Airborne Laser Scanning for Riverbank Erosion Assessment- Implications for Water Quality

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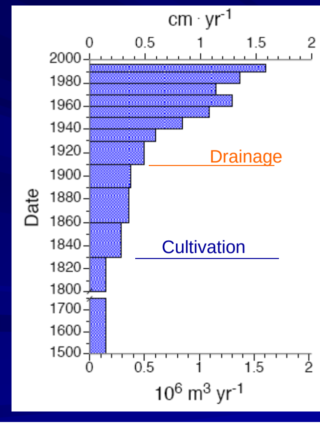
26 August 2011
Metropolitan Water Reclamation District of Greater Chicago
Cicero, IL

Lake Pepin Sedimentation



Concern

Higher sedimentation rates in recent years

Engstrom and Almendinger, 2000

Aerial View of Lake Pepin

34 km long, 2-3 km wide, Lake Area,103 km^2 water residence time about 1–7 weeks

St. Croix Watershed Research Station Fact Sheet 2000-02

Study Area

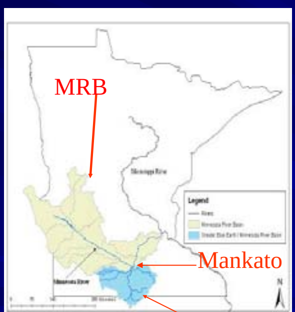
50% Flow

25% Flow

25% Flow
75% Sediment

St. Croix Watershed Research Station Fact Sheet 2000-02

Some Statistics



Minnesota River Basin (MRB)

- 33% of the land in MRB is <2% slope
- 74% of the land in MRB is <6% slope

Blue Earth River Basin (BERB)

- 54% of the land in the BERB is <2% slope
- 93% of the land in the BERB is <6%

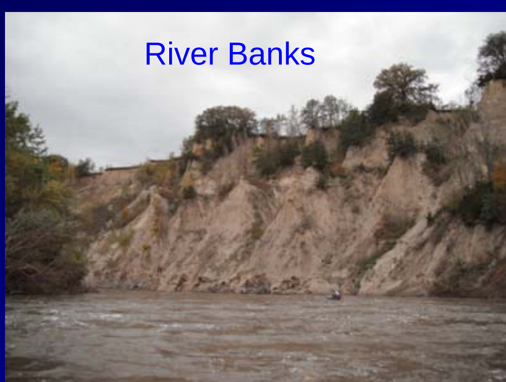
However, the Blue Earth River delivers 46% of the flow and 55% of all sediment to the Minnesota River at Mankato.

Aerial View of Potholes after Rain

Removing Excess Water

Sediment Sources in the Minnesota River Basin

Sediment Sources in the Minnesota River Basin



Peggy K, Fall 2010

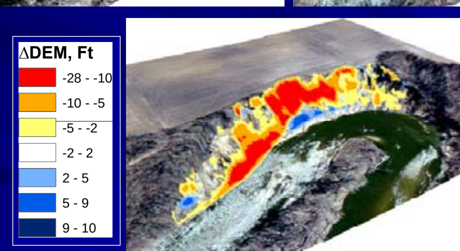
Potential Sources of Sediment

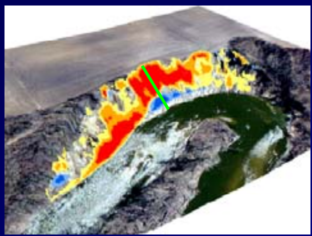
Flat upland landscape

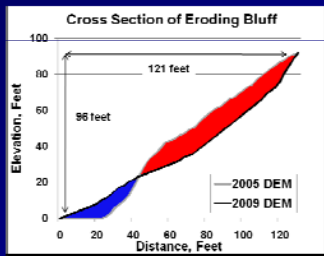
Eroding river banks

Laser Scanning

David Thoma, 2003







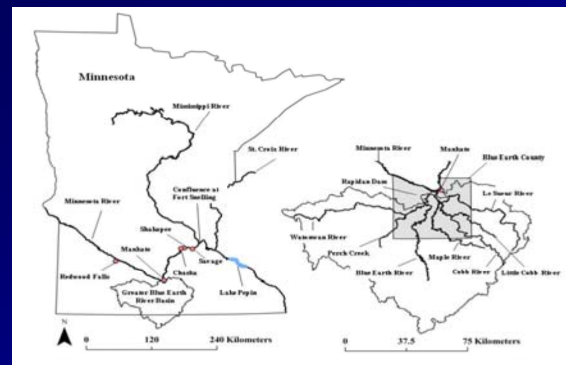
Soil Analysis

Sand	43.7 %
Silt	25.0 %
Clay	31.3%
Fines (Silt&Clay)	56.3 %
Bulk Density	1.82 Mg m^{-3}

Change Detection

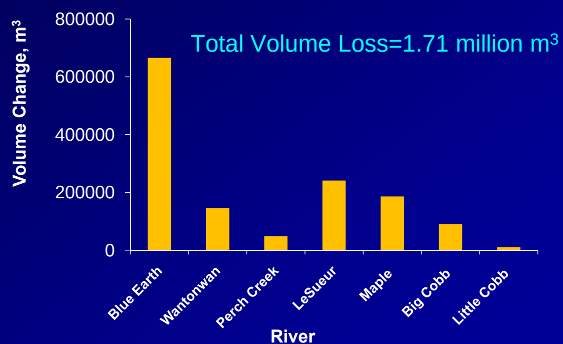
Net Volume Change	3,145 m^3 / year
Net Soil Loss (Mass Wasting)	5, 724 Mg / year
Fine Sediment Loss	3, 223 Mg / year

LiDAR Study Area

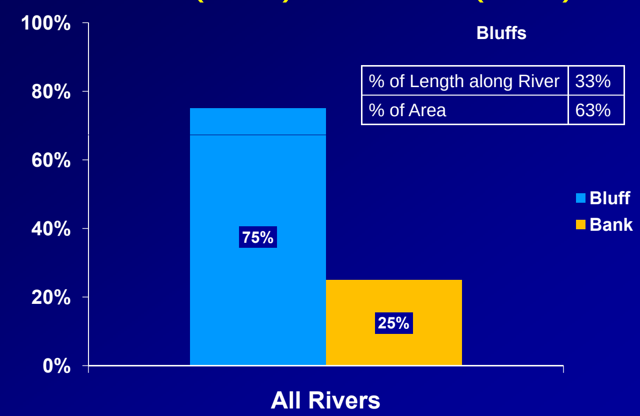


LiDAR= Light Detection and Ranging

Volume Change of River Valleys From Bank Erosion



Volume Change Bluff (>3m) vs. Bank (<3m)



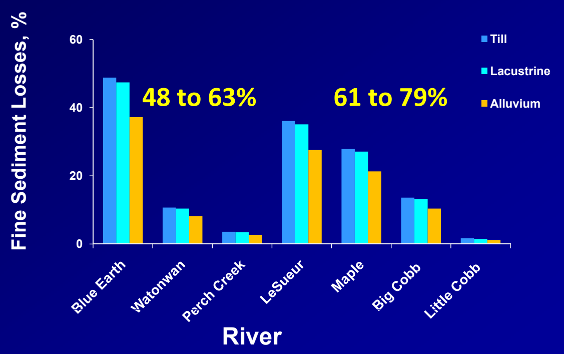
Characteristics of Parent Materials

Parent Material	Silt+Clay %	Bulk Density Mg m^{-3}	Soluble P mg kg^{-1}	Total P mg kg^{-1}
Till	56.3	1.82	0.46	408.8
Lacustrine	67.3	1.48	0.74	556.2
Alluvium	52.5	1.49	0.73	558.6

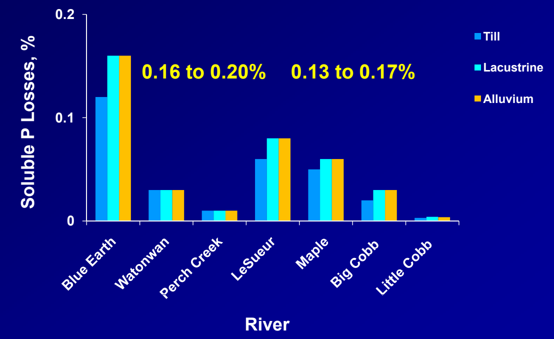
Annual Measured Losses

Rivers	Sediment Mg yr^{-1}	Soluble P kg yr^{-1}	Total P Mg yr^{-1}
Blue Earth River	216,145	191.1	166.2
Le Sueur River	132,824	117.5	102.1

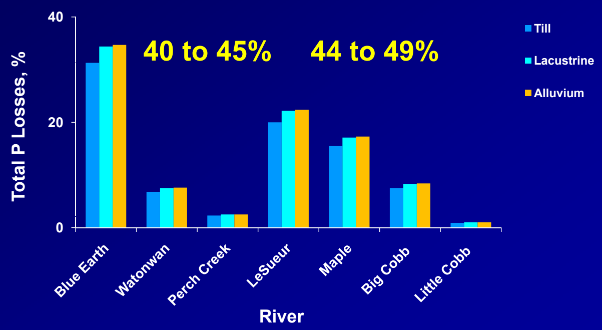
Sediment Contribution from Bank Erosion in Blue Earth County



Soluble P Contribution from Bank Erosion in Blue Earth County



Total P Contribution from Bank Erosion in Blue Earth County



Findings

- Multi-temporal lidar datasets are useful for estimating bank erosion and associated P contributions over large scales, and for river banks that are not readily accessible for conventional surveying equipment.
- This method has an advantage that it can help identify banks that are a major source of sediments in a given river system.

Mechanisms of Bank Sloughing 3 December 2009

HWY 169 Mankato

Soil Slumping in Shallow Water

Soil Slumping in Shallow Water

Soil Slumping in Shallow Water

Soil Slumping in Shallow Water

Soil Slumping in Shallow Water

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Soil Slumping in Shallow Water

Behind Leroy's House
March 19, 2009

Meg and Richard's Bank
Vernon Center

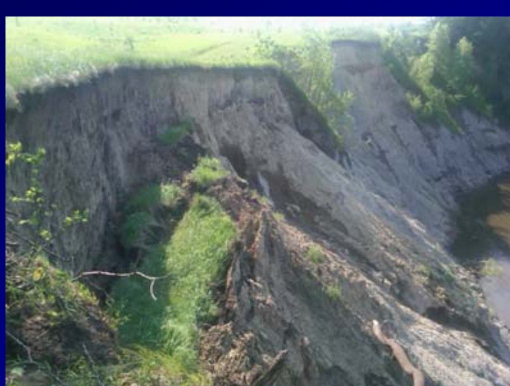
Le Sueur River

March 2010

April 2011

Scott Salsbury

Kevin's Bank (2011)



Seepage and Collateral Damage

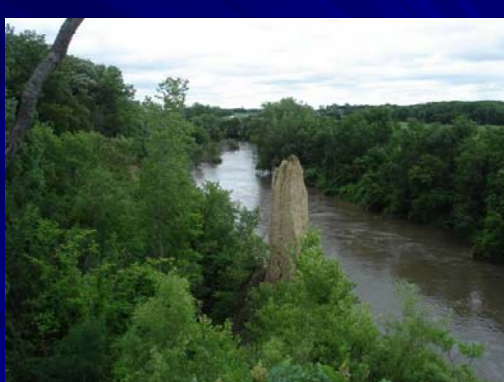
Pore Water Pressure Slumping

Pore Water Effect
Eagle Lake

Thiesen Bank
Capillarity and Failure

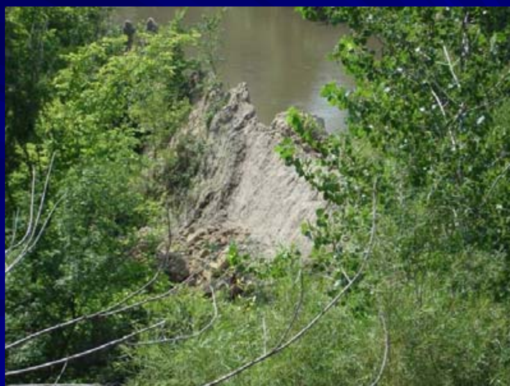
Richard and Meg's Bank
27 May 2010

Richard and Meg's Bank
28 June 2010



Richard and Meg's Bank
28 June 2010

Richard and Meg’s Bank
5 August 2010



Present Day River on 1938 Photograph

Slumping Bank at Vernon Center

Slumping Bank at Vernon Center, 2011

Slump at the top

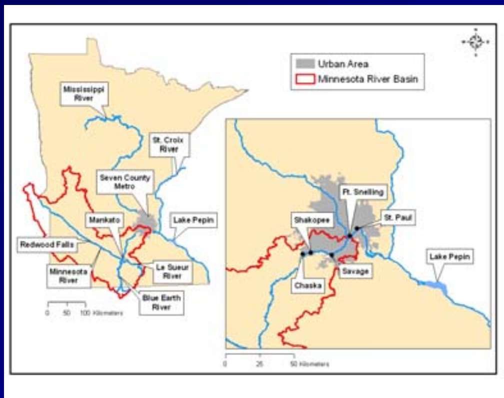
Slumping Bank at Vernon Center, 2011

Accumulation at the bottom

Findings

- Banks are sloughing from the top and has nothing to do with river levels. This sloughing appears to be due to seepage.
- Bank sloughing is also occurring due to catastrophic events and channel migration.
- Agriculture is also contributing some sediments to the rivers through surface inlets.
- Important factors are soil strength and availability of water

Minnesota River Basin



Historic Conditions of the Rivers

22 September 1835

Soon after 8 A. M. we came to the mouth of the *Māhkatoh*, or "Blue Earth River," a word composed of *māhkah* ("earth") and *tōh* ("blue"). This was a bold stream, about eighty yards wide, loaded with mud of a blueish colour, evidently the cause of the St. Peter's being so turbid. It was not far from the mouth of this river that M. le Sueur was asserted to have discovered in 1692 an immense deposit of copper ore. No traveller

G.W. Featherstonhaugh, 1847

Historic Conditions of the Rivers

September 22, 1835

The Māhkatoh appears to form about half the volume of the St. Peter's, and is a very rapid stream. The Sissitons we had met told us it forked eleven times, and that the branches abounded in rapids and shallow places. About twelve we came to a fork or branch

G.W. Featherstonhaugh, 1847

Similar to USGS measurements (Payne, 1994)

Historic Conditions of the Rivers

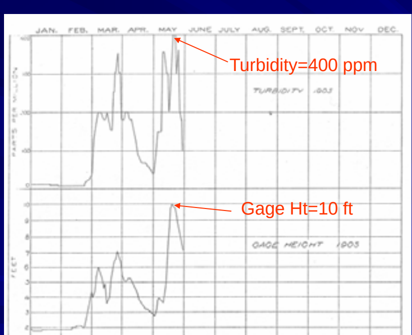
"Still, the river itself did not impress some visitors. A prejudiced traveler from the St. Croix, the handsome stream that forms Wisconsin's western boundary, put down his rather uncharitable verdict in his diary: "The Minnesota River," he wrote in 1856, "is a dirty little creek.""

St. Croix

Mississippi after its joins the Minnesota River

Jones, Evan (1962), The Minnesota: Forgotten River.

Minnesota River Turbidity and Hydrograph at Mankato, 1905

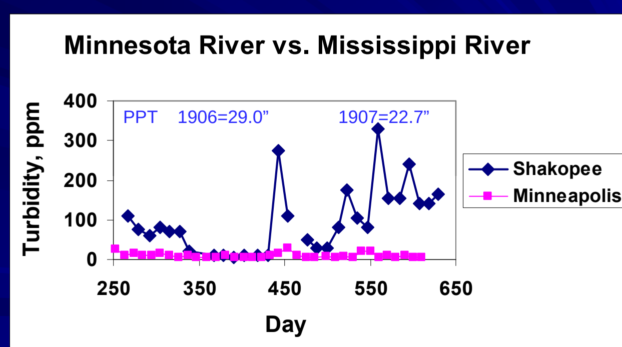


Ordinarily Turbidity 10-40 ppm

Spring Flush Turbidity often increased to 600-800 ppm

Dole and Wesbrook, 1907

Turbidity Variations, 1906-1907



Dole, R.B. (1909)

St. Croix Joining Mississippi 2 June 2004, High Flow

Mississippi after its joins the Minnesota River

David Morrison, MPCA

Mississippi-St. Croix Rivers Confluence

22 September 1937

11 July 1938

Mississippi-St. Croix Rivers Confluence

28 October 1949

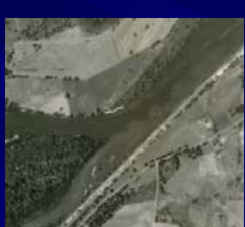
1 June 1957

15 July 1964

St. Croix Joining Mississippi 1 May 1960

Minnesota Museum of History

Minnesota at the Confluence with Mississippi



30 June 1937

25 June 1940

10 May 1957

Blue Earth Joining Minnesota

MN DNR-MHAPO-1938

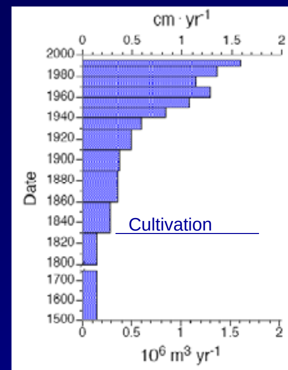
USDA-FSA 2002 Photo

Scott Salsbury

Finding

- The Minnesota River and its tributaries have been muddy or turbid since before pre-settlement times.

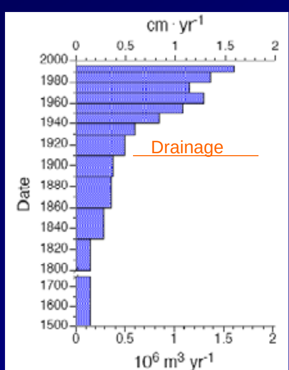
Lake Pepin Sedimentation



Engstrom and Almendinger, 2000

- 1850- Population 6,077
- Primitive agriculture-Earlier plows were wooden plows with metal tips
- Sticky soils-shallow cultivation
- Flat lands-not enough capacity to transport
- Good cover crop-Small grains, wild hay, flax, some corn

Lake Pepin Sedimentation



Engstrom and Almendinger, 2000

- Limited Drainage-surface inlet to Depressions only
- 1930s-Drought and depression
- 1940-World war II, many men were gone
- Corn in 3 to 5 year rotations-limited soil erosion
- 1950-Drainage picked up, clay and cement tiles
- 1970-Plastic tile line was available

Confluence of the Minnesota and the Mississippi Rivers

Star Tribune Image Spring 2011

USDA Image 30 June 1937

Background

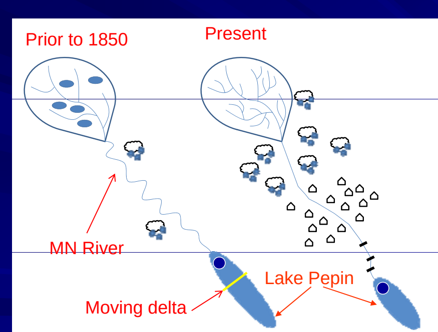
River Banks
Fields
Ravines

Sediment Production → Sediment Transport → Sediment Load to Lake Pepin

Sediment production has not changed dramatically since earlier times. A majority of them are coming from river banks which mainly depends upon precipitation.

There are some sediment coming from agricultural fields thru surface inlets

Minnesota River Watershed, Past and Present



Changes in the Basin

- Less basin storage
- Less meandering
- Dredging, deepening & levees
- More precipitation
- More impervious surfaces
- Locks and dams
- Smaller Lake Pepin

Straightening of Minnesota River Channel

10 May 1957

August 1980

Channel was straightened at Fort Snelling in 1964.

Area under Impervious Surfaces

Year	MN River Basin	Mankato To Fort Snelling
	Percent	
2000	6	13
1990	4	8

Year	MN River Basin in Metro
	Percent
2002	30
1998	27
1991	24
1986	20

Bauer, Loffelholz, and Wilson (2007)

Dredging

- 1893-1943, a sandbar formed every spring, leaving only 18 inches of water at the entrance but 6 feet deep channel for 24 miles.
- World War II-Cargill obtained a contract from the US Navy to build ocean-going tankers and towboats. They picked Savage to build naval ships.

Merritt, Raymond H. 1979. Creativity, Conflict, & Controversy: A History of the St. Paul District. U.S. Army Corps of Engineers.
U.S. Army Corps, 2010.

Launching the Chehalis at Port Cargill, Savage

16 April 1944

Minnesota Historical Society
HE5.25p24

Levee at Mankato

Scott Salsbury

Mankato, 1951 Floods

Floods
1881
1908
1916
1951
1965

North Mankato aerial photo.
Tree-lined street is Belgrade Avenue.

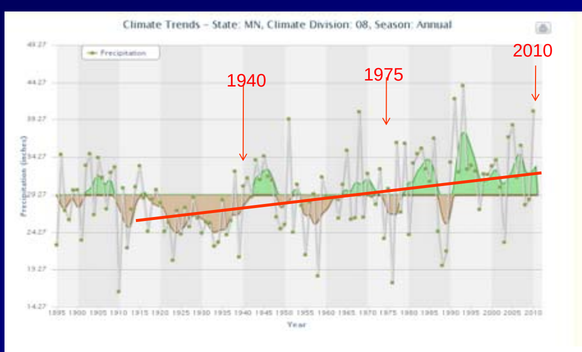
Findings

- Dredging opened up the Minnesota River to down stream transport of sediments.
- Levees eliminated flood plain interactions and are forcing more water and sediments to down stream locations including Lake Pepin.

Climate and Flow Issues

- Why is more flow in rivers?
- Why are the rivers wider?
- Why are river flows non-linear?
- Why is flow at Jordan doubled?

Trend In Precipitation South Central Minnesota

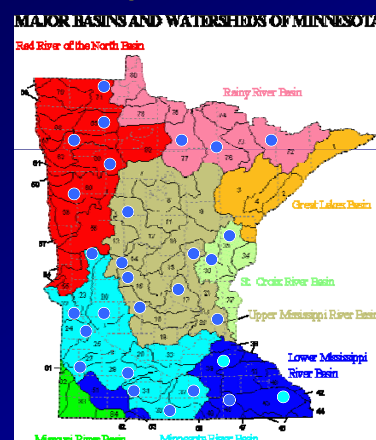


NCDC, http://www.southernclimate.org/products/trends.php

DNR Major Watersheds

12 Crow Wing
14 Long Prairie R
16 Sauk River
17 Elk River
21 Rum River
22 Whetstone
23 Pomme de Terre
24 Lac qui Parle
26 Chippewa R.

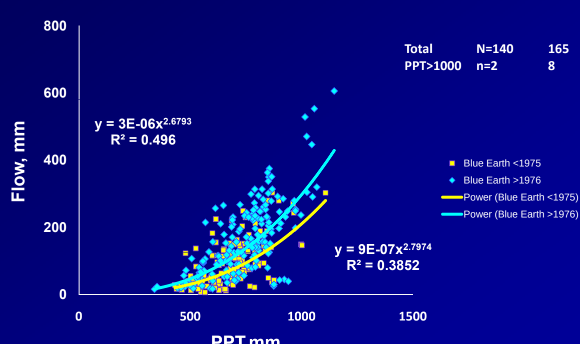
27 Redwood R.
29 Cottonwood R.
30 Blue Earth R.
31 Watonwan R.
32 Le Sueur R.
18 Middle Fork R
18 North Fork Crow R
35 Kettle River



36 Snake River
39 Cannon River
43 Root River
48 Cedar River
60 Wild Rice R
63 Red River Crookston
63 Red River Goodridge
65 Thief River Falls
66 Clearwater R
71 Roseau R Ross
76 Little Fork R.
77 Big Fork R

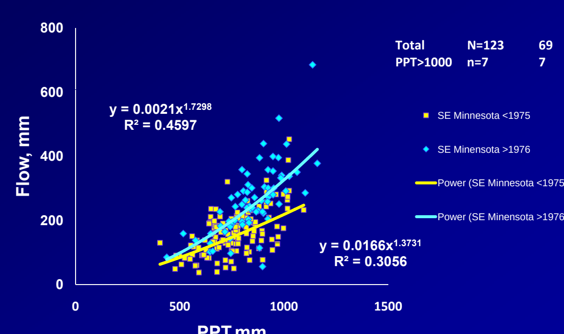
Minnesota River Basin

(Blue Earth, Le Sueur, Cottonwood, Redwood)



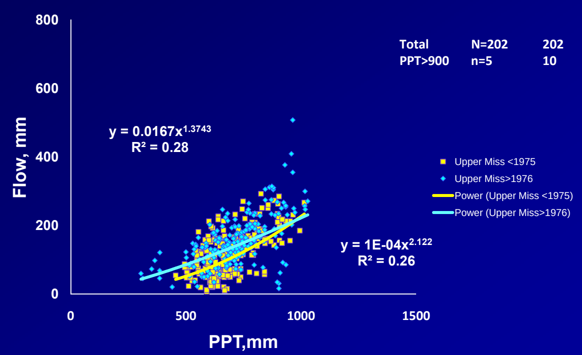
South East Minnesota

(Cannon, Cedar, Root)



Upper Mississippi River

(Middle Fork Crow, Crow R, Long Prairie, Rum, Crow Wing, Sauk, Elk)



Findings

- Increased precipitation leads to non-linear increase in runoff and river flows.
- For a given level of annual precipitation, there is no difference in river flows for the period prior to 1975 and after 1976 for HUC 8 level watersheds.
- This would suggest that tile line effect are not on the quantity of water leaving the landscape.

Findings

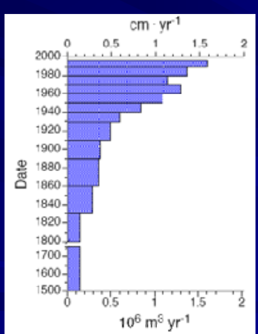
- Tiling effect could be on timing of flow and also at smaller scale (smaller watersheds or daily, weekly time scale).
- Flows in Minnesota River at Jordan are higher due to both increased precipitations in the area as well as presence of levees upstream (lack of flood plain interactions).

Presence of Delta at the Mouth of Lake Pepin

St. Croix Watershed Research Station Fact Sheet 2000-02

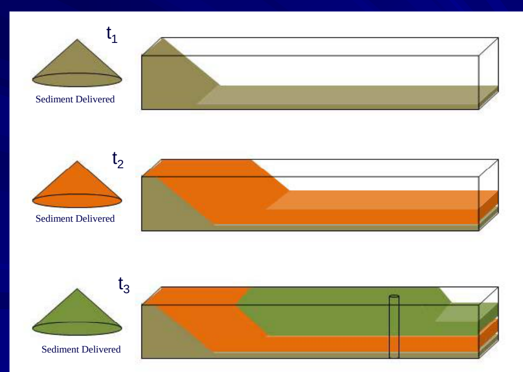
Concerns

Sedimentation Rate in Lake Pepin

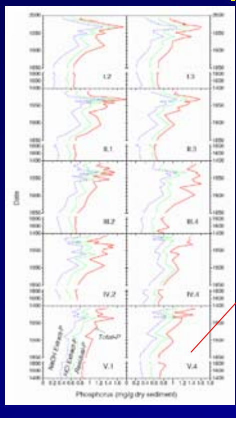


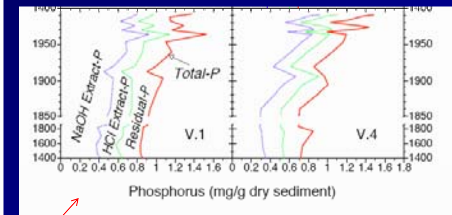
Engstrom and Almendinger, 2000

Delta Effect on Volume



Various Forms of P in Lake Pepin Sediments





Prior to 1800 Total P=0.6 to 0.8 mg/g=600-800 mg/kg

1960-1980 Total P=<1.8 mg/g=1800 mg/kg

Engstrom et al., 2009

Total, Soluble, and Enriched P in Bank Materials Under Natural Conditions

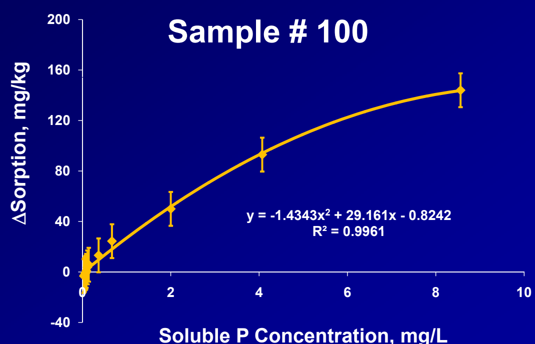
Sample	Parent M	Total P mg/kg	Soluble P mg/kg	Sand %	Silt %	Clay %	Enrichment ratio	Enriched P, mg/kg
100	Till	397	0.20	25.5	28.0	46.5	1.34	533
106	Till	462	0.18	41.7	27.5	30.9	1.71	790
113	Lacustrine	424	0.18	17.1	28.0	54.9	1.2	511
128	Alluvium	537	0.22	17.0	54.0	29.0	1.20	647

Engstrom et al. 2009

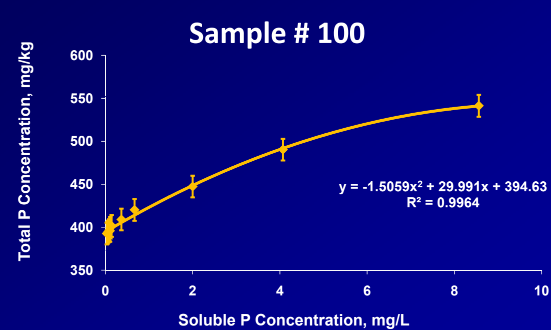
Prior to 1800 Total P=0.6 to 0.8 mg/g=600-800 mg/kg

1960-1980 Total P=<1.8 mg/g=1800 mg/kg

P Adsorption Isotherm



P Adsorption Isotherm



Total, Soluble, and Enriched P in Bank Materials after Adsorption

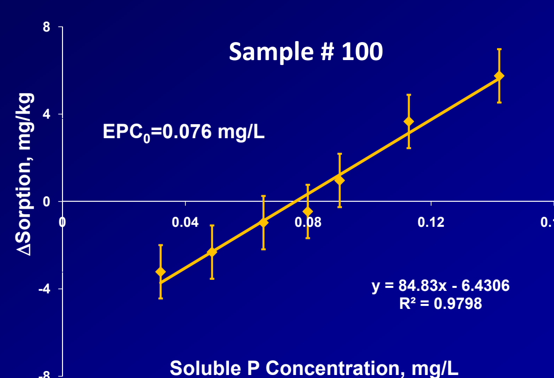
Sample	Parent M	Natural Total P mg/kg	Total P after Adsorption at 10 mg/L Soluble P mg/kg	Enrichment ratio	Natural Enriched P, mg/kg	Enriched P after Adsorption
100	Till	397	571	1.34	533	765
106	Till	462	593	1.71	790	1,014
113	Lacustrine	424	549	1.2	511	659
128	Alluvium	537	653	1.20	647	784

Engstrom et al. 2009

Prior to 1800 Total P=0.6 to 0.8 mg/g=600-800 mg/kg

1960-1980 Total P=<1.8 mg/g=1800 mg/kg

P Adsorption Curve



Findings

- P in Lake Pepin sediments from 1400-1850 can be explained based on bank sediment enrichment.
- Subsequent increases in lake sediment appears to be linked to past practices of P input in rivers and P adsorption by river sediments as they are tumbling downstream.

Conclusion I

- Sediment production has not changed drastically. There are some additional sediments coming from agricultural fields.
- Sediment transport has changed drastically.
- More research is needed to quantify the effects channel modifications, increased impervious surfaces, and increased precipitation on sediment transport.

Researchers and Funding

- Drew Kessler, University of Minnesota
- Ashley Grundtner, University of Minnesota
- Dr. Holly Dolliver, University of Wisconsin
- Dr. David Thoma, National Park Service

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Thank you