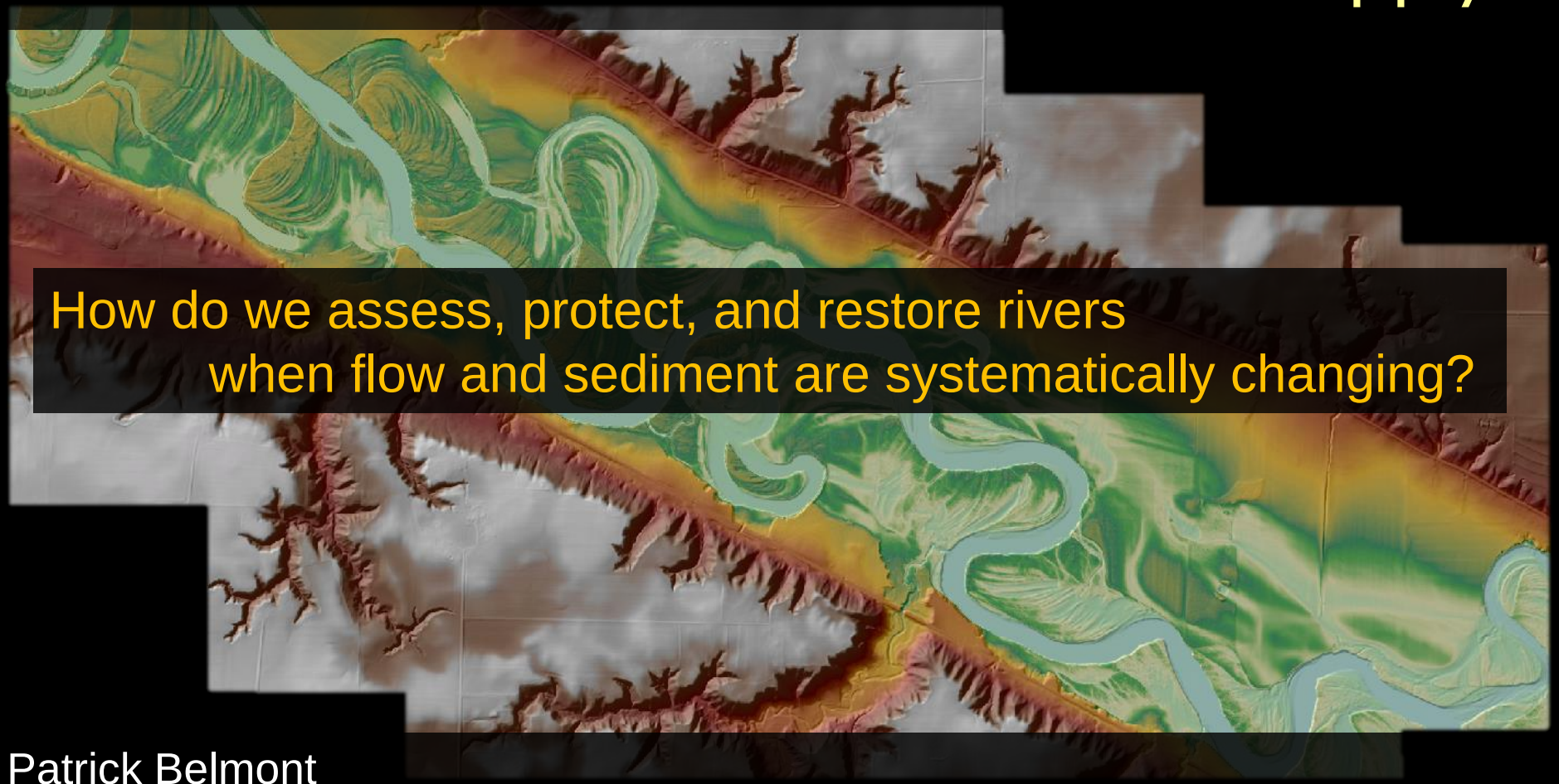
River channel responses to large increases in flows and sediment supply



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

Patrick Belmont
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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.

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NSF

USDA

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

DEPARTMENT OF NATURAL RESOURCES

Minnesota Pollution Control Agency

MAWRC MINNESOTA AGRICULTURAL WATER RESOURCE CENTER

MINNESOTA DEPARTMENT OF AGRICULTURE

MinnesotaCorn RESEARCH & PROMOTION COUNCIL

In the next 30 min…

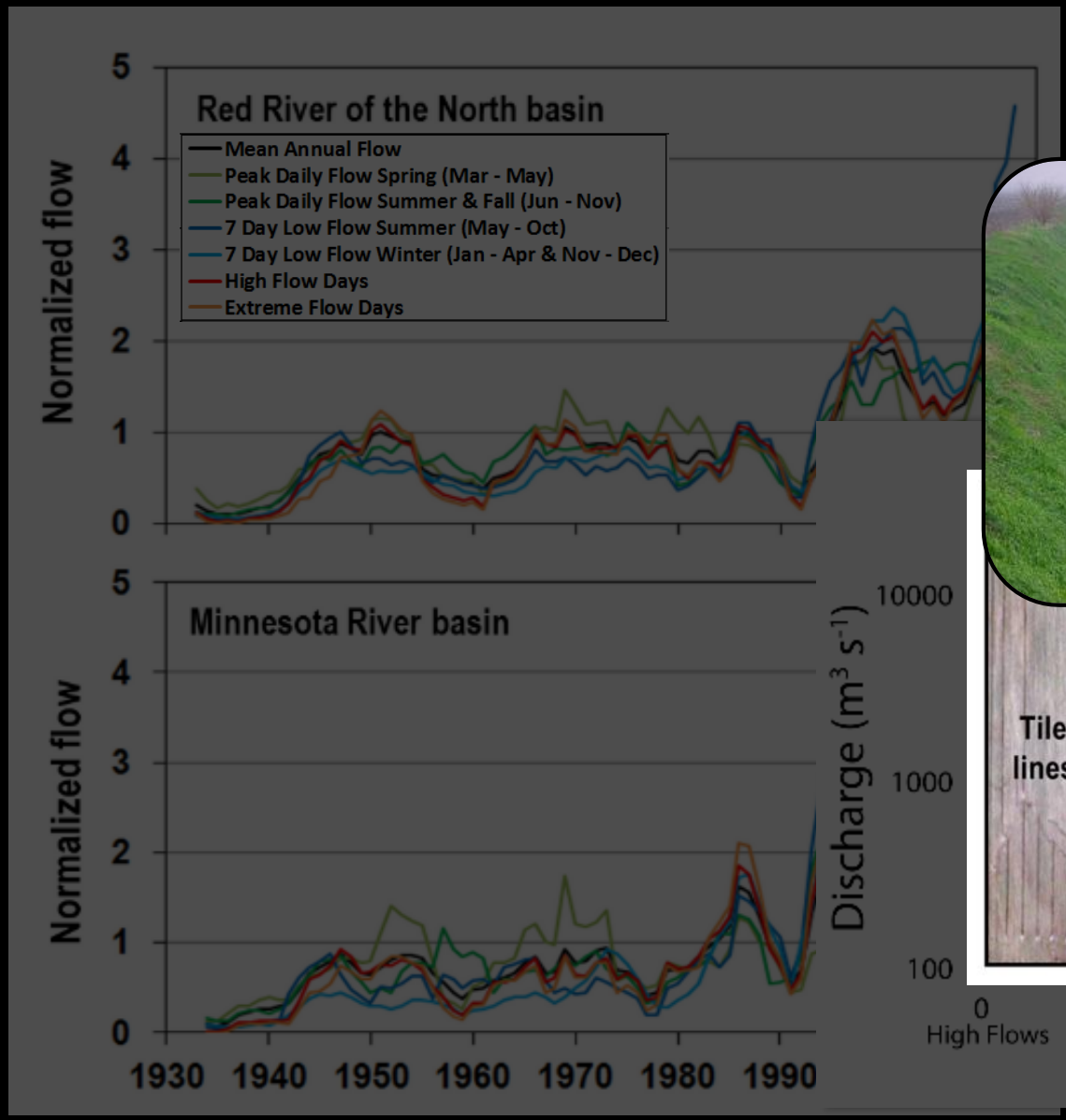
For the flows, they are a changin’

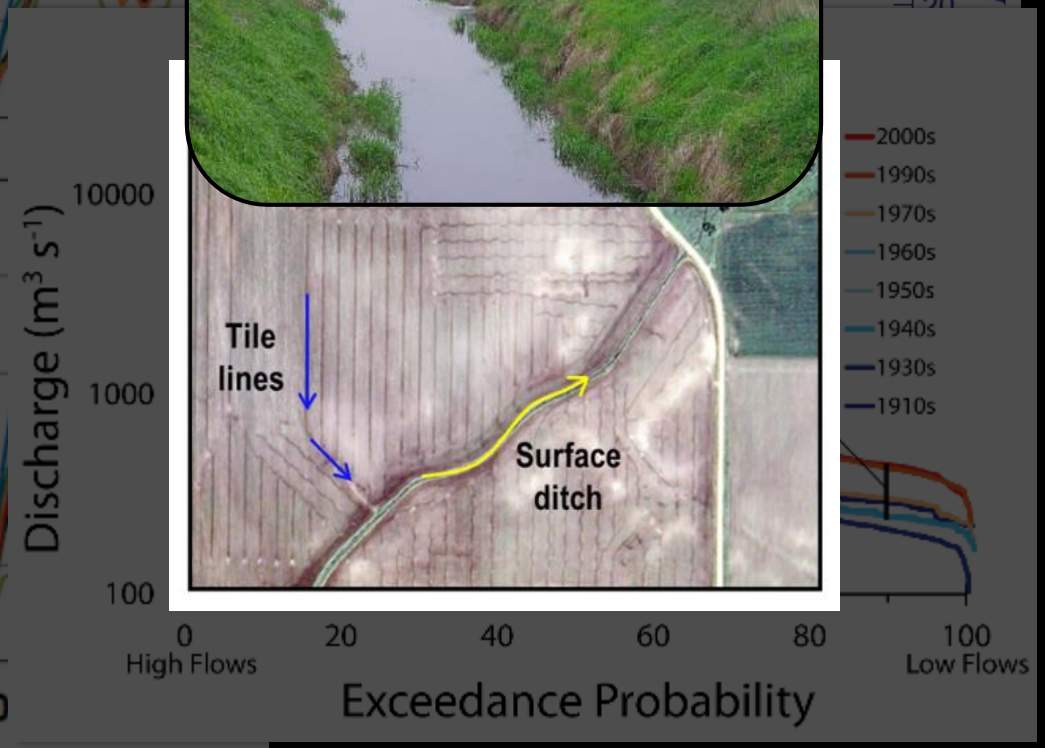
“Come gather ‘round people, wherever you roam
and admit that the waters around you have grown”

Different rivers, different responses

Determining sediment sources and sinks to inform restoration

Flows have gone waayyy up



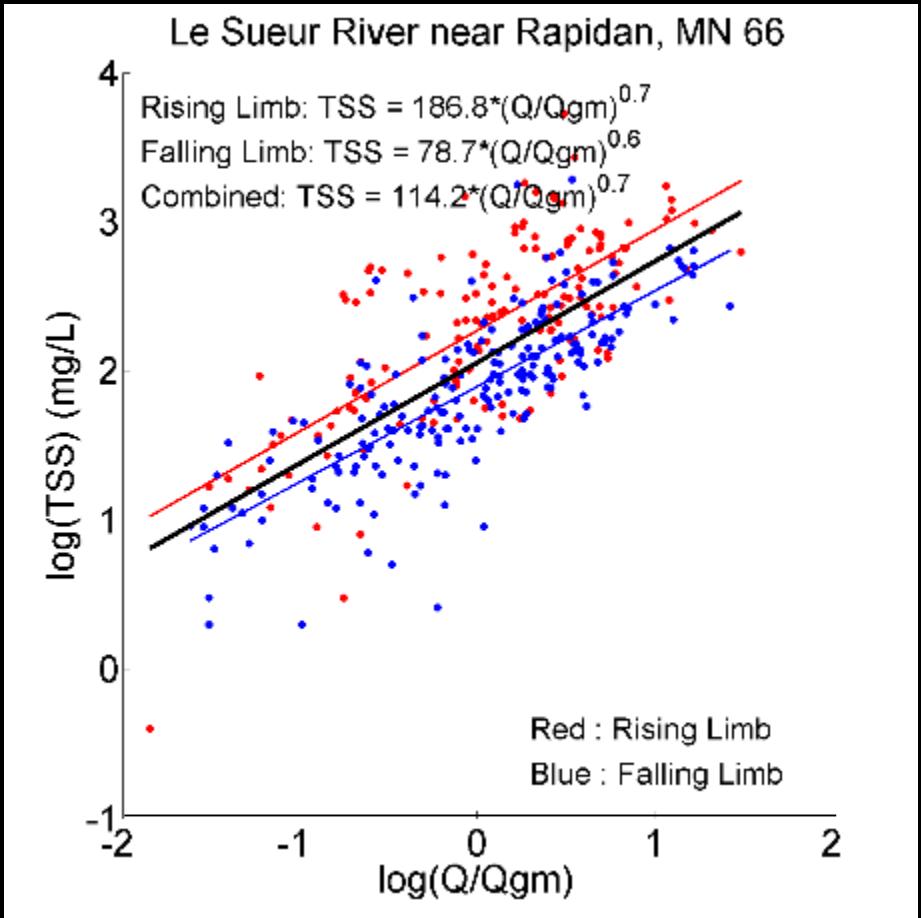


Schottler et al., 2014; Foufoula-Georgiou et al., 2015; Belmont et al., 2016; Kelly et al., 2017

Relationships between flow and sediment
Sediment Rating Curves

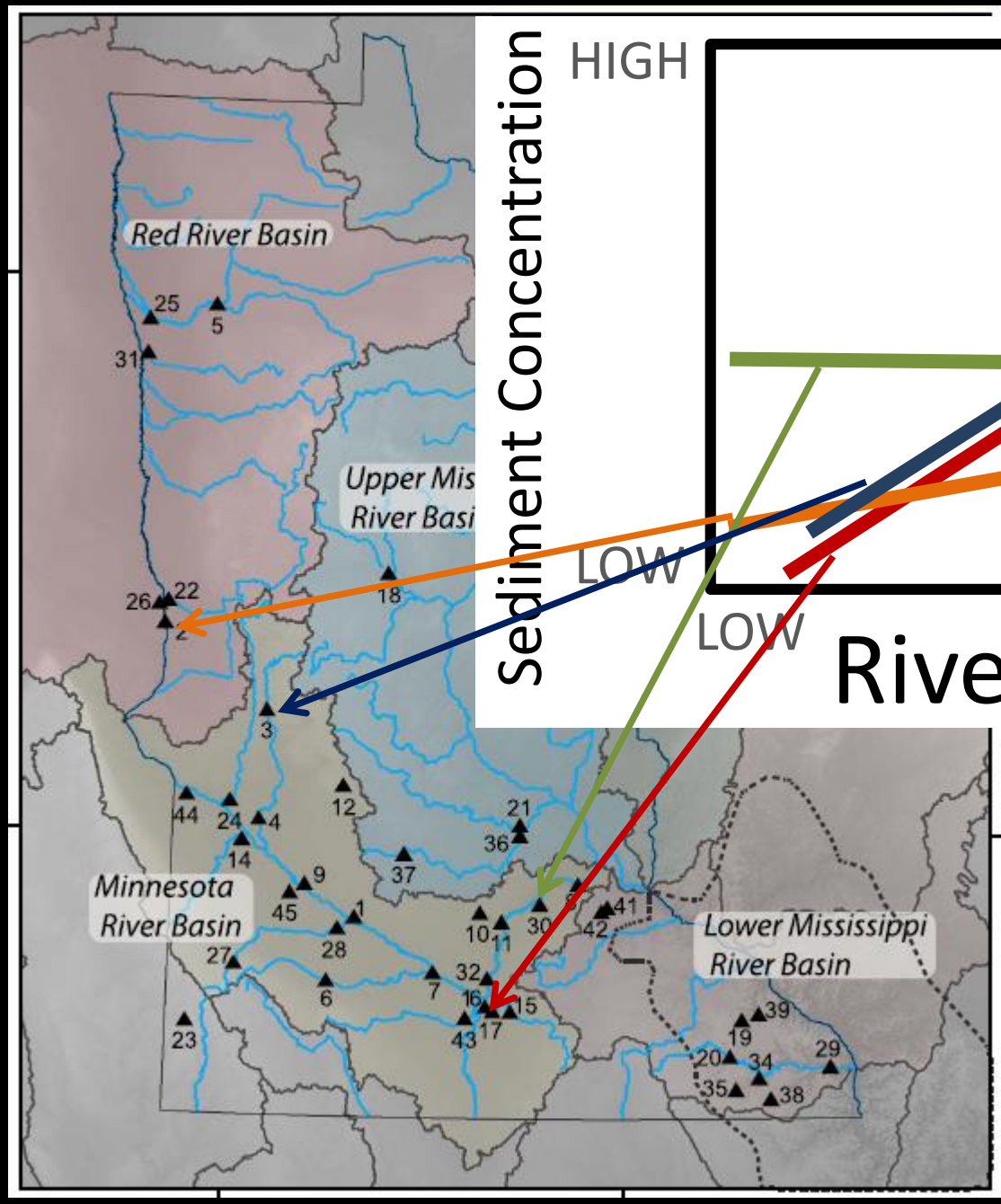
- Persistent, distinguishing characteristics of a river's sediment regime that integrate sediment supply and transport capacity across the range of flows.

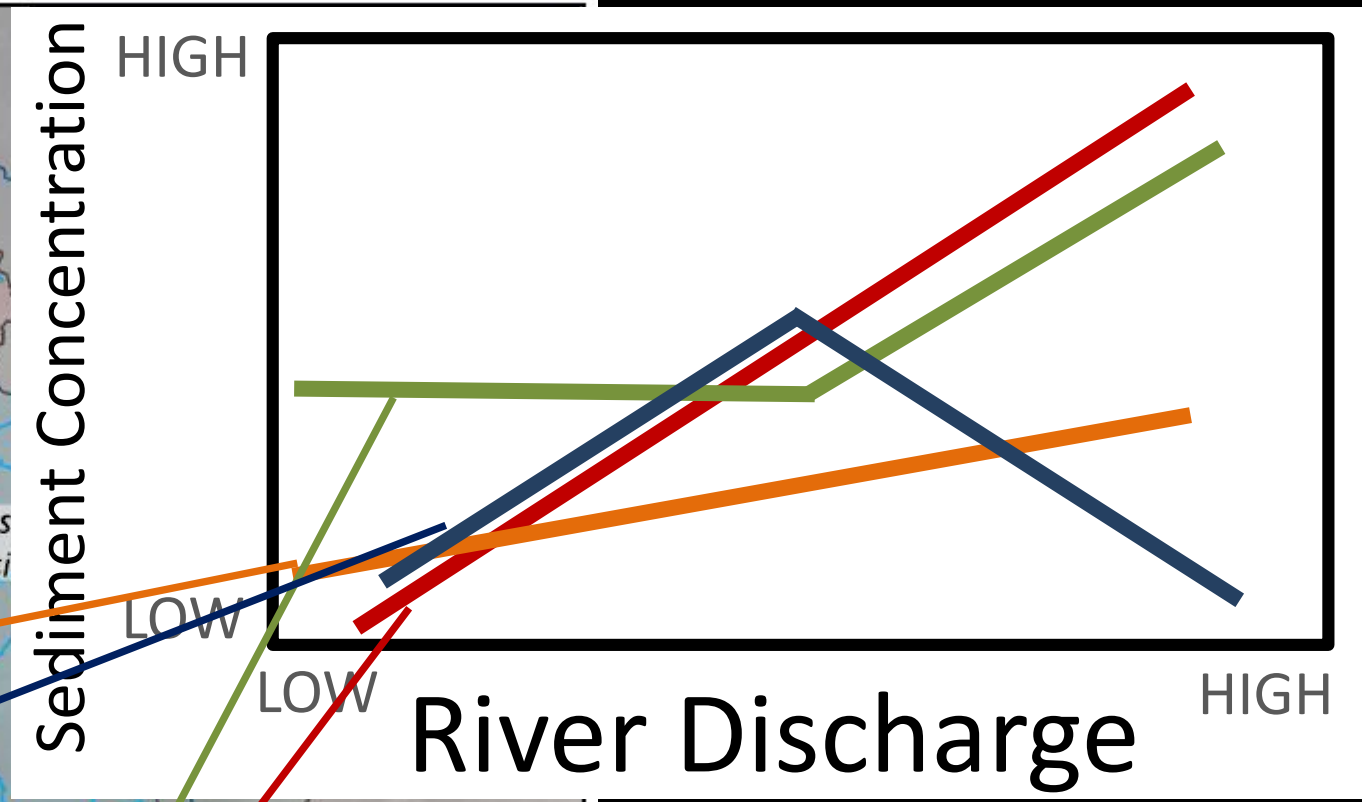
- Separate rising/falling limb samples



Vaughan et al., 2017

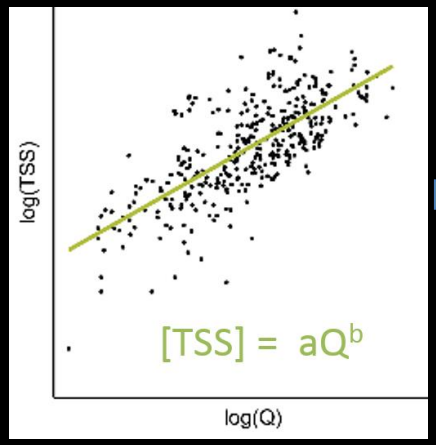
Distinct relations between Q and suspended sediment





- What controls the shape and other characteristics of Sediment Rating Curves?
- Role of land use versus geomorphic setting/history?

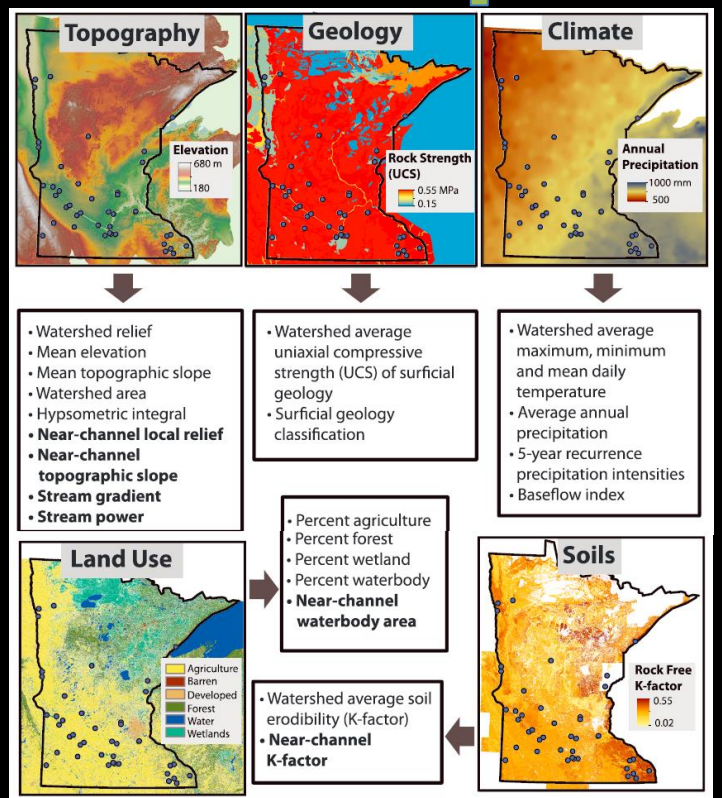
Predict gage-to-gage variation in SRC characteristics using landscape and environmental variables

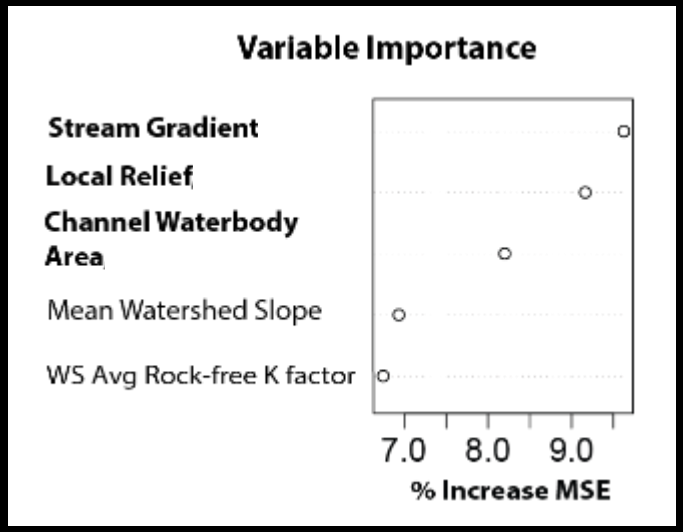


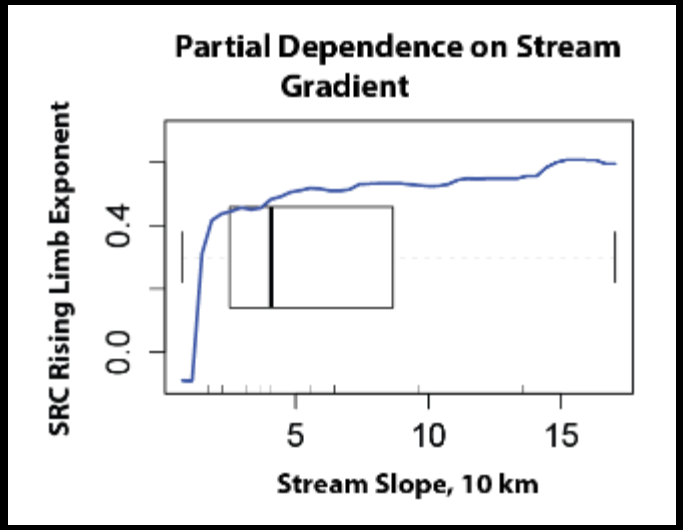
×45

NC
WS

Random Forest Models





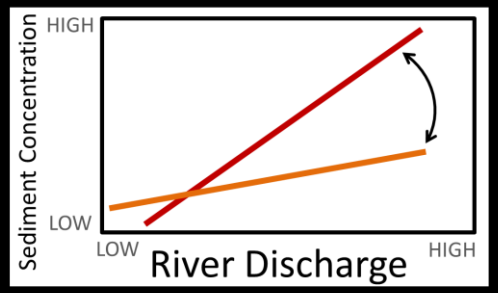


Vaughan et al., 2017

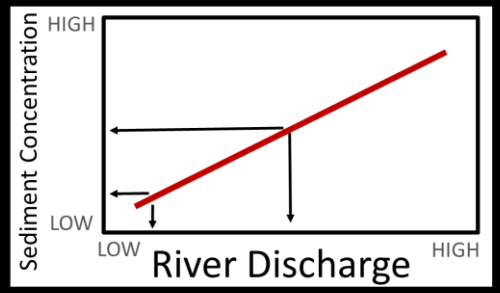
What controls Q/TSS relations throughout Minnesota?

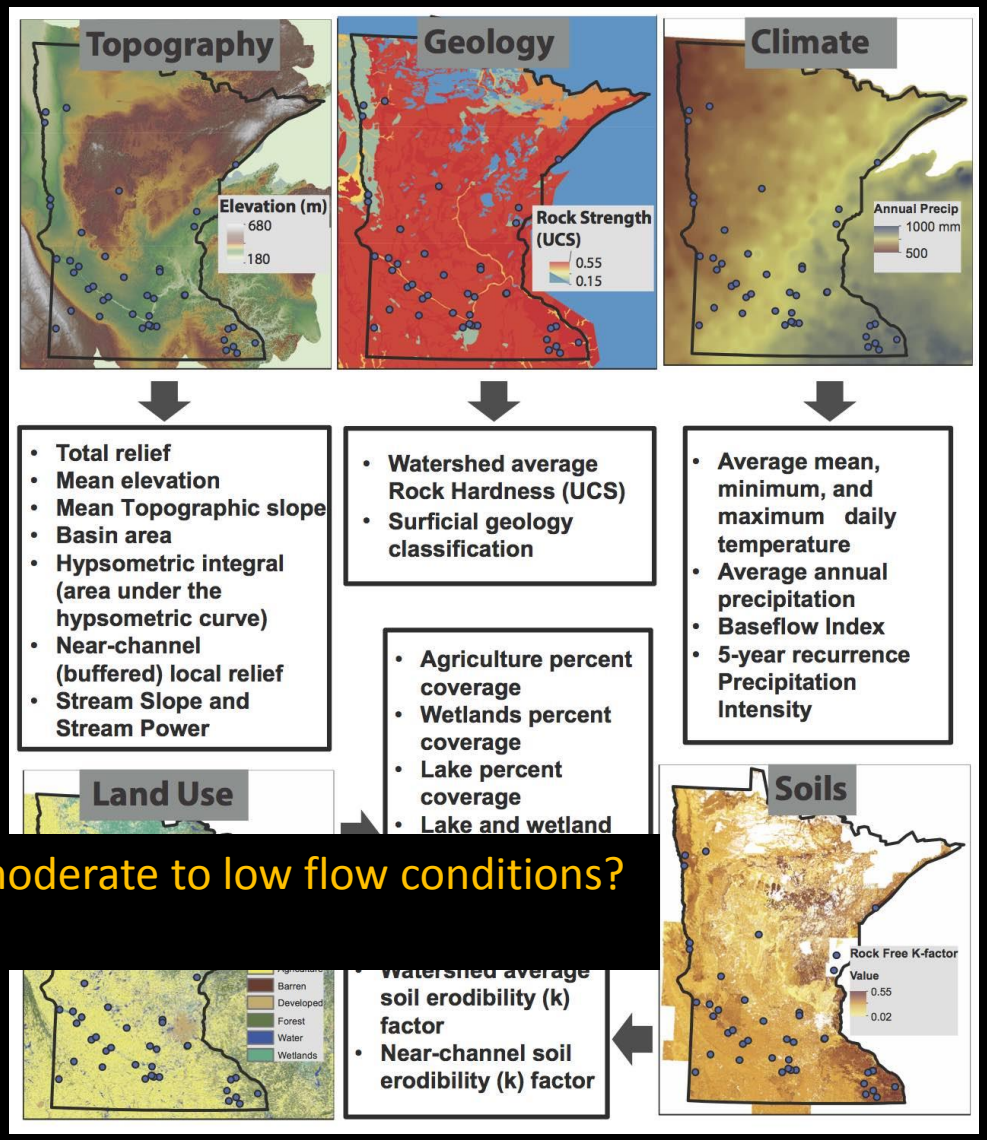
What controls the SHAPE of the curves?
…geologic setting/history

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…

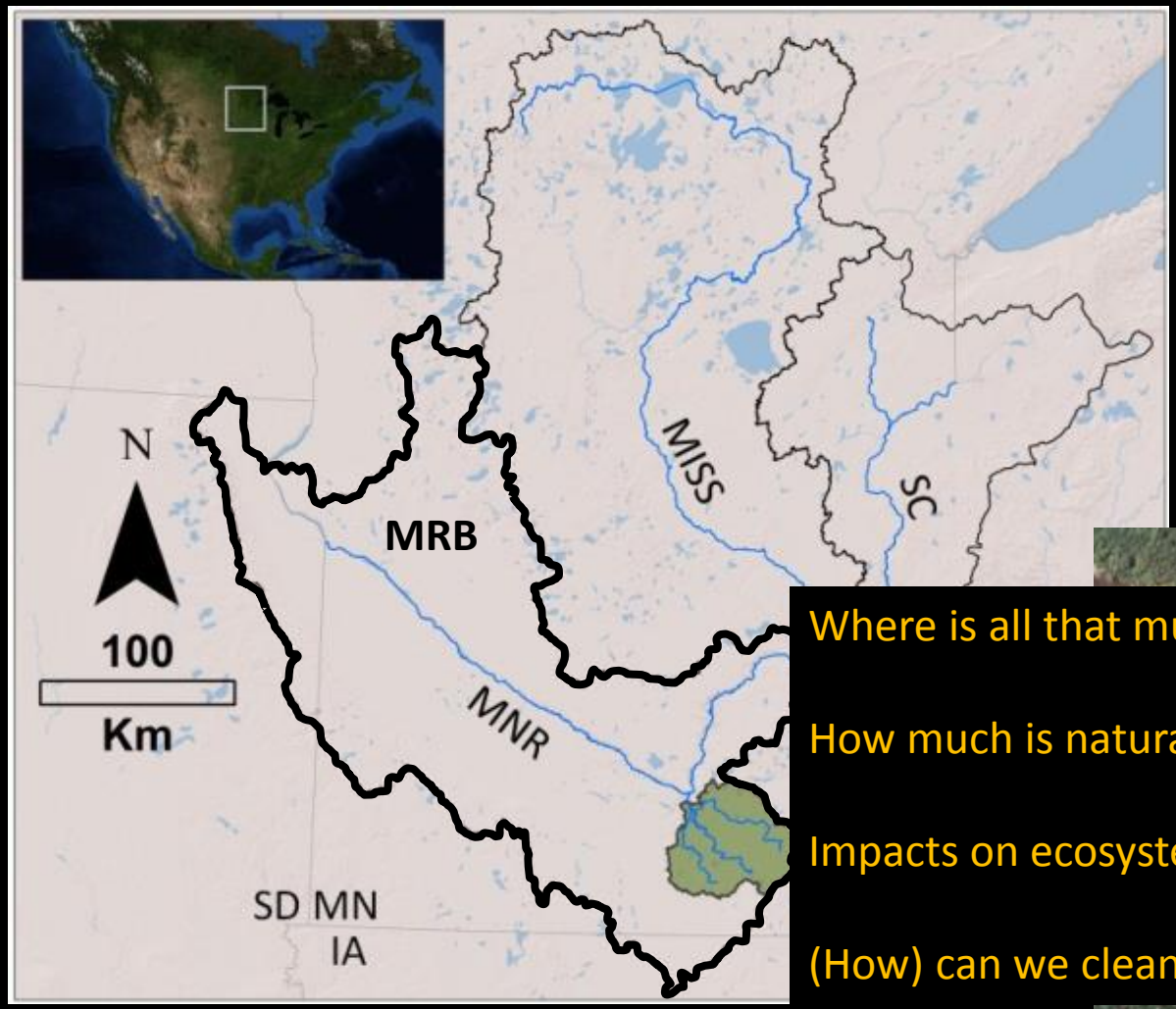
For the flows, they are a changin'

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

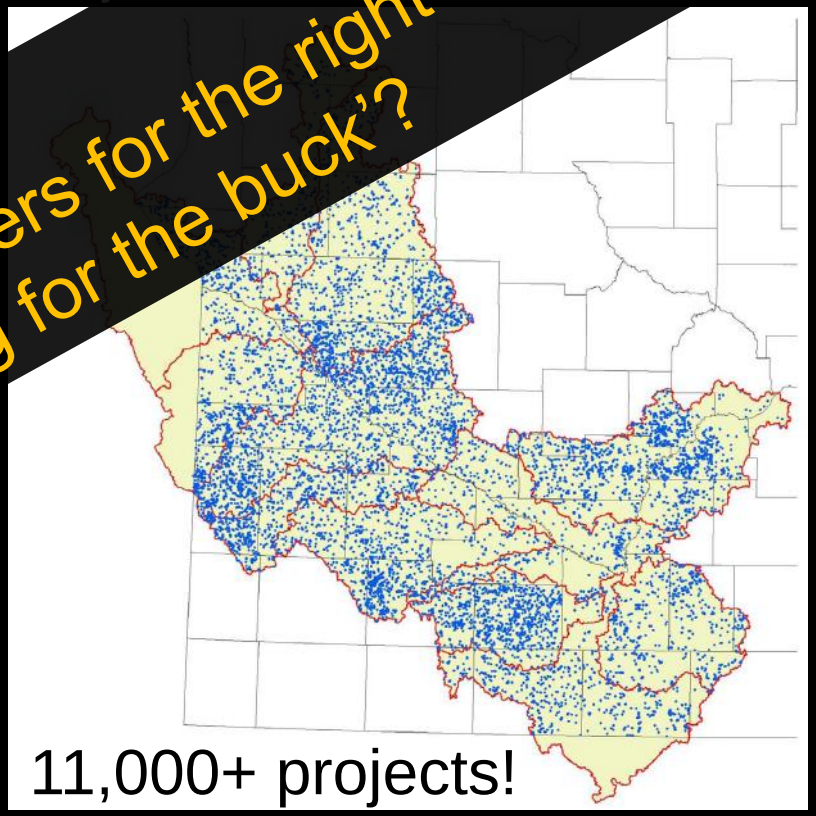
The cause of the problem is obvious, right?

Past and future investments in water quality…

Lots of money invested, but no reduction in sediment?

Musser et al., 2009

Sediment and nutrient management Projects 1997 - 2008



Lots more to be invested…
- need to get the right answers for the right reasons
- how to get the best 'bang for the buck'?

How to quantify sediment sources?

Semi-quantitative models

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

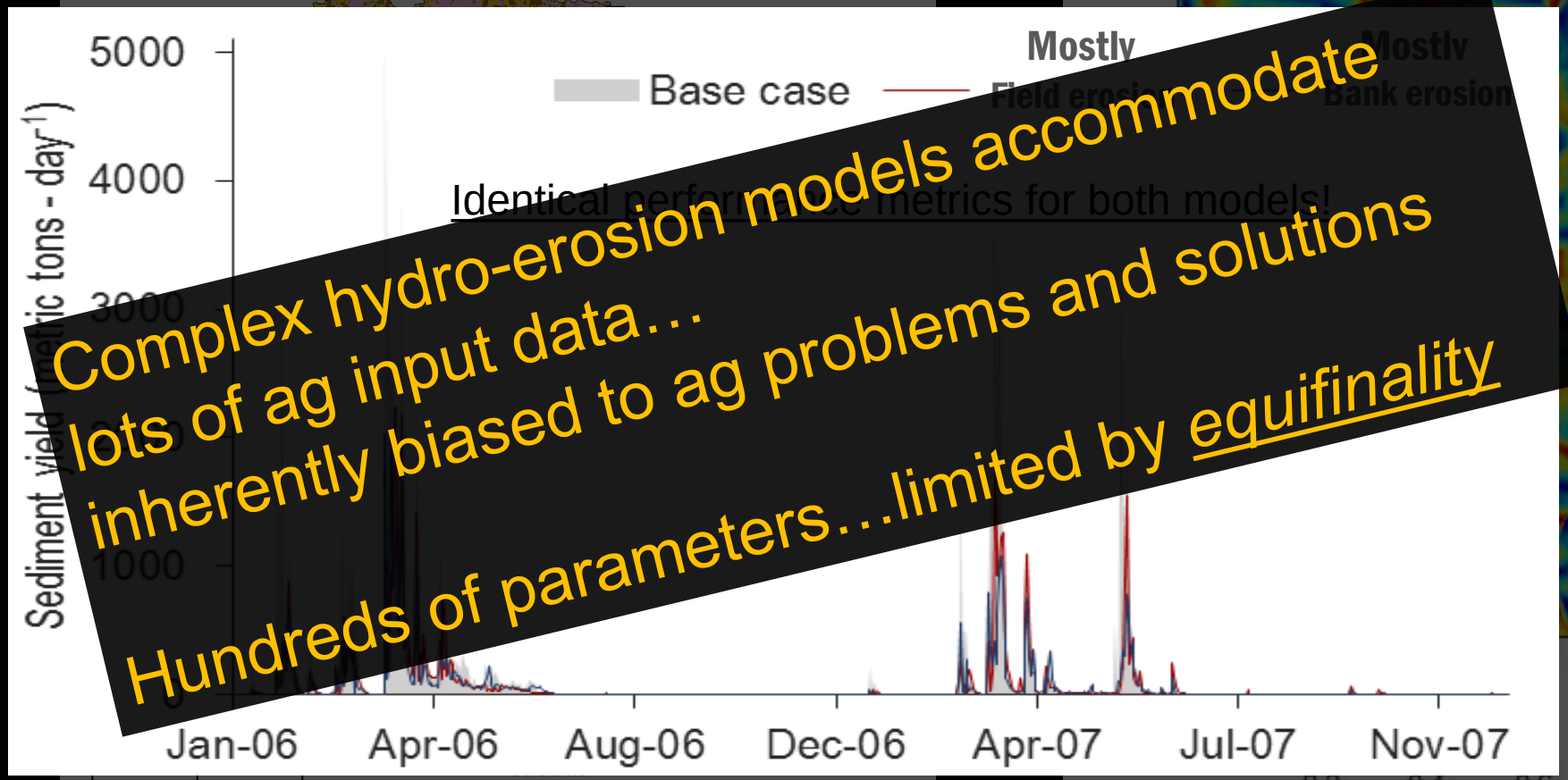
$$SSY = 4139 * A^{-0.44} + 7.77 * FSMIndex - 310.99$$

Must be calibrated to a particular landscape

Common critique: these evaluations may be more likely to *reinforce pre-conceptions* than provide new, objective insight

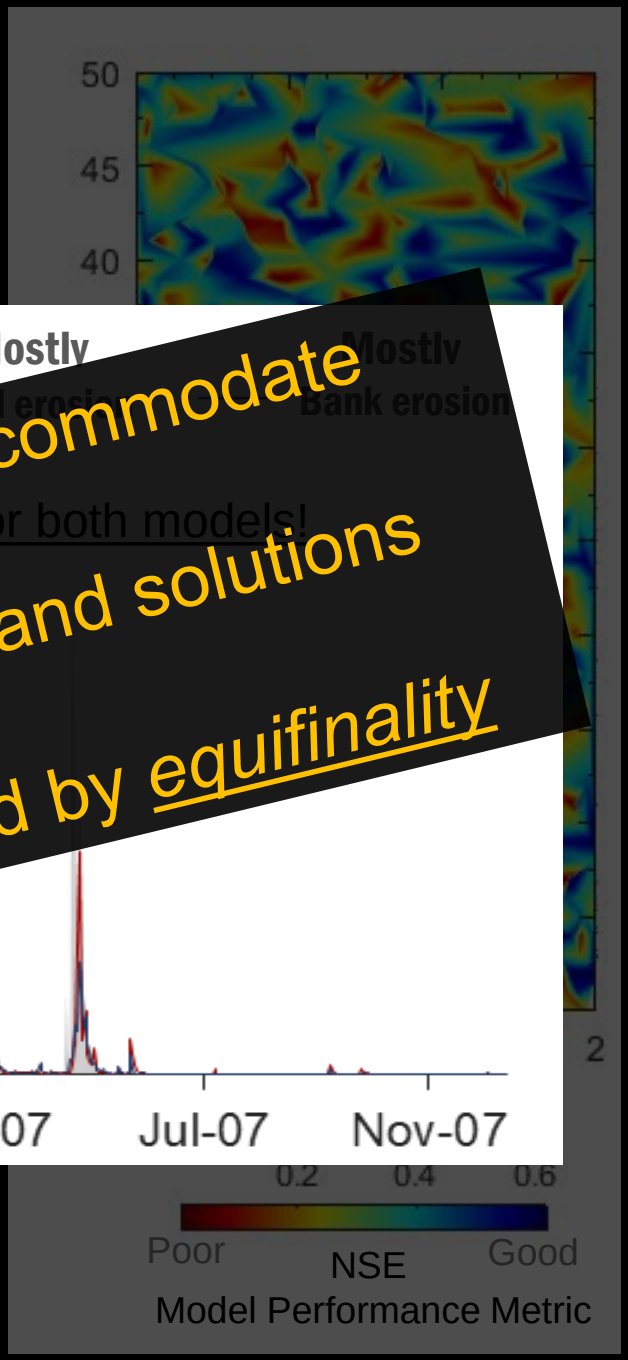
Factor	Score	Description
Topography	1	very gentle slopes near reservoir and main rivers; elevation difference <200 m within 5 km
	2	moderate slopes near reservoir and main rivers; elevation difference 200–500 m within 5 km
	3	steep slopes near reservoir and main rivers; elevation difference >500 m within 5 km
Vegetation cover	1	good contact cover of the soil (>75% surface protected)
	2	moderate contact cover (25–75% protected surface)
	3	poor contact cover (<25% protected)
Gullies	1	bank and ephemeral gullies are very rare
	2	few bank and/or ephemeral gullies can be observed
	3	many bank and/or ephemeral gullies can be observed
Lithology	1	dominant limestone, sandstone or conglomerate (low weathering degree)
	2	dominant Neogene sedimentary deposits (gravels, etc.)
	3	strongly weathered (loose) material and/or marls
Catchment shape	1	elongated catchment shape with one main river channel draining to the reservoir; no significant direct runoff from slopes into the reservoir
	2	between elongated and (semi-) circular catchment shape
	3	(semi-) circular catchment shape with many rivers draining into the reservoir and/or much direct runoff from hill slopes to the reservoir

Comparable hydro-erosion models may give you very different answers

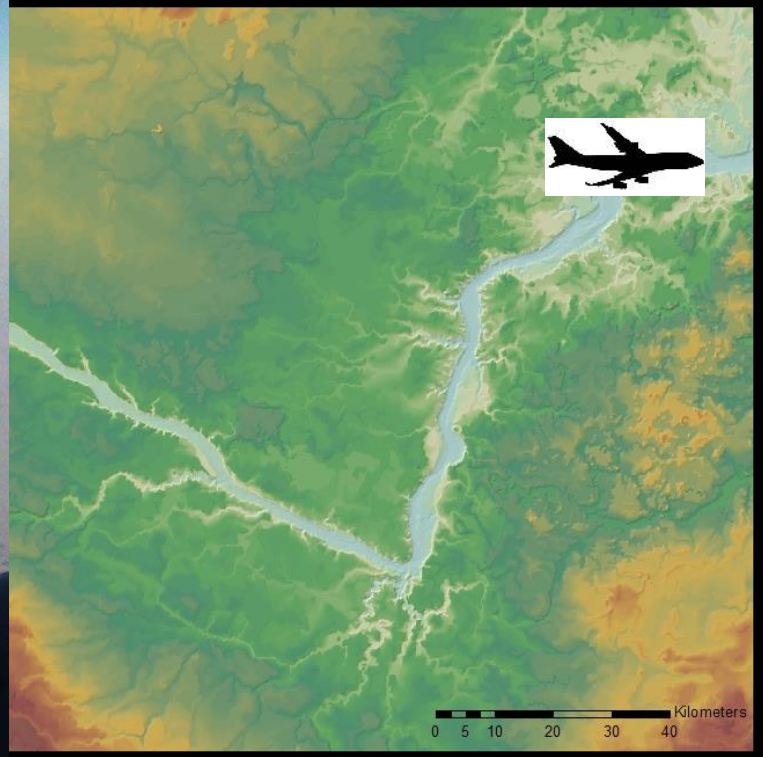


Complex hydro-erosion models accommodate
lots of ag input data…
inherently biased to ag problems and solutions

Hundreds of parameters…limited by <u>equifinality</u>

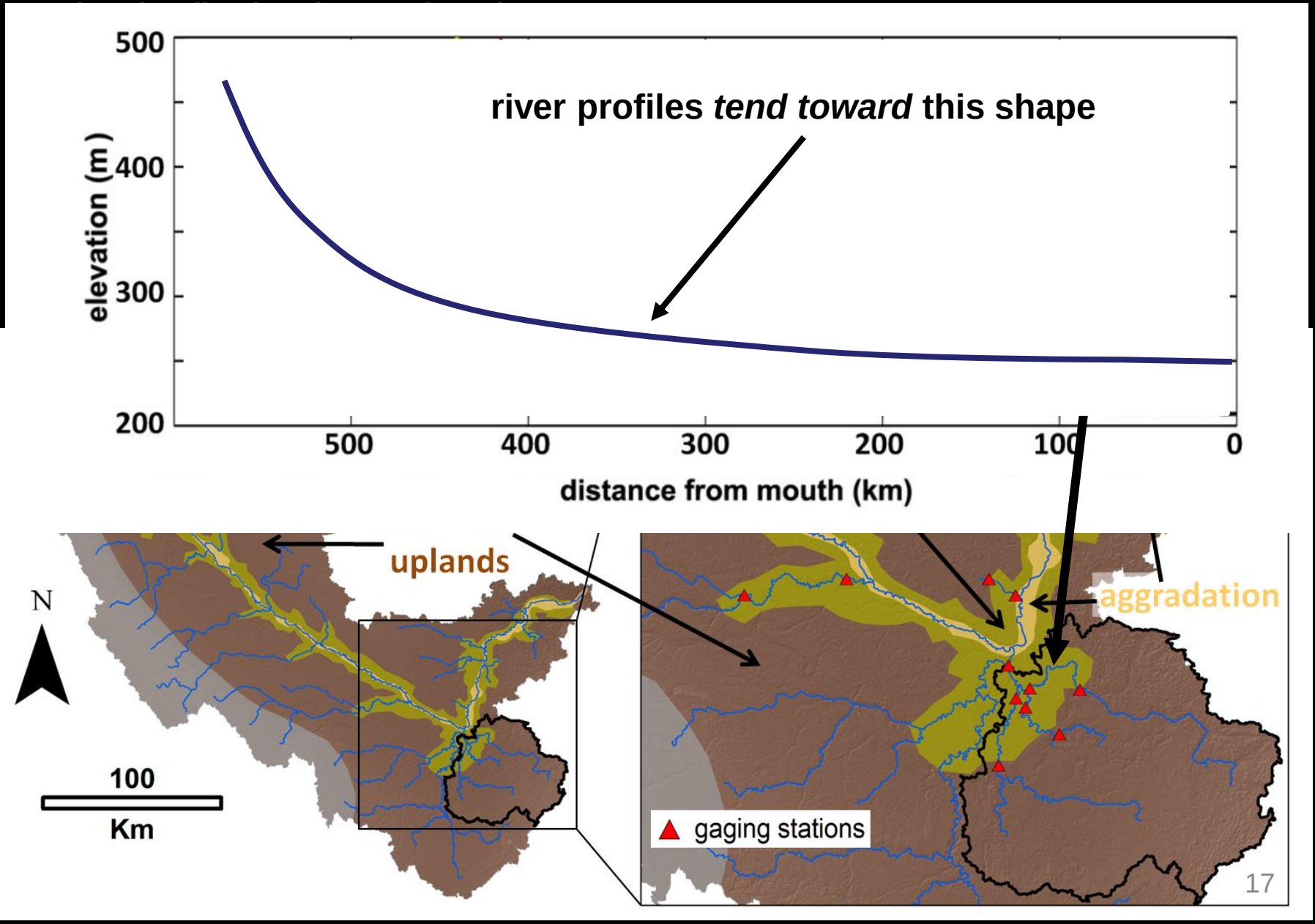


Geologic history made this a very sensitive landscape



Belmont, 2011; Gran et al., 2013

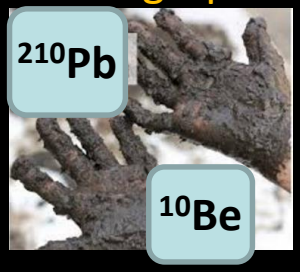
Geologic history makes this a very sensitive landscape



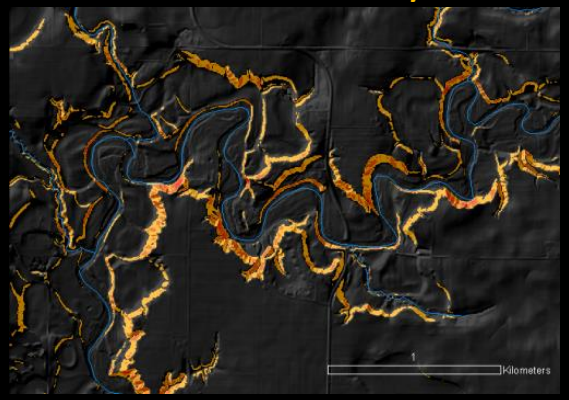
Le Sueur River Watershed Sediment Budget

Many tools employed...

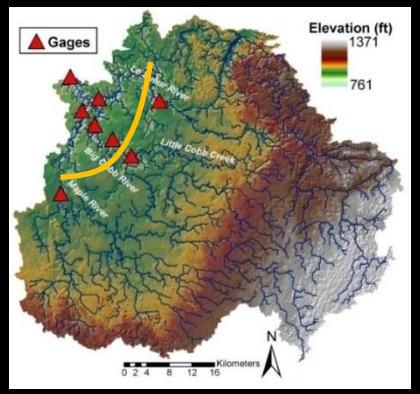
Sediment fingerprinting



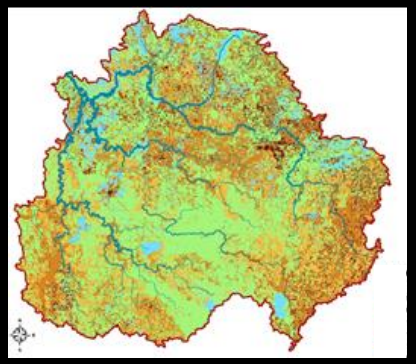
Aerial Lidar analysis



Gages galore!

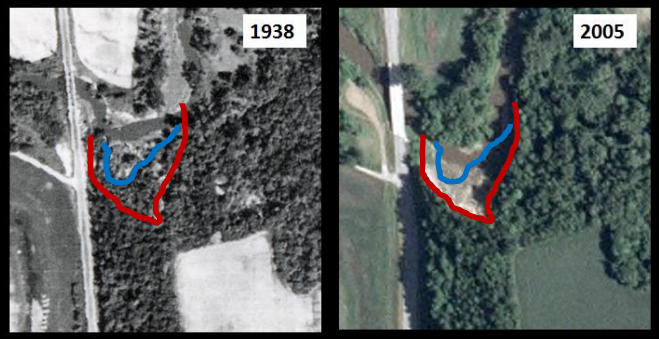


Modeled Soil erosion rates

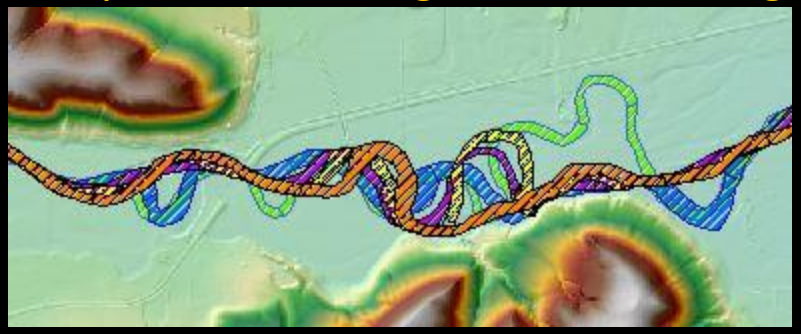


50+Field surveys

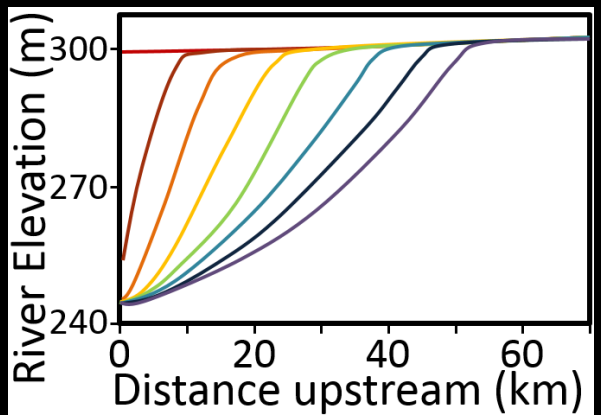
70 years of bluff erosion rates



70 years of river migration & widening

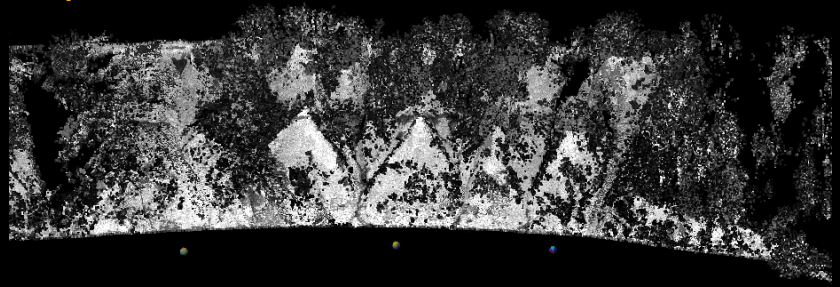


14C & OSL-Dates for incision history

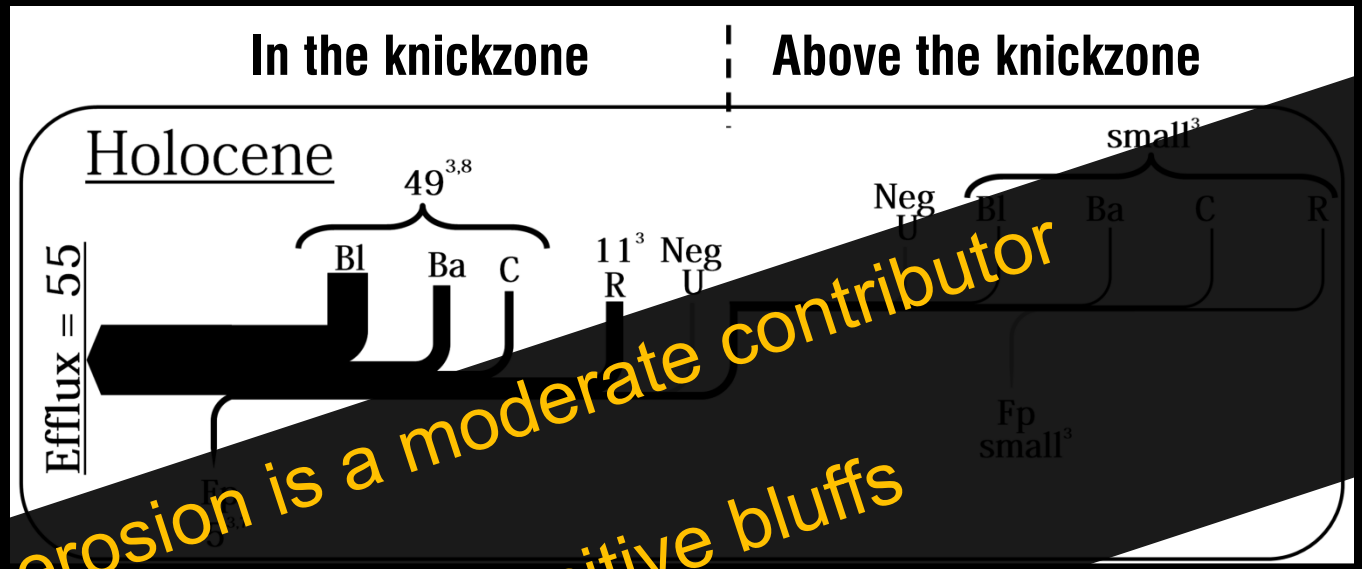


Belmont et al., 2011

4 years of terrestrial lidar



Le Sueur Fine Sediment Budget



Sources

U: Uplands
F_p: Floodplain
Bl: Bluffs
Ba: Banks
C: Channel incision
R: Ravines

Upland soil erosion is a moderate contributor

Erosion of geologically-sensitive bluffs has been *amplified* by high flows

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

Corroboration 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

10 km

How can we reduce runoff, keep soil erosion low and maintain this as a productive ag landscape?

Drain management

Ditch management

Wetland restoration

Buffer strips

Water retention

Soil organic matter

Cover crops

Bank stabilization

Collaborative for Sediment Source Reduction (CSSR)

2012 — 2013 — 2014 — 2015 — 2016 — 2017

1 — 2 — 3 — 4 — 5 — 6 — 7 — 8 — 9 — 10

Management
Options
Extents
Rates
Costs

Processes
Hydrologic Modeling

Predict Erosion & Deposition

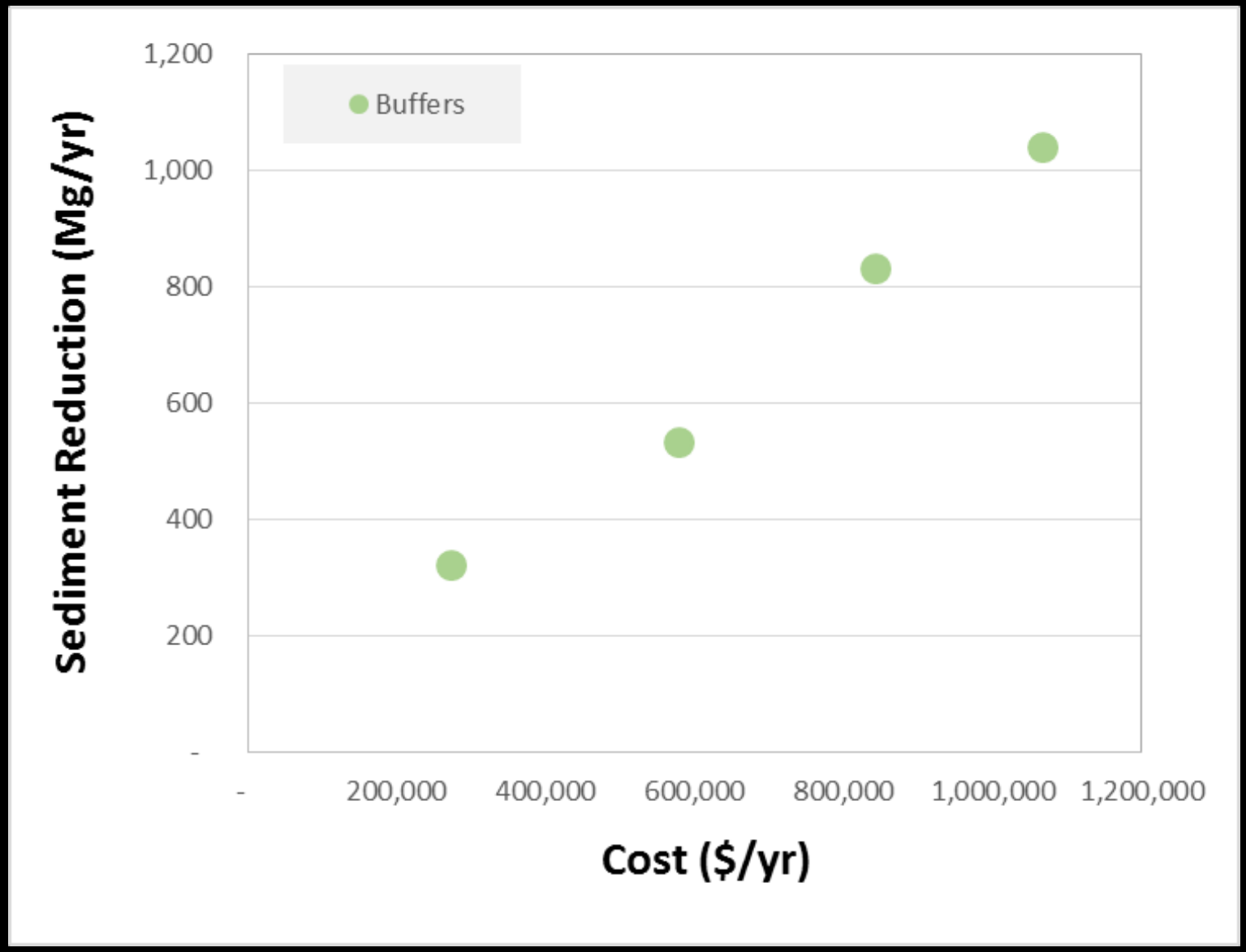
Water & Sediment Routing

Simulation
Model

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

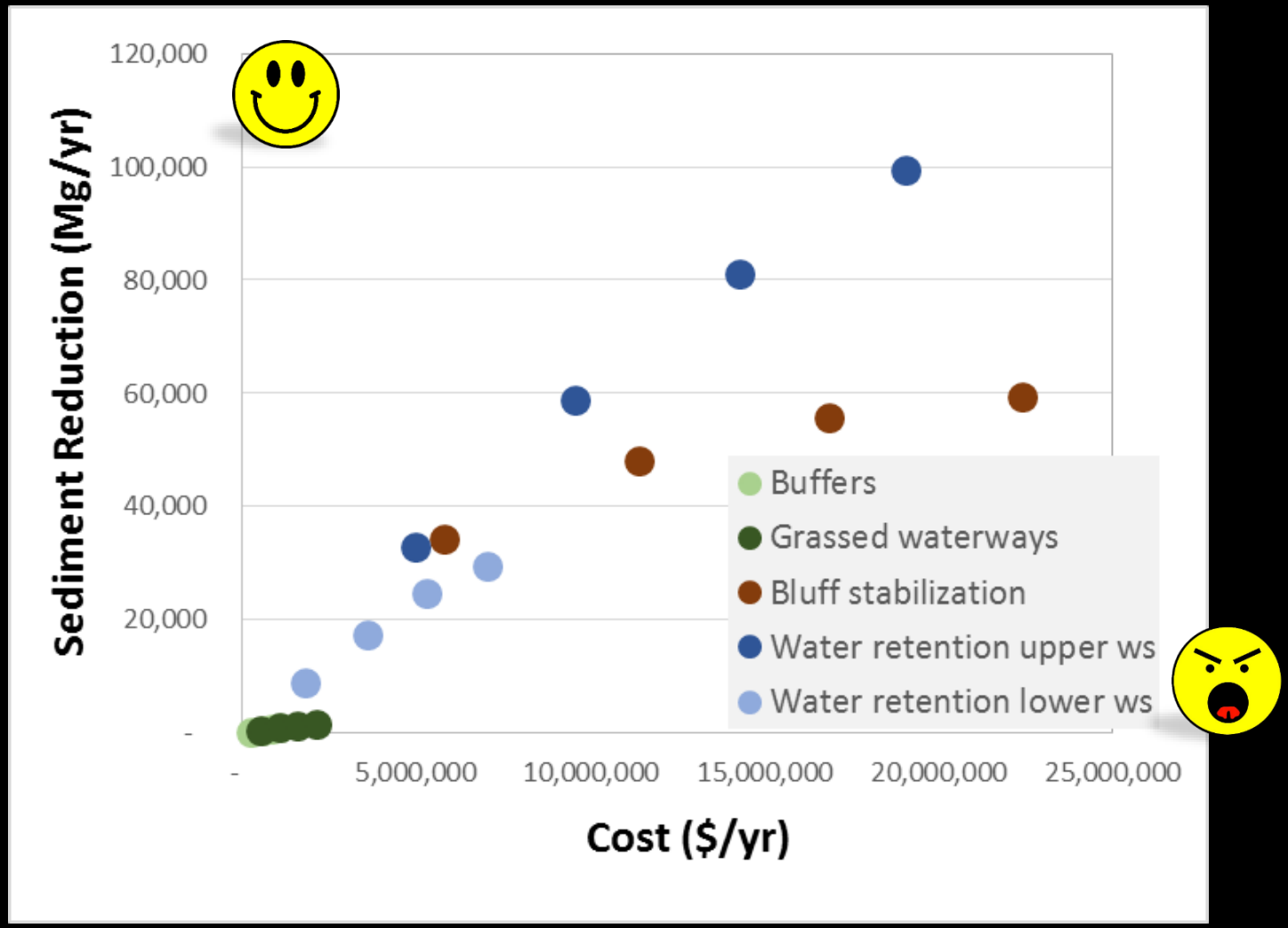
Wilcock et al., 2016; Cho et al., 2018; Cho et al., in review

How do we get the most 'bang for the buck'?



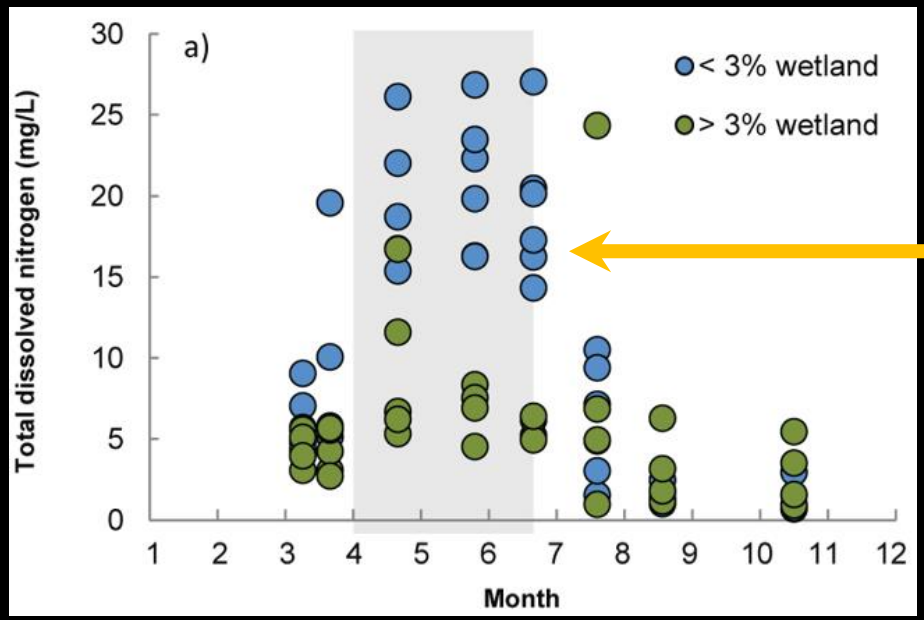
CSSR MOSM Model Results for Le Sueur watershed, for demonstration

How do we get the most 'bang for the buck'?

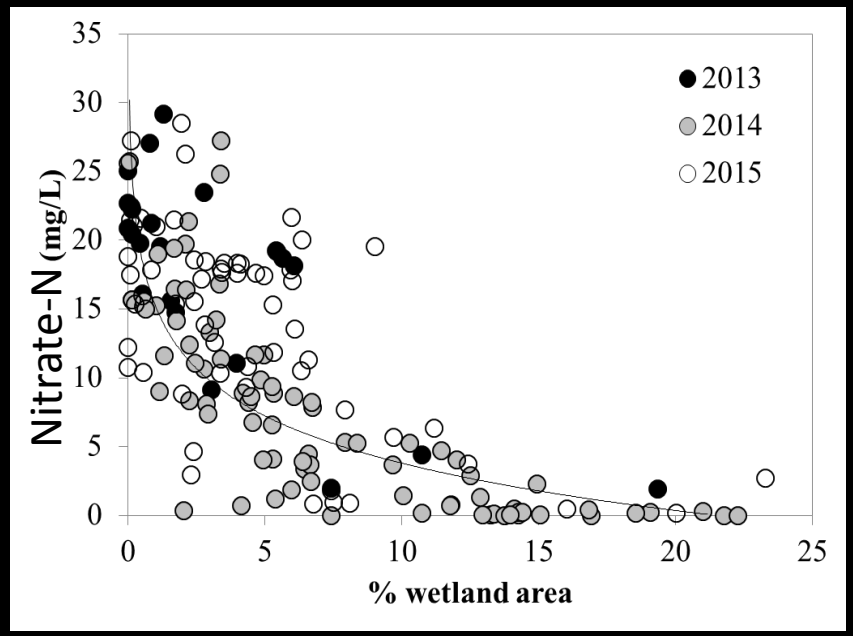


CSSR MOSM Model Results for Le Sueur watershed, for demonstration

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 km^2) sampled same week

A. Hansen, J. Finlay

Consensus!

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

Collaborative for Sediment Source Reduction – Greater Blue Earth River Basin
Summary of Findings

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 rea
sediment loading from th
Minnesota River and man
Blue Earth, are known
solids. This causes pro
causes deposition proble
River, degrades water qua
increases the rate at which
the Minnesota River deliv
water to the Mississippi R
more than two-thirds of t
of sediment to the Minn
River Basin, which includ
Rivers.

The citizens of Minnesot
public funding to improve
River, particularly with t

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.

David Ward	Farmer, Mapleton, MN
Steve Sodeman	Farmer, Consultant, St James, MN
Dave Bucklin	GBERBA, Cottonwood SWCD
Eric Gulbransen	Waseca SWCD
Wayne Cords	Waseca SWCD
Leann Buck	MN Association of SWCD
Julie Conrad	Blue Earth County
Warren Formo	MN Ag Water Resources Center
Adam Birr	MN Corn Growers Assoc.
Paul Meints	MN Corn Growers Assoc.
Heidi Peterson	MN Dept. Agriculture
Jon Lore	MN Dept. Natural Resources
Linda Loomis	Lwr MN R Watershed District
Ed Lenz	BWSR
Shaina Keseley	BWSR
Al Kean	BWSR
Jill Sackett Eberhart	BWSR
Paul Davis	MN Pollution Control Agency
Chris Lenhart	Univ. Minnesota
Brad Gordon	Univ. Minnesota
Les Everett	UM Water Resources Center
Ann Lewandowski	UM Water Resources Center
Scott Sparlin	Coalition for a Clean MN River
Duane Ninneman	Clean Up the River Environment
Carrie Jennings	Freshwater Society
Rebecca Seal Soileau	US Army Corps of Engineers
Kimberly Musser	MNSU Water Resources Center

Minnesota Pollution Control Agency · Clean Water Land & Legacy Amendment · Minnesota Department of Agriculture · Freshwater Society · MAWRC Minnesota Agricultural Water Resource Center · NSF · St. Anthony Falls Laboratory, College of Science & Engineering, University of Minnesota

Cho et al., in review

Not done yet, but close!

For the flows, they are a changin'

Different rivers, different responses

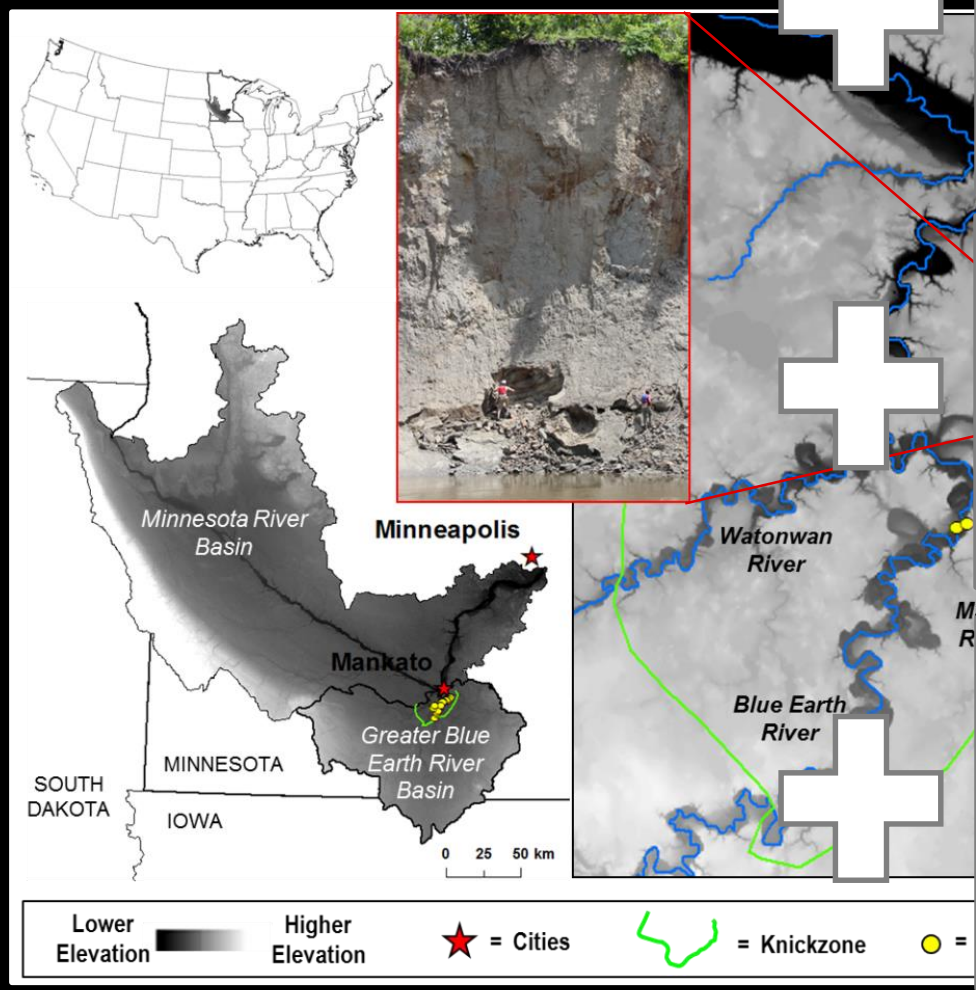
Determining sediment sources and sinks to inform restoration

- 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

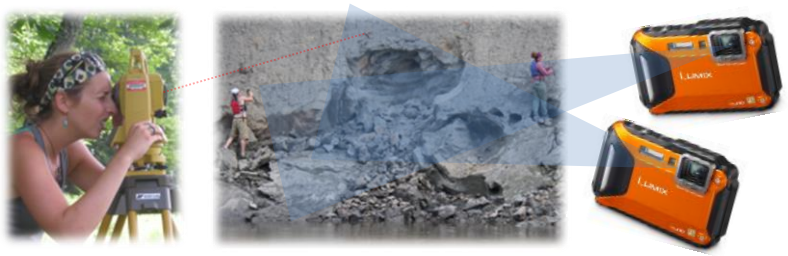
Coarse sediment sources and transport: A closer look at bluff erosion

Monitoring bluff erosion

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

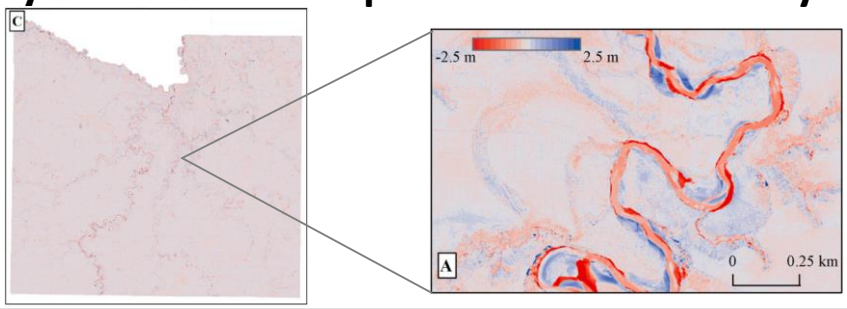


3 years of high resolution TS, SfM surveys



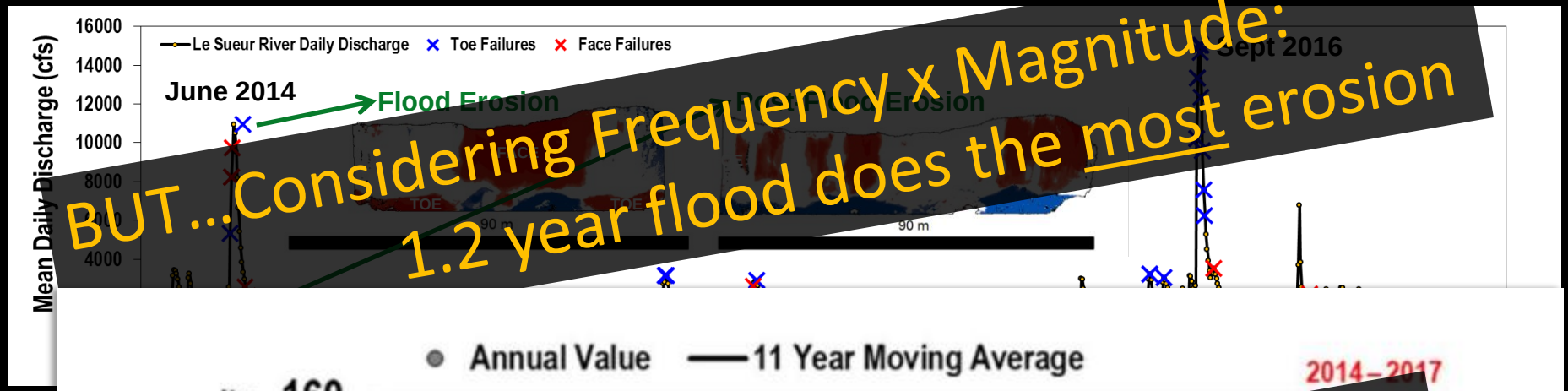
4 years of terrestrial lidar surveys

7 years between repeat aerial lidar surveys



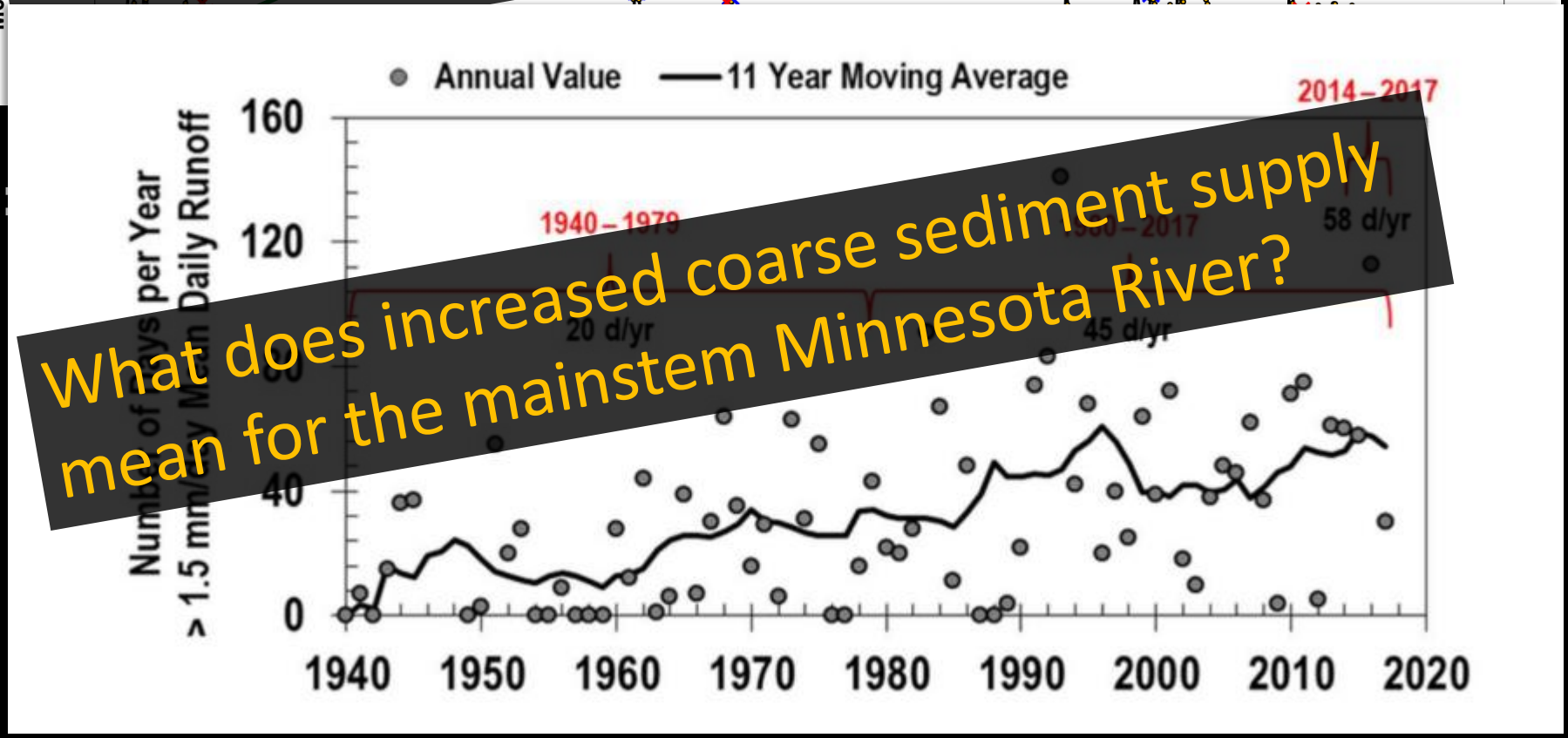
Day et al., 2013; Kelly and Belmont, 2018; Schaffrath et al., 2015

When and why do bluffs erode?



BUT…Considering Frequency x Magnitude:
1.2 year flood does the most erosion

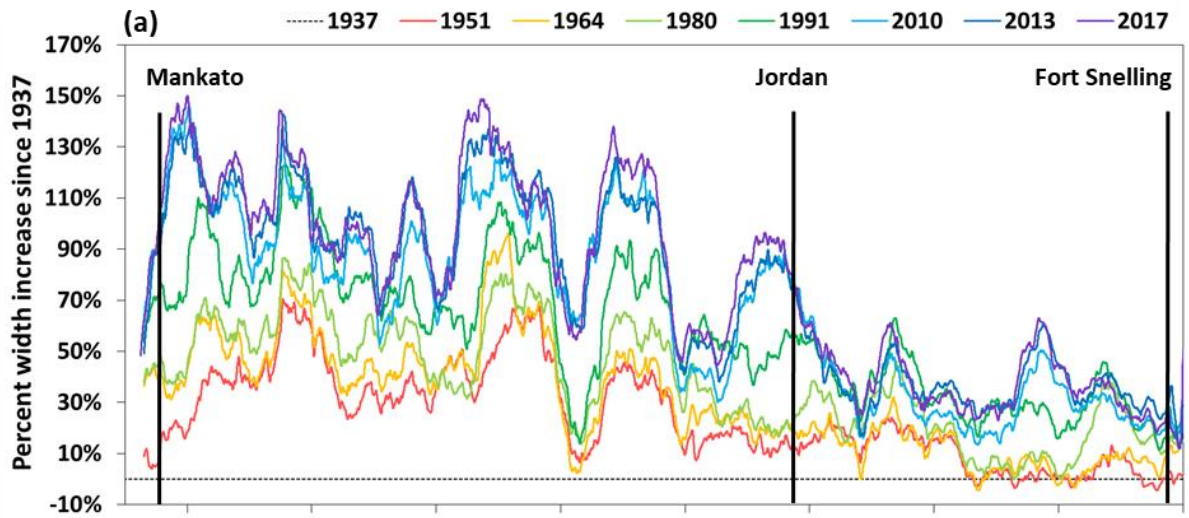
A



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

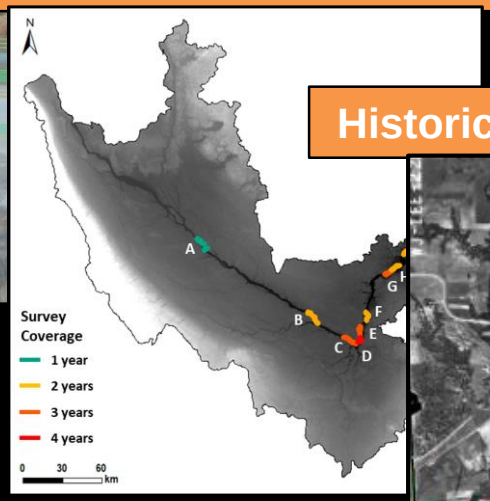
Very different behavior in the two river reaches



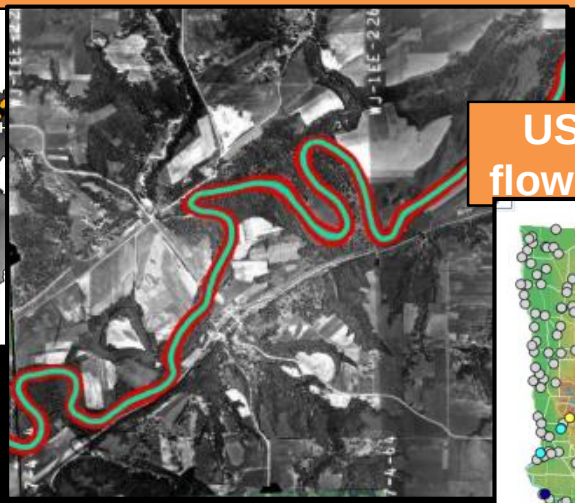
Lots of data to constrain a sediment budget

Grain size samples

234 km of MNR bathymetry

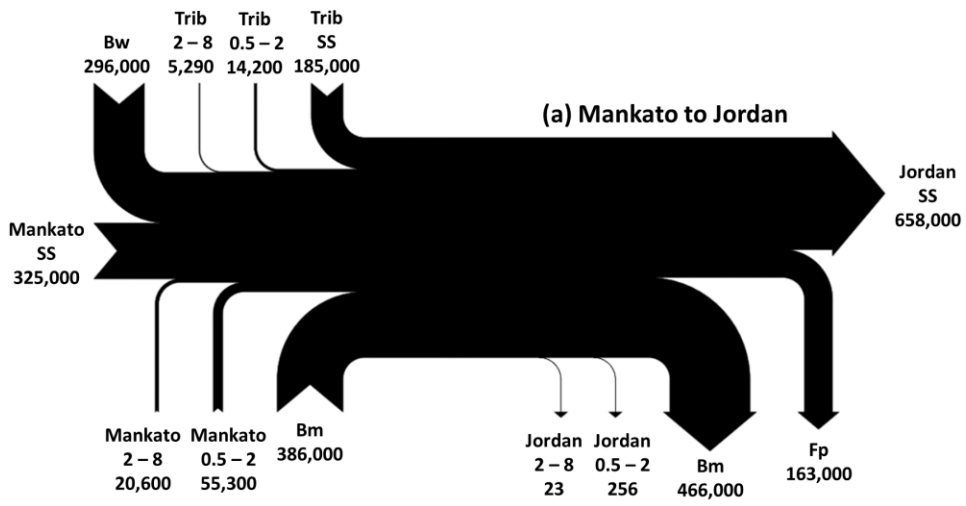


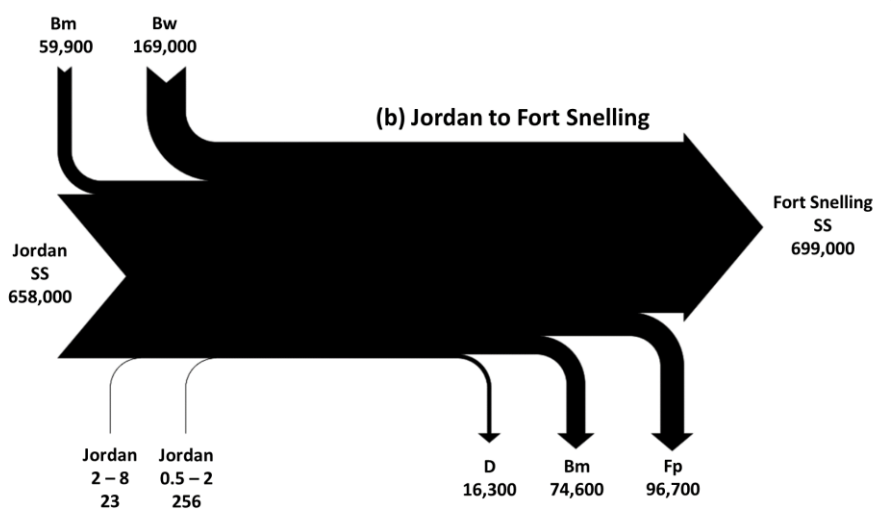
Historical aerial photos: 1937-2017



USGS/DNR/MPCA flow & sediment data

Sediment budgets for mainstem Minnesota River





Mixed bedload and suspended load

Bedload at Mankato: 19%

Bedload at Jordan: <0.5%

Migration (30%) and widening (23%) dominate supply

Channel migration contributes more than widening

Suspended load dominated

Bedload at Fort Snelling: 0%

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

Peter Wilcock (course director) - Professor and Head, Watershed Sciences, Utah State University

Tyler Allred, Principal, Allred Restoration

Patrick Belmont, Professor, Watershed Sciences, Utah State University

UtahState University
DEPARTMENT OF WATERSHED SCIENCES

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.

UCI	UMN-D	UMN	USU	USU
				
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Nate Mitchell
Tim Beach
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CLEAN WATER LAND & LEGACY AMENDMENT

NSF

USDA

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

DEPARTMENT OF NATURAL RESOURCES

Minnesota Pollution Control Agency

MAWRC MINNESOTA AGRICULTURAL WATER RESOURCE CENTER

MINNESOTA DEPARTMENT OF AGRICULTURE

MinnesotaCorn RESEARCH & PROMOTION COUNCIL

Some take-away points

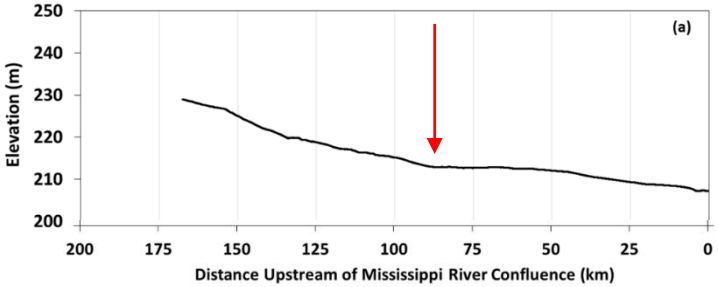
1. **Geologic history** makes the MRB a very sensitive system.

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

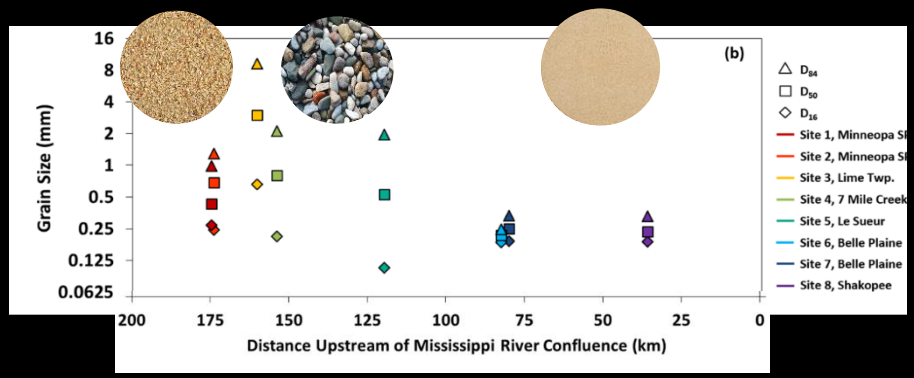


Slope break upstream of Jordan near river km 85

Slope Mankato to Jordan: 0.0002

Slope Jordan to Fort Snelling: 0.0001

Channel form – slope, bed grain size, and bar topography

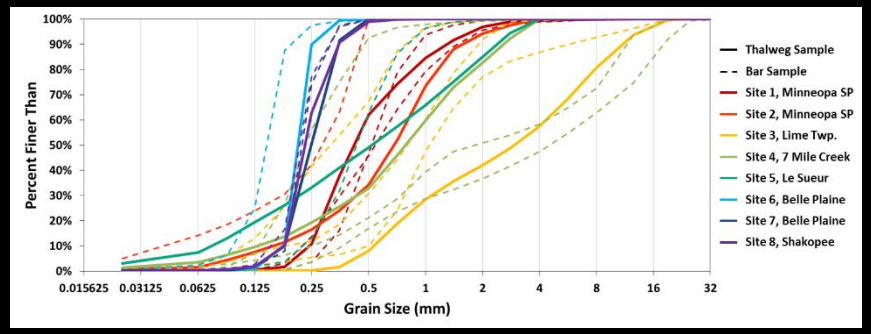


Significant downstream fining, coarsening at tributary junctions

D_{50} Mankato to Jordan: 1 mm

D_{50} Jordan to Fort Snelling: 0.25 mm

No trends between bars and bed (thalweg)



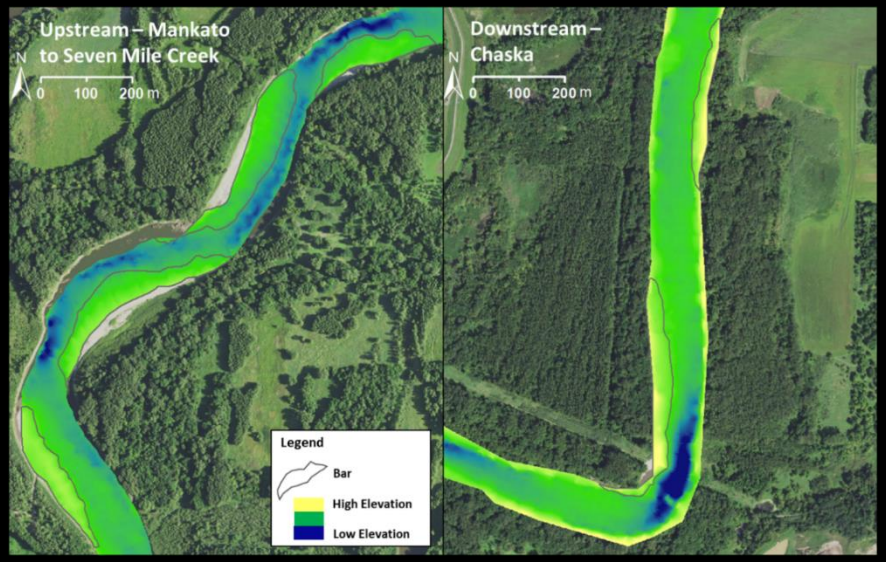
Channel form – slope, bed grain size, and bar topography

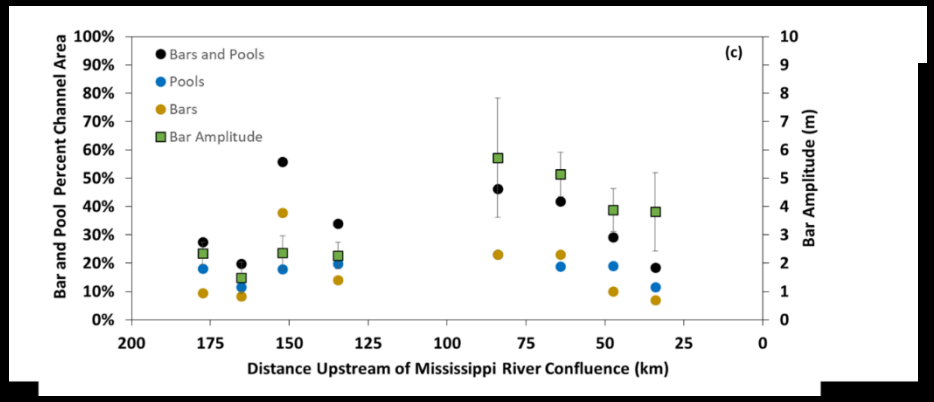
Bars taller downstream

Bars Mankato to Jordan: broad, alternate and point bars

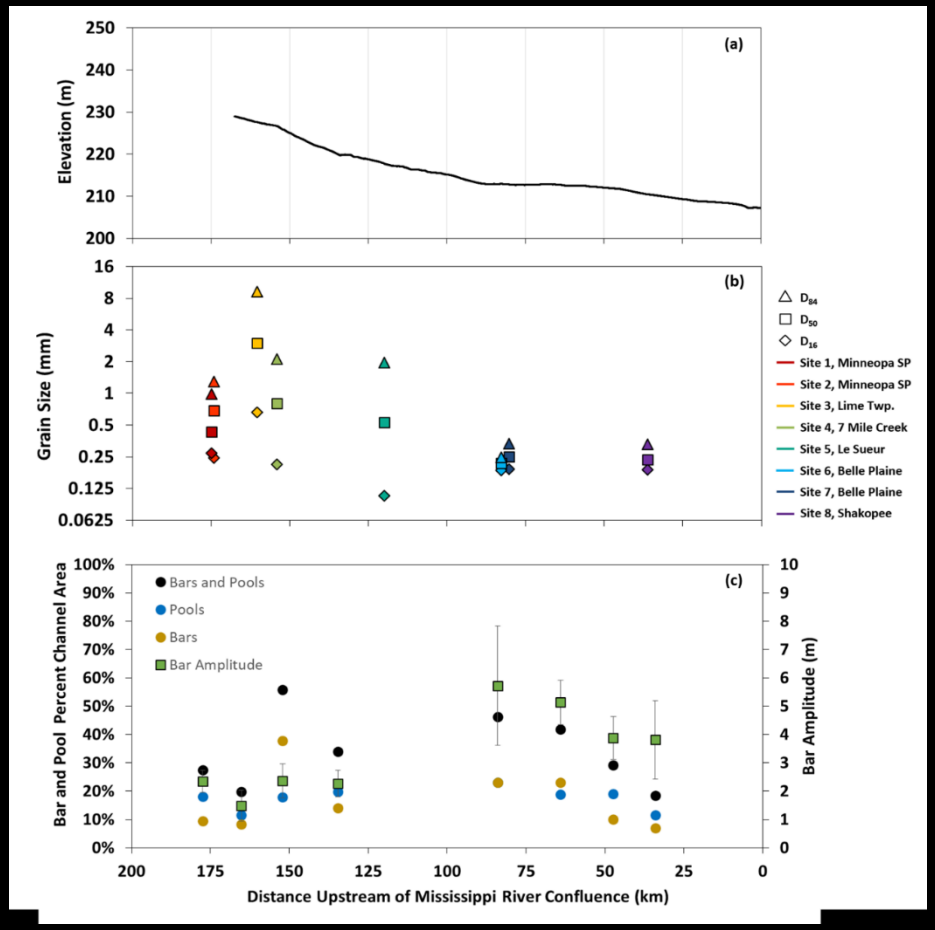
Bars Jordan to Fort Snelling: narrow, forced point bars

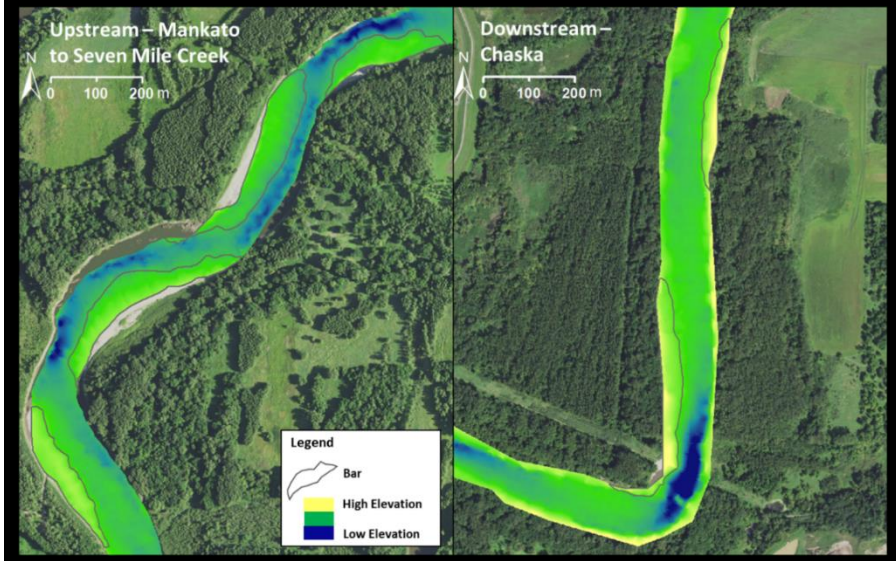
No trend for pools





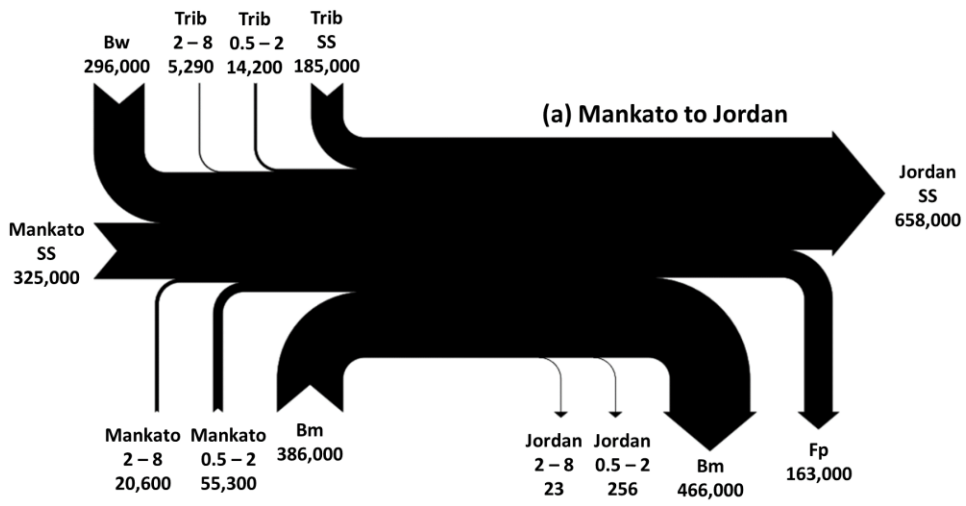
Channel form – slope, bed grain size, and bar topography

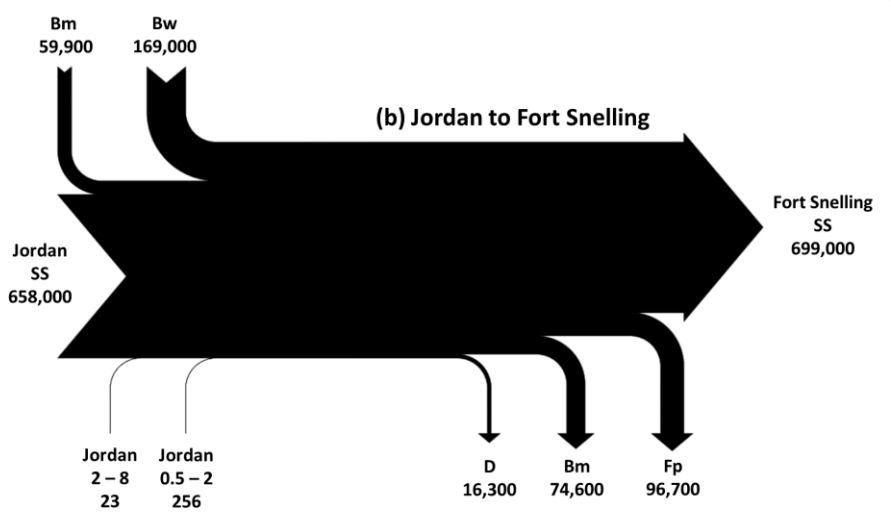




Upper 100 km is very different than lower 65 km

Sediment supply and transport – sediment budgets





Mixed bedload and suspended load

Migration and widening (53%)

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

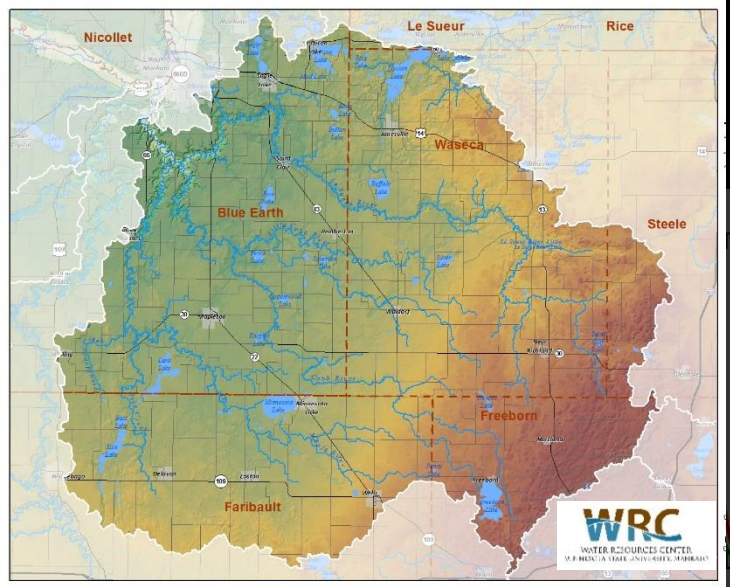
Suspended load dominated

Material already in transport (74%)

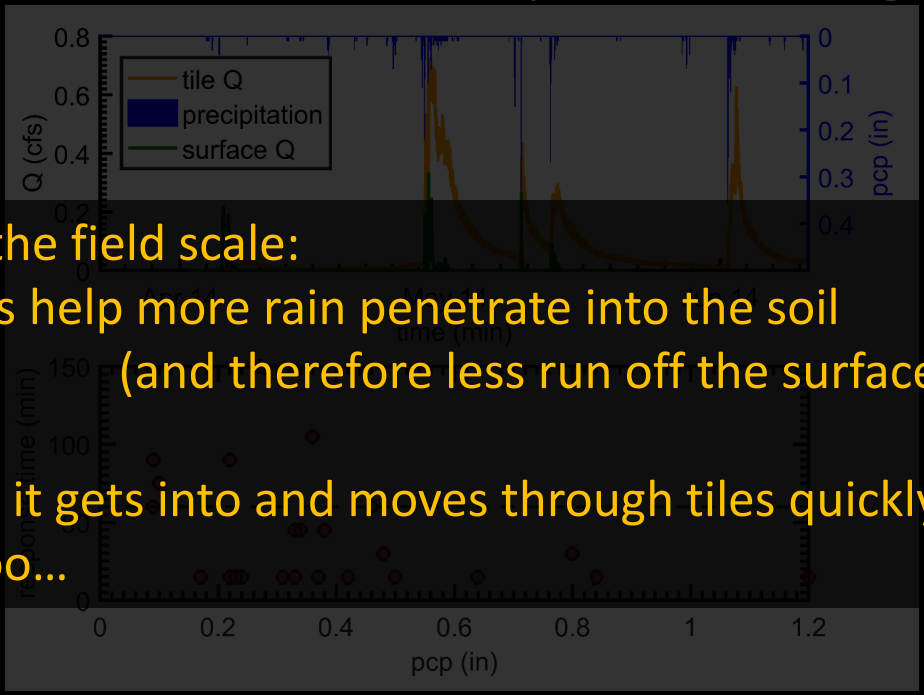
Channel widening (19%) > migration (7%)

How does artificial drainage affect streamflow?

regional analysis of large watersheds



Discovery Farms monitoring



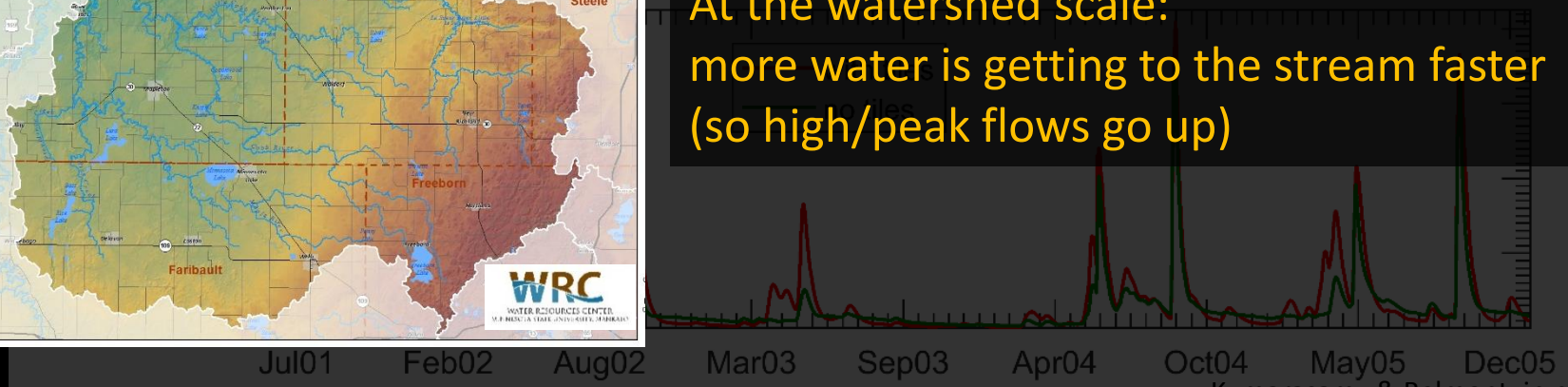
Kumarasamy & Belmont, in prep

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…

SWAT model results

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



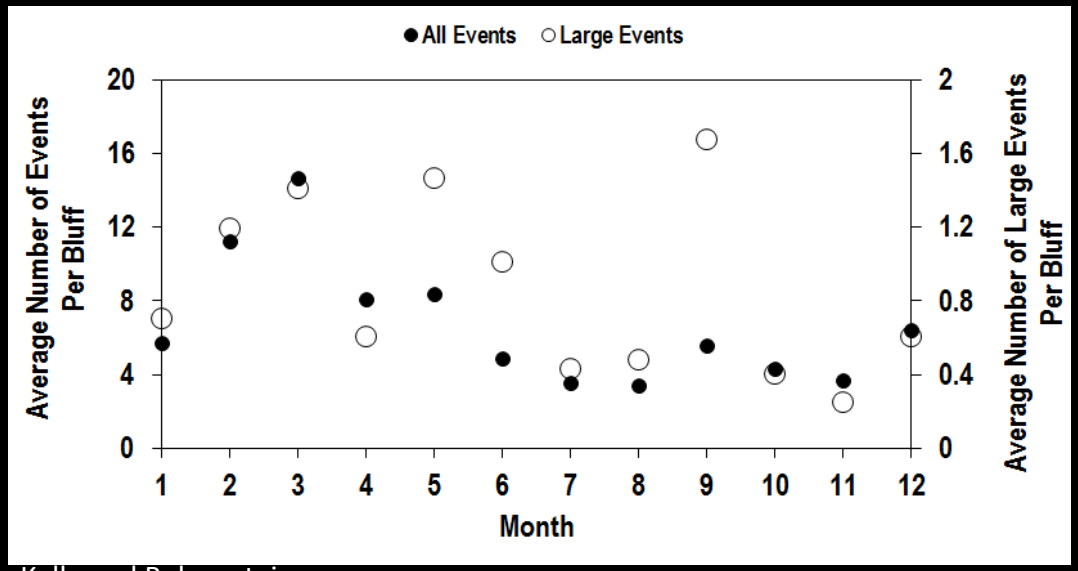
Kumarasamy & Belmont, in prep

When and why do bluffs erode?

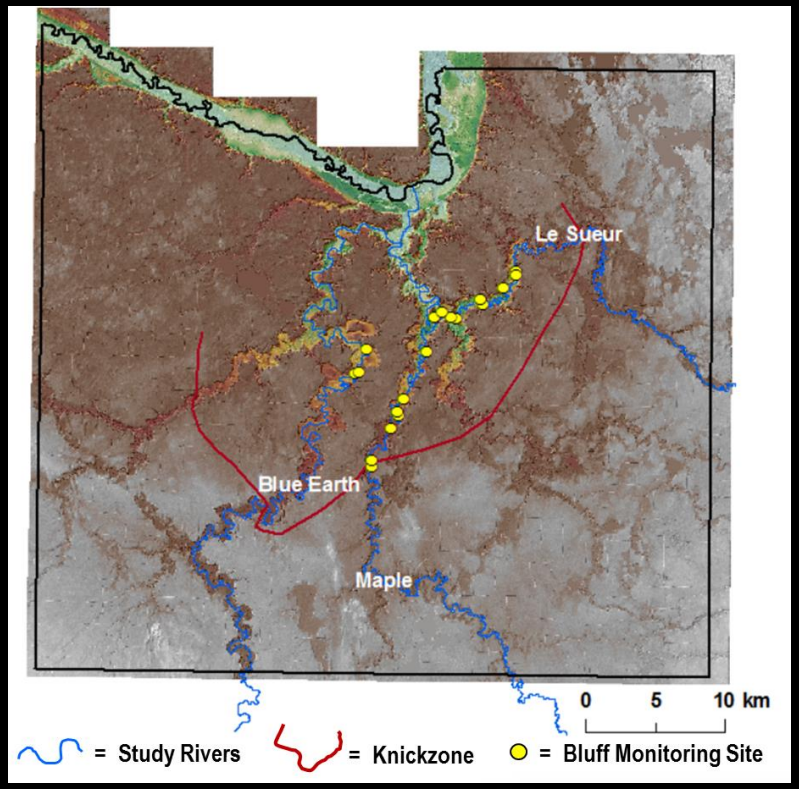
20 cameras x 600+ days = >12,000 photos

Total Erosion Events n = 2705

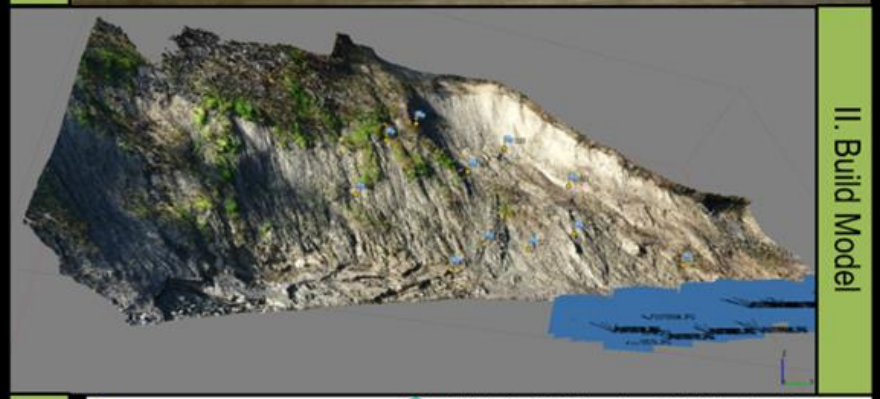
Large Erosion Events n = 347

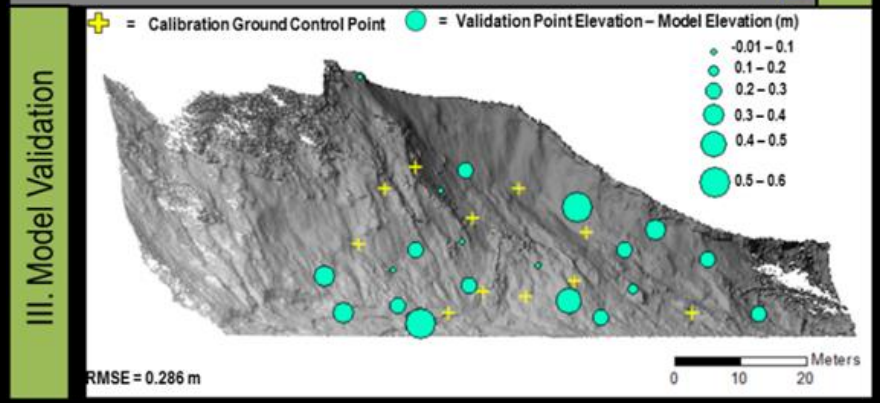


Kelly and Belmont, in prep



When and why do bluffs erode?

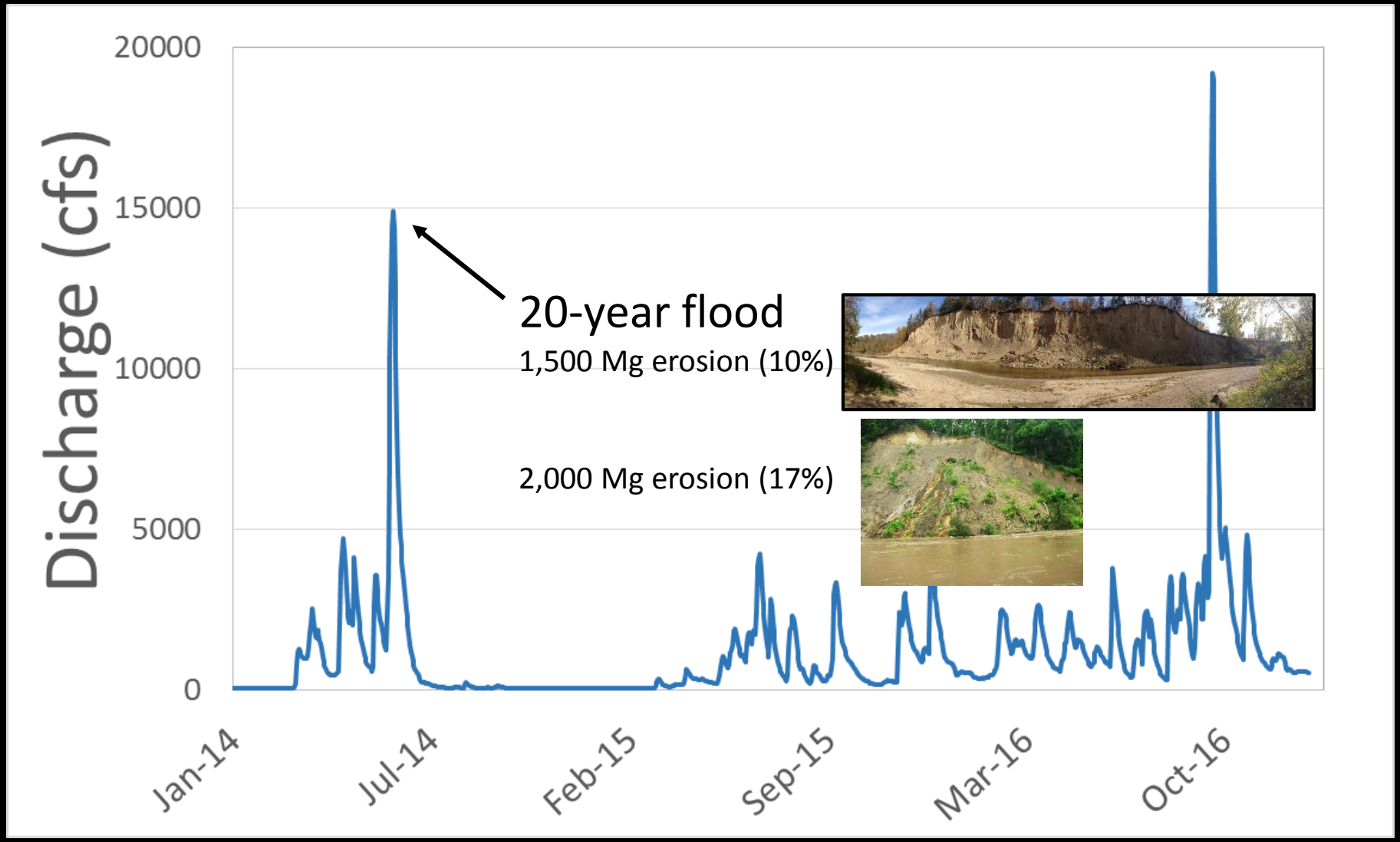




Kelly and Belmont, in prep

2 sites monitored for 3 years

When and why do bluffs erode?



Kelly and Belmont, in prep

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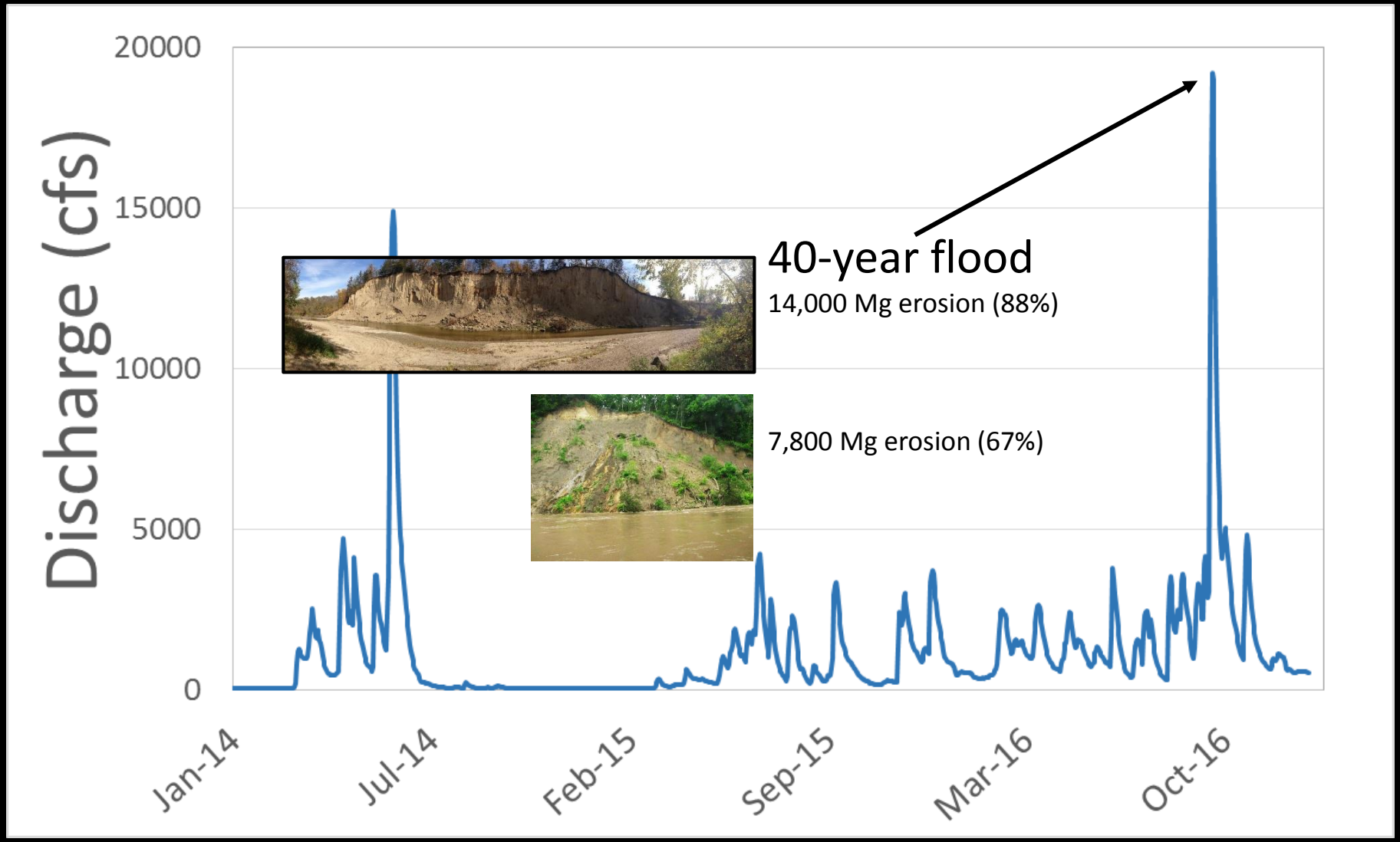
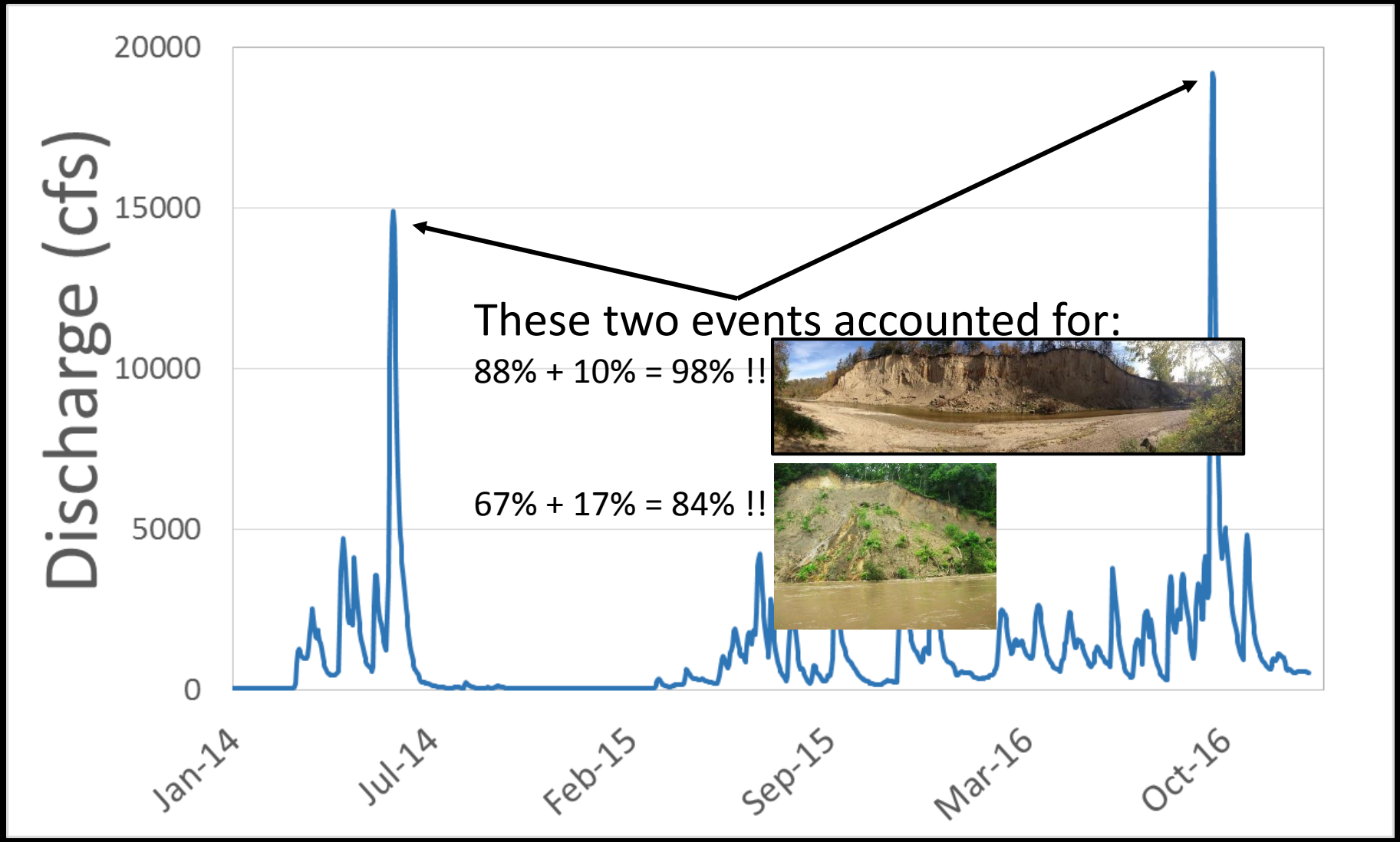


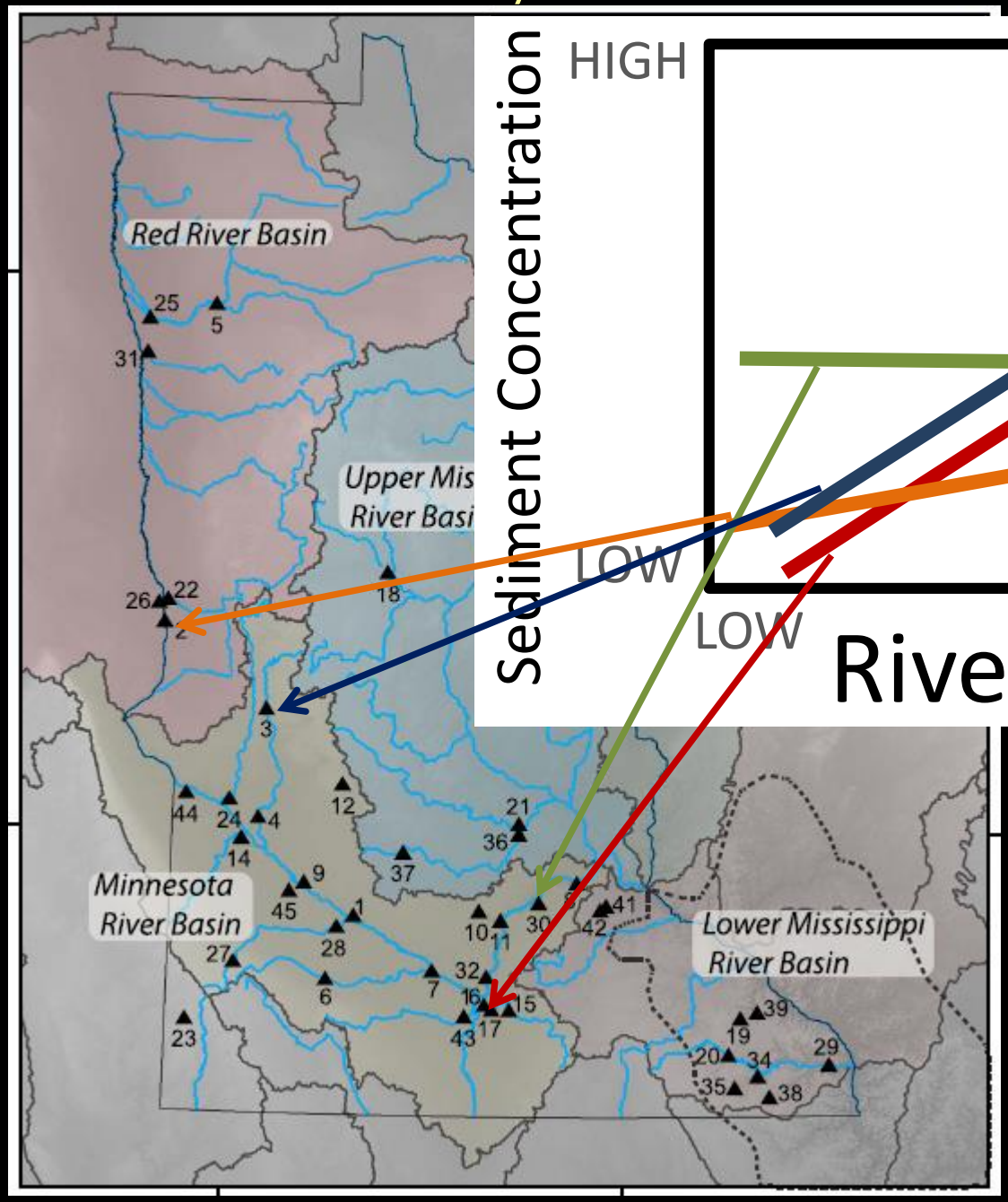
Kelly and Belmont, in prep

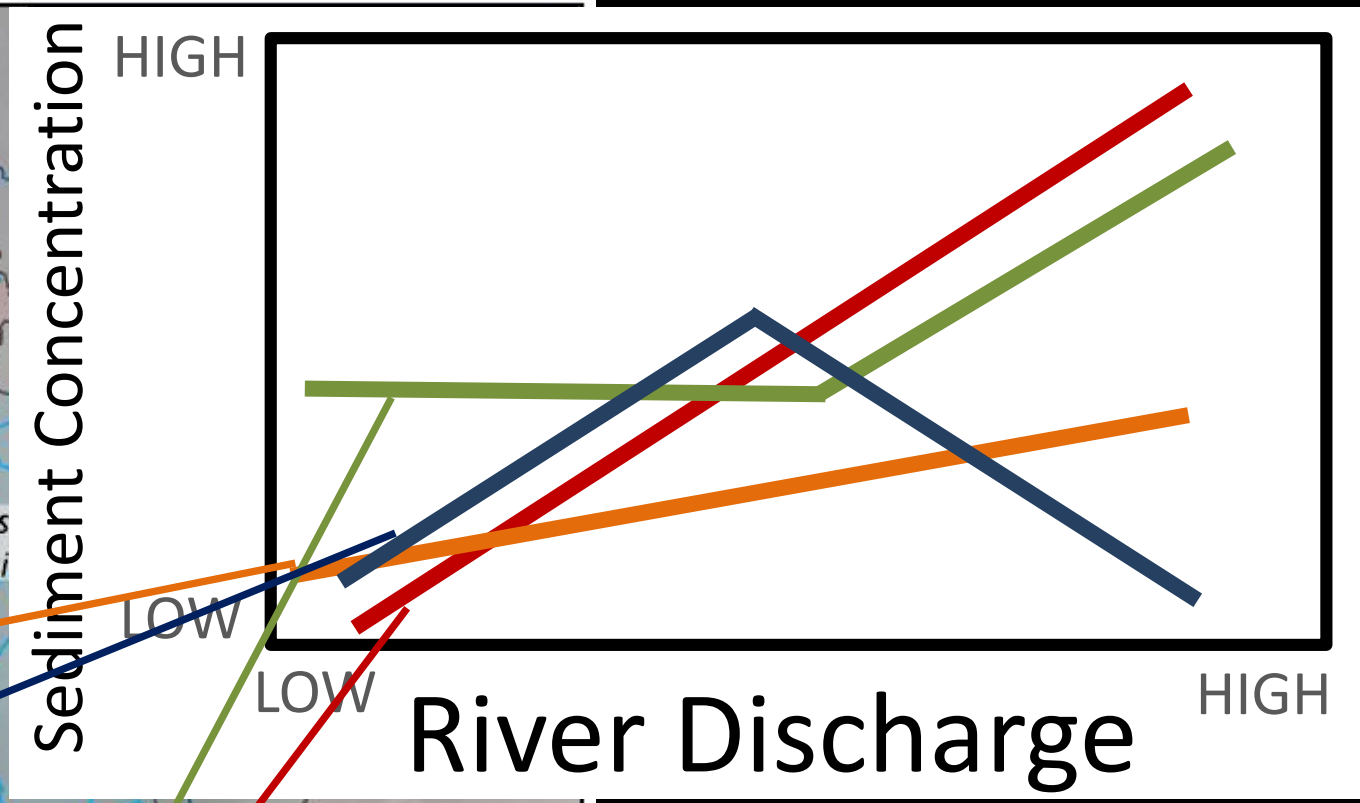
When and why do bluffs erode?



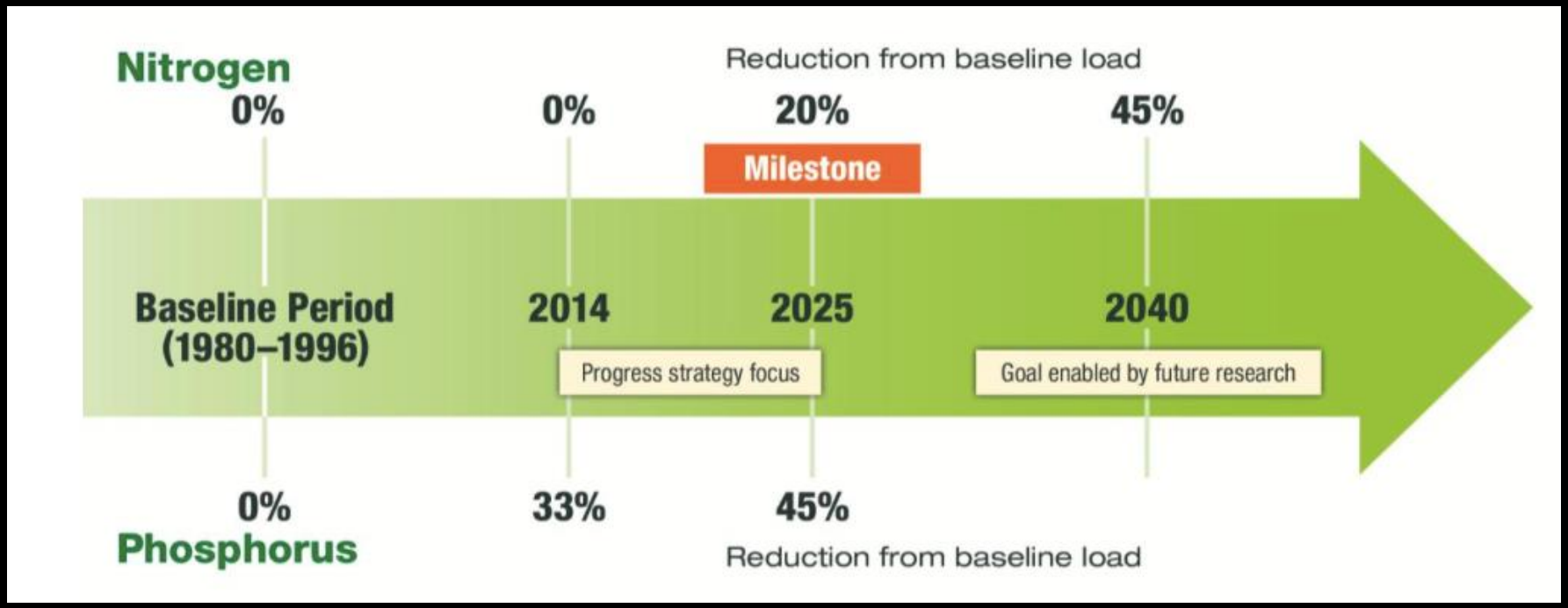
Kelly and Belmont, in prep

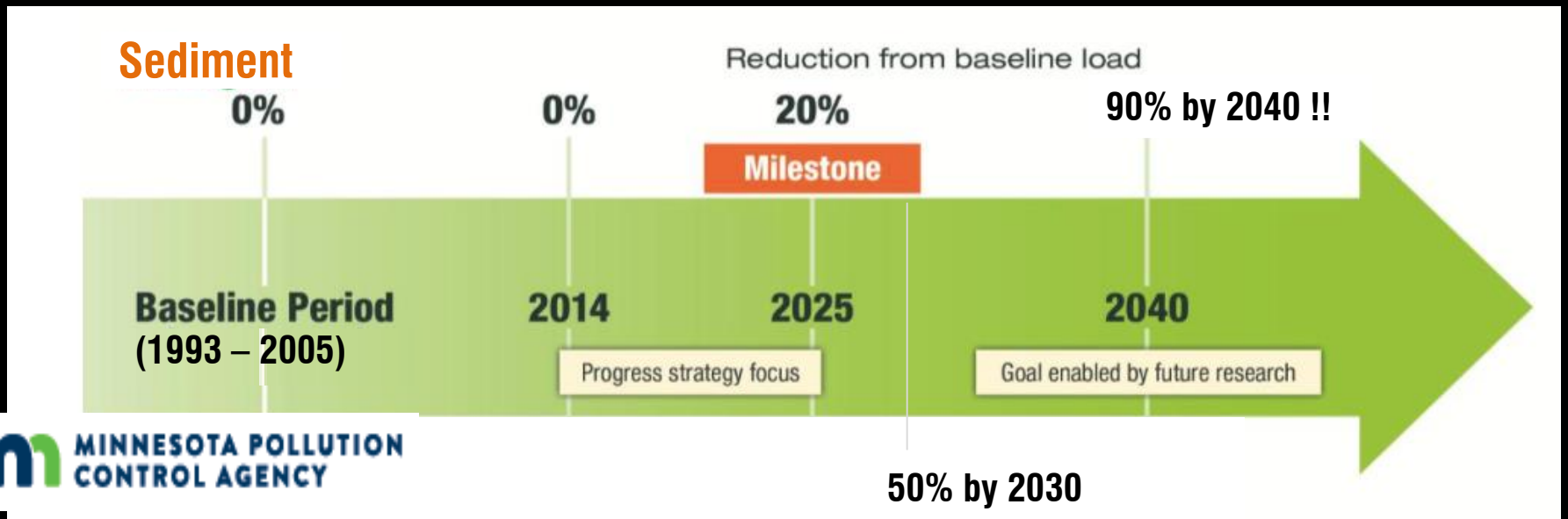
What controls Q/TSS relations throughout Minnesota?





Pollutant reduction targets for Minnesota River



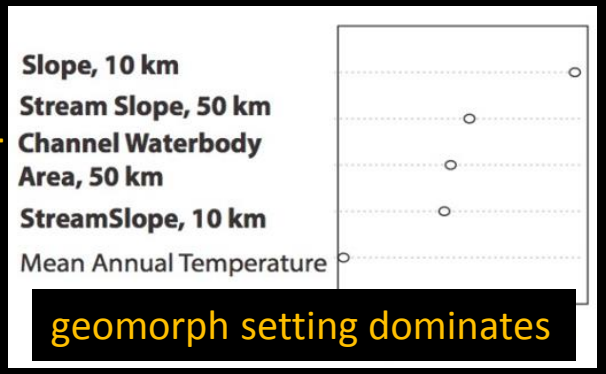


MINNESOTA POLLUTION CONTROL AGENCY

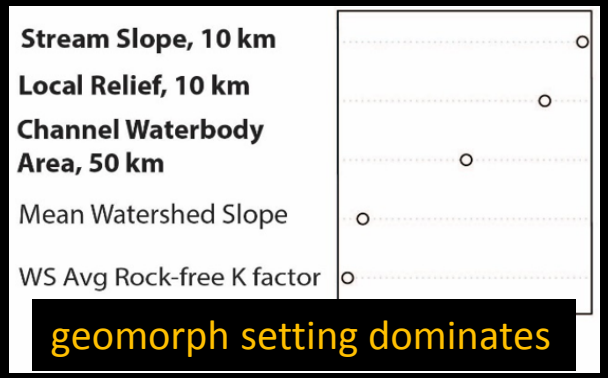
What controls Q/TSS relations?

near-channel metrics in bold

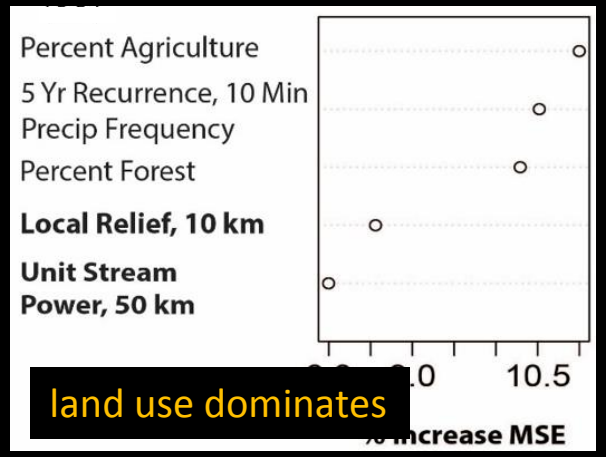
Shape

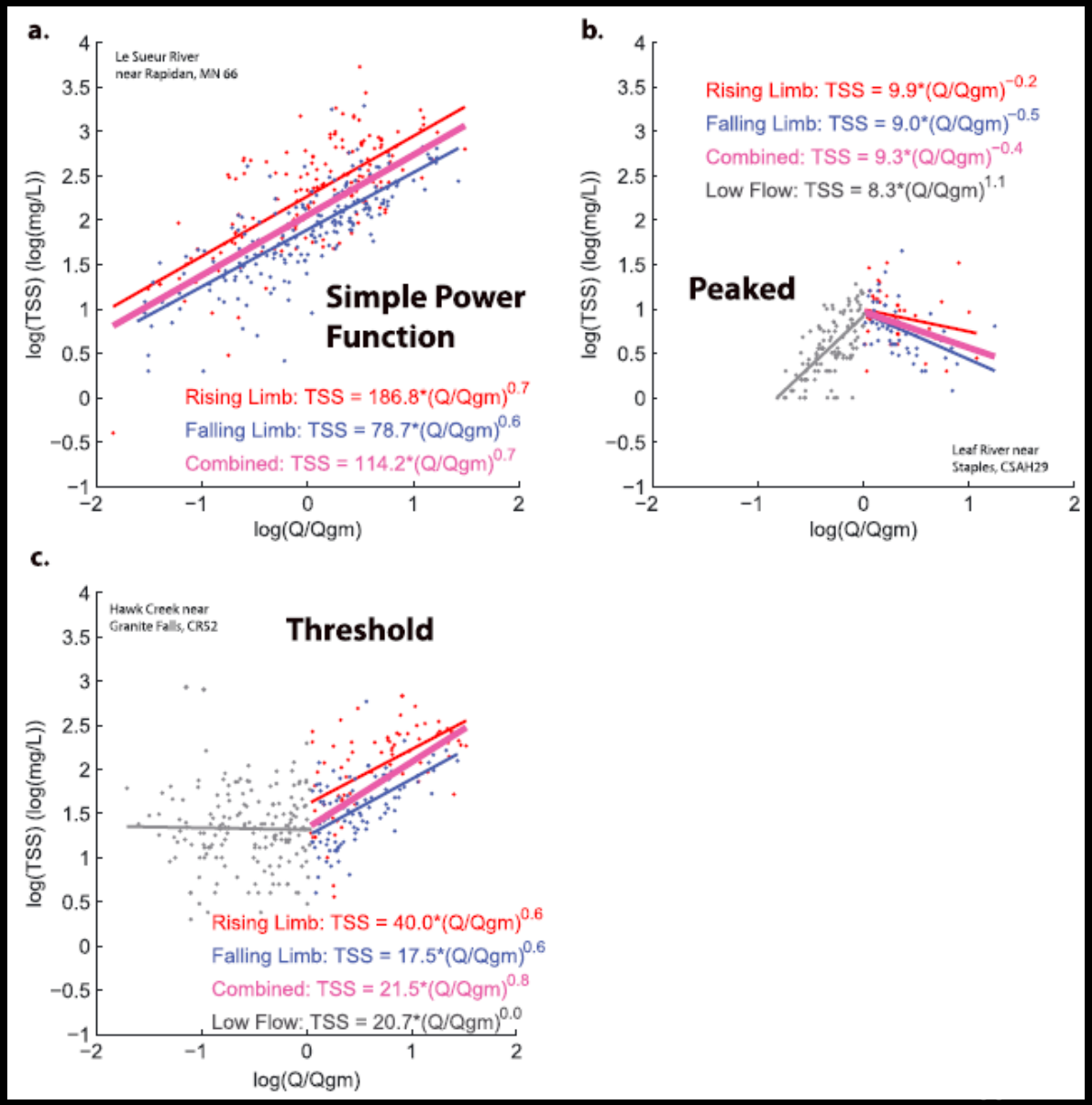


Exponent



Coefficient





In the last 14 min…

The current situation

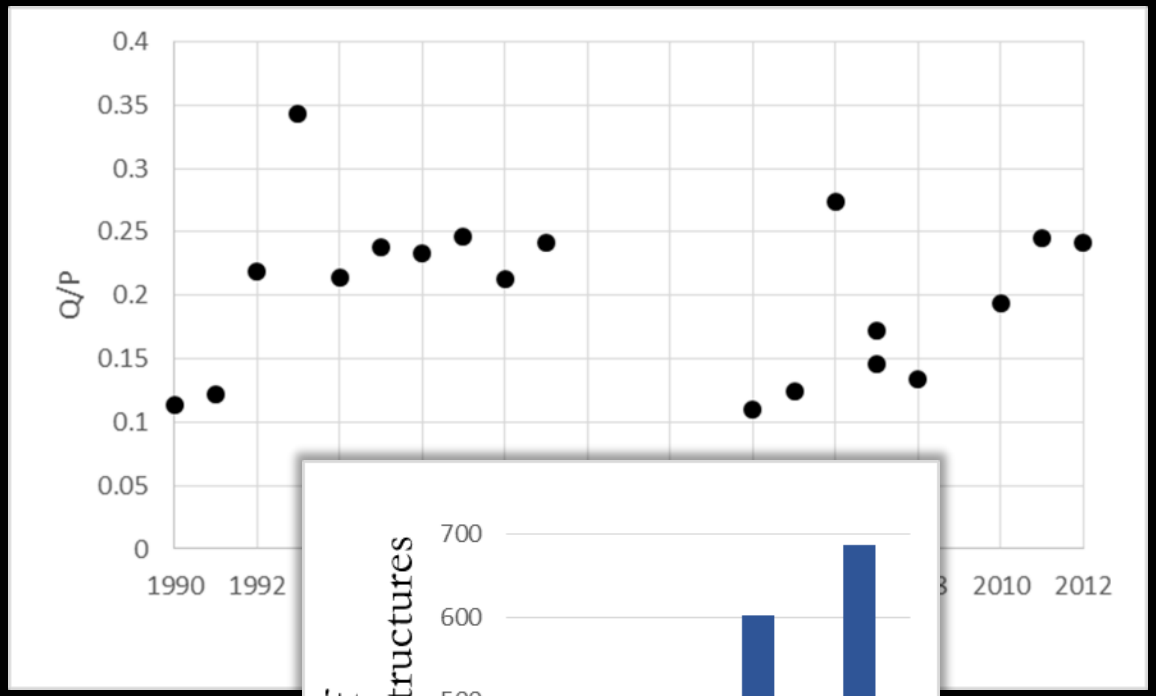
What we have learned from the past

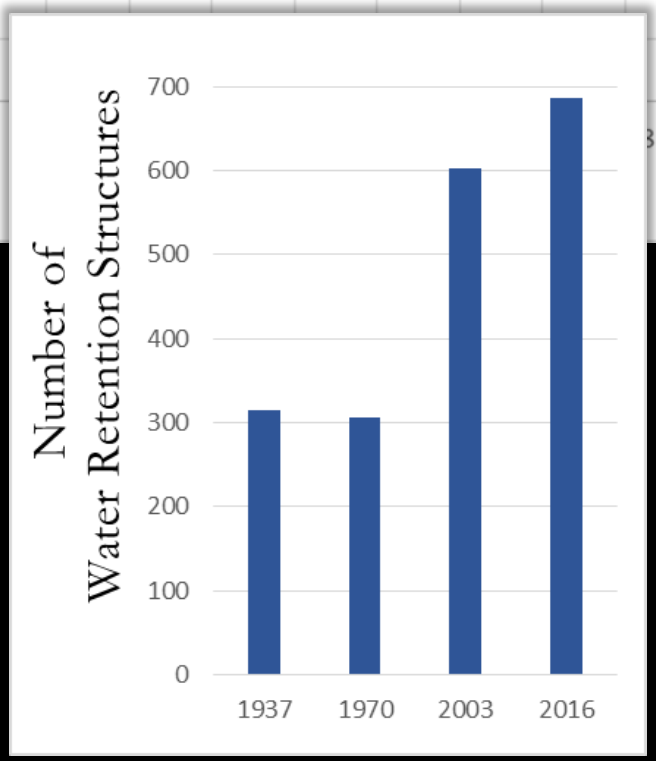
Some new data and insights

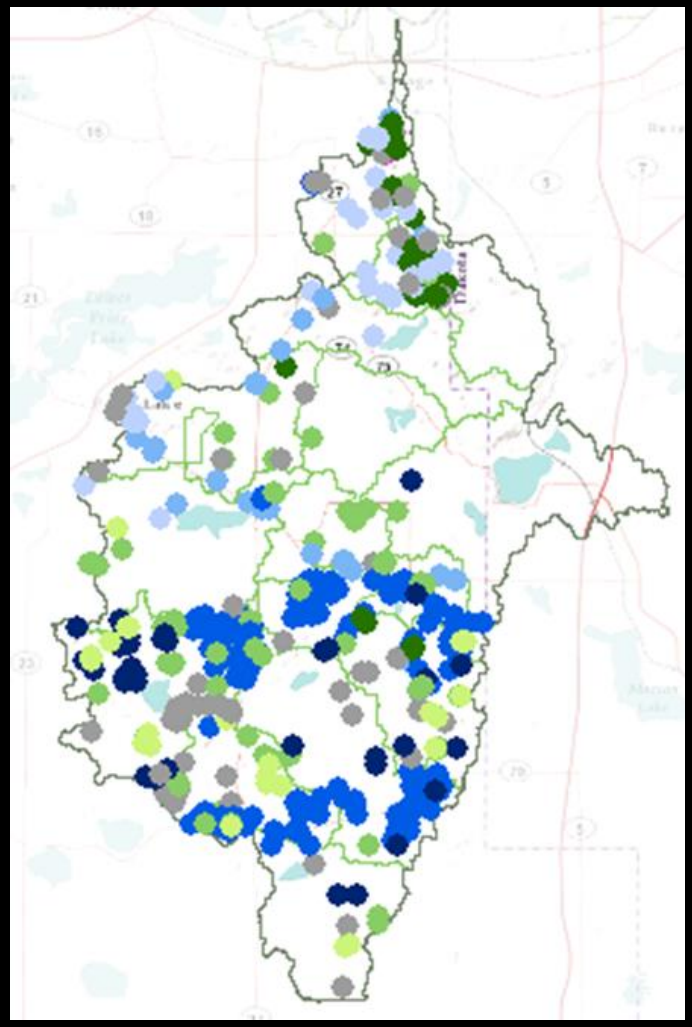
How to proceed from here?

Water storage in Credit River watershed

Credit River runoff ratio







Wetland Restoration
Storm Ponds
Raingardens
Other
Streambank protection
Native Grasses
Filter Strips/Buffers
Restoring declining habitat

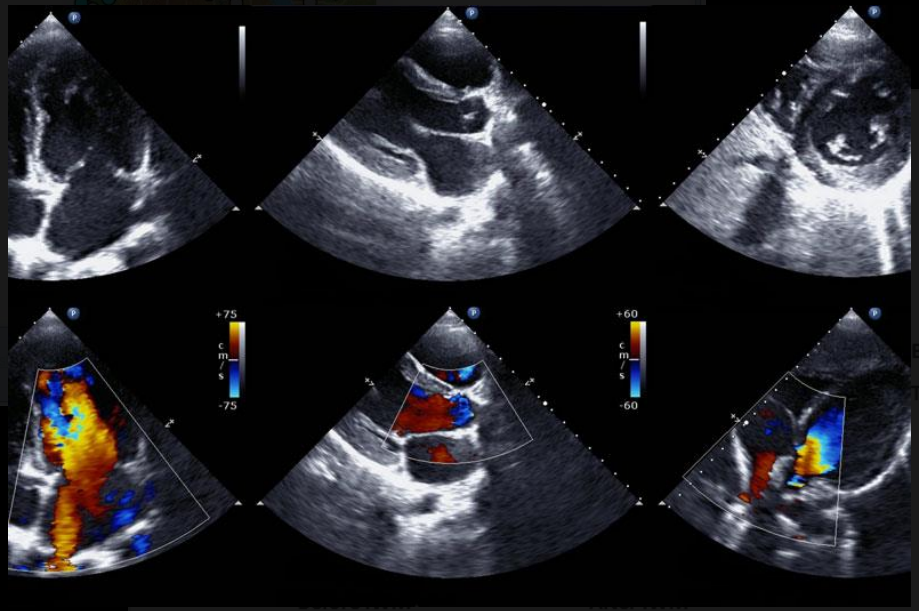
A metaphor…

…and a few words about the buffer bill

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

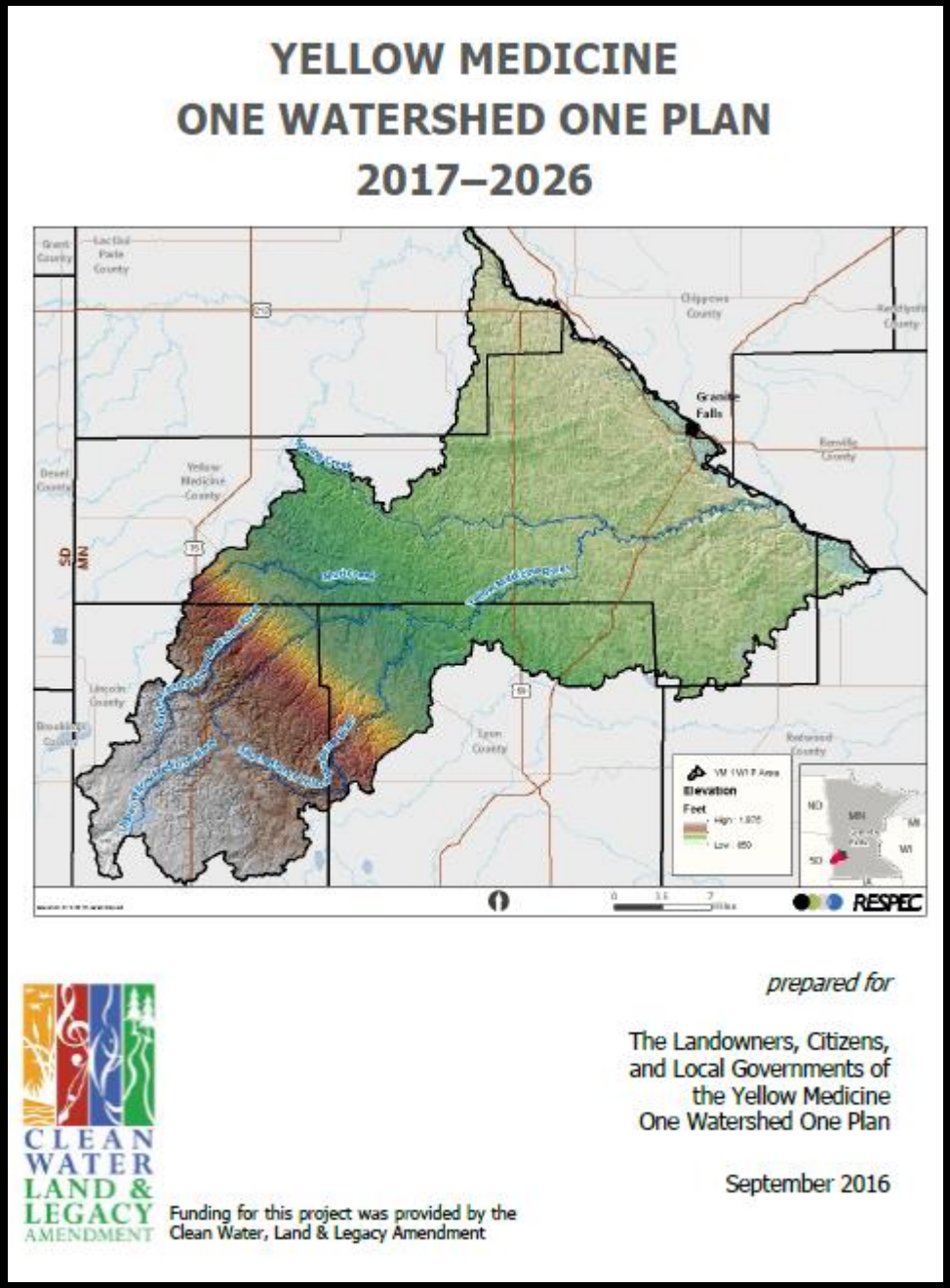
Locally developed & implemented

Facilitates targeting & prioritization

Coordinates efforts

Engages broad range of stakeholders

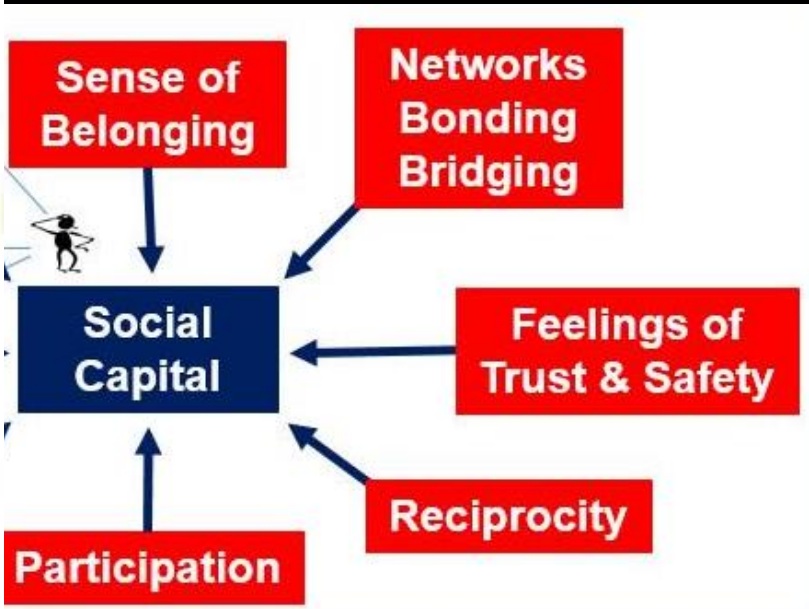
Formal agreements, but adaptable



Consider all types of capital (i.e., accumulated wealth)

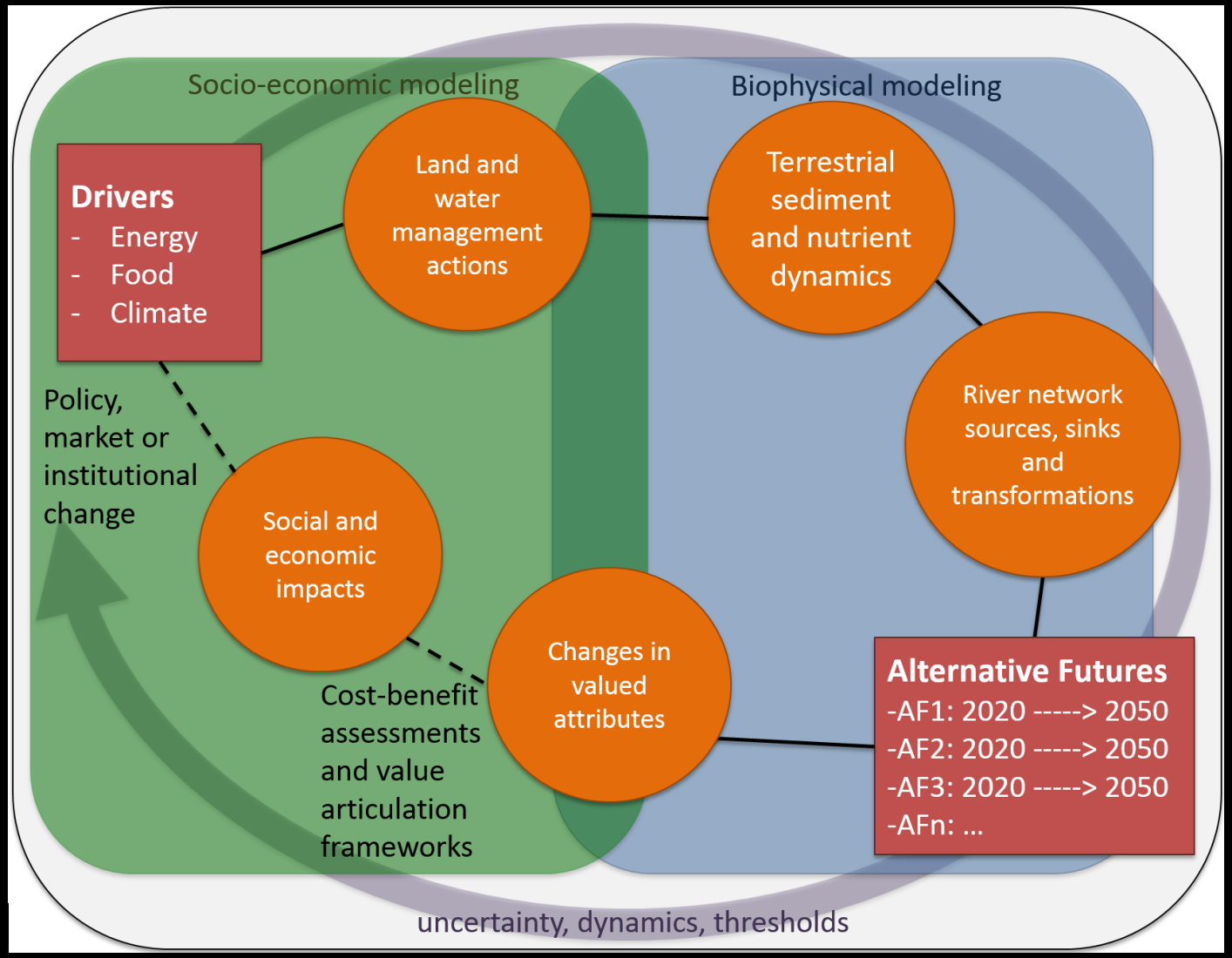
Natural capital

Social capital



Political capital

Integrated modeling of Minnesota River System



natural capital PROJECT

IOWA STATE UNIVERSITY

UtahStateUniversity DEPARTMENT OF WATERSHED SCIENCES

Random Forest Modeling

Machine learning technique based on

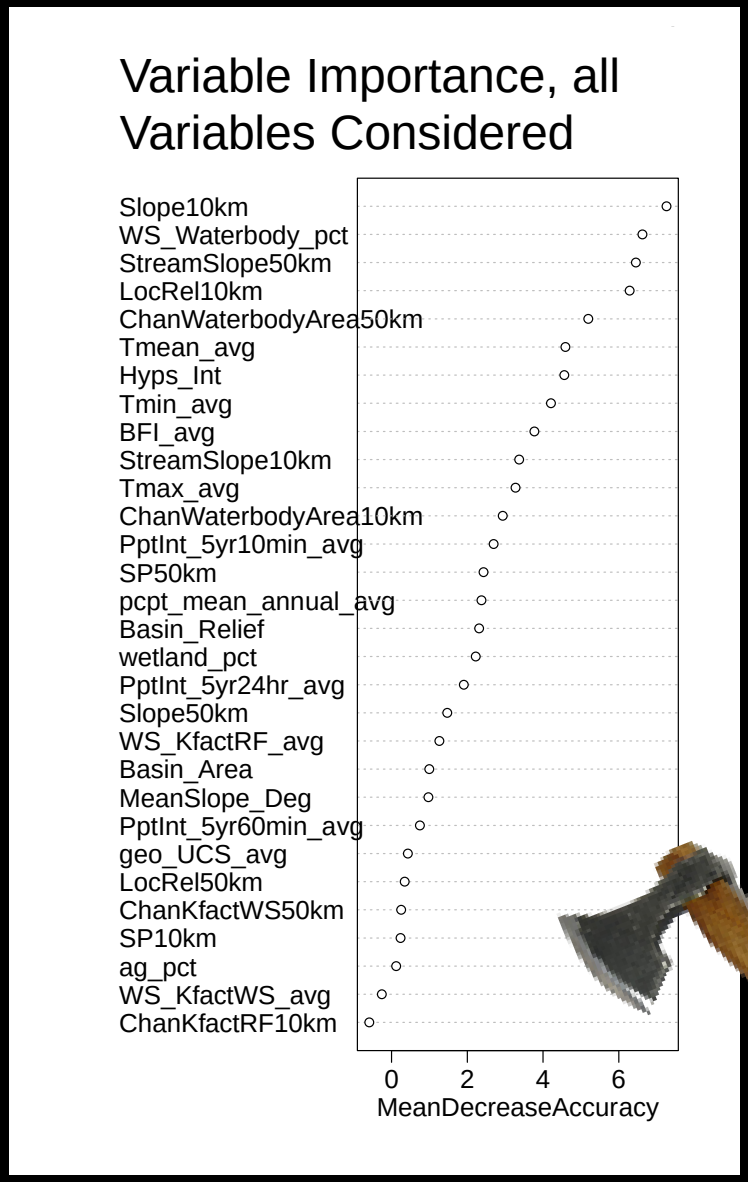
boot-strapped classification and regression trees

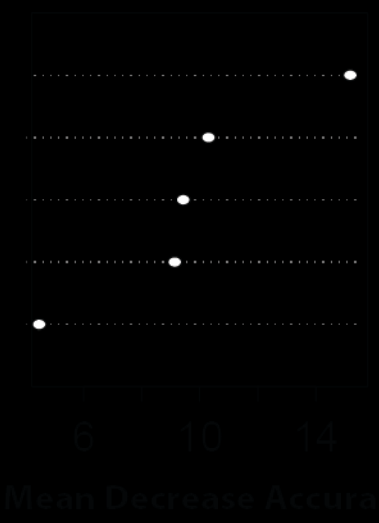
Advantages of RF models:

- 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

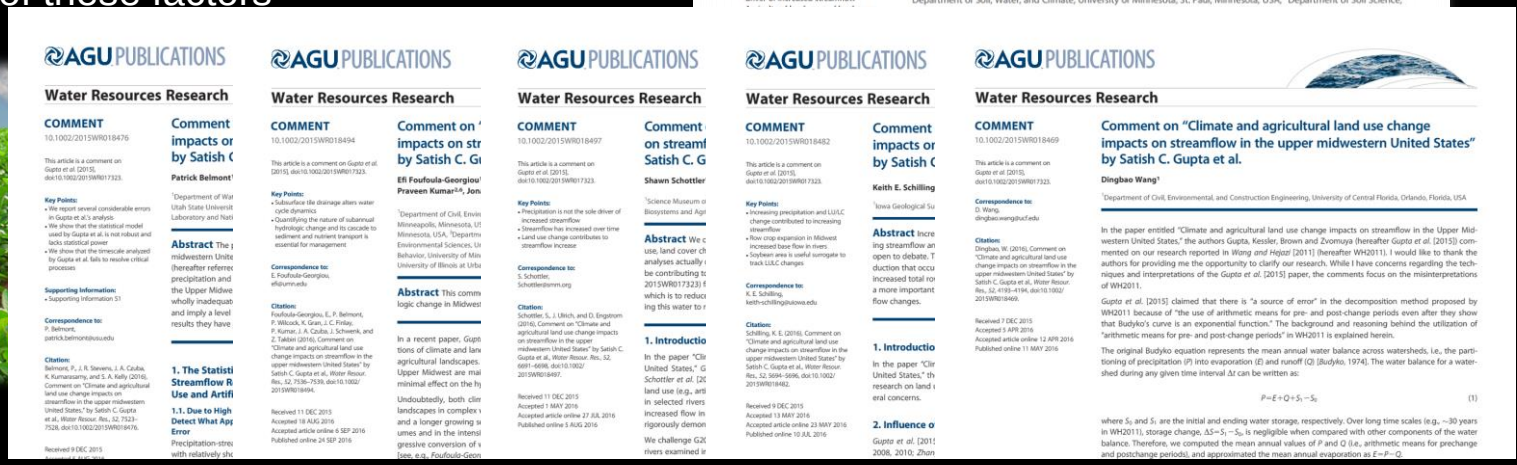




Human-amplified hydrologic change

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


AGU PUBLICATIONS
Water Resources Research
RESEARCH ARTICLE
10.1002/2015WR017323
Climate and agricultural land use change impacts on streamflow in the upper midwestern United States
Satish C. Gupta[1], Andrew C. Kessler[1], Melinda K. Brown[1], and Francis Zvomuya[2]


AGU PUBLICATIONS
Water Resources Research
COMMENT
10.1002/2015WR018476
Comment on "Climate and agricultural land use change impacts on streamflow in the upper midwestern United States" by Satish C. Gupta et al.
Dingbao Wang[1]

If,

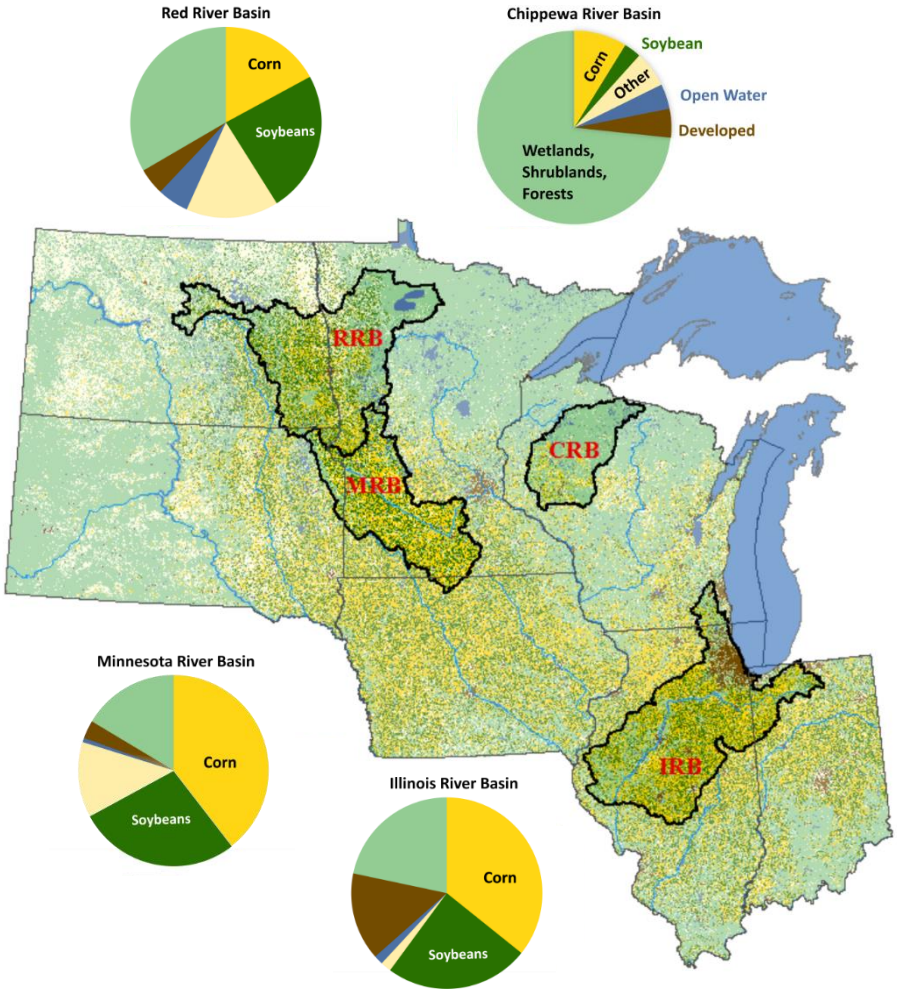
- <u>streamflows have been amplified by agricultural drainage</u>
- sediment problems in the Minnesota River Basin are exacerbated by streamflow increases

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



Credit: Zeinab Takbiri

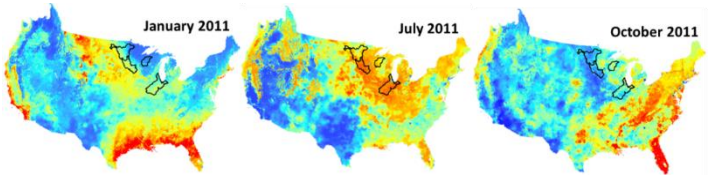
Similar glacial histories:
Watersheds underlain by glacial till

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

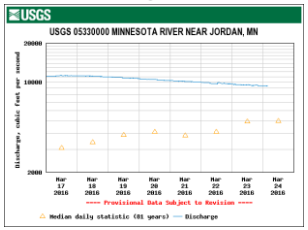
Data

PRISM Precipitation



Modeled Evapotranspiration from Livneh et al. 2013

USGS Daily Streamflow



US Census of Agriculture (NASS)

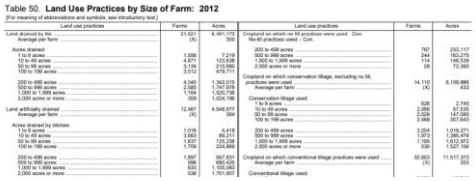


Table 50. **Land Use Practices by Size of Farm: 2012**

[For meaning of abbreviations and symbols, see introductory text.]

Land use practices	Farms	Acres
Land drained by tile	31,621	6,461,178
Average per farm	(X)	305
Acres drained:		
1 to 9 acres	1,508	7,219
10 to 49 acres	4,871	123,938
50 to 99 acres	3,136	215,985
100 to 199 acres	3,312	478,111
200 to 499 acres	4,340	1,342,015
500 to 999 acres	3,164	2,208,738
1,000 to 1,999 acres	1,164	1,520,736
2,000 acres or more	399	1,024,196
Land artificially drained	12,487	4,548,977
Average per farm	(X)	364
Acres drained by ditches:		
1 to 9 acres	1,016	4,418
10 to 49 acres	3,663	89,211
50 to 99 acres	1,837	125,238
100 to 199 acres	1,759	224,865
200 to 499 acres	1,897	567,831
500 to 999 acres	998	685,420
1,000 to 1,999 acres	633	1,155,083
2,000 acres or more	536	1,701,907

Land use practices	Farms	Acres
Cropland on which no till practices were used (Con. No till practices used – Con.		
200 to 499 acres	767	233,117
500 to 999 acres	244	163,275
1,000 to 1,999 acres	114	145,536
2,000 acres or more	28	72,360
Cropland on which conservation tillage, excluding no till, practices were used	14,110	6,108,886
Average per farm	(X)	433
Conservation tillage used:		
1 to 9 acres	606	2,745
10 to 49 acres	2,066	67,535
50 to 99 acres	2,388	167,936
100 to 199 acres	2,488	357,540
200 to 499 acres	3,204	1,019,271
500 to 999 acres	1,973	1,386,876
1,000 to 1,999 acres	1,190	1,612,972
2,000 acres or more	530	1,537,158
Cropland on which conventional tillage practices were used	32,653	11,517,373
Average per farm	(X)	352
Conventional tillage used:		

Methods

Normalized streamflow time series

Student's t-test

Kolmogorov–Smirnov test

Wavelet analysis

Piecewise linear regression

Water budget

$$P - ET - Q = dS/dt$$

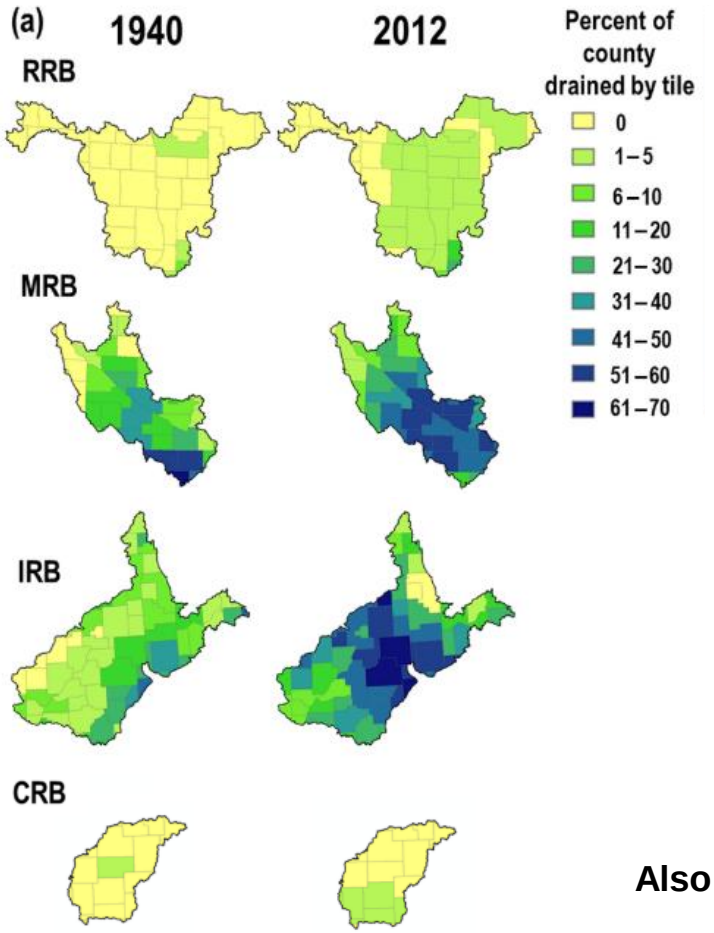
P = precipitation
ET = evapotranspiration
Q = streamflow
dS/dt = change in soil moisture, groundwater, and/or lake/reservoir storage

Tile Drainage Extent

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

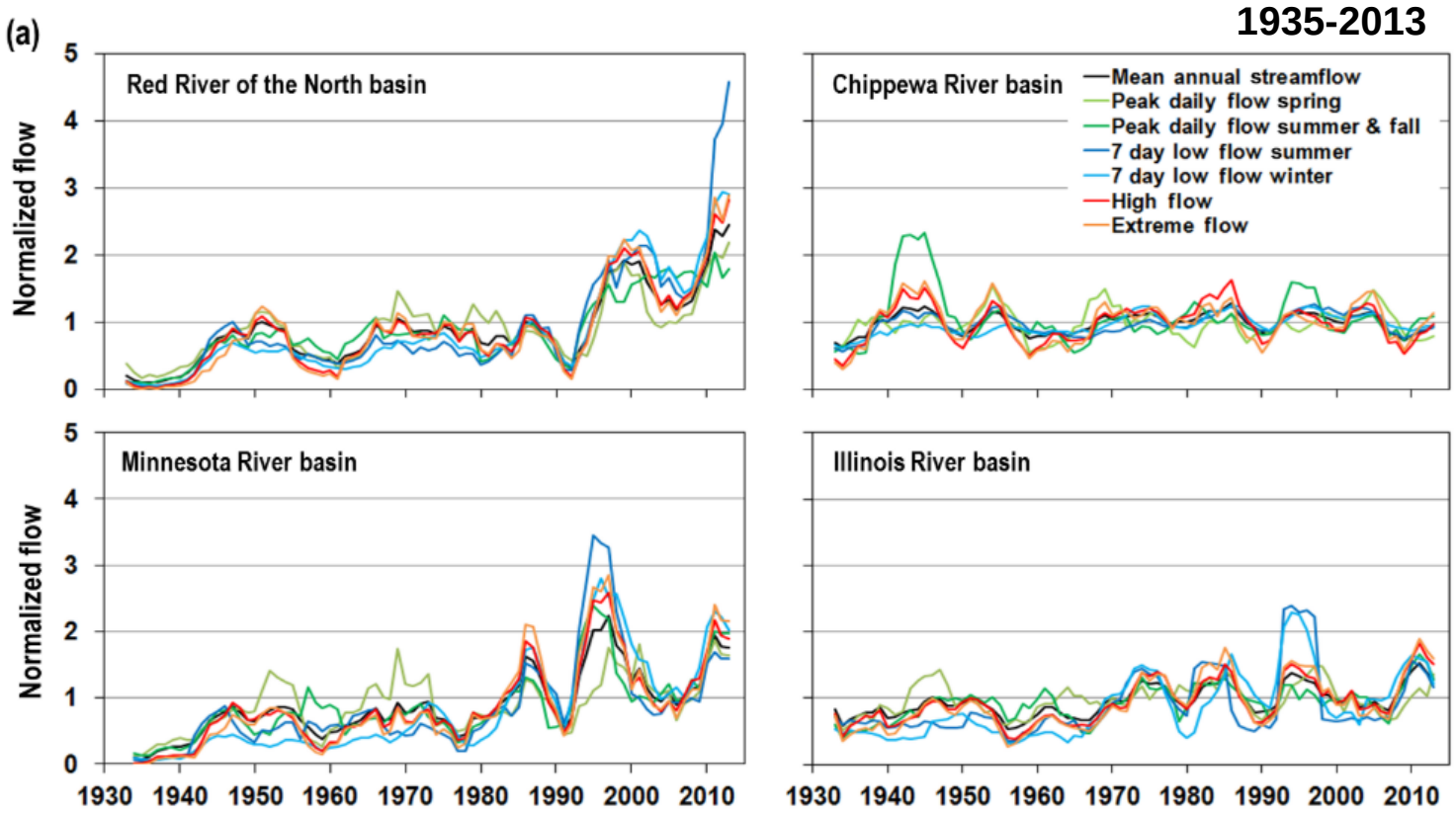
Drainage most extensive and increasing in Illinois and Minnesota River basins

County level data does not reflect tile density



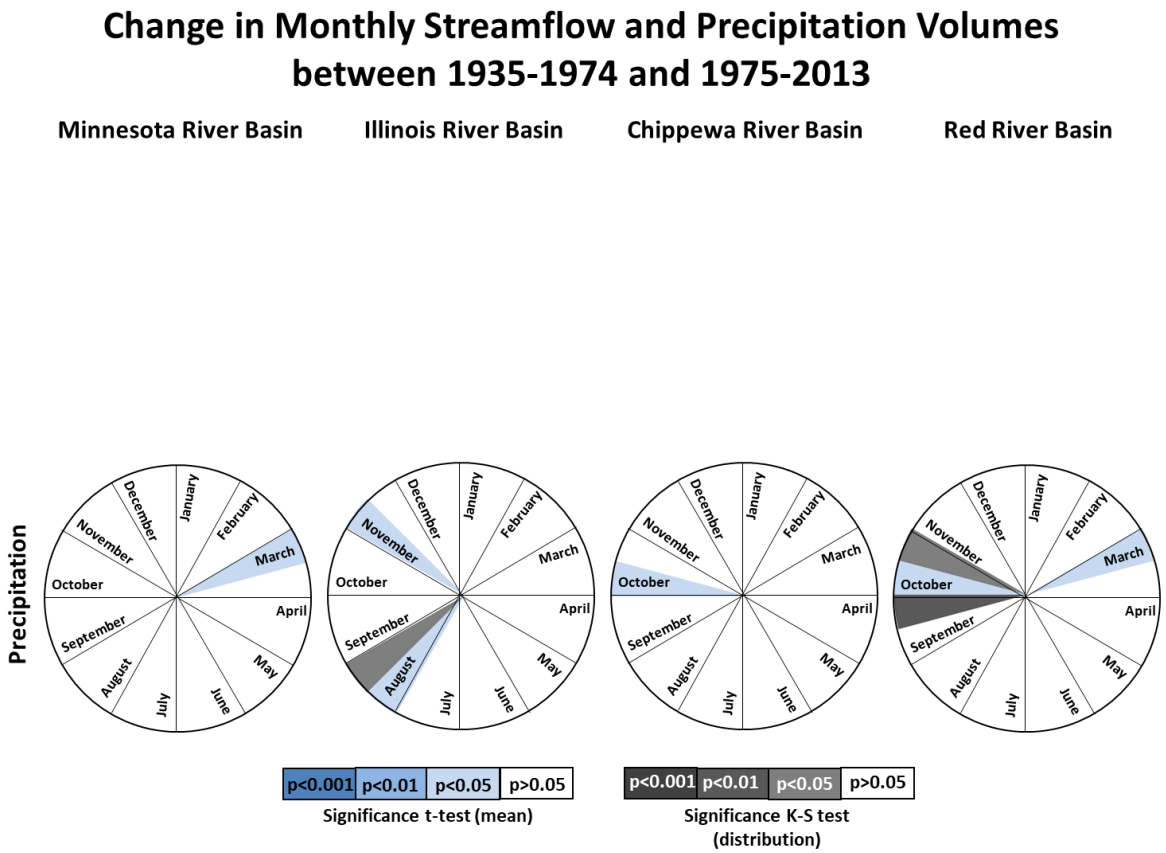
Also compiled annual crop data

Annual Streamflow Trends

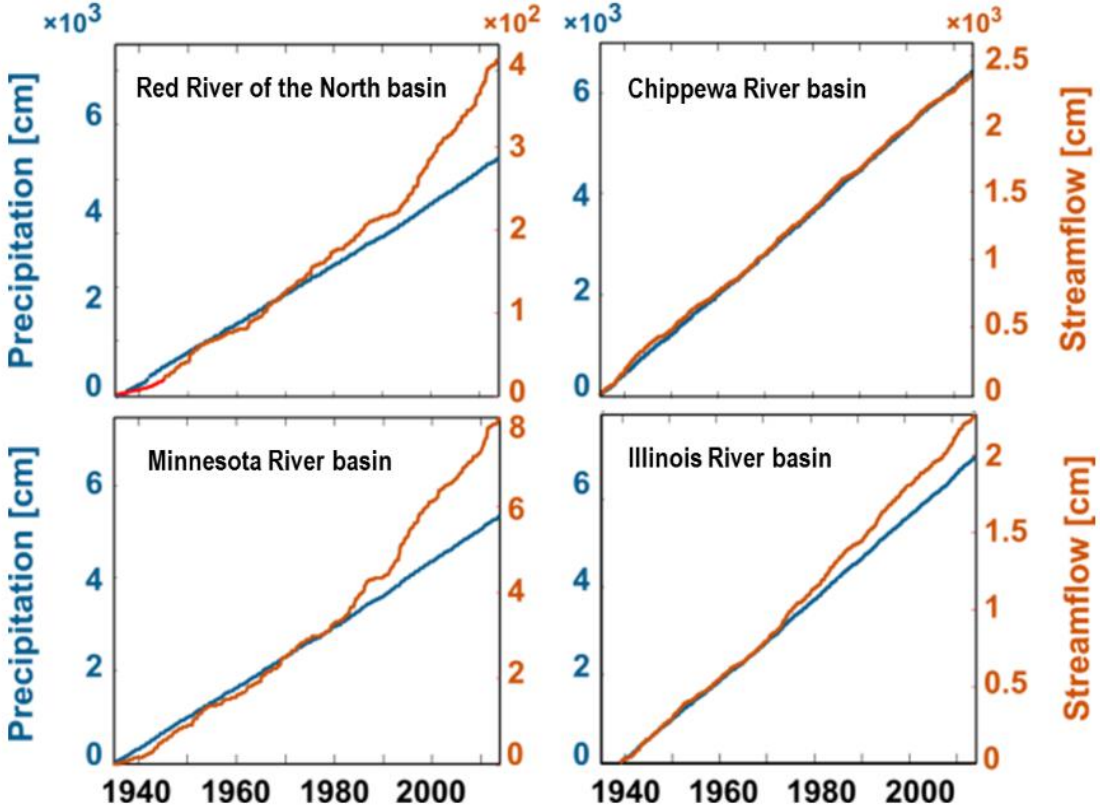


Three agricultural basins show increasing trend for all metrics

Monthly Precipitation and Streamflow



Cumulative Streamflow and Precipitation



Three agricultural basins show an increase in runoff

Different inflection point for each basin

Water Budgets

$$\uparrow P \; - \uparrow ET - \Uparrow Q = \Downarrow dS/dt$$

What is dS/dt?

Water Budgets

Minnesota River Basin:
1935-1978 to 1979-2011

10%

P

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

16%

P

Illinois River Basin:
1939-1961 to 1962-2011

5%

P

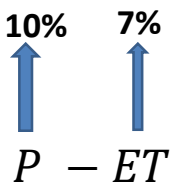
Chippewa River Basin:
1935-1974 to 1975-2011

3%

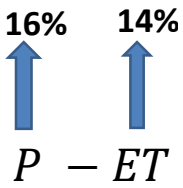
P

Water Budgets

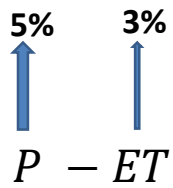
Minnesota River Basin:
1935-1978 to 1979-2011



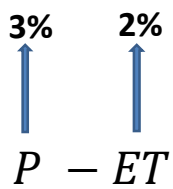
Red River of the North Basin:
1935-2003 to 2004-2011



Illinois River Basin:
1939-1961 to 1962-2011

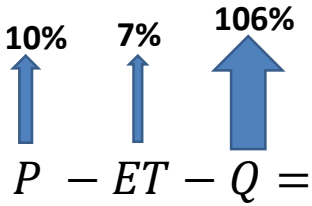


Chippewa River Basin:
1935-1974 to 1975-2011

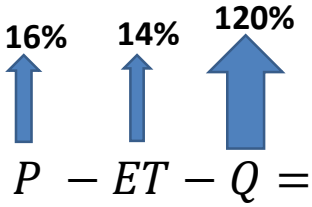


Water Budgets

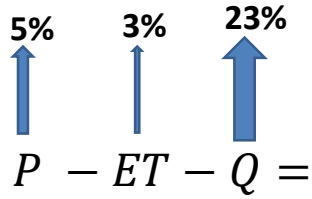
Minnesota River Basin:
1935-1978 to 1979-2011



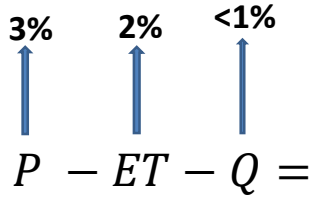
Red River of the North Basin:
1935-2003 to 2004-2011



Illinois River Basin:
1939-1961 to 1962-2011

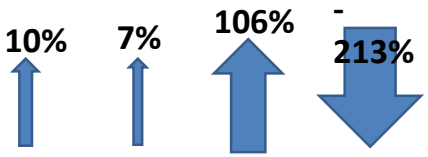


Chippewa River Basin:
1935-1974 to 1975-2011



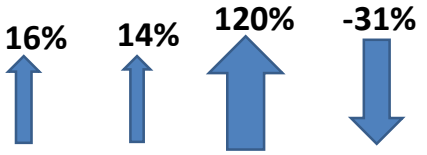
Water Budgets

Minnesota River Basin:
1935-1978 to 1979-2011



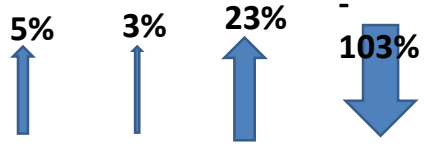
$$P - ET - Q = dS/dt$$

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



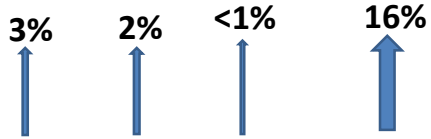
$$P - ET - Q = dS/dt$$

Illinois River Basin:
1939-1961 to 1962-2011



$$P - ET - Q = dS/dt$$

Chippewa River Basin:
1935-1974 to 1975-2011



$$P - ET - Q = dS/dt$$

dS/dt

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

Kelly, S. A., Takbiri, Z., Belmont, P., & Foufoula-Georgiou, E. (2017). Human amplified changes in precipitation-runoff patterns in large river basins of the Midwestern United States. *Hydrology and Earth System Sciences*, 1–37. https://doi.org/10.5194/hess-2017-133


DANGER
SWINGING
UNSAFE

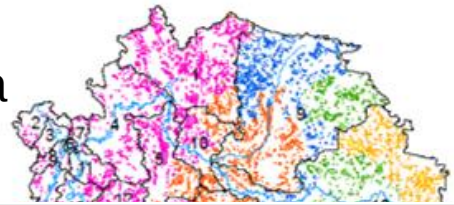
Water detention basins (aka. ephemeral wetlands) reduce sediment loading downstream

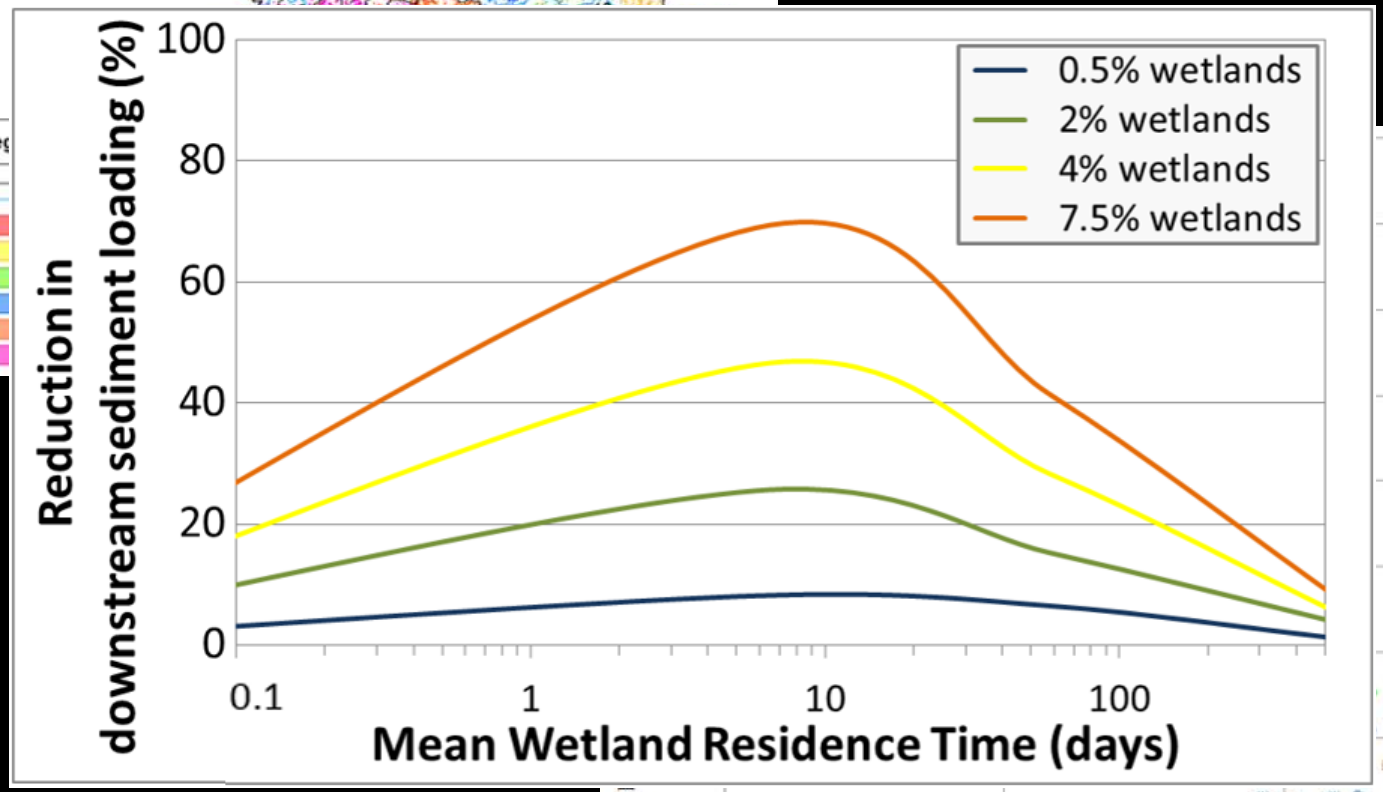
Temporary water storage

→ Reduces peak flows downstream

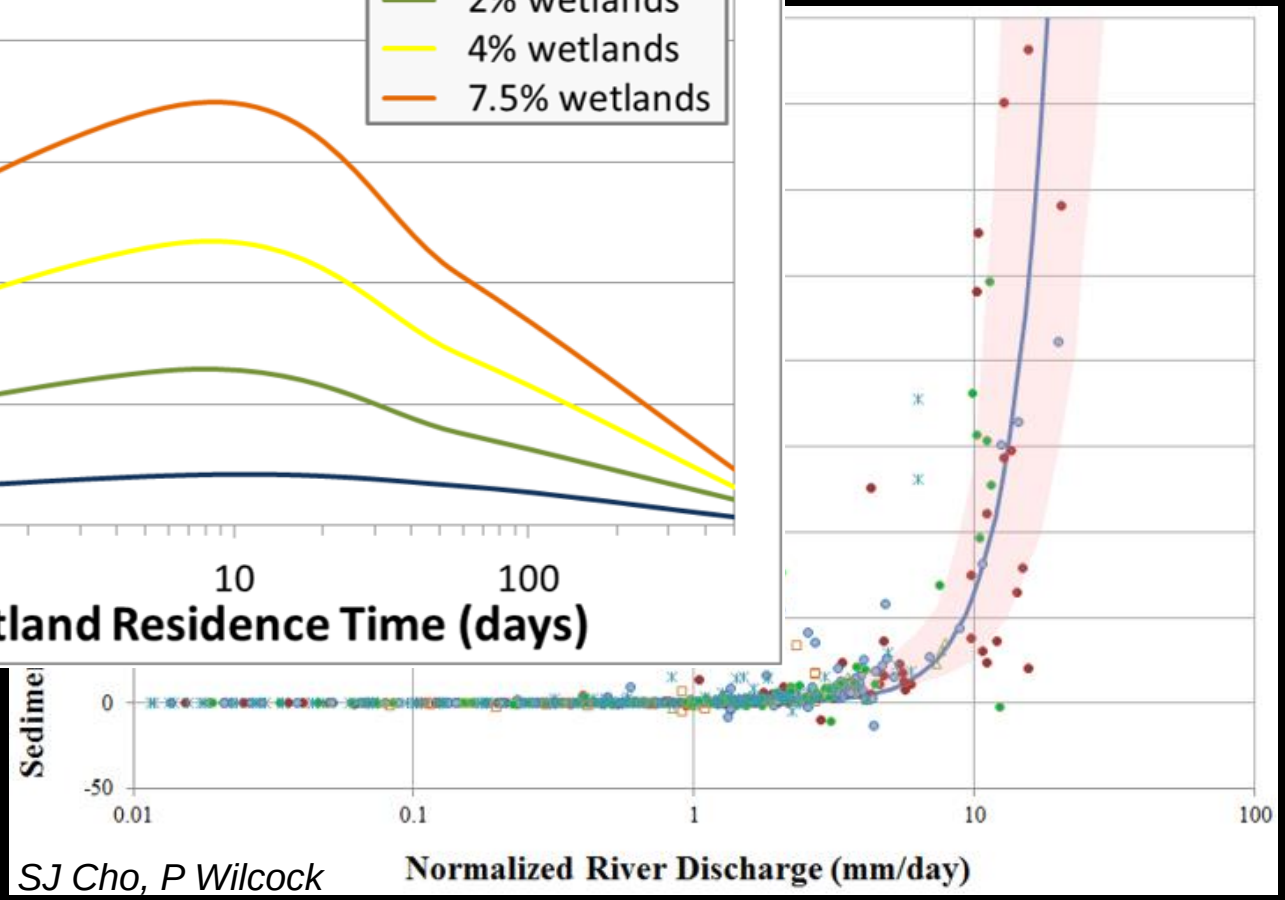
→ Reduces bluff erosion in the knick zone

0.5 - 7.5% of total area





N Mitchell, K Gran



SJ Cho, P Wilcock

Approaches to reporting e.g.,
How to report – CDSB, IIRC
What to report –
GRI, SASB, CDP, GHG Protocol

Strategic initiatives e.g.,
UN Sustainable Development Goals
Climate targets, commitments
or declarations
The Circular Economy
Net Positive Impact

The Protocol helps to integrate natural capital into existing decision making processes

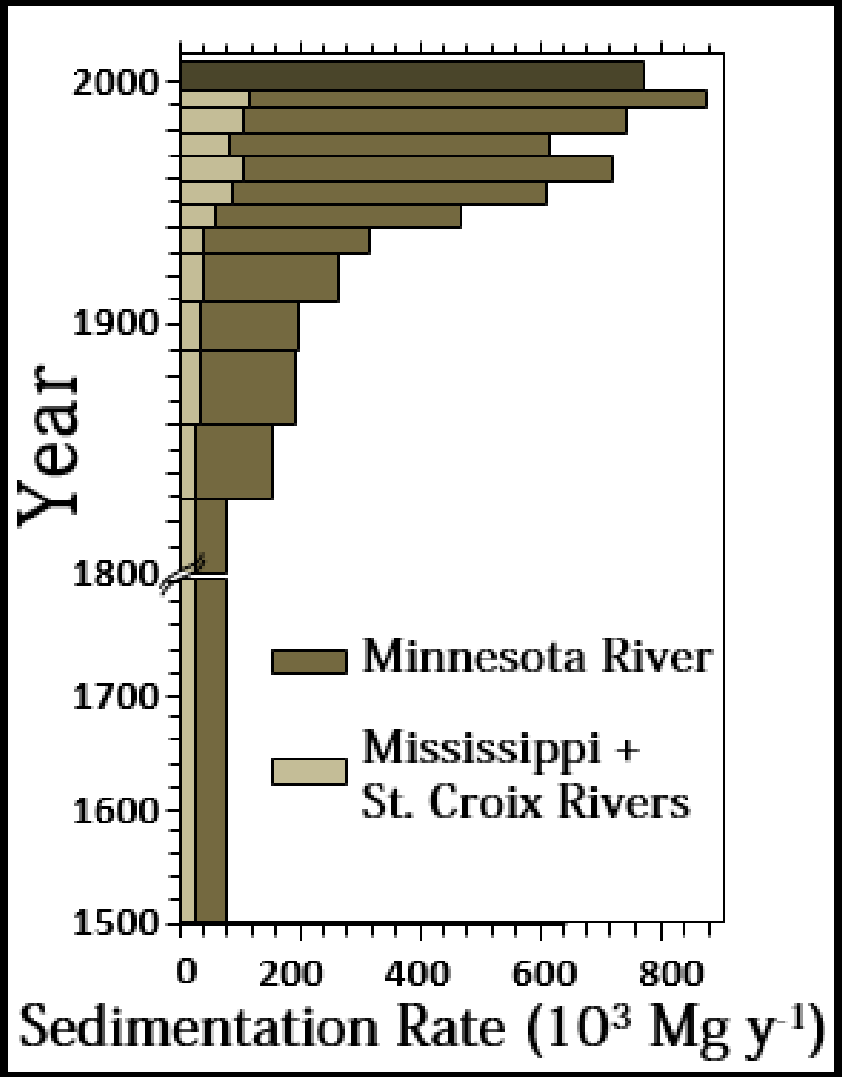
Depending upon the decision that you want to inform there are various tools and methodologies to help you value natural capital

Measurement approaches e.g.,
Environmental Management Systems
(ISO 14001) GHG Protocol

CDP – Carbon Disclosure Project
CDSB – Climate Disclosure Standards Board
IIRC – International Integrated Reporting Council
ISO – International Organization for Standardization
GHG – Greenhouse Gas
GRI – Global Reporting Initiative
SASB – Sustainability Accounting Standards Board

INTEGRATING NATURAL CAPITAL INTO BUSINESS DECISION MAKING

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

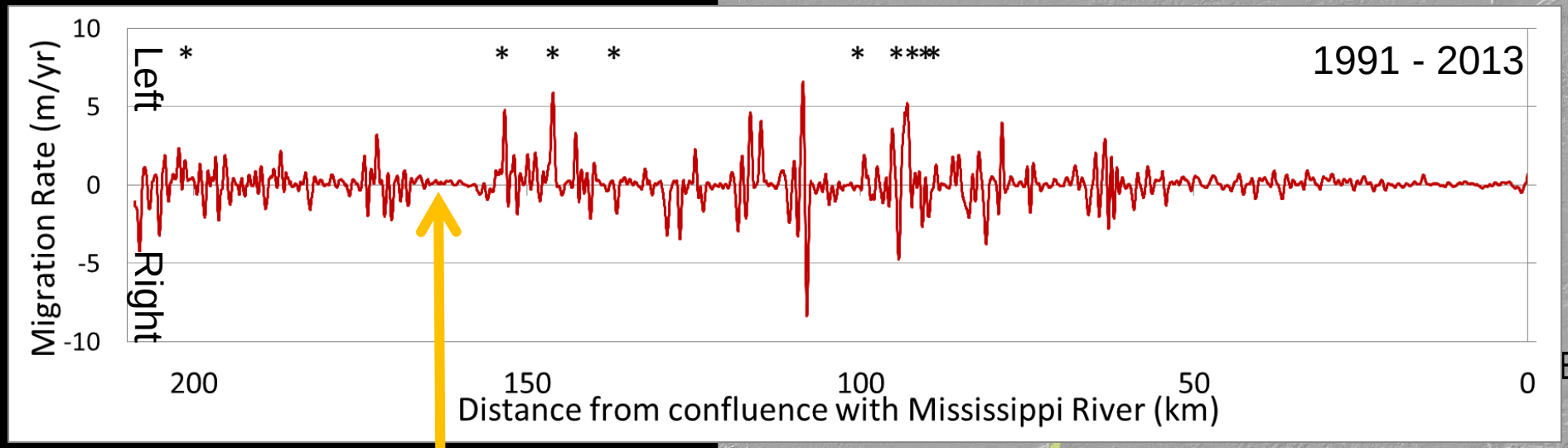
Step 1 : Monitoring and Assessment
Intensely monitor waters and assess whether meet standards (MPCA leads)

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

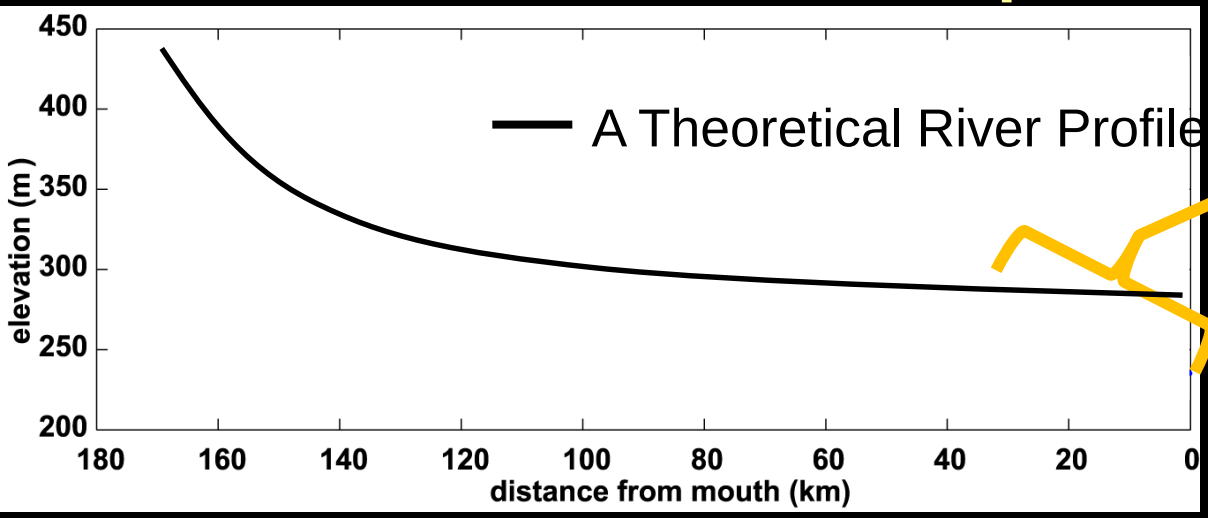


Greater Blue Earth confluence

0 5 10 20
Km

Width Change (m/y)
0
1

Le Sueur River example



knick zone

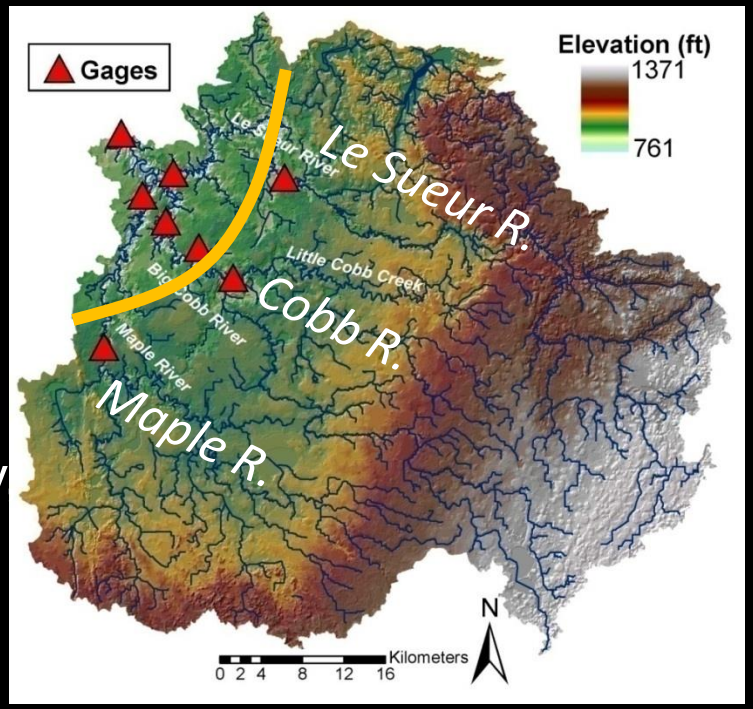
NATURAL

Poorly drained, fine textured soils

Down-cutting rapidly for past 13,400 years

HUMAN

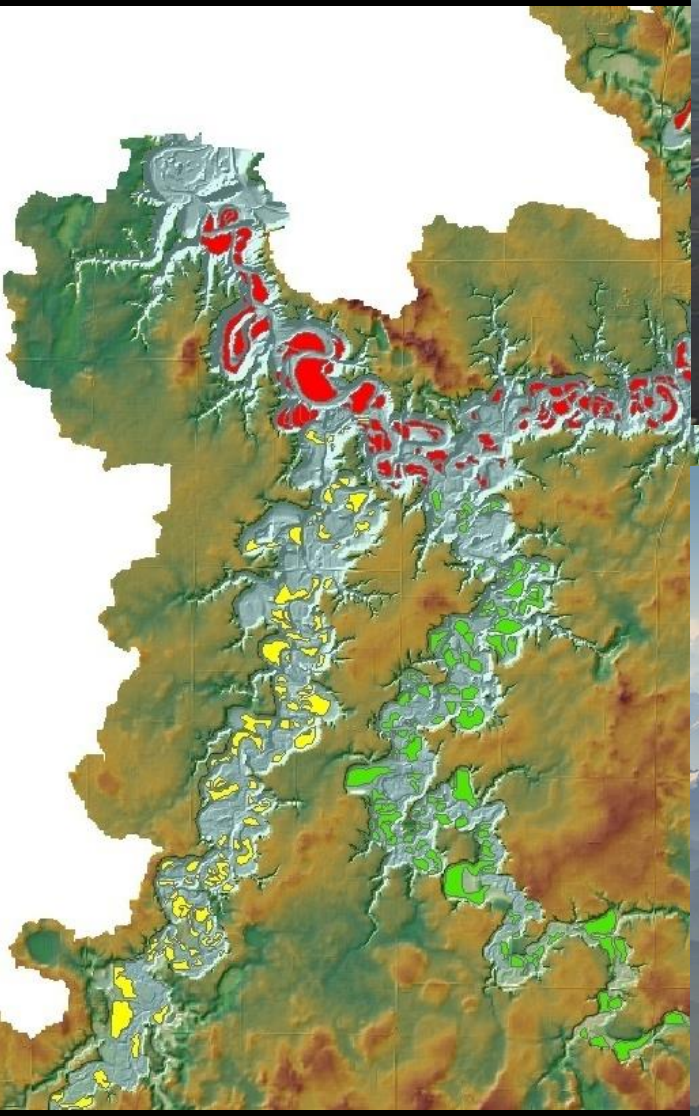
Agriculture and drainage began mid 1800s
Continue to evolve in effectiveness, intensity
precision, productivity, etc.

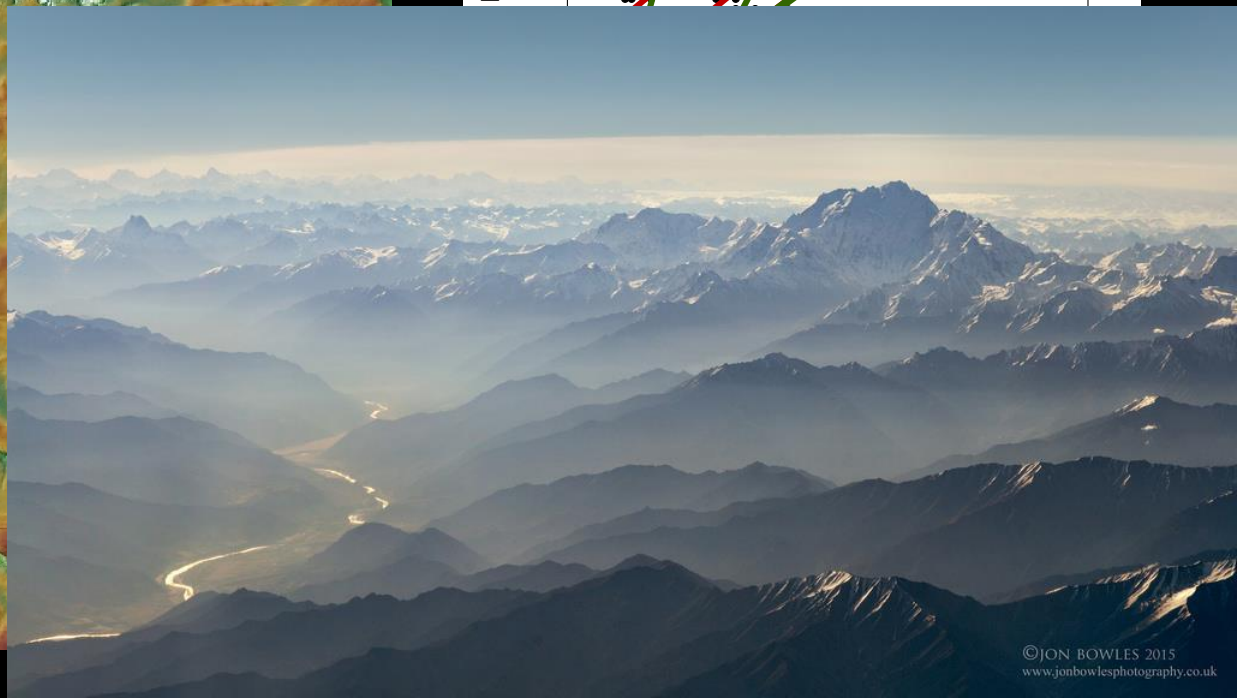


Hundreds of old floodplains record the history

Fluvial Terrace

The Record of Inc



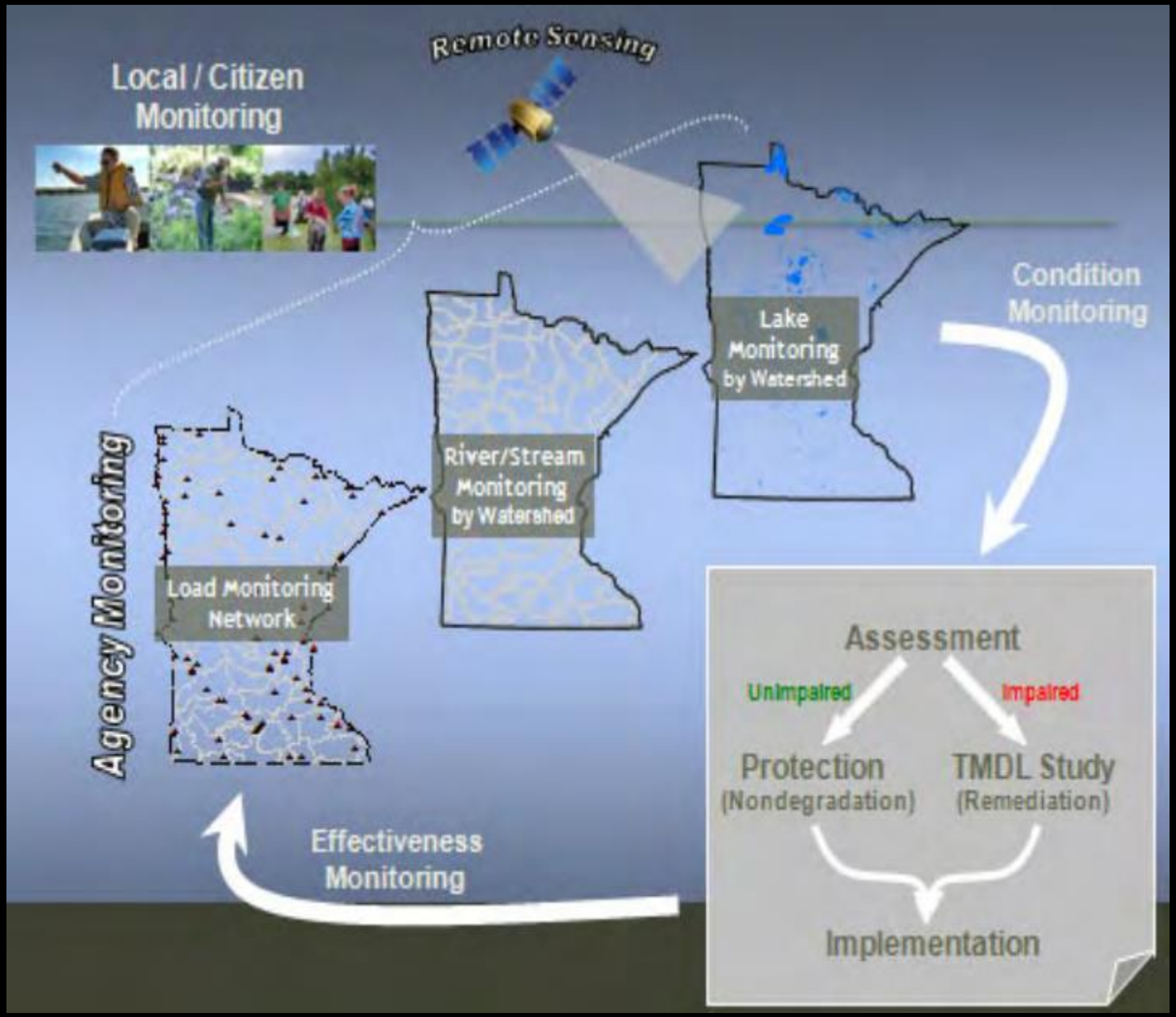


We've got to do everything we can…all practices we can do.

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.


Remote Sensing
Local / Citizen Monitoring
Condition Monitoring
Lake Monitoring by Watershed
River/Stream Monitoring by Watershed
Agency Monitoring
Load Monitoring Network
Assessment
Unimpaired
Impaired
Protection (Nondegradation)
TMDL Study (Remediation)
Implementation
Effectiveness Monitoring

October, 2017

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

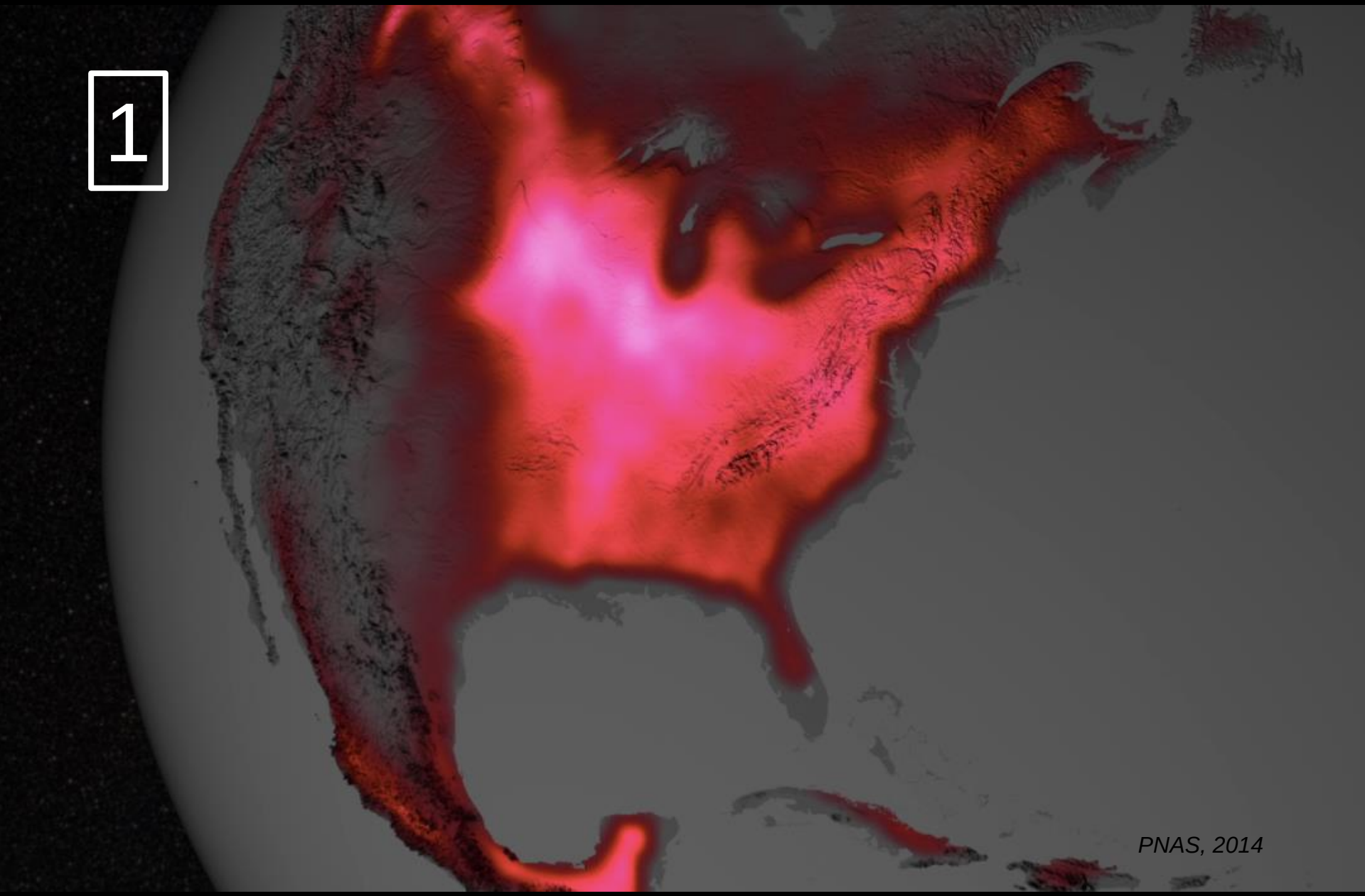
Build soil health

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

MINNESOTA POLLUTION CONTROL AGENCY

A wide variety of stakeholder interests

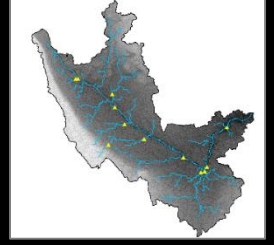

1
PNAS, 2014

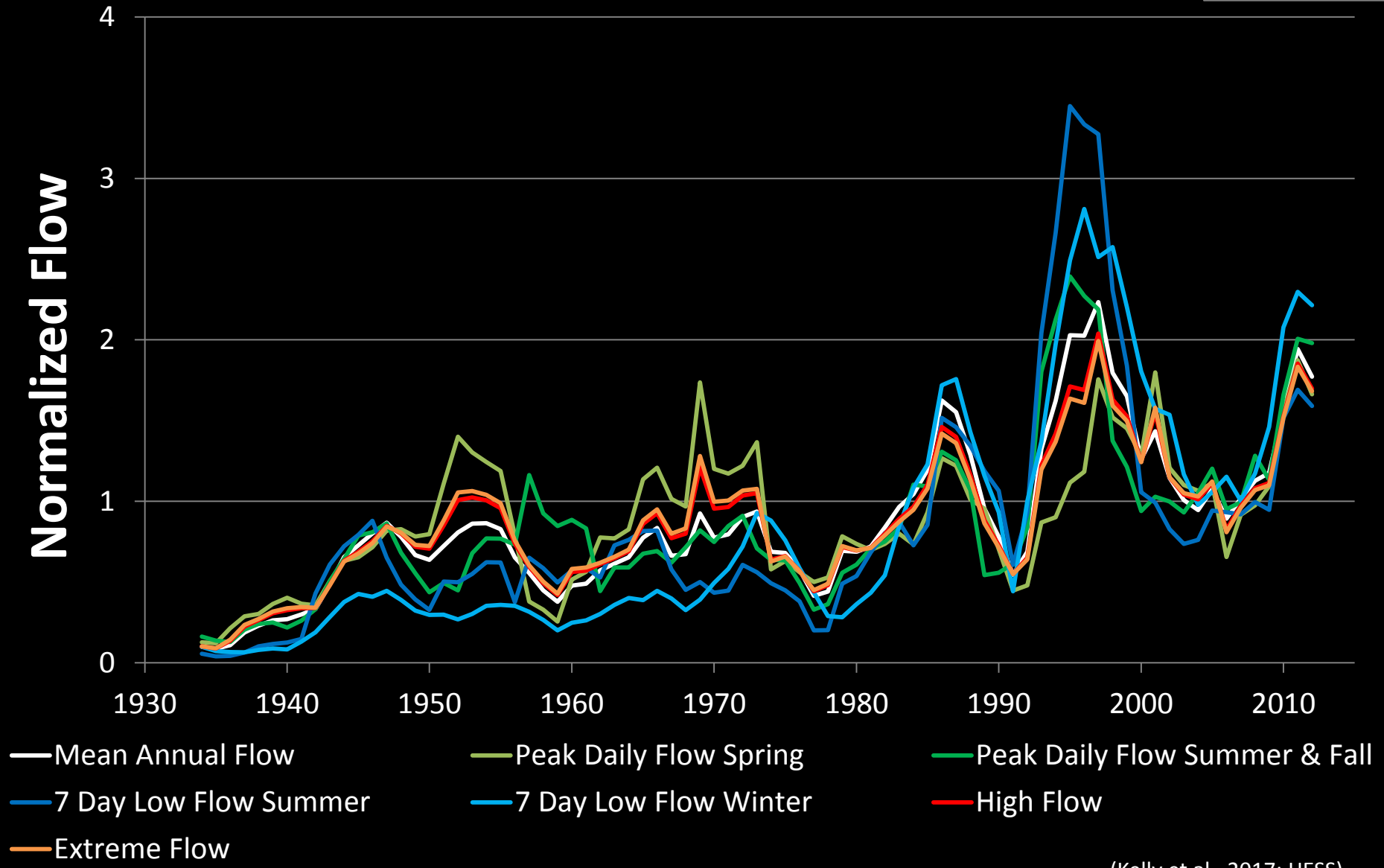

2


3

4

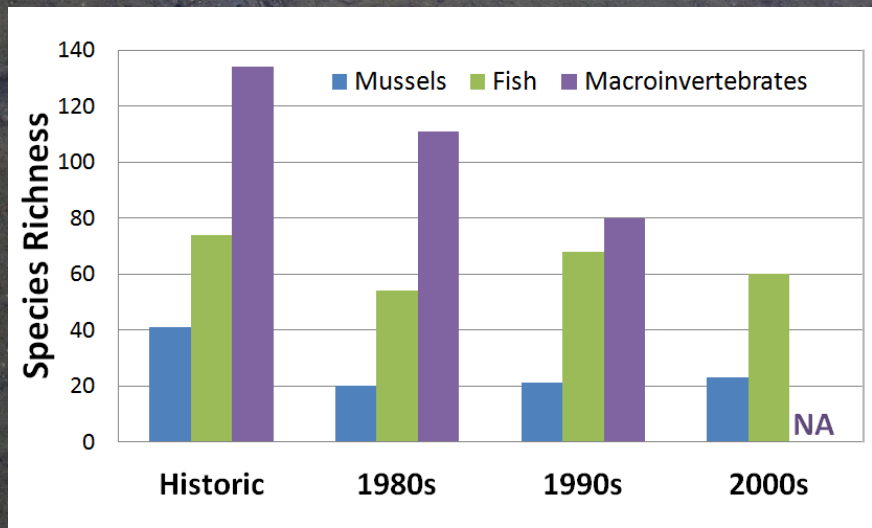
Streamflow: Minnesota River Basin



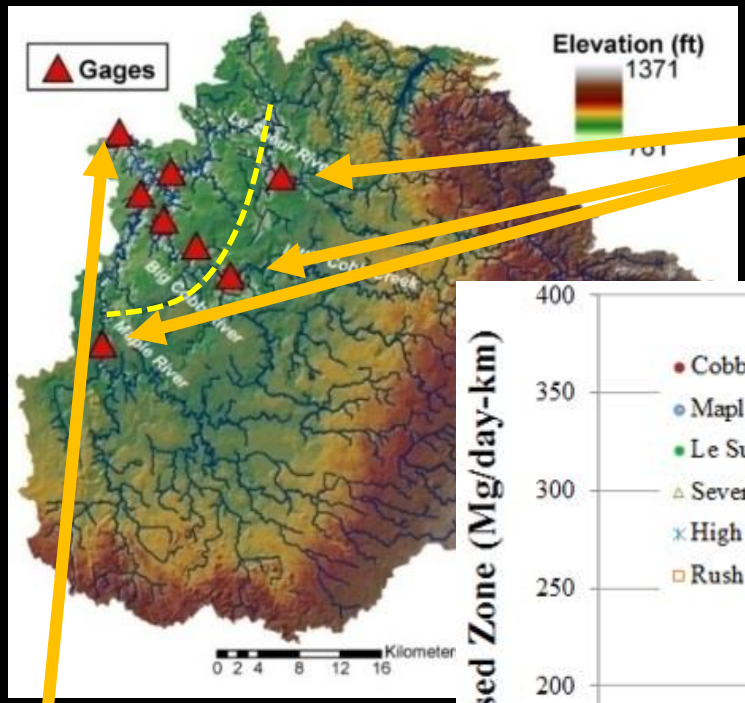


(Kelly et al., 2017; HESS)

6

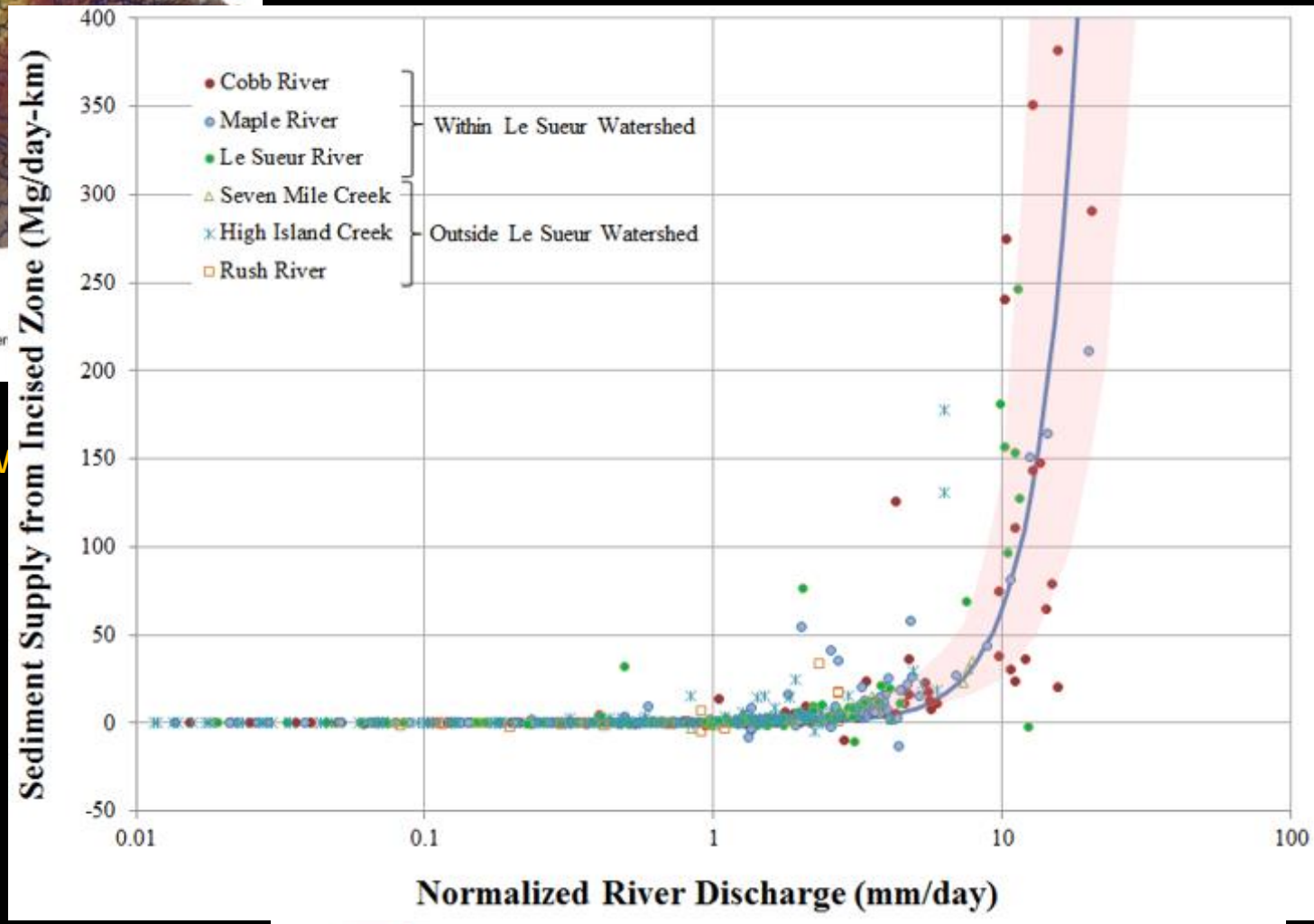

Mussels
Fish
Macroinvertebrates
Species Richness
140
120
100
80
60
40
20
0
NA
Historic
1980s
1990s
2000s

Lots of sediment comes from a small area



Sediment loads up here are moderately high

Sediment loads dow
are very, very high



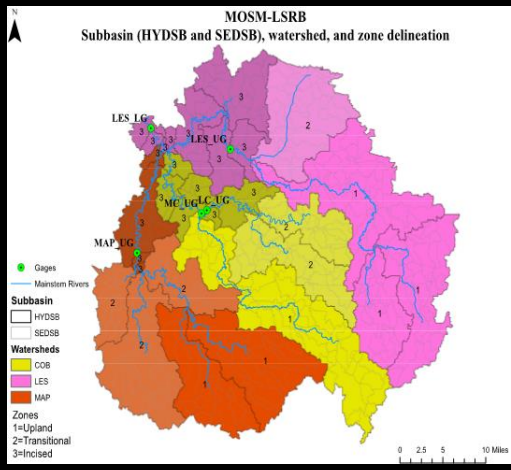
Moving the conversation towards a more transparent and verifiable connection between cause & effect

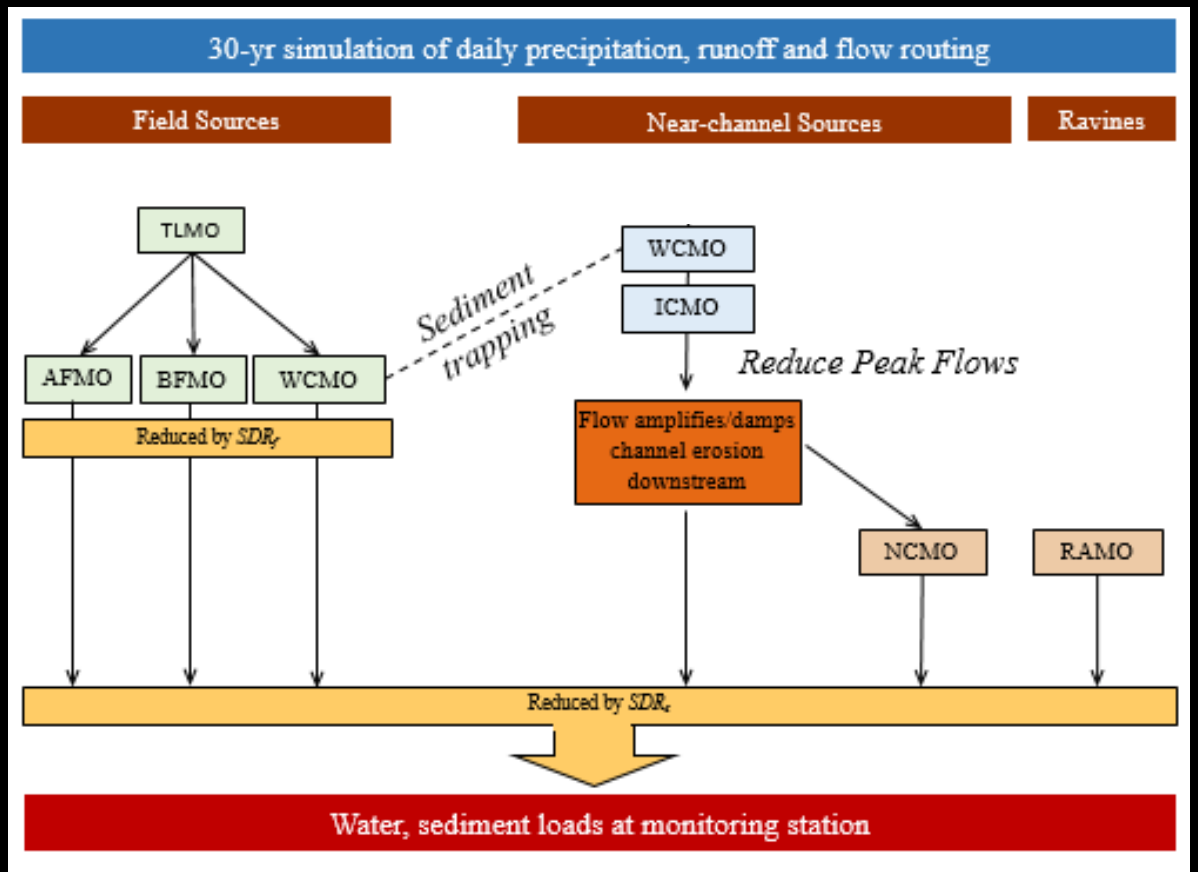
(1) Sediment budget

(2) Suite of management options, explicit on size, location, efficiency, cost, with uncertainty

(3) Reduced complexity simulation model

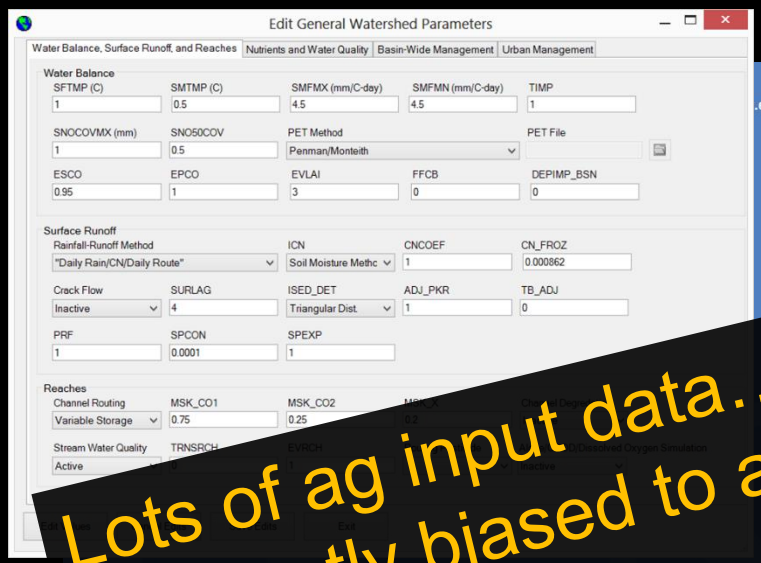
(4) Decision analysis framework

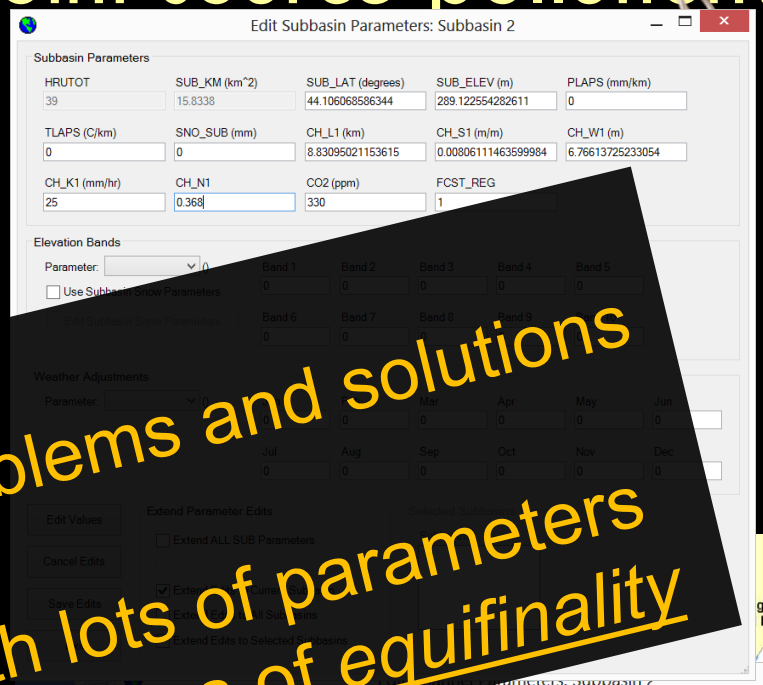




S. Cho, P. Wilcock

How to predict non-point source pollution?

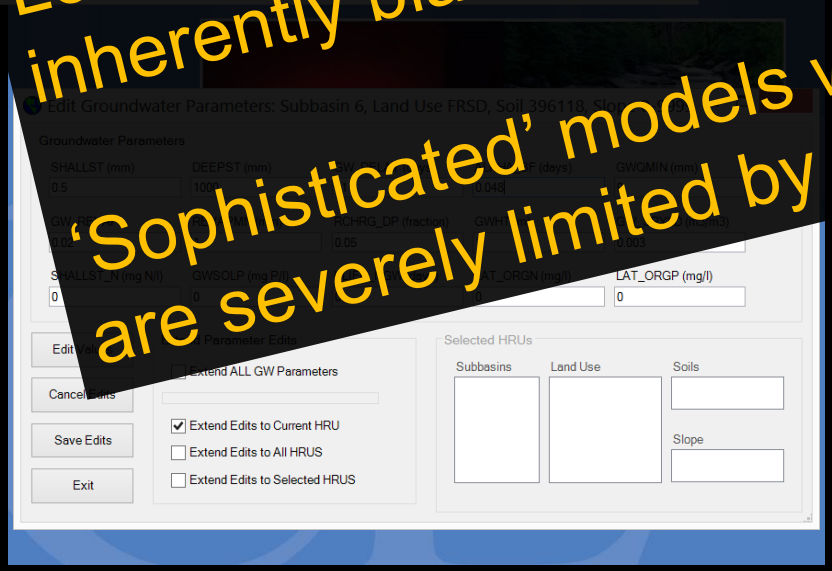


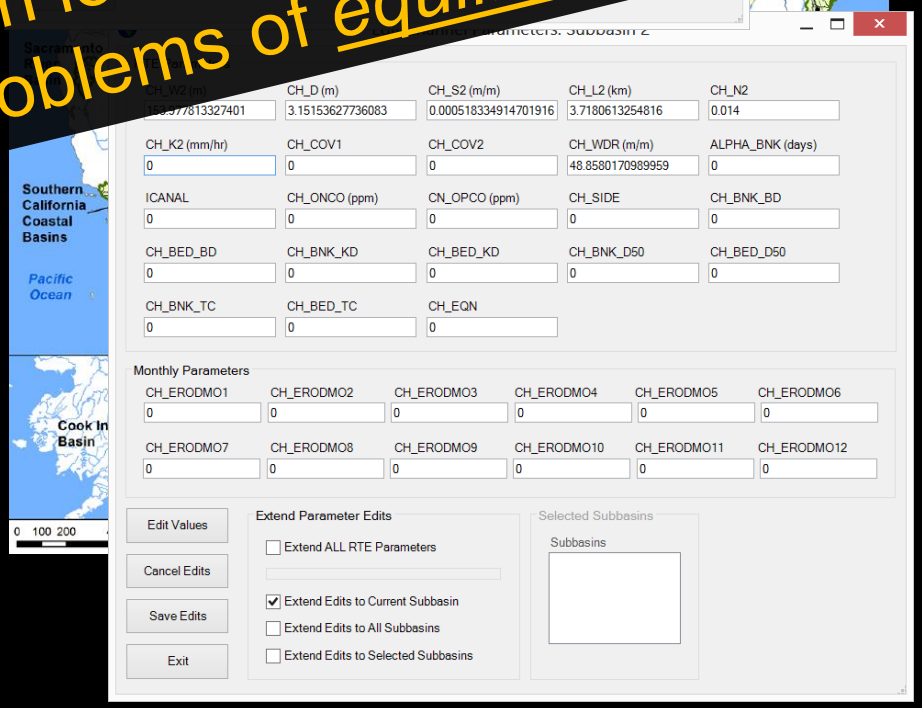


Lots of ag input data…
inherently biased to ag problems and solutions

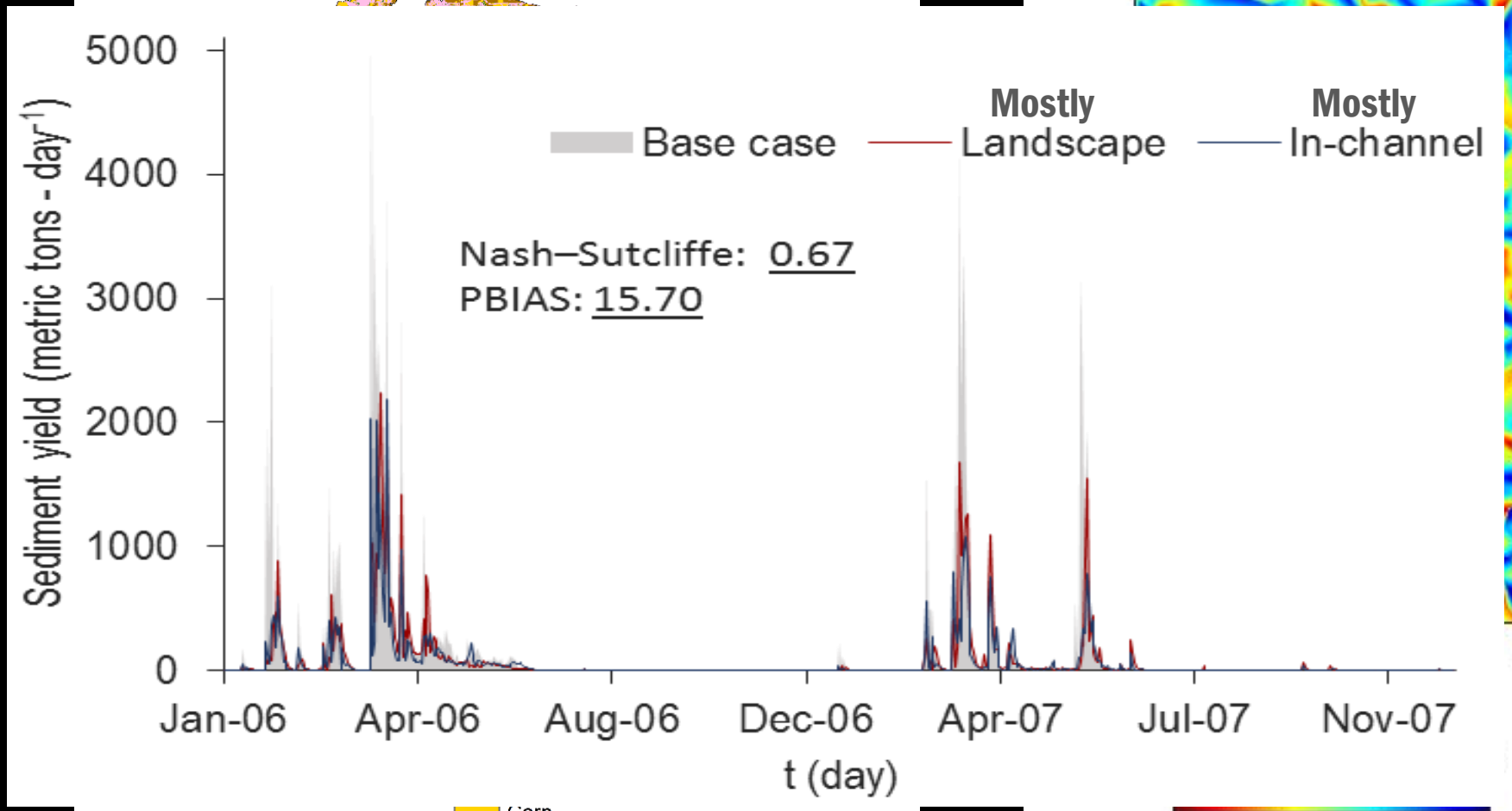
'Sophisticated' models with lots of parameters
are severely limited by problems of *equifinality*

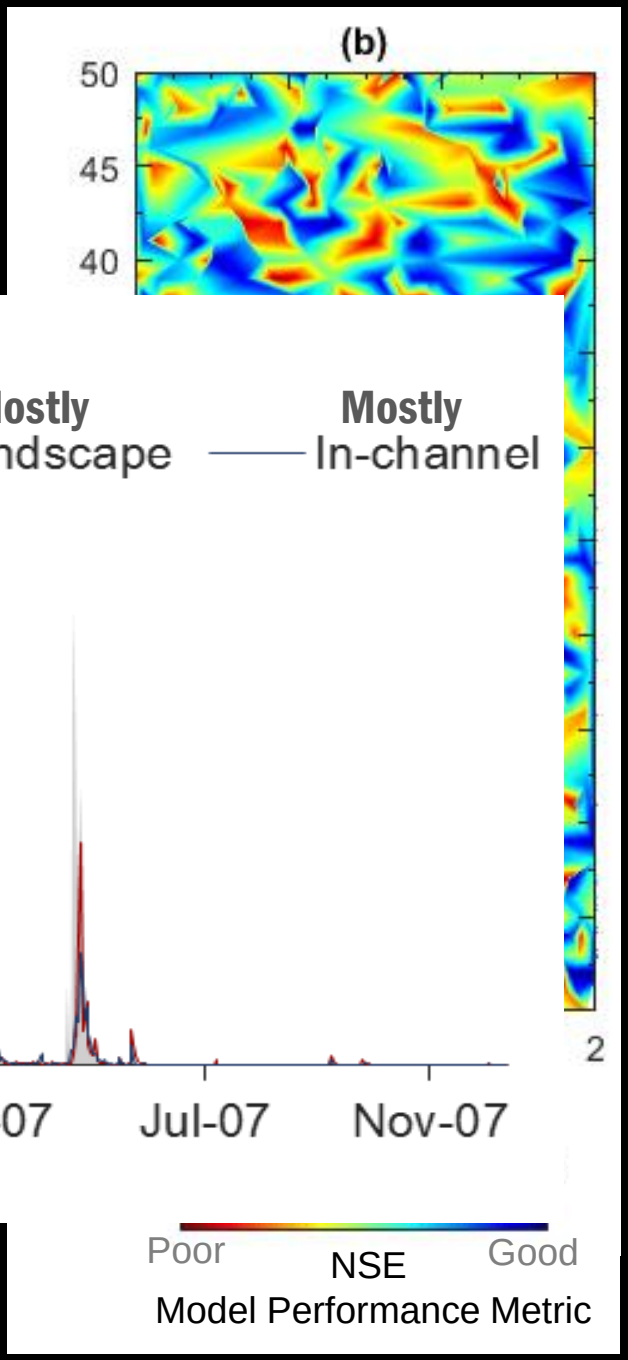
!?





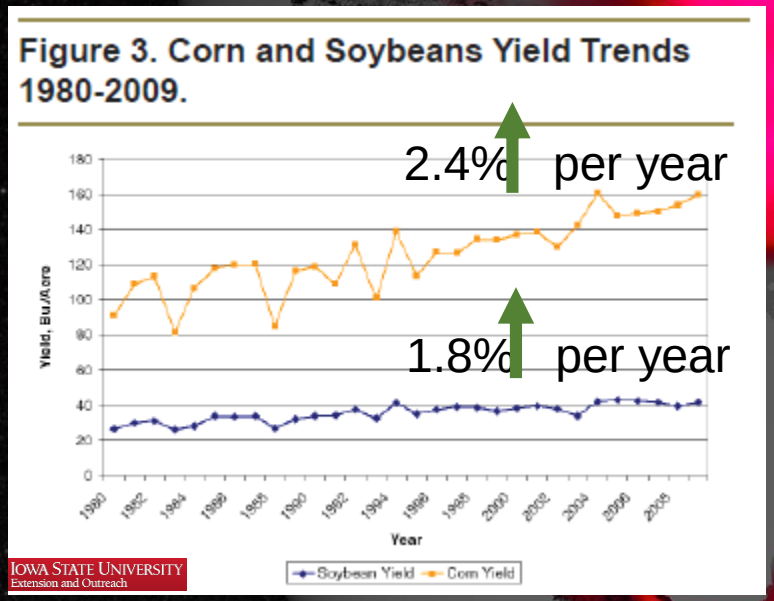
Gaming equifinality problems where we know the right answer





The up-sides of drainage

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

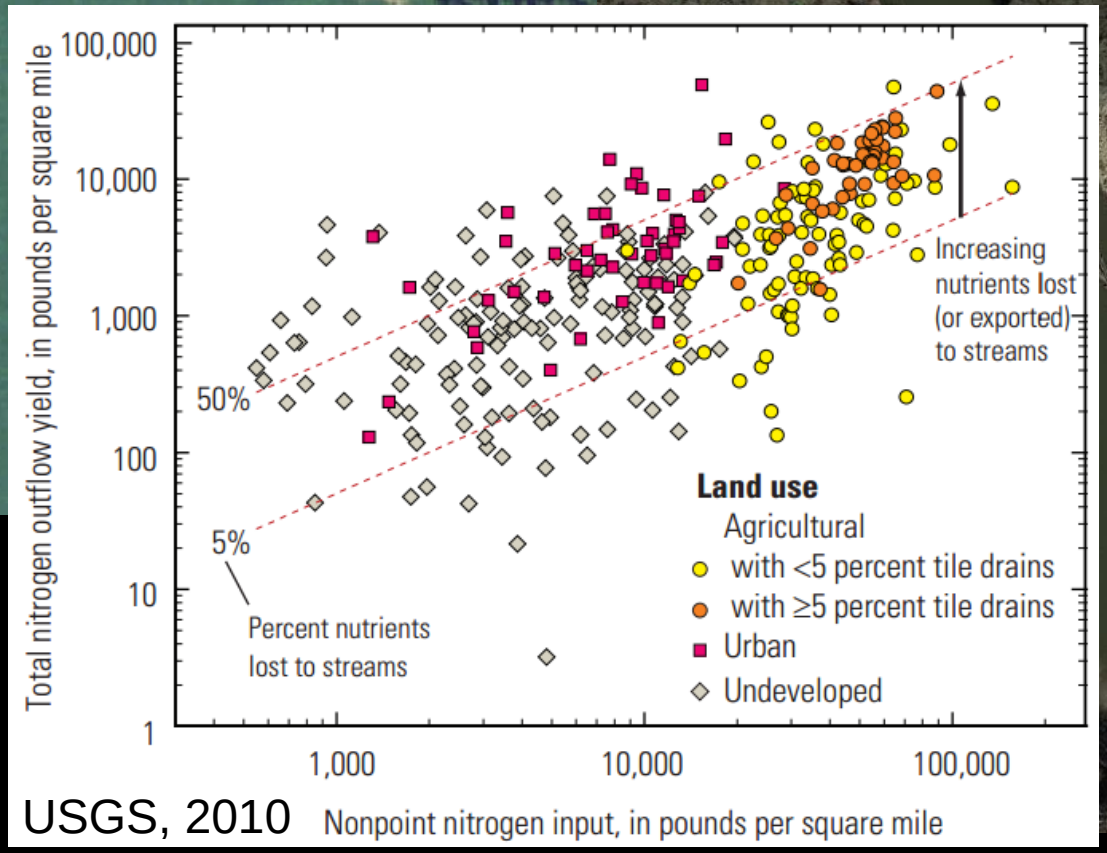


July 2013 fluorescence

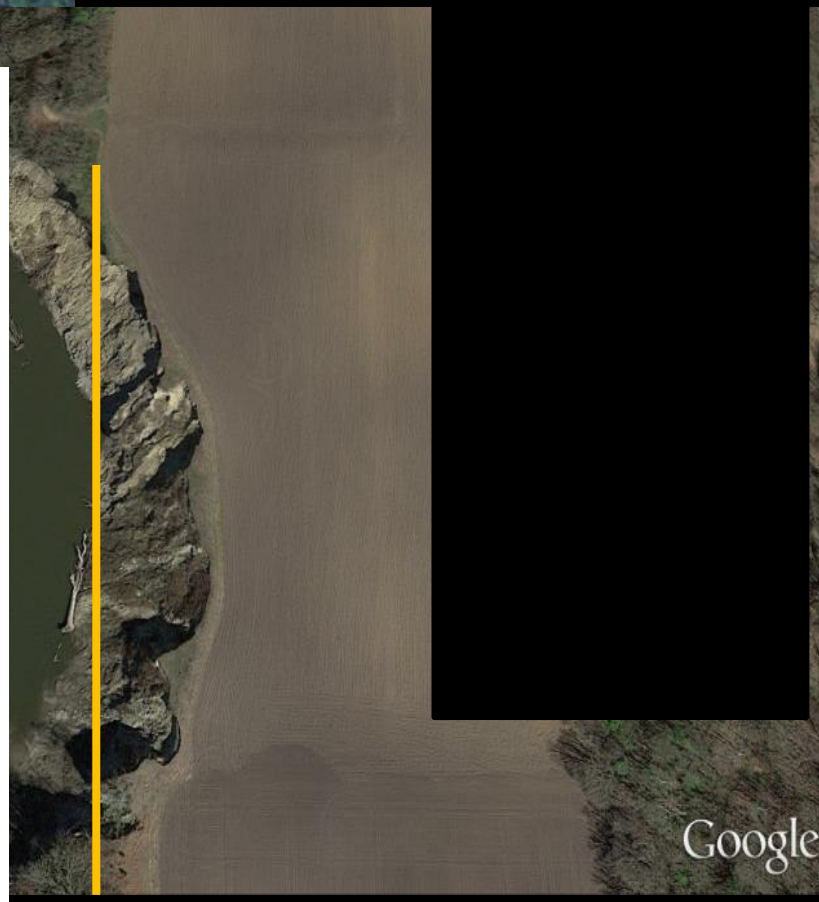
NASA's Goddard Space Flight Cen

The down-sides 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



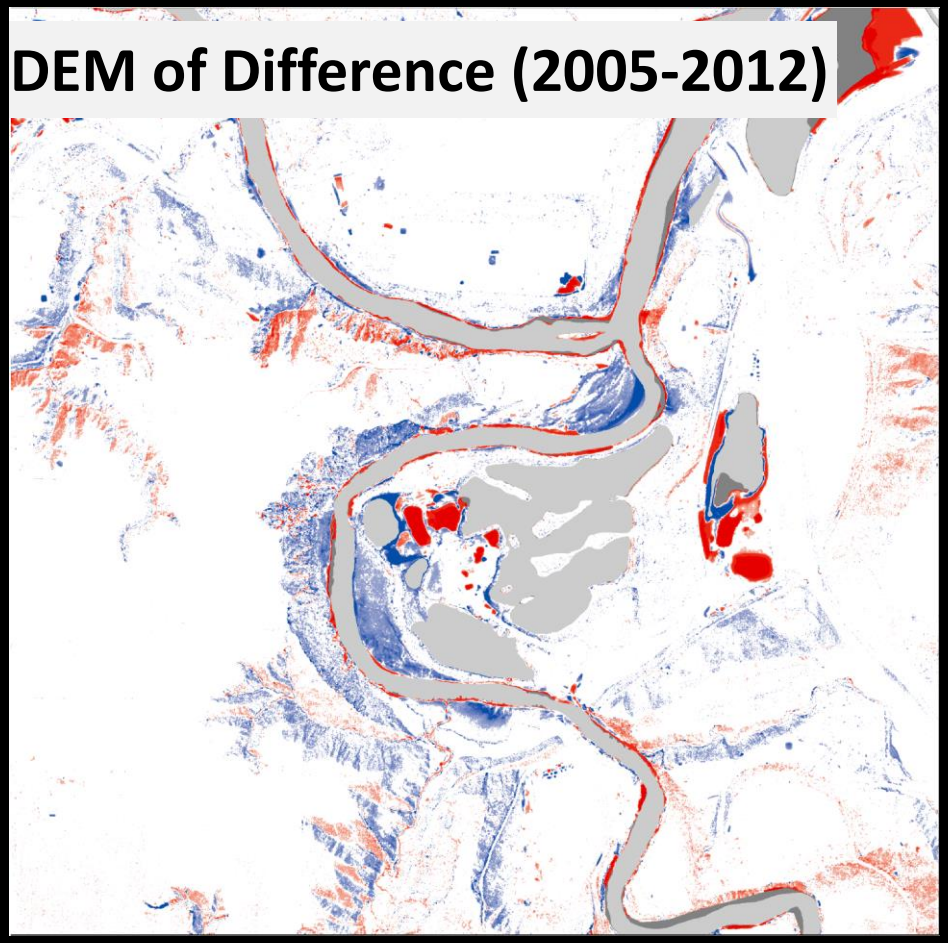
USGS, 2010

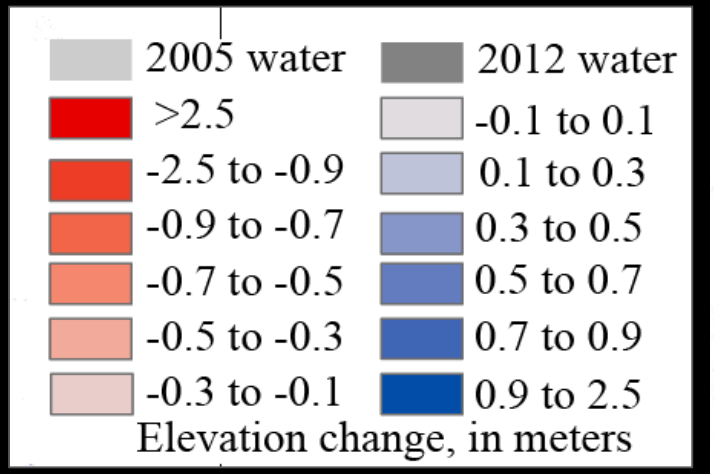


Observatory Highlights:
Lidar analysis and feature extraction

Change detection from 1m DEMs over 2000 km^2
Largest GCD study to date!

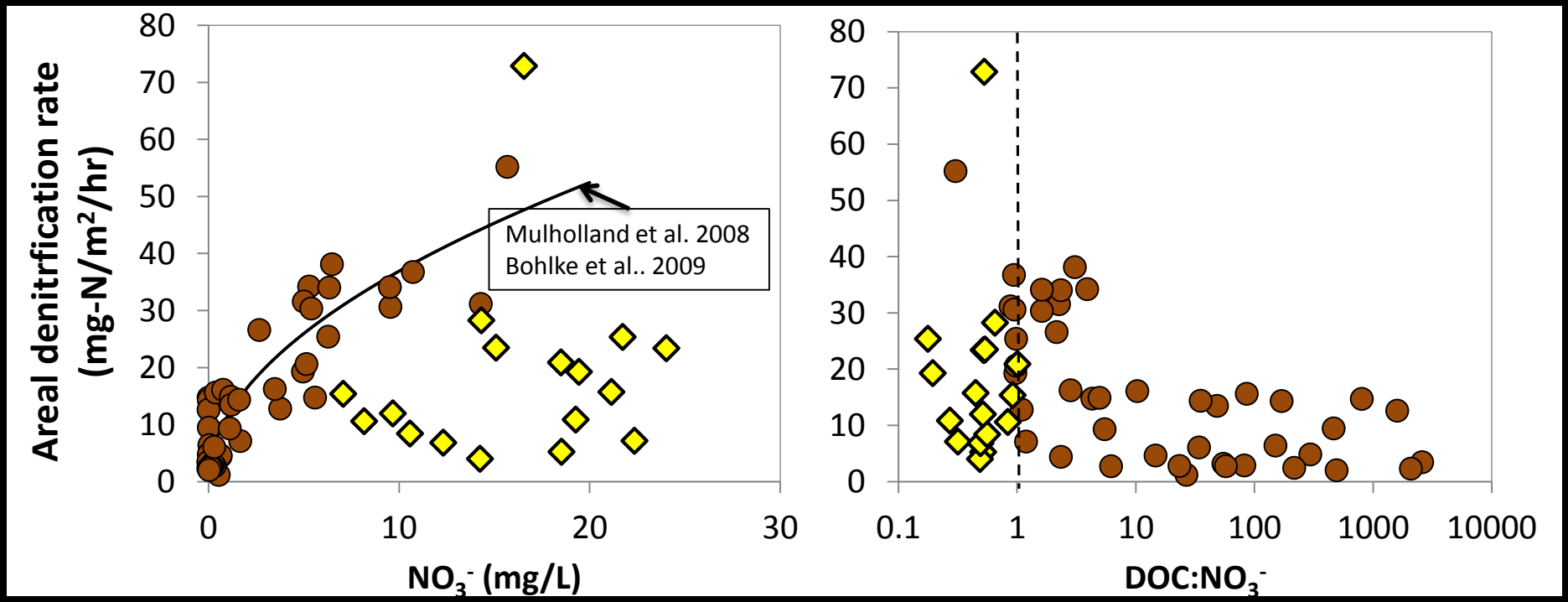
Spatially variable uncertainty





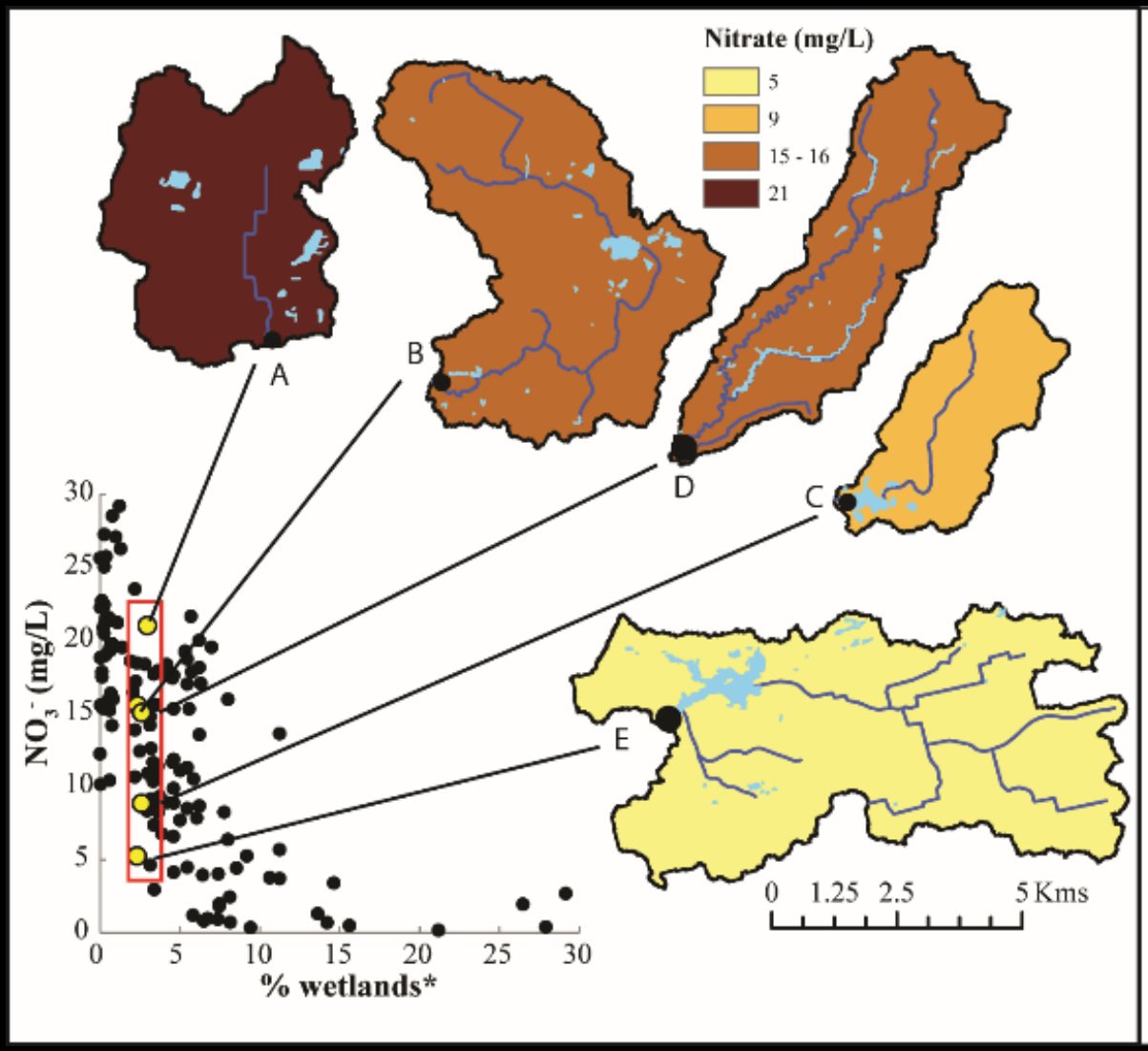
Denitrification rates are carbon limited

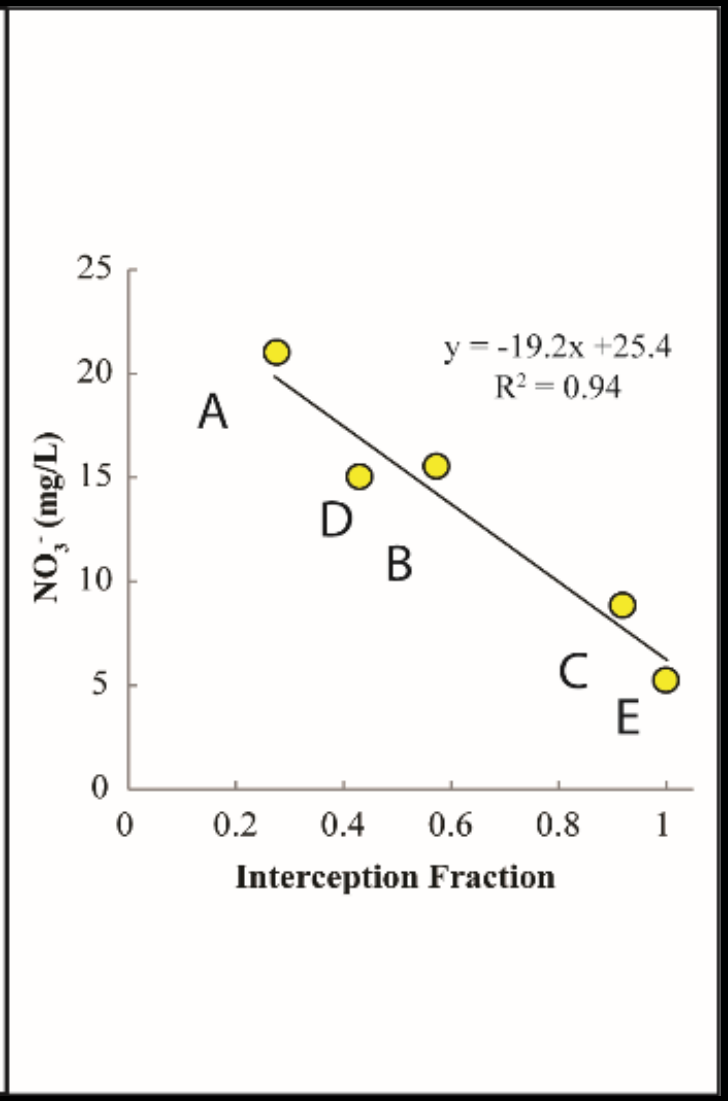
An important caveat:
Nitrate removal depends on carbon availability



A. Hansen, J. Finlay

Wetland composition and location matter





AGU PUBLICATIONS

Water Resources Research

COMMENTARY

10.1002/2017WR020839

Special Section:
Earth and Space Science is Essential for Society

Key Points:

- Changes in climate and land use cascade through agricultural systems in complex ways intensifying challenges in meeting water quality goals
- Effective solutions emerge from understanding the system and identifying hot spots and feedback loops where efforts would do the most good

Solving water quality problems in agricultural landscapes: New approaches for these nonlinear, multiprocess, multiscale systems

Patrick Belmont[1] and Efi Foufoula-Georgiou[2]

[1]Department of Watershed Sciences, Utah State University, Logan, Utah, USA, [2]Department of Civil and Environmental Engineering, University of California, Irvine, California, USA

Abstract Changes in climate and agricultural practices are putting pressure on agroenvironmental systems all over the world. Predicting the effects of future management or conservation actions has proven exceptionally challenging in these complex landscapes. We present a perspective, gained from a decade of research and stakeholder involvement in the Minnesota River Basin, where research findings have influenced solutions and policy in directions not obvious at the outset. Our approach has focused on identifying places, times, and processes of accelerated change and developing reduced complexity predictive frame-

Hansen et al., The interactive effect of wetlands, crop lands and stream network on riverine nitrate, *Nature Geosciences*, to appear, 2017

Timeline of Minnesota's historic mega-rain events 1866-2014

1866-1965
Four mega-rains in 100 years

Aug. 6, 1866
Killed 16 people in Fillmore County.

July 17-19,1867
Known as the state's greatest flash flood, in central Minnesota.

July 20-22, 1909
Extensive across northern Minnesota, killed 2 children in Duluth.

September 9-10, 1947
More than 8 inches in five hours at Hibbing.

1966-1999
Three mega-rains in 33 years

July 21-22, 1972
Nearly 11 inches in 24 hours at Ft. Ripley, state record at the time.

June 28-29 and July 1-2, 1975
Intense rain in northwestern Minnesota in two events.

July 23-24, 1987
9 inches at Minneapolis-St. Paul International Airport, a record.

2000-2014
Five mega-rains in 14 years

June 9-10, 2002
More than 12 inches in 48 hours in northern Minnesota.

Sept. 14-15, 2004
More than 10 inches in 36 hours in Faribault and Freeborn counties.

Aug. 18-20, 2007
15 inches near Hokah, state record for 24 hours.

Sept. 22-23, 2010
More than 10 inches at Amboy.

June 19-20, 2012
7 inches in two days in Duluth, St. Louis River at record level.

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

One Big Watershed
One Big Plan

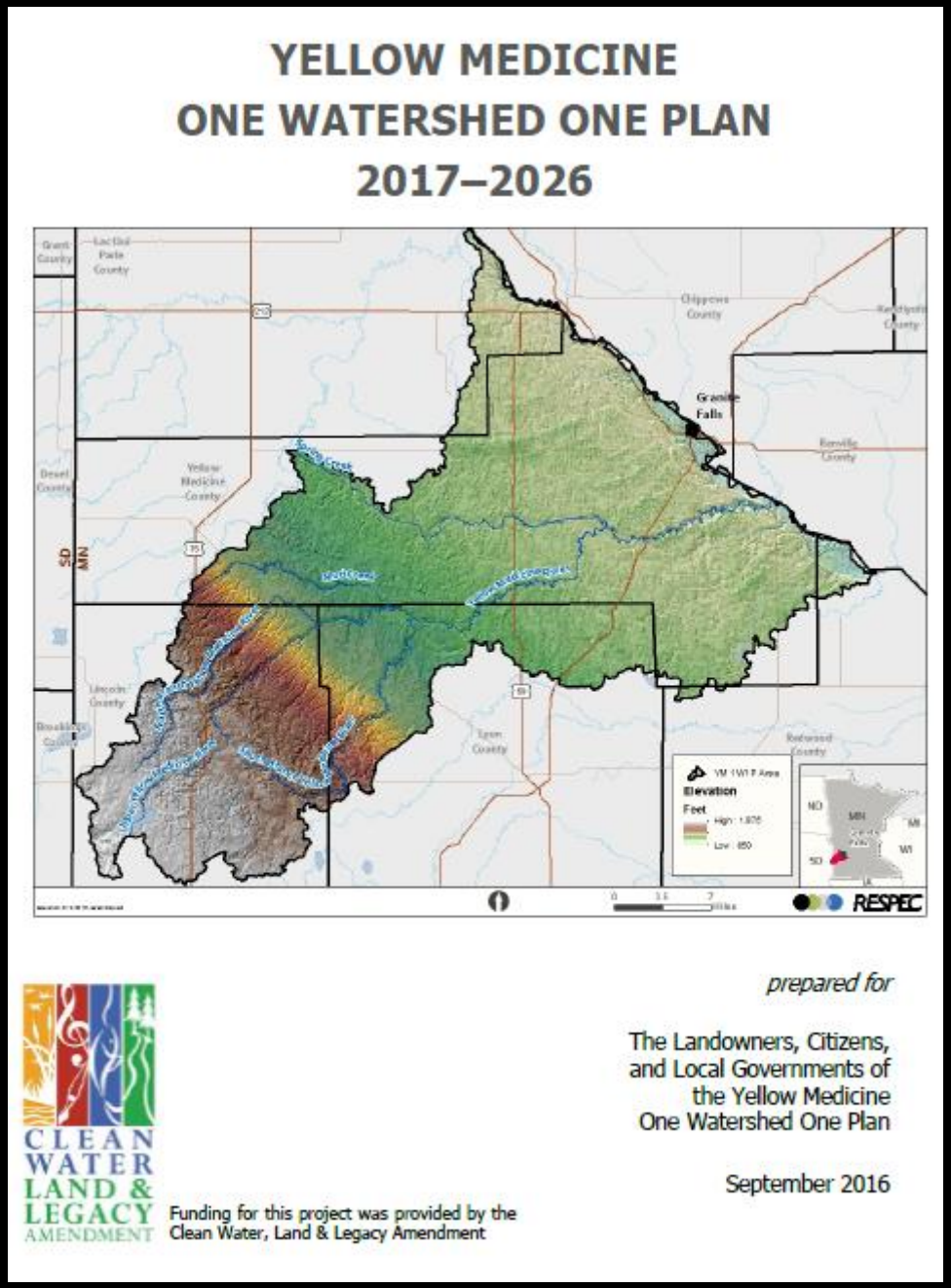
Locally developed & implemented

Facilitates targeting & prioritization

Coordinates efforts

Engages broad range of stakeholders

Formal agreements, but adaptable


YELLOW MEDICINE
ONE WATERSHED ONE PLAN
2017–2026

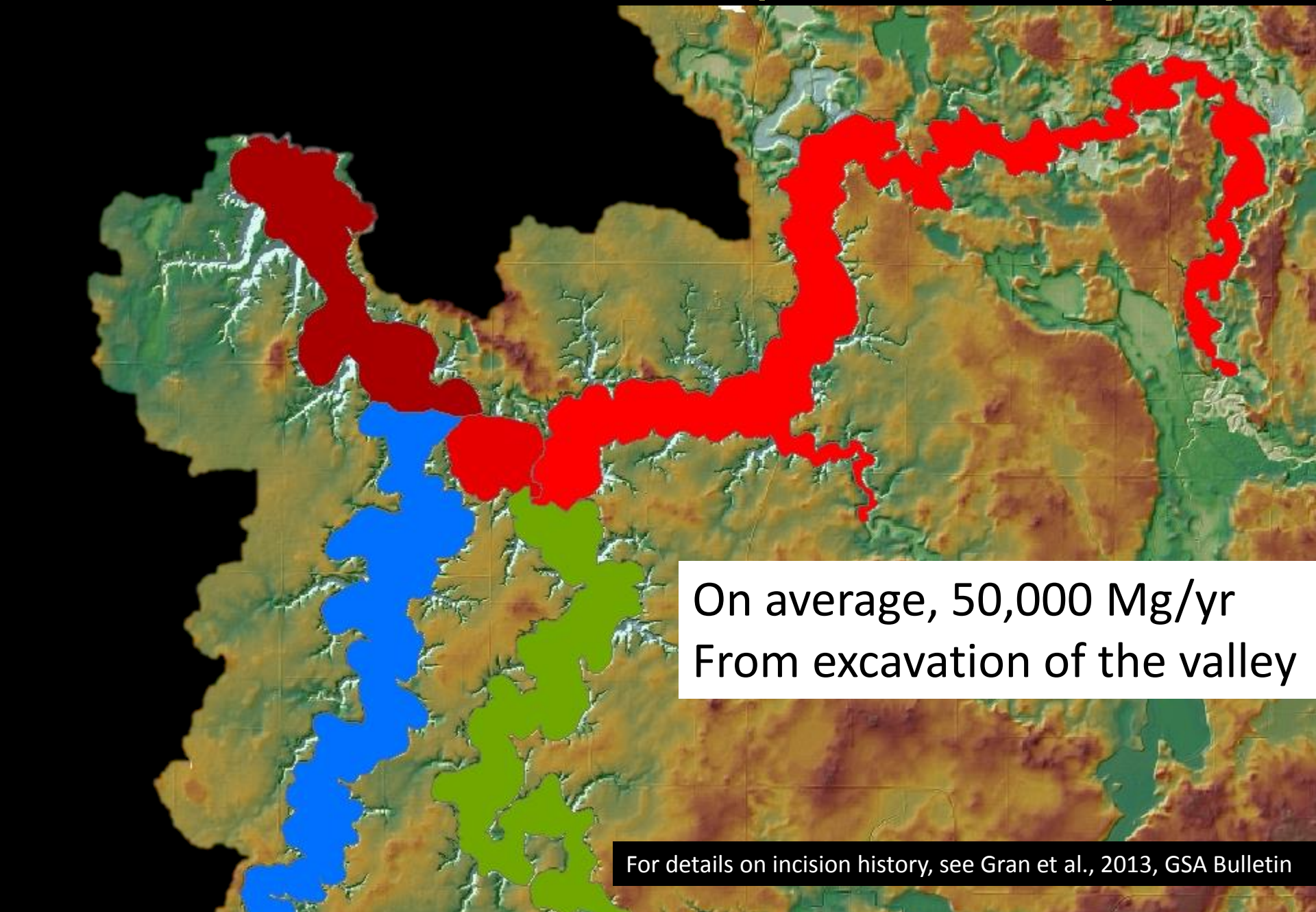
prepared for

The Landowners, Citizens, and Local Governments of the Yellow Medicine One Watershed One Plan

September 2016

Funding for this project was provided by the Clean Water, Land & Legacy Amendment

Volume excavated over the past 13,400 years

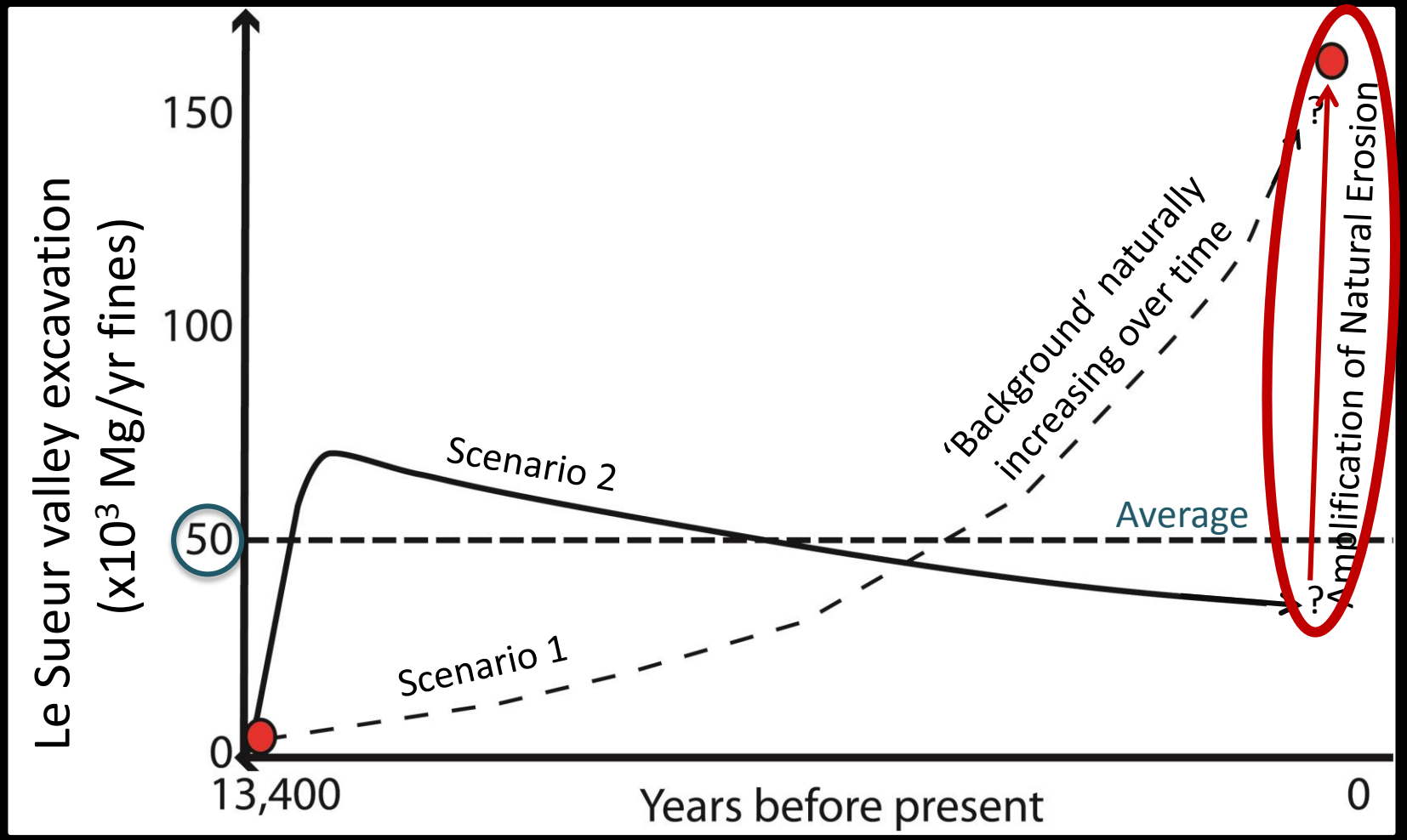


On average, 50,000 Mg/yr
From excavation of the valley

For details on incision history, see Gran et al., 2013, GSA Bulletin

Recent erosion estimates suggests 170 Mg/yr contributed within the knick zone

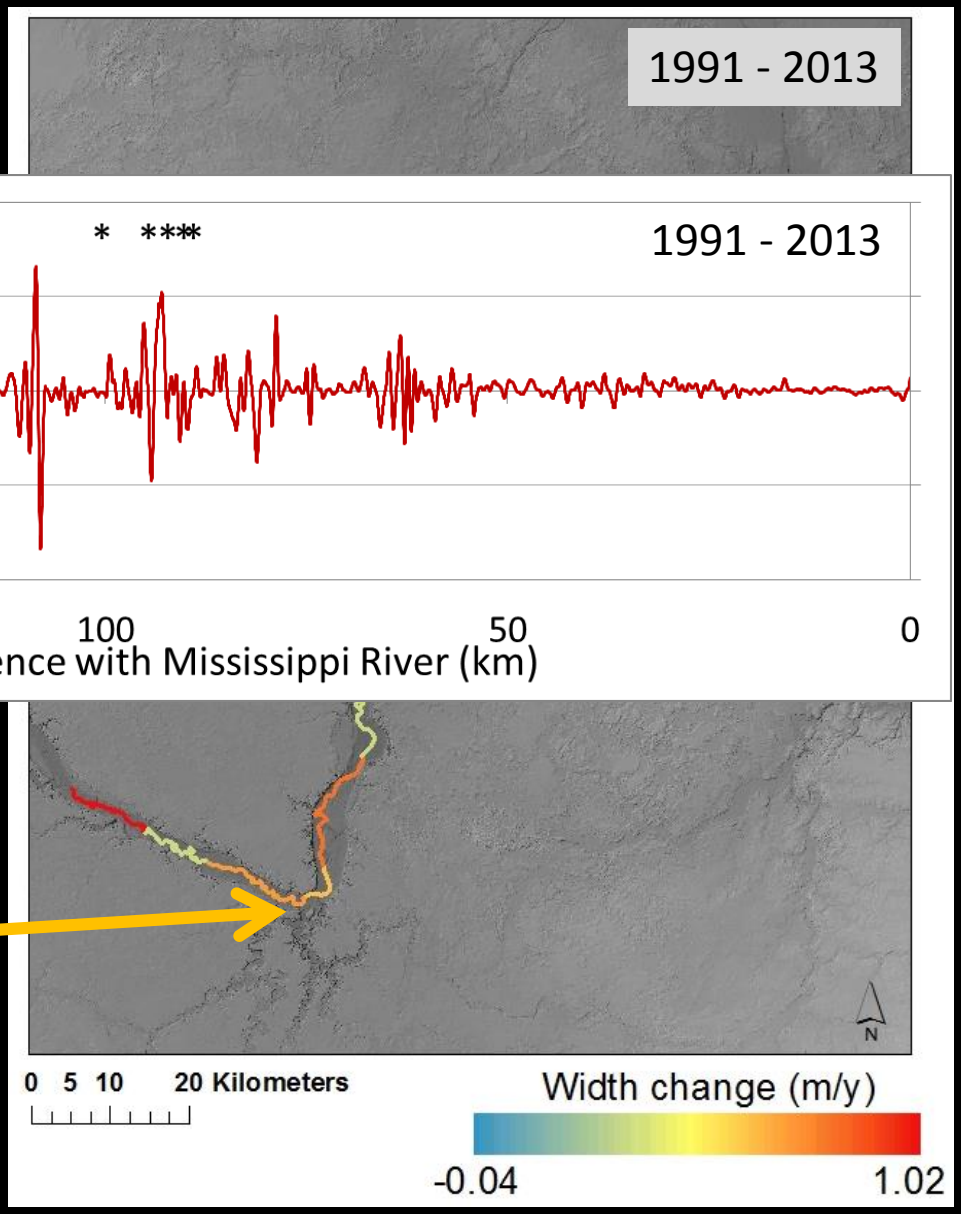
But how did we get here?

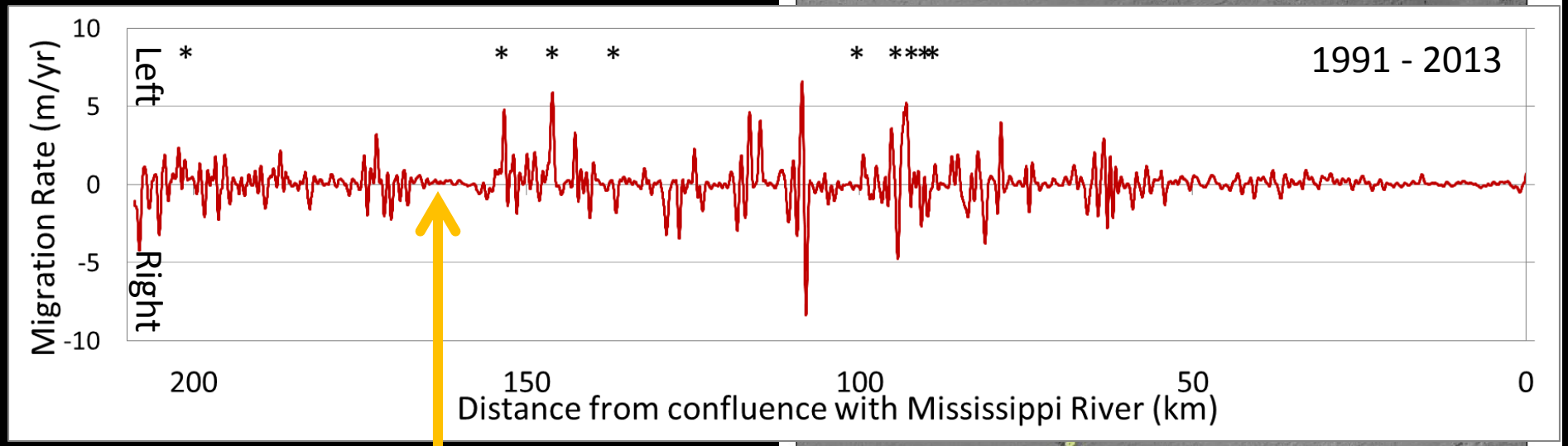


Gran et al., 2013

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

All point source discharges

Repeat terrestrial lidar

12 bluffs, 6 years

^{18}O water source tracers

700 samples

Structure-from-motion photogrammetry and stationary photo stations

2 sites, 3 years daily photos

17 sites started 2015

WSC

Minnesota River Basin Observatory

Compile and synthesize Prec & Q data

Benthic light availability

40 sites for cal/val

Map river channel bathymetry using ADCP

180+ km

40+ grain size

Model Repository

CSSR

Non-stationary channel/floodplain

Network routing

Meander toolbox

Mussel dynamics

Nested SWAT

Measurements of aquatic nutrient cycling

100 Denitrification,

70 P-sediment interactions

diurnal O_2 23 snapshots

Sediment fingerprinting

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

Land use history and agroeconomic data

Measure Holocene erosional and depositional history with OSL, ^{14}C, GPR

31 terraces, 6 alluvial fans

5 paleo-channels GPR

Compile and collect biological + food web data

Algal biomass, mussels, IBIs

1000 13C, 15N, 2H stable isotope

3200 biomonitoring -MPCA

Channel Morphology

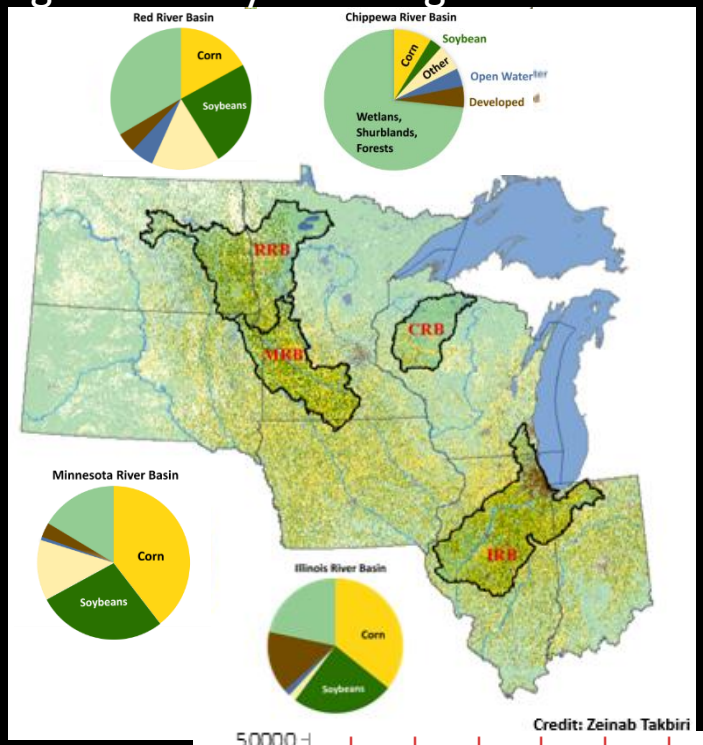
Migration, widening

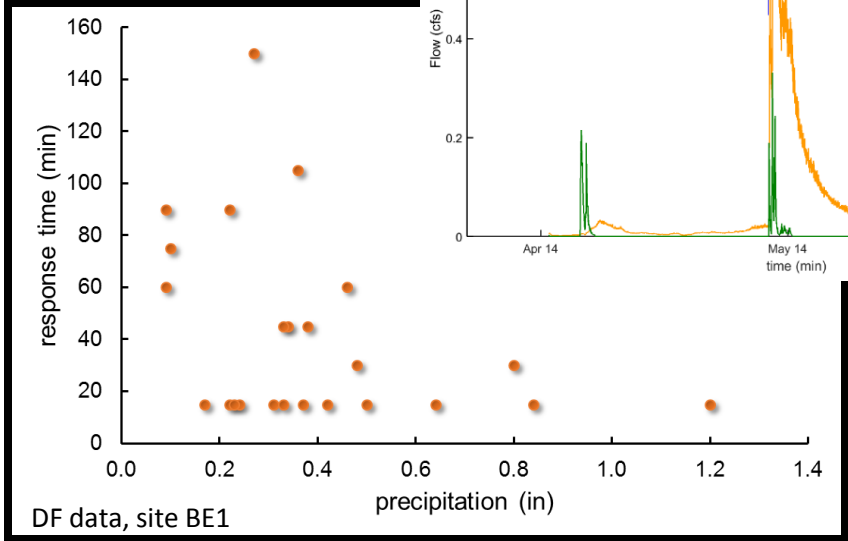
7000+ km banks mapped

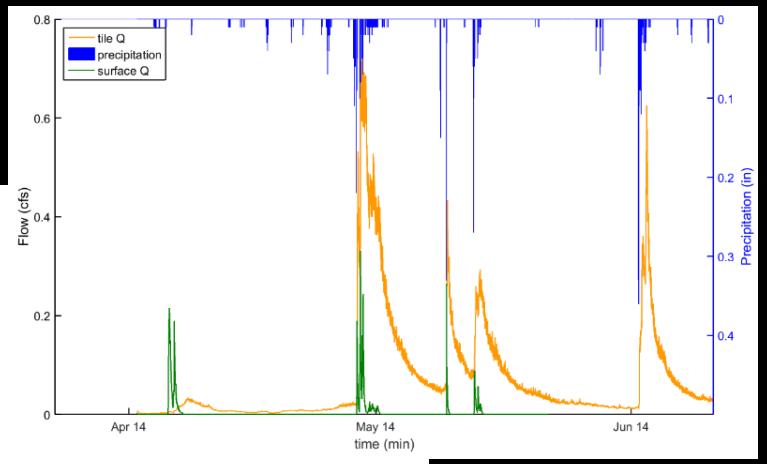
47 cross sections 2008-2015

How does artificial drainage affect streamflow?

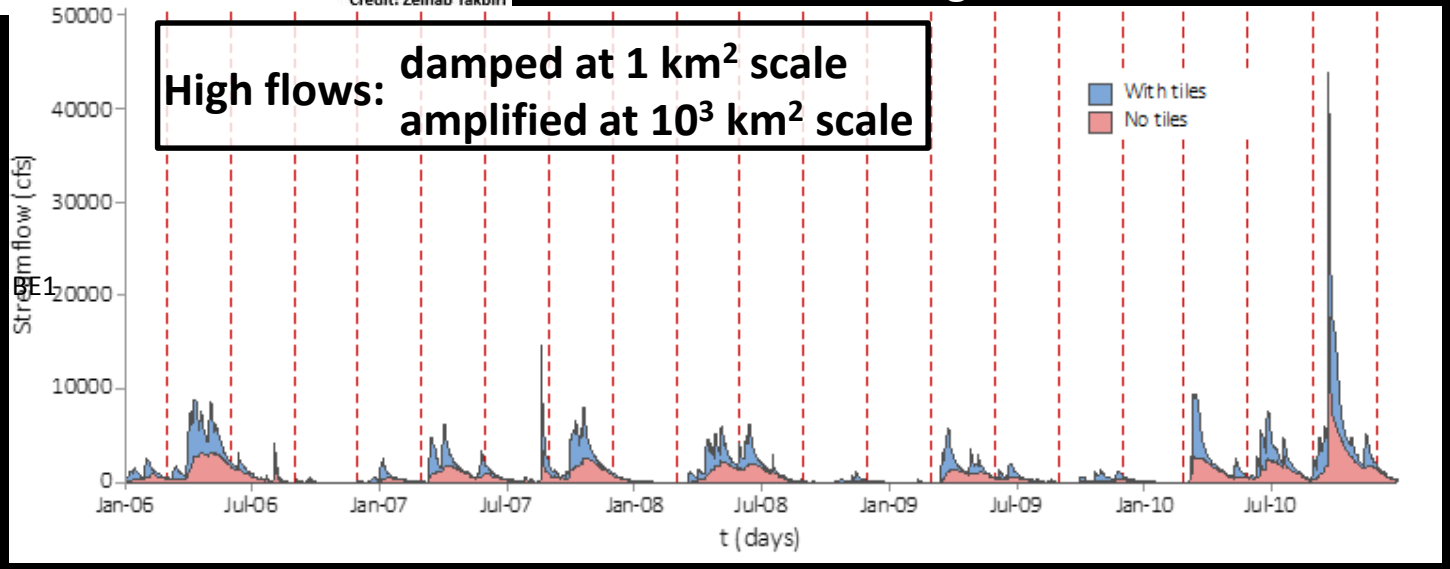
regional analysis of large watersheds



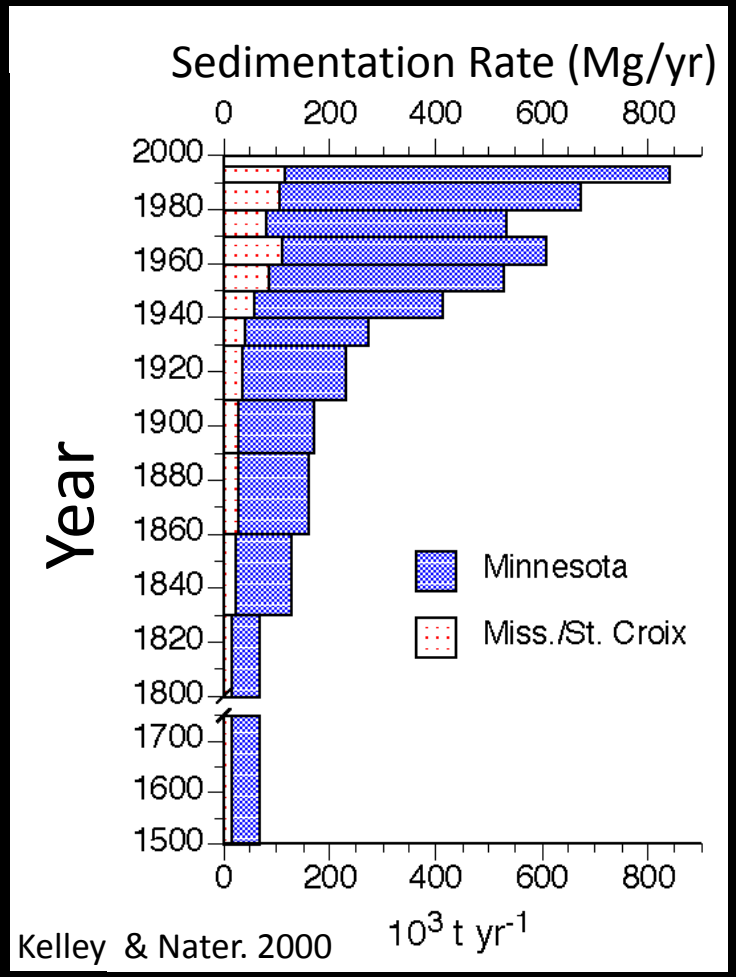




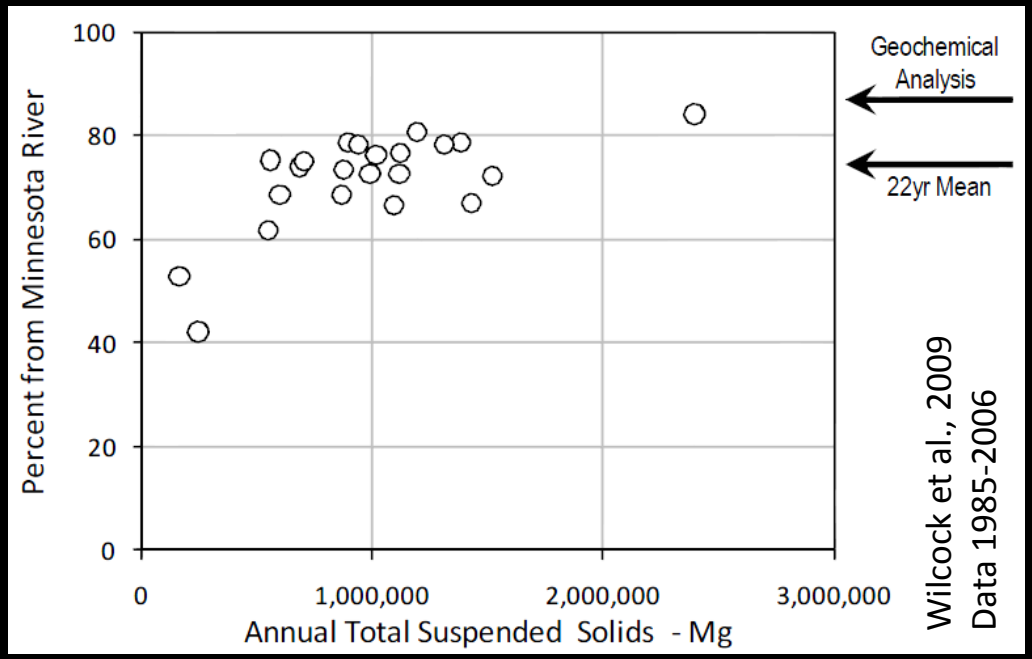
High resolution SWAT model



Sediment from the Minnesota River causes problems in Lake Pepin



Kelley & Nater. 2000



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?