*County level data does not reflect tile density*

*Also compiled annual crop data*
Annual Streamflow Trends

Three agricultural basins show increasing trend for all metrics
Monthly Precipitation and Streamflow

Change in Monthly Streamflow and Precipitation Volumes between 1935-1974 and 1975-2013

Minnesota River Basin  Illinois River Basin  Chippewa River Basin  Red River Basin
Cumulative Streamflow and Precipitation

Three agricultural basins show an increase in runoff

Different inflection point for each basin
Water Budgets

\[ P - ET - Q = \frac{dS}{dt} \]

What is \( \frac{dS}{dt} \)?
### Water Budgets

<table>
<thead>
<tr>
<th>Basin</th>
<th>Period</th>
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</thead>
<tbody>
<tr>
<td><strong>Minnesota River Basin:</strong></td>
<td>1935-1978 to 1979-2011</td>
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<tr>
<td><strong>Red River of the North Basin:</strong></td>
<td>1935-2003 to 2004-2011</td>
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<tr>
<td><strong>Illinois River Basin:</strong></td>
<td>1939-1961 to 1962-2011</td>
</tr>
<tr>
<td><strong>Chippewa River Basin:</strong></td>
<td>1935-1974 to 1975-2011</td>
</tr>
</tbody>
</table>

\[
P - E - Q = \frac{dS}{dt}\]

- **Minnesota River Basin:**
  - \(P\): 10%
  - \(E\): 7%
  - \(Q\): 106%
  - \(S\): -213%

- **Red River of the North Basin:**
  - \(P\): 16%
  - \(E\): 14%
  - \(Q\): 120%
  - \(S\): -31%

- **Illinois River Basin:**
  - \(P\): 5%
  - \(E\): 3%
  - \(Q\): 23%
  - \(S\): -103%

- **Chippewa River Basin:**
  - \(P\): 3%
  - \(E\): 2%
  - \(Q\): <1%
  - \(S\): 16%
Water Budgets

**Minnesota River Basin:**
1935-1978 to 1979-2011

\[ P - ET = \frac{dS}{dt} \]

10% 7%

**Red River of the North Basin:**
1935-2003 to 2004-2011

\[ P - ET = \frac{dS}{dt} \]

16% 14%

**Illinois River Basin:**
1939-1961 to 1962-2011

\[ P - ET = \frac{dS}{dt} \]

5% 3%

**Chippewa River Basin:**
1935-1974 to 1975-2011

\[ P - ET = \frac{dS}{dt} \]

3% 2%
Water Budgets

**Minnesota River Basin:**
1935-1978 to 1979-2011

\[ P - ET - Q = \]

- 10% (\uparrow)
- 7% (\uparrow)
- 106% (\uparrow)

**Red River of the North Basin:**
1935-2003 to 2004-2011

\[ P - ET - Q = \]

- 16% (\uparrow)
- 14% (\uparrow)
- 120% (\uparrow)

**Illinois River Basin:**
1939-1961 to 1962-2011

\[ P - ET - Q = \]

- 5% (\uparrow)
- 3% (\uparrow)
- 23% (\uparrow)

**Chippewa River Basin:**
1935-1974 to 1975-2011

\[ P - ET - Q = \]

- 3% (\uparrow)
- 2% (\uparrow)
- <1% (\uparrow)
Water Budgets

Minnesota River Basin:
1935-1978 to 1979-2011

\[ P - ET - Q = \frac{dS}{dt} \]

10% 7% 106% -213%

Red River of the North Basin:
1935-2003 to 2004-2011

\[ P - ET - Q = \frac{dS}{dt} \]

16% 14% 120% -31%

Illinois River Basin:
1939-1961 to 1962-2011

\[ P - ET - Q = \frac{dS}{dt} \]

5% 3% 23% -103%

Chippewa River Basin:
1935-1974 to 1975-2011

\[ P - ET - Q = \frac{dS}{dt} \]

3% 2% <1% 16%
Part 1. Human-amplified hydrologic change

Summary of Findings

Quantify **streamflow** trends in four large agricultural river basins
– *greatly increasing in all but one, less intensive agricultural basin*

Quantify and discuss metrics of **climate** and **land use** change
– *indicate increasing precipitation, land conversion to corn/soy, and drainage extent*

Build a **water budget** to determine whether climate alone can explain streamflow trends
– *demonstrates that precipitation and evapotranspiration cannot explain streamflow trends*

We need better documentation and management of drainage practices…

…to decrease the erosive power of Midwest rivers!

DANGER
SWIMMING
UNSAFE
Water detention basins (aka. ephemeral wetlands) reduce sediment loading downstream.

0.5 - 7.5% of total area

Temporary water storage

- Reduces peak flows downstream
- Reduces bluff erosion in the knick zone

Graph showing reduction in downstream sediment loading (%)

- 0.5% wetlands
- 2% wetlands
- 4% wetlands
- 7.5% wetlands

Mean Wetland Residence Time (days)

Sediment

Normalized River Discharge (mm/day)

N Mitchell, K Gran

SJ Cho, P Wilcock
Sediment delivery to Lake Pepin remains high

Where is all that mud coming from?

How much is natural and how much is pollution?

Impacts on ecosystem? Economic costs?

(How) can we clean these rivers up?
**Engage citizens**

Step 1: Monitoring and Assessment
Intensely monitor waters and assess whether meet standards (MPCA leads)

Step 2: Stressor ID
Convene panel of experts to study data and identify conditions stressing water quality and fostering healthy waters (MPCA leads)

Step 3: Watershed Restoration and Protection Strategies (WRAPS)
Develop strategies with local partners and citizens (MPCA leads)

Step 4: Implementation
Local partners implement projects to restore and protect waters (Local partners lead)
Sand and gravel inputs from bluffs cause the river to ‘wiggle’ more.

Greater Blue Earth confluence
Poorly drained, fine textured soils
Down-cutting rapidly for past 13,400 years
Agriculture and drainage began mid 1800s
Continue to evolve in effectiveness, intensity, precision, productivity, etc.
Hundreds of old floodplains record the history.
Fluvial Terraces
The Record of Incision
We’ve got to do everything we can…all practices we can do.

Add MRB long profiles

need slide showing majority of the problems are in GBE

drainage work group has made many recommendations…but you have to want to do it
the recommendations don’t have any teeth.
not looking to make drainage law into water planning law.
if farmers say ‘I only have 1 purpose…I don’t care about multipurpose drainage’
that may end up biting them in the ass.
**Actions to Take**

**Invest in Water Storage**
Methods that filter and store rainwater lead to cleaner water in the rivers.
- Increase temporary storage areas
- Manage drainage with outlet controls, grass waterways, ditch buffers, saturated buffers
- Install more stormwater treatment basins

**Build Soil Health**
Actions that increase soil health also help the land absorb more water during heavy rains.
- Expand use of cover crops and keep roots in the soil for more of the year
- Increase soil organic matter for better water infiltration
- Reduce tillage to keep valuable soil in farmers’ fields
A wide variety of stakeholder interests
Streamflow: Minnesota River Basin

Normalized Flow


- Mean Annual Flow
- Peak Daily Flow Spring
- Peak Daily Flow Summer & Fall
- 7 Day Low Flow Summer
- 7 Day Low Flow Winter
- High Flow
- Extreme Flow

(Kelly et al., 2017; HESS)
Lots of sediment comes from a small area.

Sediment loads up here are moderately high.

Sediment loads down here are very, very high.
Moving the conversation towards a more transparent and verifiable connection between cause & effect

(1) Sediment budget
(2) Suite of management options, explicit on size, location, efficiency, cost, with uncertainty
(3) Reduced complexity simulation model
(4) Decision analysis framework
How to predict non-point source pollution?

Lots of ag input data… inherently biased to ag problems and solutions

'Sophisticated' models with lots of parameters are severely limited by problems of equifinality
Gaming equifinality problems where we know the right answer.

NSE Model Performance Metric

Poor

Good

Gaming equifinality problems where we know the right answer.

Nash–Sutcliffe: 0.67
PBIAS: 15.70

NSE Model Performance Metric
The up-sides of drainage

1. Crop productivity is way up!
2. More rainfall infiltrates into the soil, less runs off the surface

July 2013 fluorescence

Figure 3. Corn and Soybeans Yield Trends 1980-2009.

- 2.4% per year
- 1.8% per year
The downsides of drainage

1. Concentrating flow in some sensitive areas
2. Increasing the amount and rate of water delivered to the river
3. Increasing N export
Observatory Highlights:
Lidar analysis and feature extraction

Change detection from 1m DEMs over 2000 km²
Largest GCD study to date!

Spatially variable uncertainty
Denitrification rates are carbon limited

An important caveat:
Nitrate removal depends on carbon availability

Areal denitrification rate (mg-N/m²/hr)

NO₃⁻ (mg/L)

DOC:NO₃⁻

A. Hansen, J. Finlay

Mulholland et al. 2008
Bohlke et al. 2009
Wetland composition and location matter.
Hansen et al., The interactive effect of wetlands, crop lands and stream network on riverine nitrate, Nature Geosciences, to appear, 2017
Megarains: 6” rain fall over an area of 1,000 or more square miles and the core of the storm generates at least 8 inches of rain
Locally developed & implemented

Facilitates targeting & prioritization

Coordinates efforts

Engages broad range of stakeholders

Formal agreements, but adaptable
On average, 50,000 Mg/yr
From excavation of the valley

For details on incision history, see Gran et al., 2013, GSA Bulletin
Recent erosion estimates suggest 170 Mg/yr contributed within the knick zone.

But how did we get here?

Gran et al., 2013
Channel dynamics amplified near point inputs

Signal dampened 100 km downstream!

Greater Blue Earth confluence
Collect and synthesize new and existing information for river C, N, P, Chla, TSS

- 9200 wq samples
- 10 ditches, 10 visits
- 235 sites, ~6 times

WSC
Minnesota River Basin Observatory

Model Repository

CSSR
Non-stationary channel/floodplain
Network routing
Meander toolbox
Mussel dynamics
Nested SWAT

Channel Morphology
Migration, widening
7000+ km banks mapped
47 cross sections 2008-2015

Repeat terrestrial lidar
12 bluffs, 6 years

Structure-from-motion photogrammetry and stationary photo stations
2 sites, 3 years daily photos
17 sites started 2015

Map river channel bathymetry using ADCP
180+ km
40+ grain size

Sediment fingerprinting
200+ $^{10}$Be, $^{210}$Pb, $^{137}$Cs samples

Measure Holocene erosional and depositional history with
OSL, $^{14}$C, GPR
31 terraces, 6 alluvial fans
5 paleo-channels GPR

Benthic light availability
40 sites for cal/val

$^{18}$O water source tracers
700 samples

Compile and collect biological + food web data
Algal biomass, mussels, IBIs
1000 13C, 15N, 2H stable isotope
3200 biomonitoring - MPCA

All point source discharges

Measurements of aquatic nutrient cycling
100 Denitrification,
70 P-sediment interactions
diurnal $O_2$ 23 snapshots

Land use history and agroeconomic data

Compile and synthesize
Prec & Q data

Mussel dynamics
Nested SWAT
How does artificial drainage affect streamflow?

Regional analysis of large watersheds

High resolution SWAT model

High flows: damped at 1 km² scale
amplified at $10^3$ km² scale
Sediment from the Minnesota River causes problems in Lake Pepin

Where is all that mud coming from?
How much is natural and how much is pollution?
Impacts on ecosystem? Economic costs?
(How) can we clean these rivers up?