20th Century Agricultural Drainage Creates More Erosive Rivers

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Abstract

Rivers in watersheds dominated by agriculture throughout the US are impaired by excess sediment, a significant portion of which comes from non-field, near-channel sources. Both land-use and climate have been implicated in altering river flows and thereby increasing stream-channel erosion and sediment loading. In the wetland-rich landscapes of the upper Mississippi basin, twentieth century crop conversions have lead to an intensification of artificial drainage, which is now a critical component of modern agriculture. At the same time, much of the region has experienced increased annual rainfall. Uncertainty in separating these drivers of streamflow fuels debate between agricultural and environmental interests on responsibility and solutions for excess riverine sediment. To disentangle the effects of climate and land-use we compared changes in precipitation, crop conversions, and extent of drained depressional area in 21 Minnesota watersheds over the past 70 years. Watersheds with large land-use changes had increases in seasonal and annual water yields of >50% since 1940. On average, changes in precipitation and crop evapotranspiration explained less than one-half of the increase, with the remainder highly correlated with artificial drainage and loss of depressional area. Rivers with increased flow have experienced channel widening of 10-40% highlighting a source of sediment seldom addressed by agricultural best management practices.

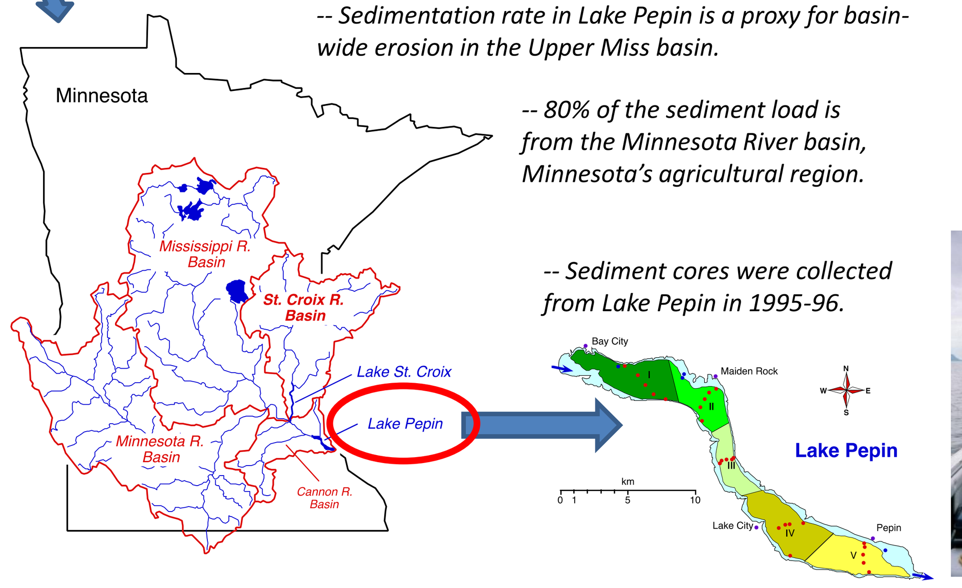
1. Erosion and turbidity are serious problems in the Corn Belt of the Upper Midwest USA

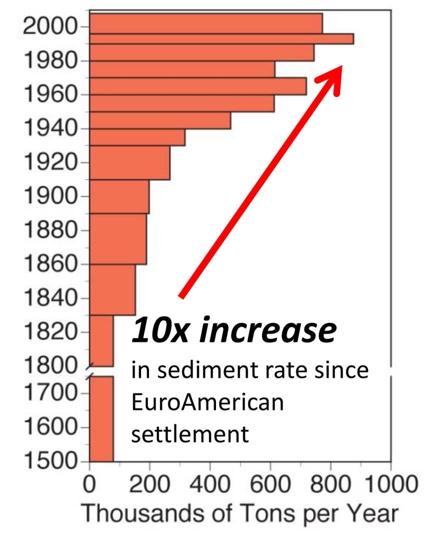
Turbidity from the agricultural Minnesota River, which muddies the Mississippi River at its confluence with the much cleaner St. Croix River.

-- Lake Pepin traps most of the suspended sediment from the entire Upper Mississippi River drainage basin.
-- Sedimentation rate in Lake Pepin is a proxy for basin-wide erosion in the Upper Miss basin.

-- 80% of the sediment load is from the Minnesota River basin, Minnesota's agricultural region.

-- Sediment cores were collected from Lake Pepin in 1995-96.

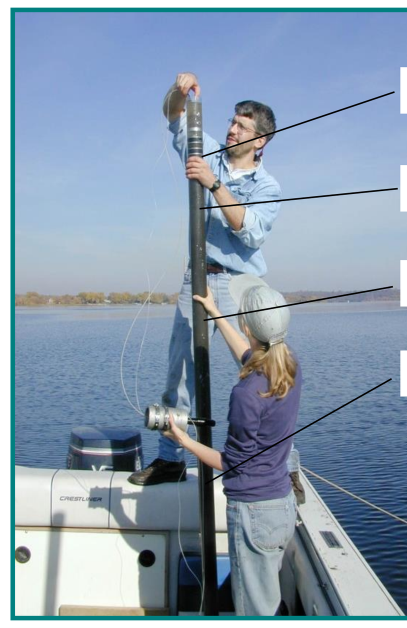


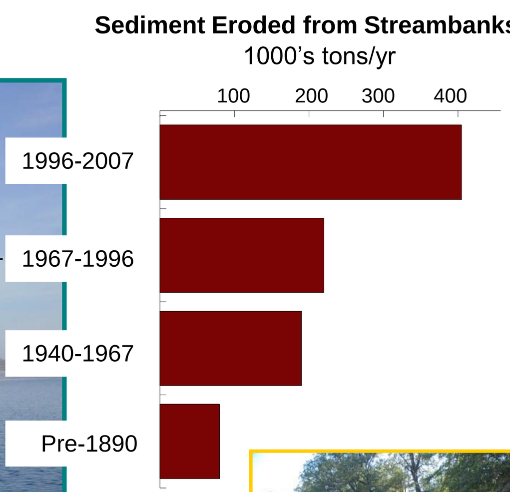


2. Streambank and bluff erosion is at least half of the problem

Lake Pepin Sediment Isotopic Fingerprinting

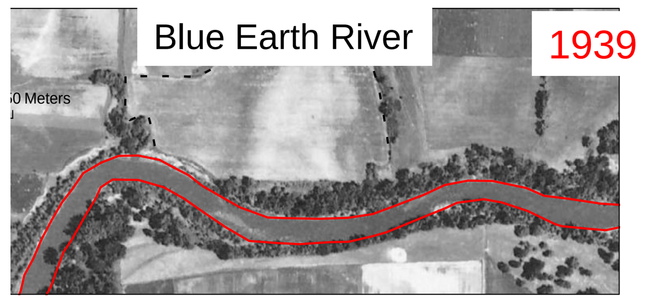
Indicates increasing erosion from stream banks and bluffs.

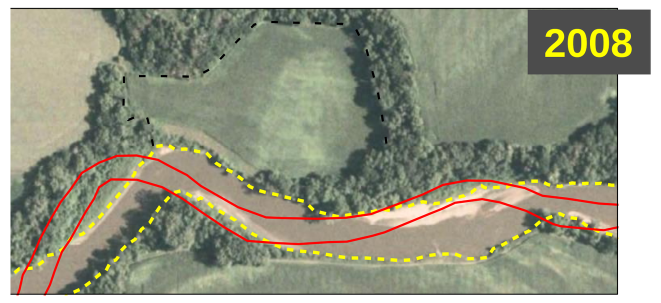




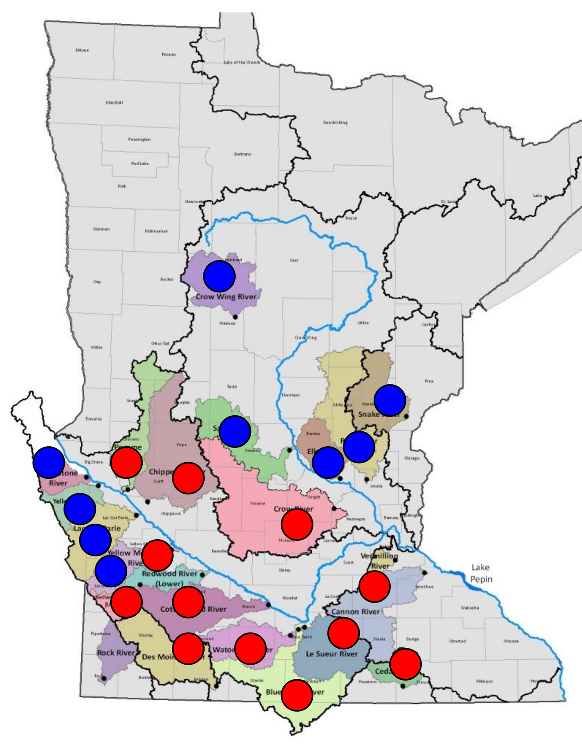
Aerial photo analysis

Quantifies channel widening (bank erosion)





3. Channels are widening because of increased flows



Increase in Flow

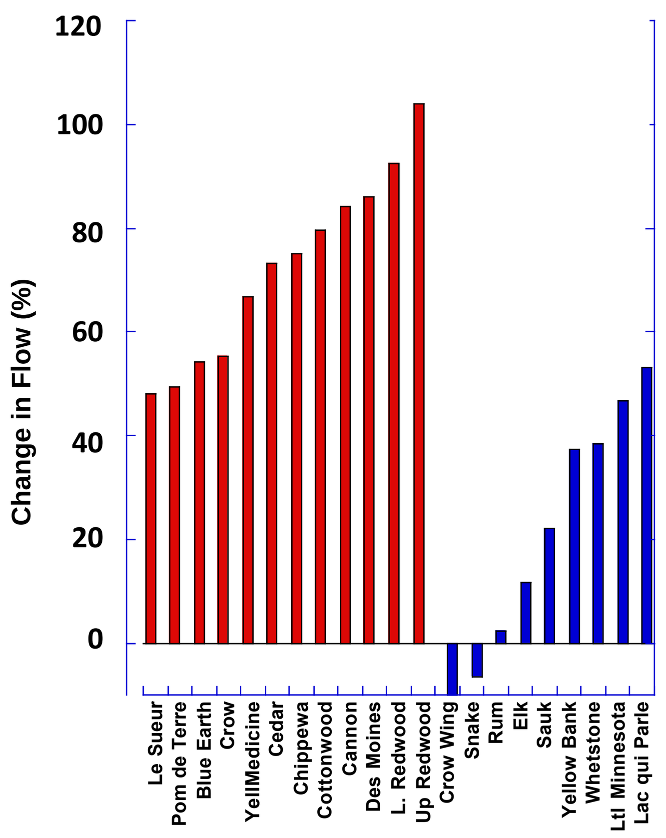
1940-1975 vs 1976- 2009

21 watersheds with with flow monitoring, 1940 -2009

Red *= significant change in flow*

Blue *= non-significant change in flow*

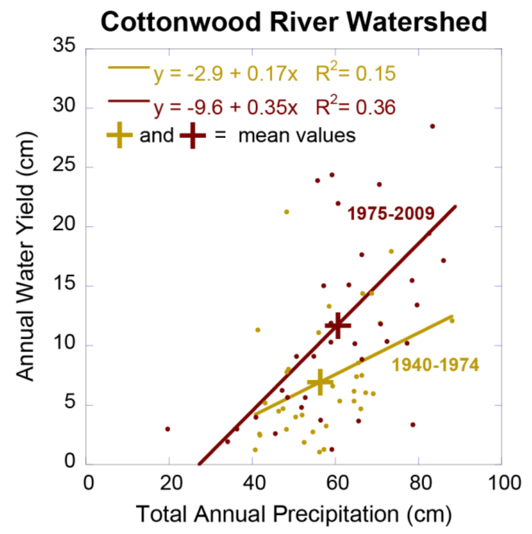
HINT: Note correspondence between red dots on this map, and the increase in runoff ratio (Panel 4a) and percent of tile-drained land (Panel 4c).



4. *So why has flow increased?*

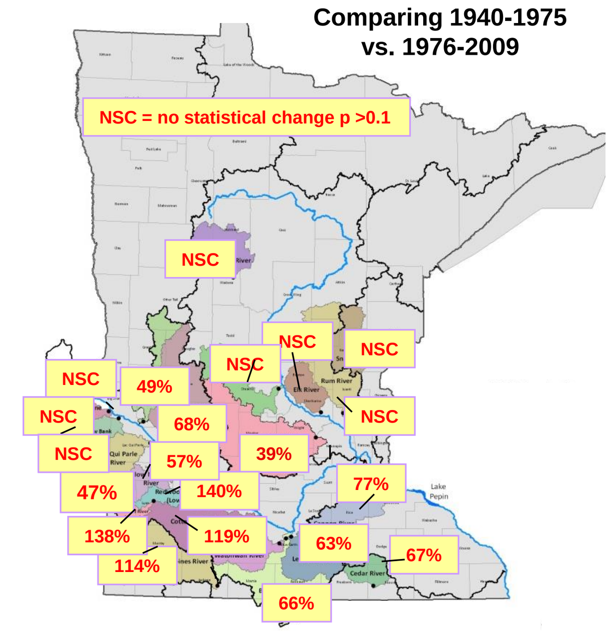
4a. Because precipitation has increased?

Yes, somewhat.



-- Rainfall has increased in most basins, and of course flow increased as well.

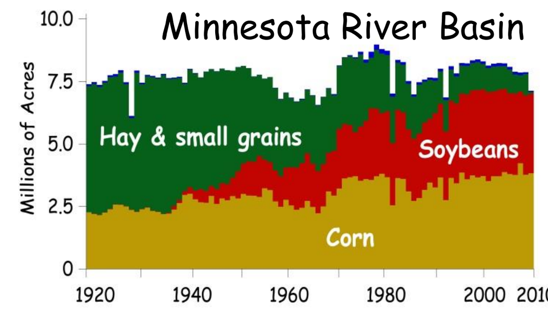
-- We expect an increase in runoff ratio (RR = slope = Q/P), but here RR doubles. Is that reasonable?



-- Increases in runoff ratios (RRs) across southern Minnesota are significant and larger than increases in precipitation.

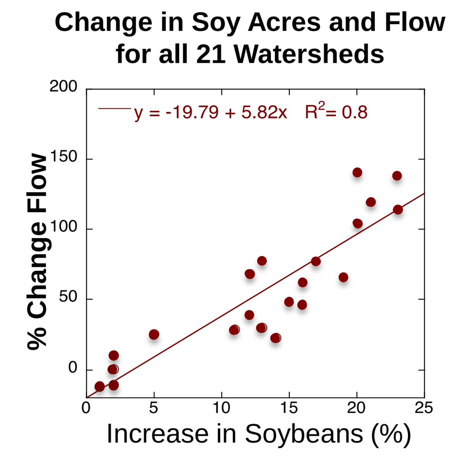
4b. Because soybeans have replaced perennials?

Yes, but only a little.



-- Soybeans have replaced hay and small grains.

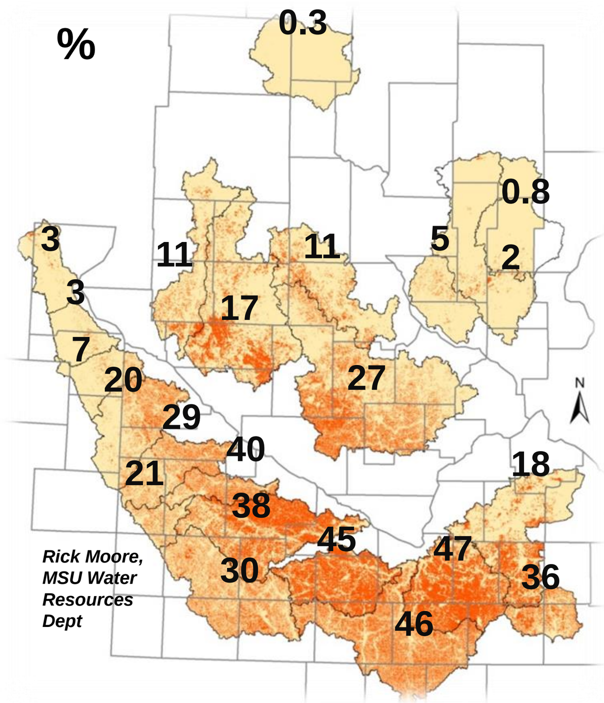
-- Soybeans are planted later in spring than most other crops, leaving fields bare in spring, with therefore less ET and more runoff.



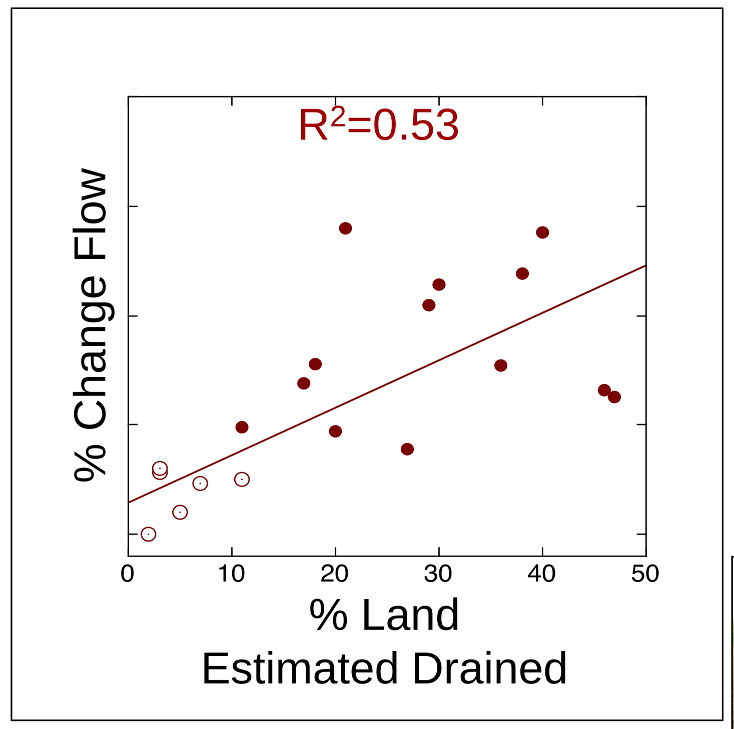
-- And flow increases are correlated with soybean acreage.

-- But: correlation is not cause-and-effect, and most of this correlation appears to be spurious.

4c. Because artificial drainage has reduced evapotranspiration by eliminating wetlands, minimizing ephemeral ponding, and reducing soil moisture? *Yes, by a lot.*



% of each watershed tile drained, estimated from amount of poorly drained soil types.



-- Tile drainage removes wetlands, minimizes ponding of water, and reduces soil moisture

-- All of these factors REDUCE ET and thus INCREASE FLOW.

5. How can we distinguish between these three drivers: precipitation, crop conversion, and drainage? *With some basic math.*

$$\Delta Q = \Delta P - \Delta ET$$

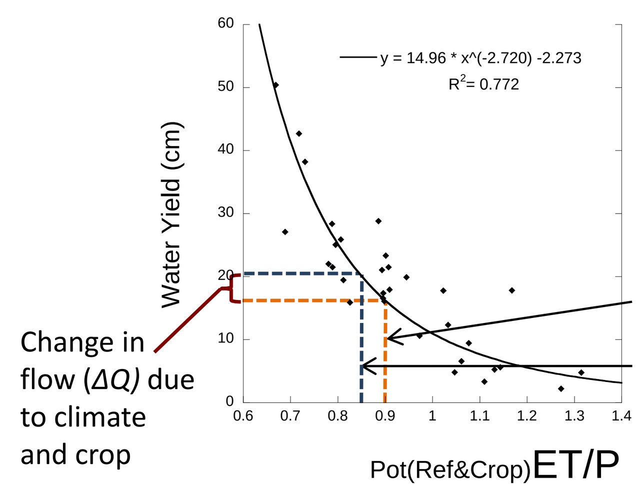
Measured Measured ... but this has several components:

ΔET = *net result of:*

⬆ $\Delta ET_{weather}$ (increased P = ***increased ET***)

⬇ $\Delta ET_{crop\ change}$ (increased soybeans = ***decreased ET in spring***)

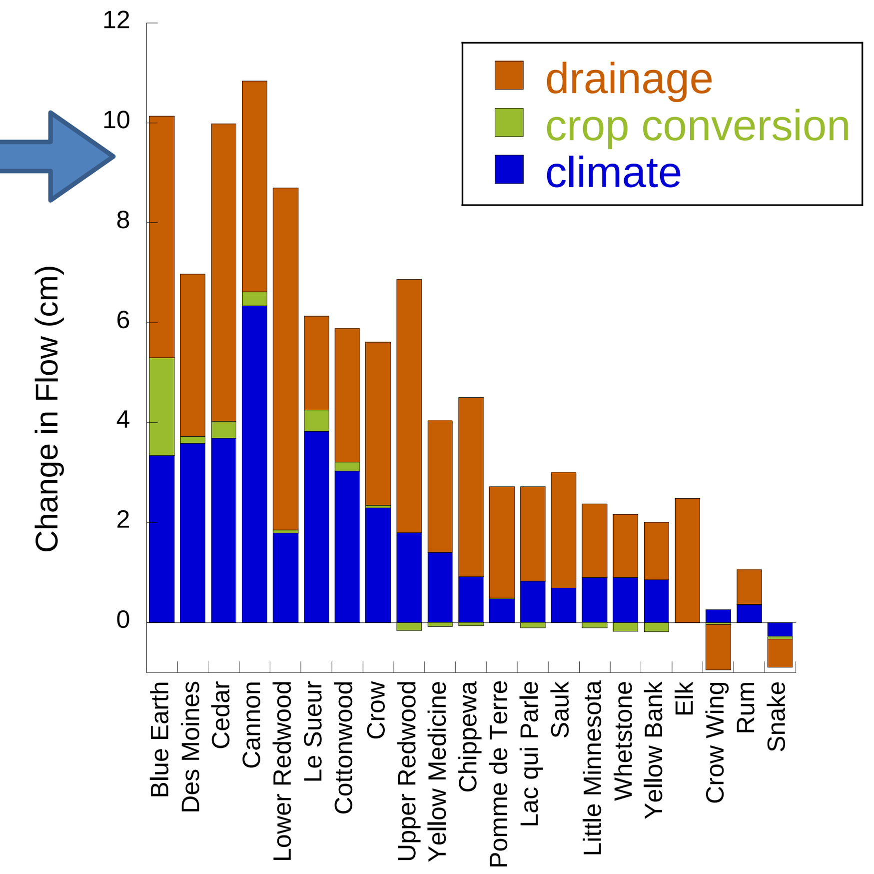
⬇ $\Delta ET_{tile\ drainage}$ (reduced ponding & soil moisture = ***decreased ET***)



-- Solve for ΔET due to crop conversion to soybeans with Penman-Monteith

-- Solve for ΔET due to both crop conversion and precipitation increase with a modified Budyko-style curve (see plot at left)

-- Solve for ΔET due to tile drainage by difference



CONCLUSION:

- ***About 35% of flow increase is from increased precipitation and conversion to soybeans***
- ***>50% of the flow increase is due to artificial drainage that has reduced expected ET from the landscape***