Legacy phosphorus and bank erosion: overlooked contributors to phosphorus loading of Illinois surface waters?

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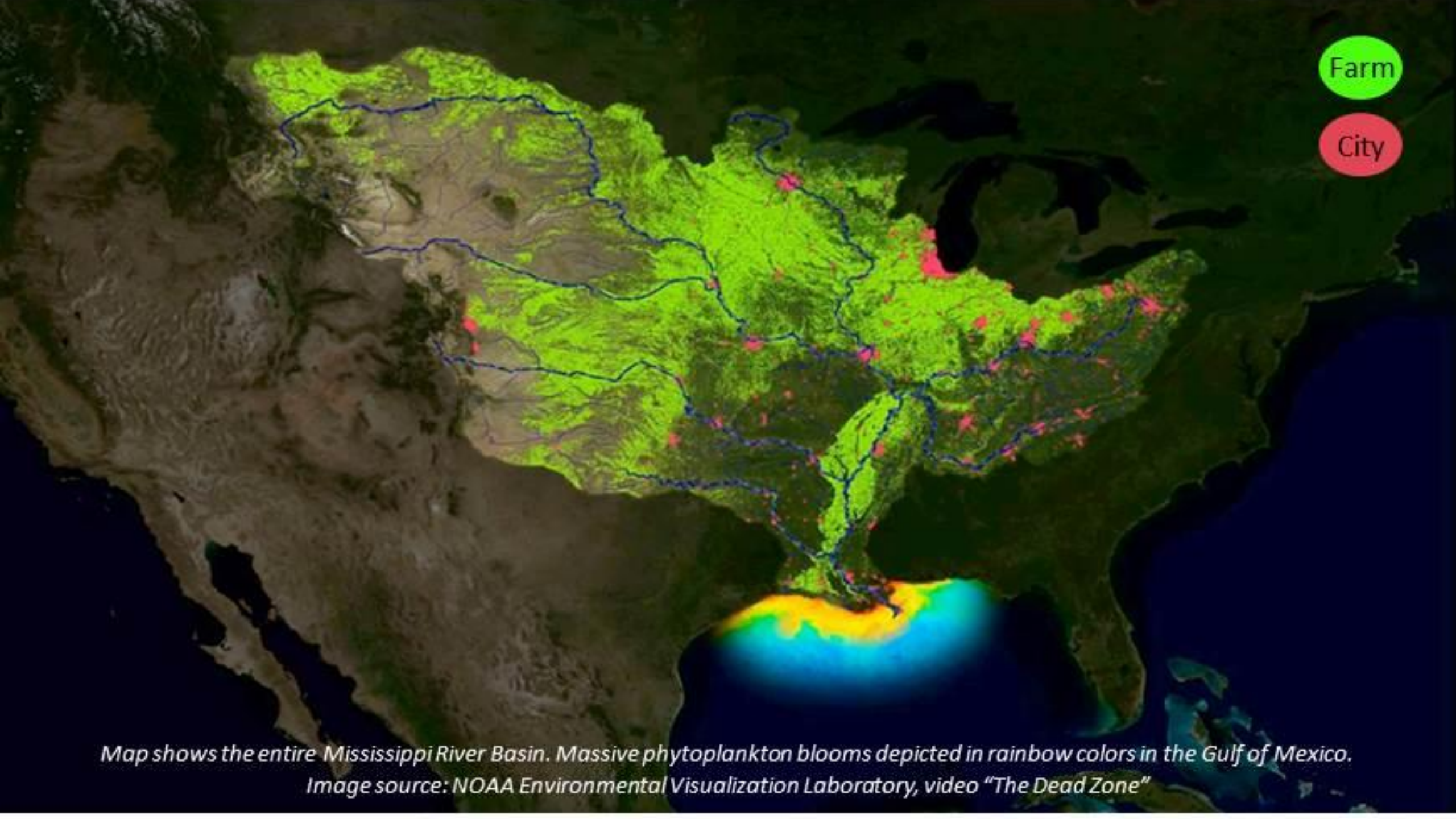
Overview

Goal of the research group: integrate history and biogeochemistry of P in Illinois croplands to support agronomic production, and support Illinois NLRS goals on nutrient loss reductions

Goal of this talk: overview of key overlooked pathways of P loss and implications for lag time in achieving NLRS reduction goals

1. Legacy P: soil
2. Streambank erosion: a non-ag, non-point source
3. Legacy P: sediments

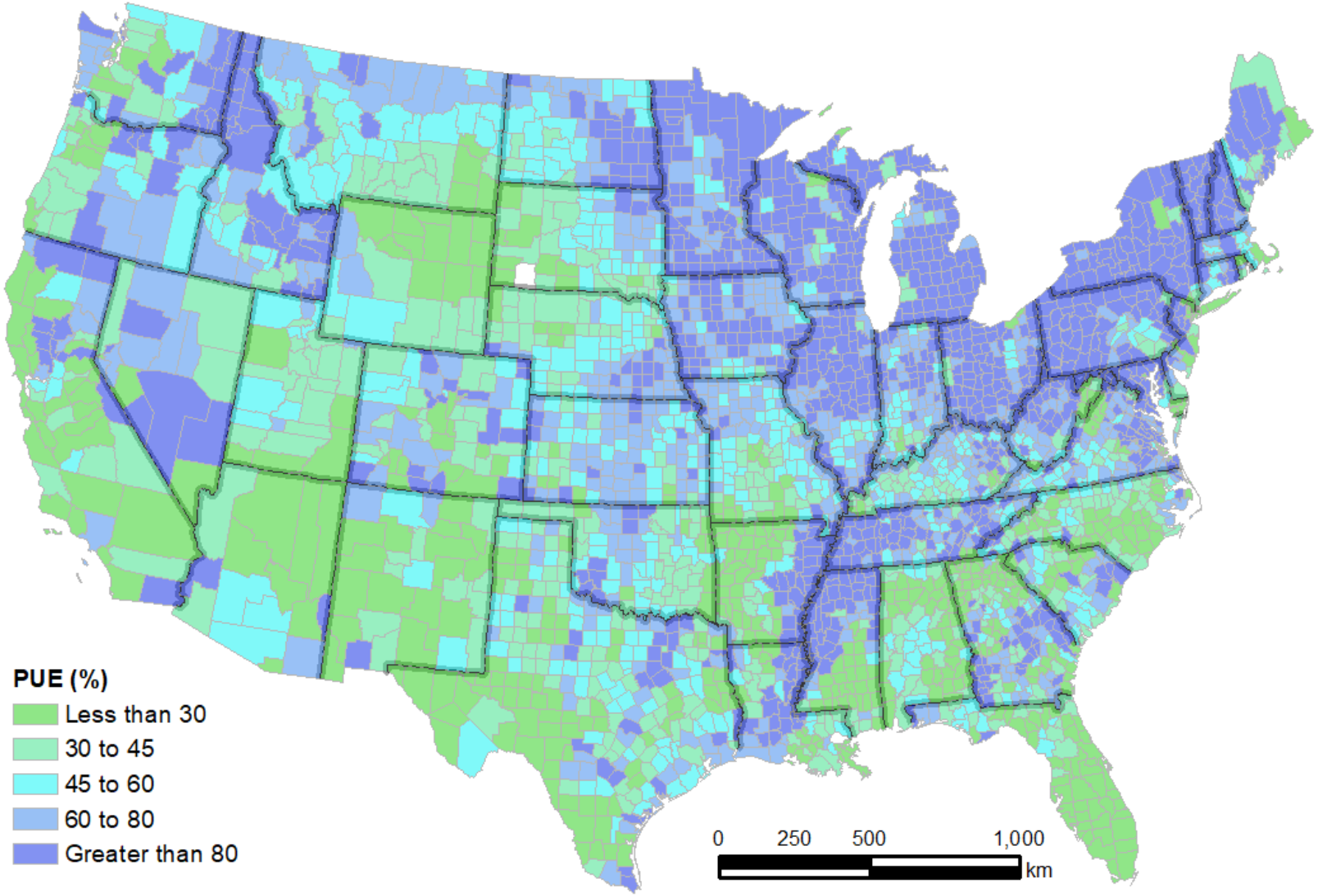


Map shows the entire Mississippi River Basin. Massive phytoplankton blooms depicted in rainbow colors in the Gulf of Mexico.
Image source: NOAA Environmental Visualization Laboratory, video "The Dead Zone"

Phosphorus paradox?

How can there be such high agronomic PUE in Illinois,
but also
high P loading from agricultural fields to surface waters?

Agronomic phosphorus use efficiency (PUE) is high in Illinois



USDA

- PUE by difference
  - County-level
  - Grain P harvested / P fertilizer sales
  - Likely overestimated (and because of legacy P!)
- Global PUE: ~16%

Total P losses

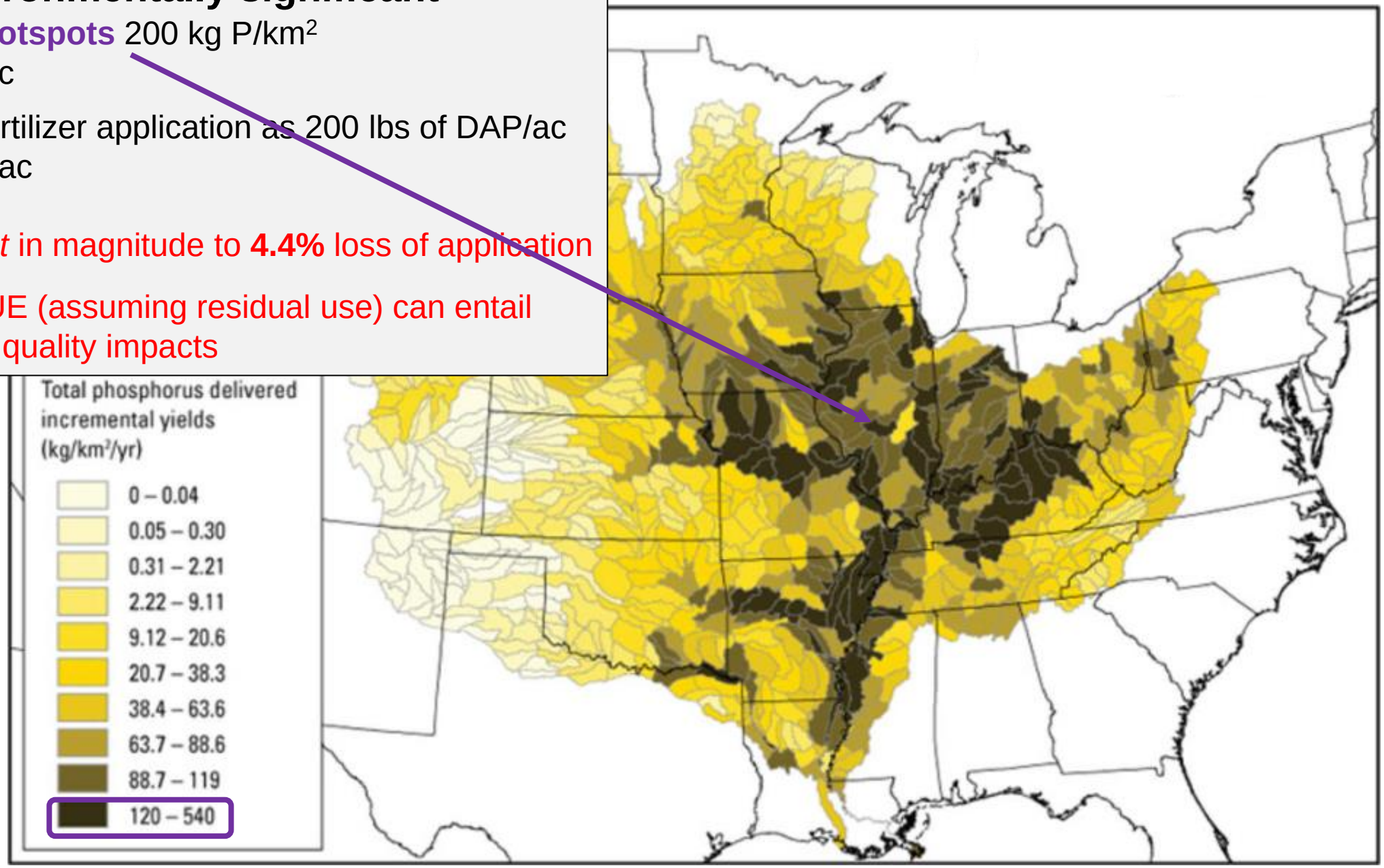
Agronomically minor but environmentally significant

Example: **hotspots** 200 kg P/km^2
= 1.8 lb P/ac

Typical P fertilizer application as 200 lbs of DAP/ac
= 40.5 lb P/ac

= *equivalent* in magnitude to **4.4%** loss of application

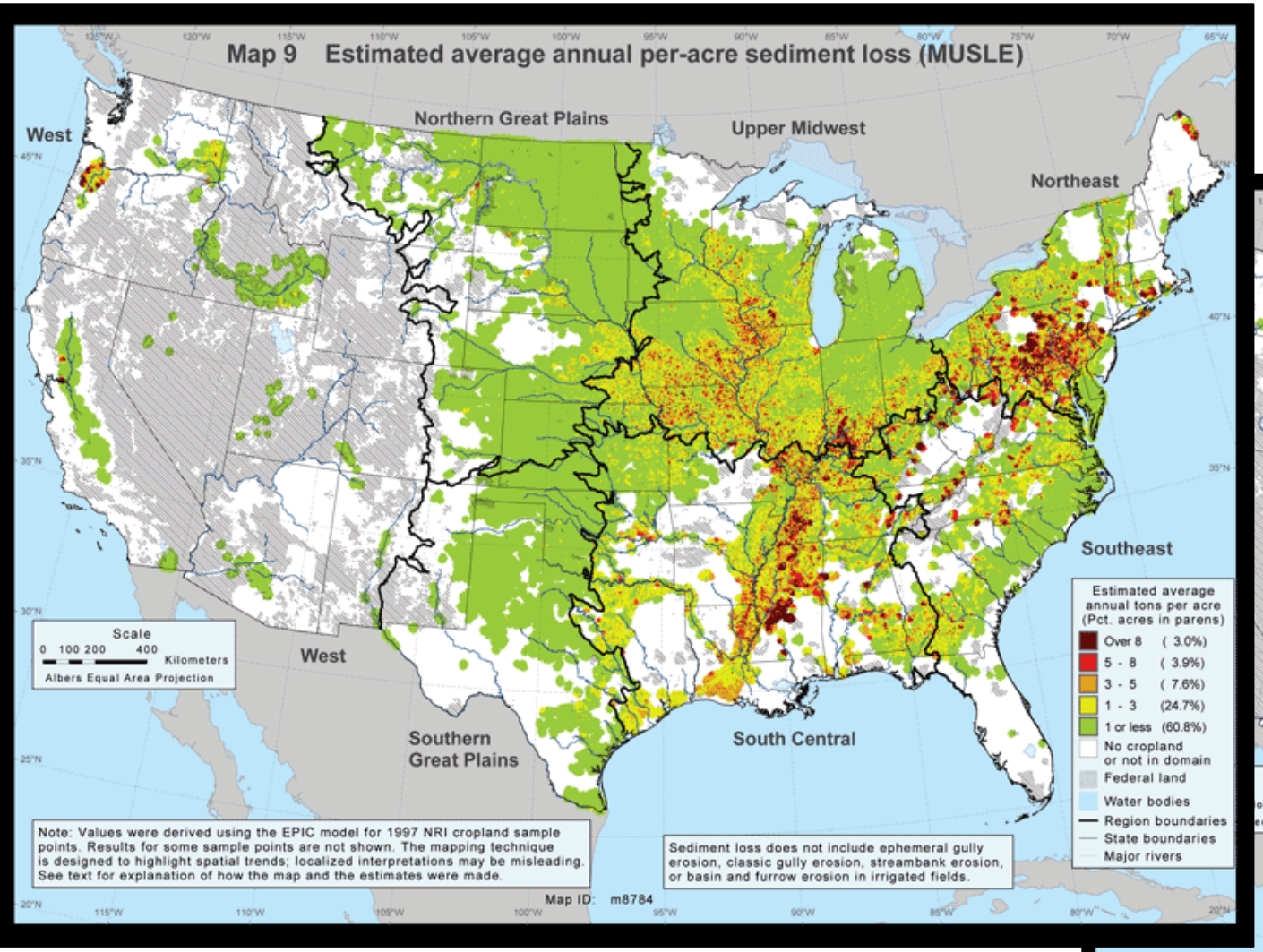
Or: 95% PUE (assuming residual use) can entail large water quality impacts



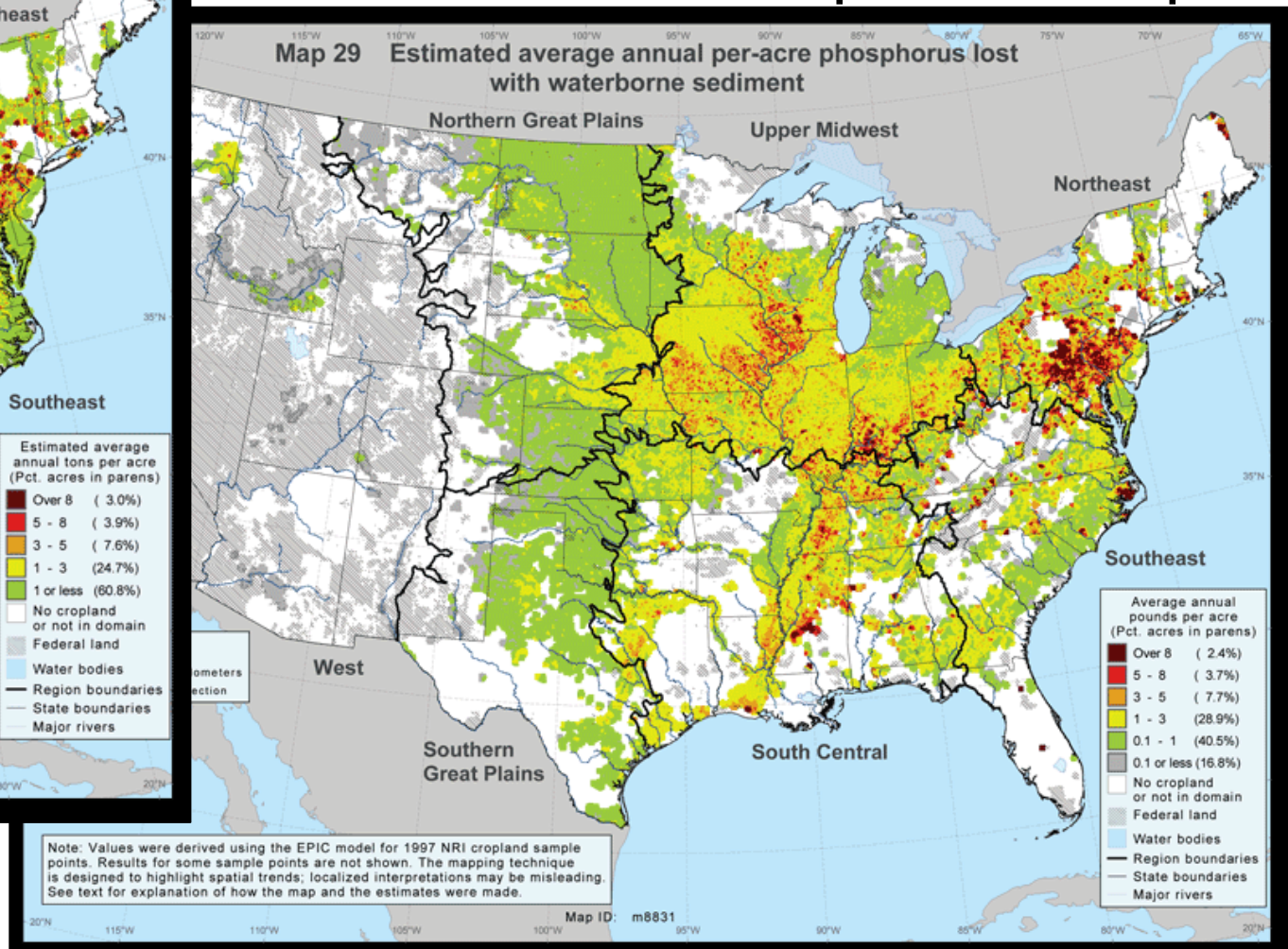
USGS Wisconsin Water Science Center

How much of our P losses are from fertilizer?

Soil erosion…..



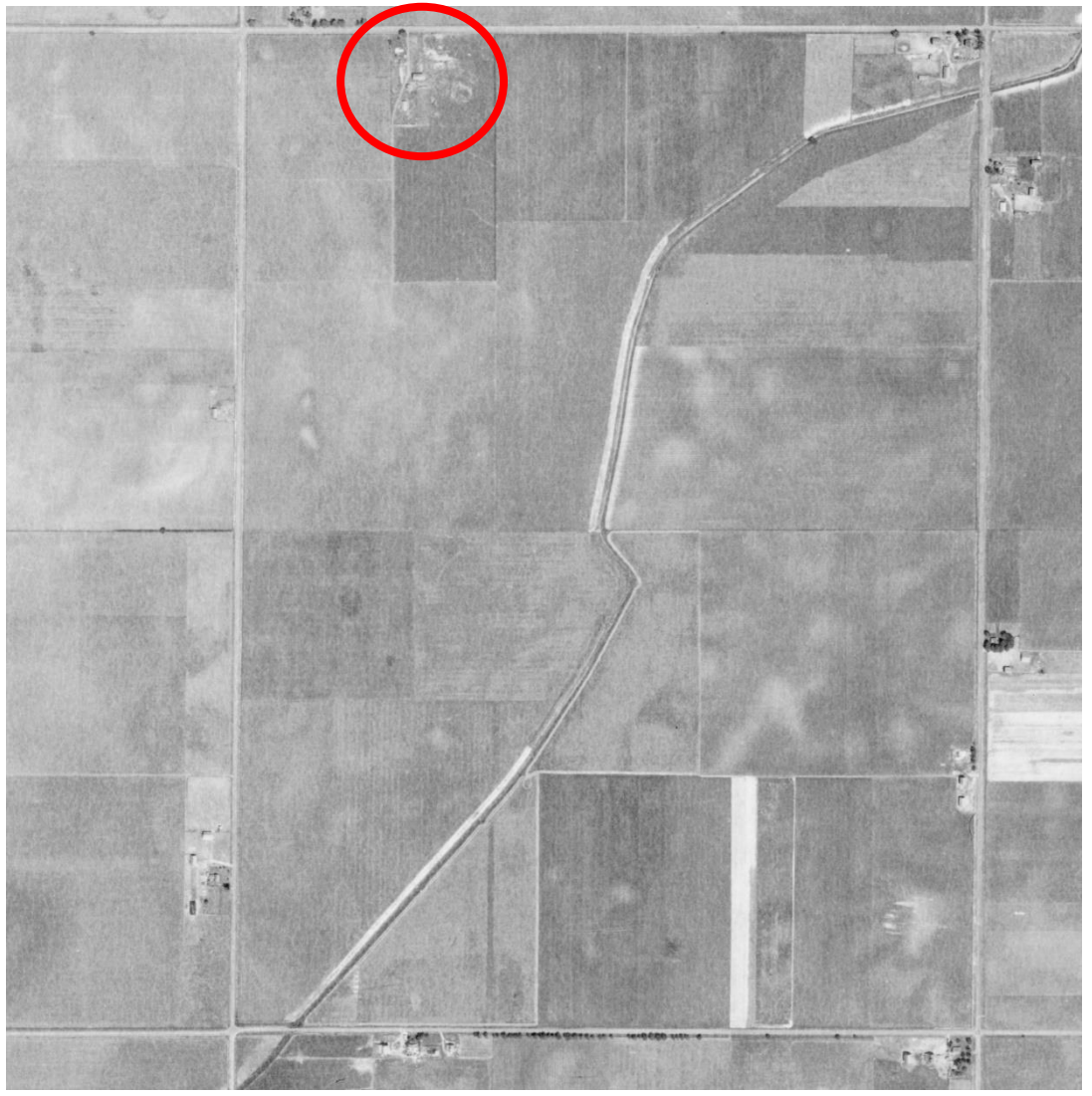
….is a driver of cropland P export



USDA NRCS

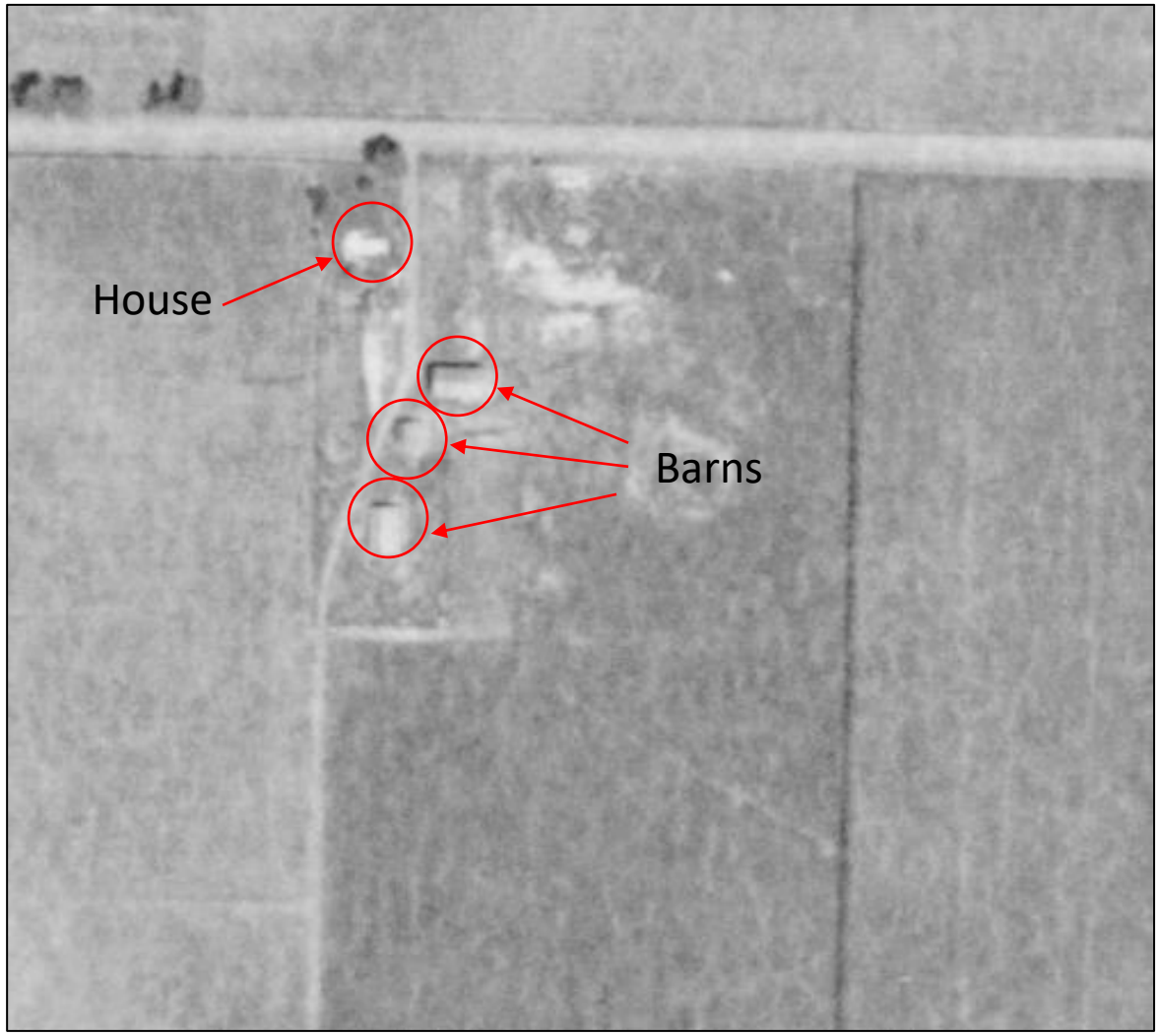
How much is from *contemporary* fertilizer/manure? Example of legacy P: Douglas Co.

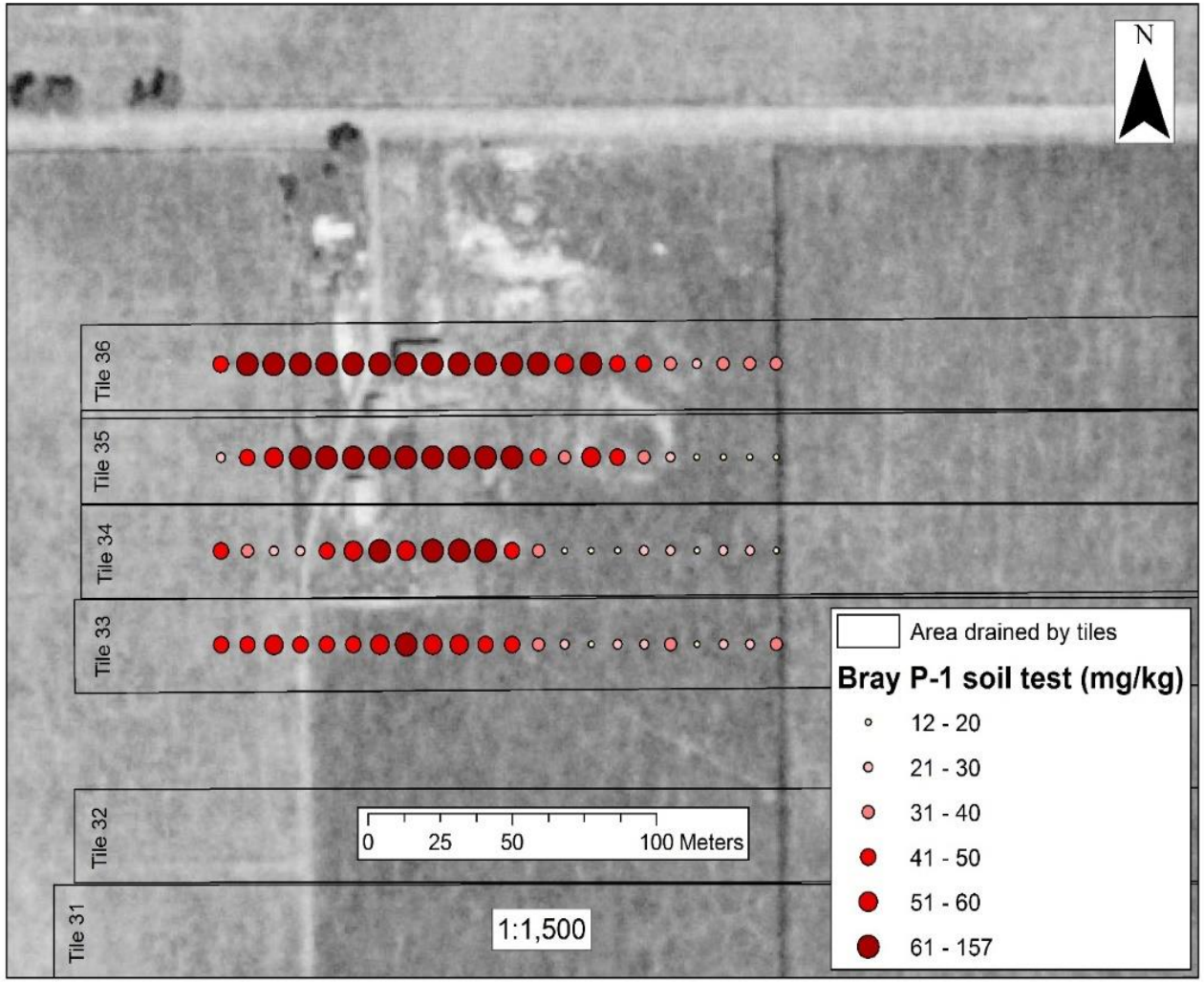
1940 image



Courtesy of **Lowell Gentry**

Soil P hotspots from former barns….





…partly explains higher DRP loads from tiles

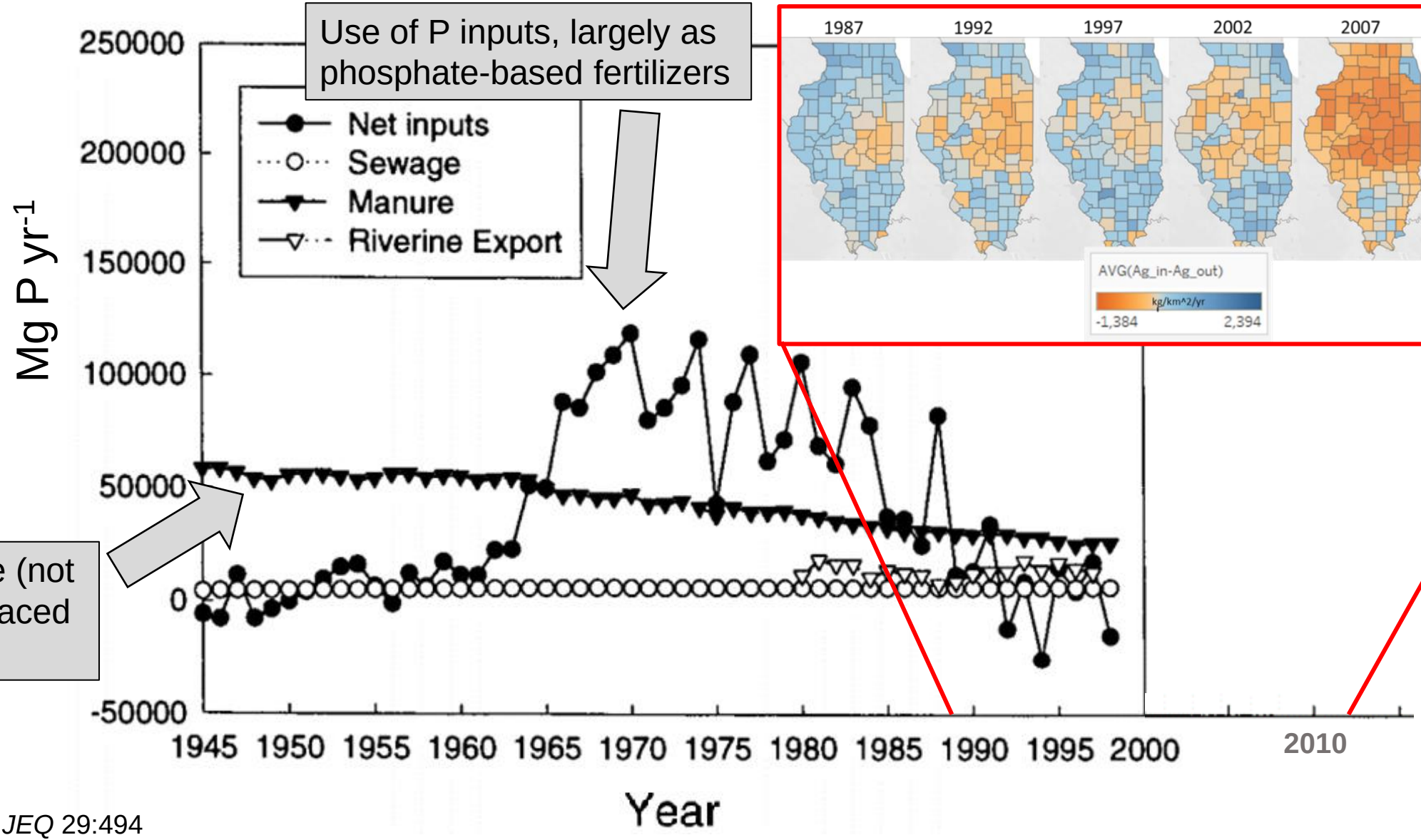
Andino et al 2020 *JEQ* 49(5):1273

Agronomic balances: state

“No net inputs since 1990” (through 2000)

Use of P inputs, largely as phosphate-based fertilizers

Manure usage (not net input) replaced by fertilizer

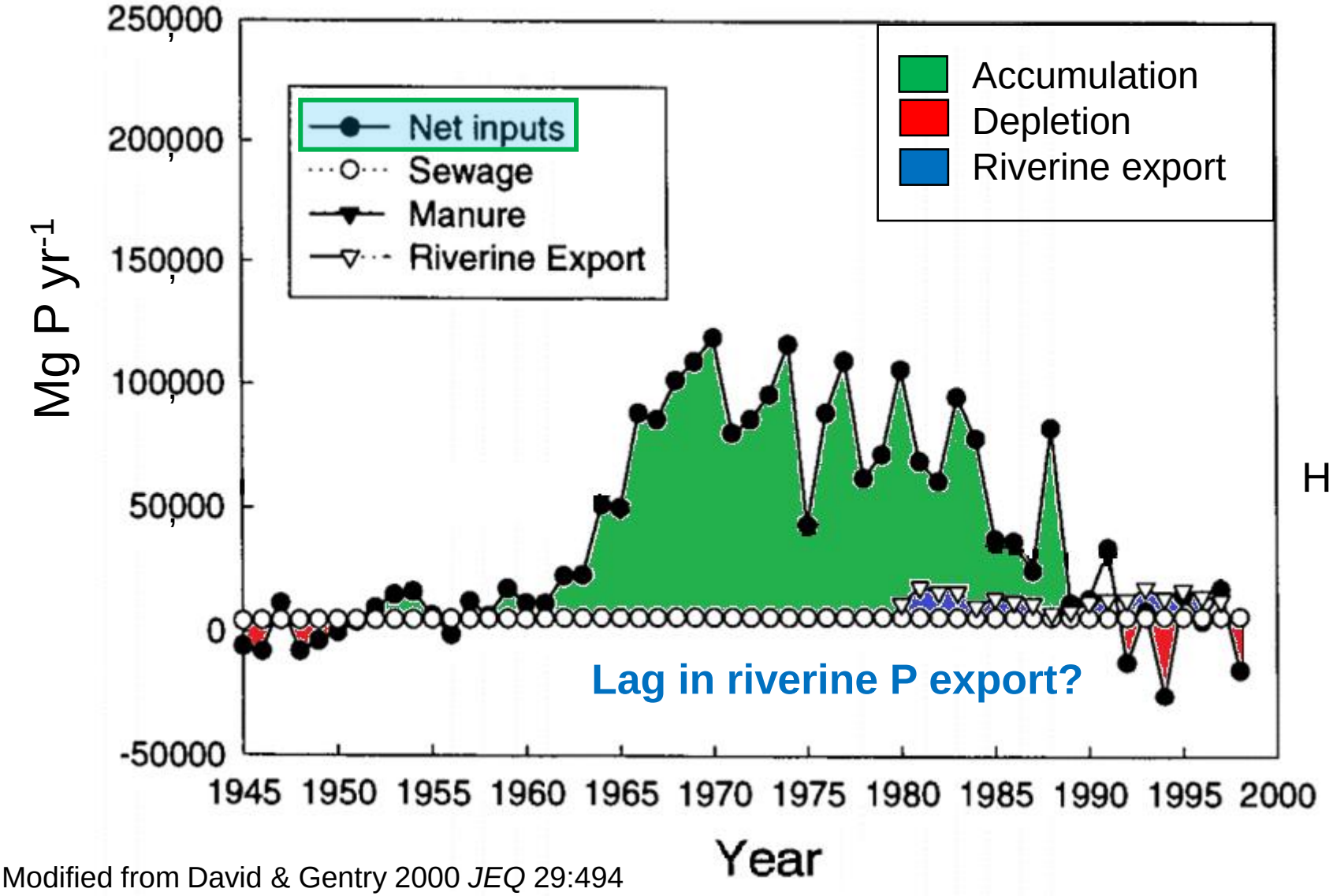


2010

David & Gentry 2000 *JEQ* 29:494

Legacy P in Illinois: how much?

Large positive balance encumbered in ≈ 25 year period



Modified from David & Gentry 2000 *JEQ* 29:494

≈ +4.85 billion lbs P
(2.2 million Mg) **positive balance**

203 lb P/ac across Illinois Cropland

How much of a *relative* enrichment?

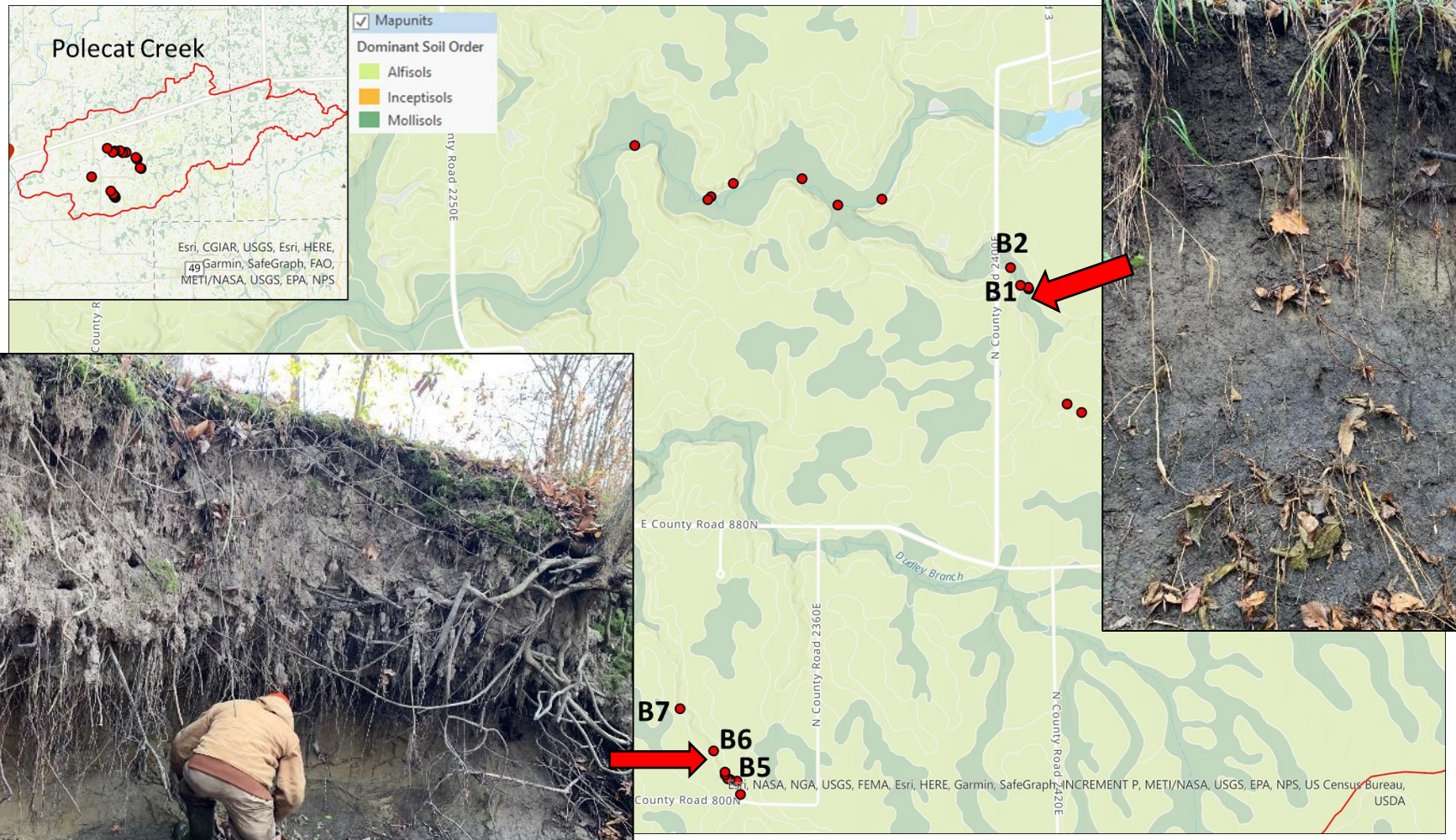
21 million ha of cropland
Assume 4500 lb P/ac to 3' depth
=94.5 billion lbs P

≈ +5% of soil P stocks

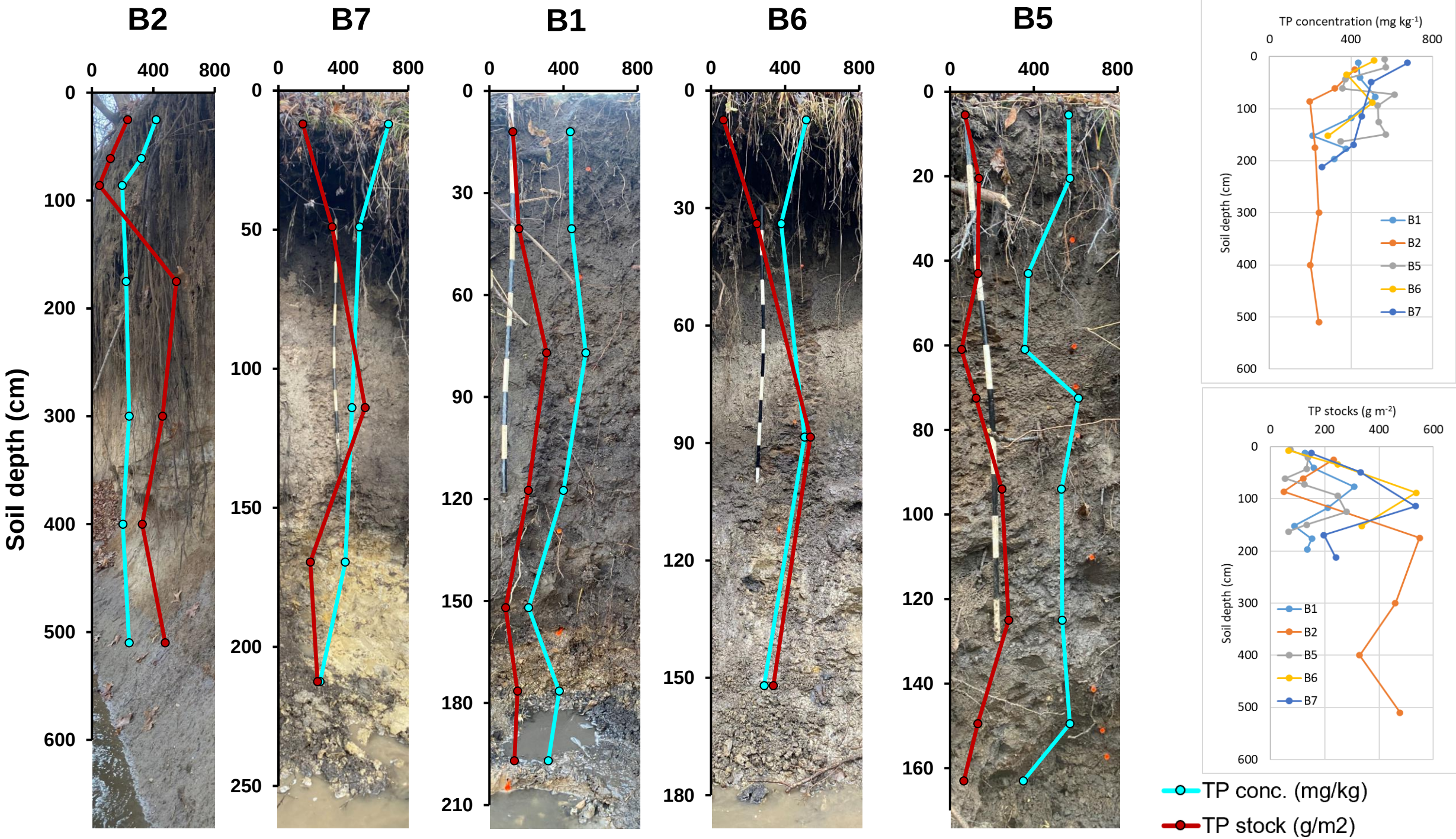
Streambank erosion


How much P is injected into streams with streambank erosion?

Example of magnitudes and variability of potential streambank P erosional loading in Illinois: Embarras watershed

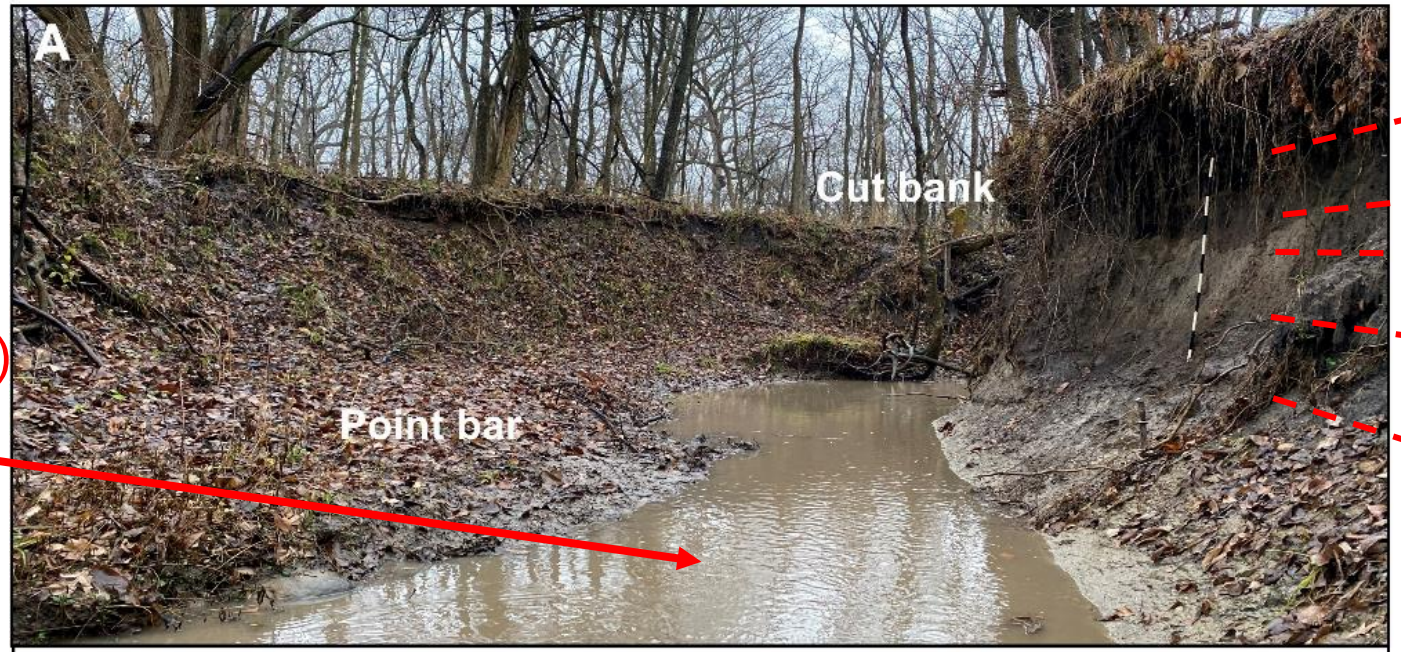


Polecat Creek (HUC-12), tributary of the Embarras

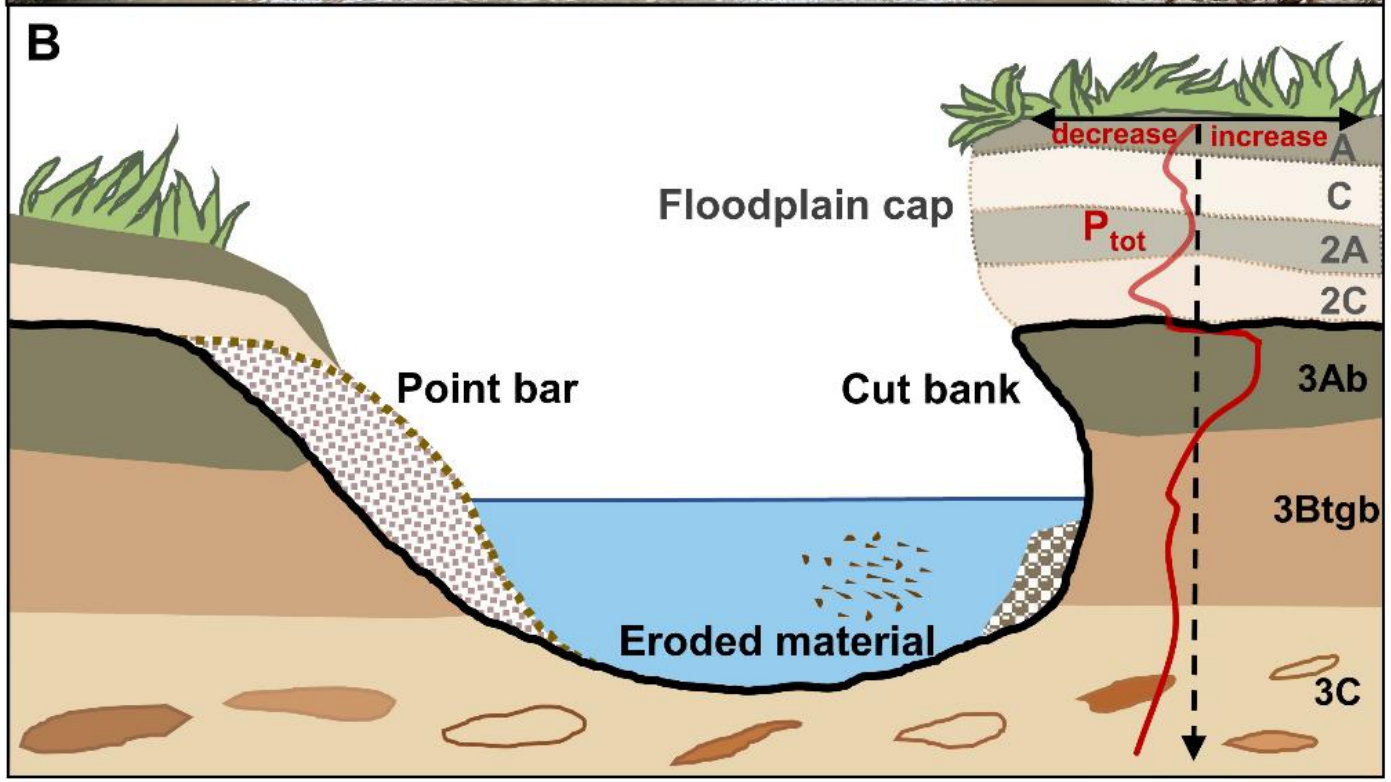

B2
B7
B1
B6
B5
Soil depth (cm)
TP concentration (mg kg-1)
TP stocks (g m-2)
B1
B2
B5
B6
B7
TP conc. (mg/kg)
TP stock (g/m2)

The “other” legacy P: sediment *already* in the channel (past streambank erosion)

Sediments in Polecat Creek ranged **254 – 462 mg/kg**



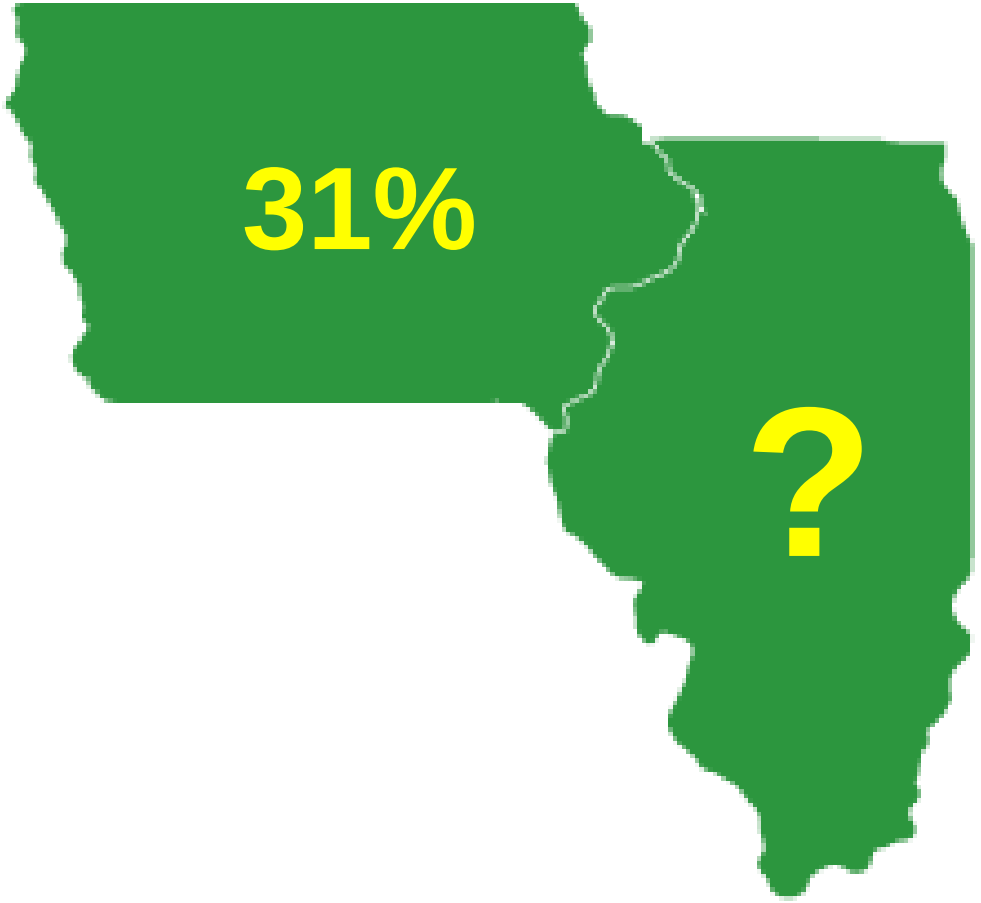
mg/kg
678
499
453
412
257



Streambank height is 95 in height = **12,900 lb P/ac**

If 6” along 3’ of the bank erodes (a big erosion event), **3.2 lbs P**

How much does streambank erosion contribute to state riverine P loads?



Streambank erosion is counted as non-point source (NPS), but it is *not* agricultural NPS

Streambank erosion adds up

Total streambank P contributions = eroding bank length × recession rate × bank height × bulk density × total P conc.

Assume (from Iowa Geological Survey):

- Eroding bank length of 35,200 km
- Average recession rate ~ 12.4 cm/year
- Average height of bank: 3.2 m
- Bulk density of 1170 kg/m^3 (low)

Total streambank soil load =

- 35,200,000 m x 0.124 m x 3.2 m x 1170 kg/m^3
  = 16.3 million tons of sediment
- At 470 mg P/kg soil (conservative),
  = 7,680 tons of P

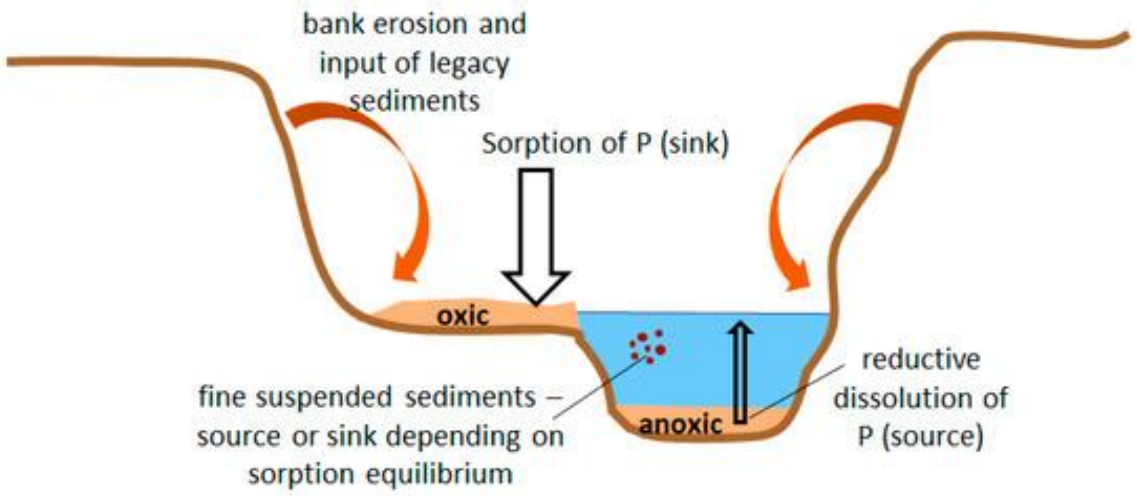
~ 16.9 million lbs P = exactly the Illinois NLRS full reduction goal

Legacy P: sediments

- Streams are important for transport and storage of P
- Streambank erosion + overland erosion = sediment P

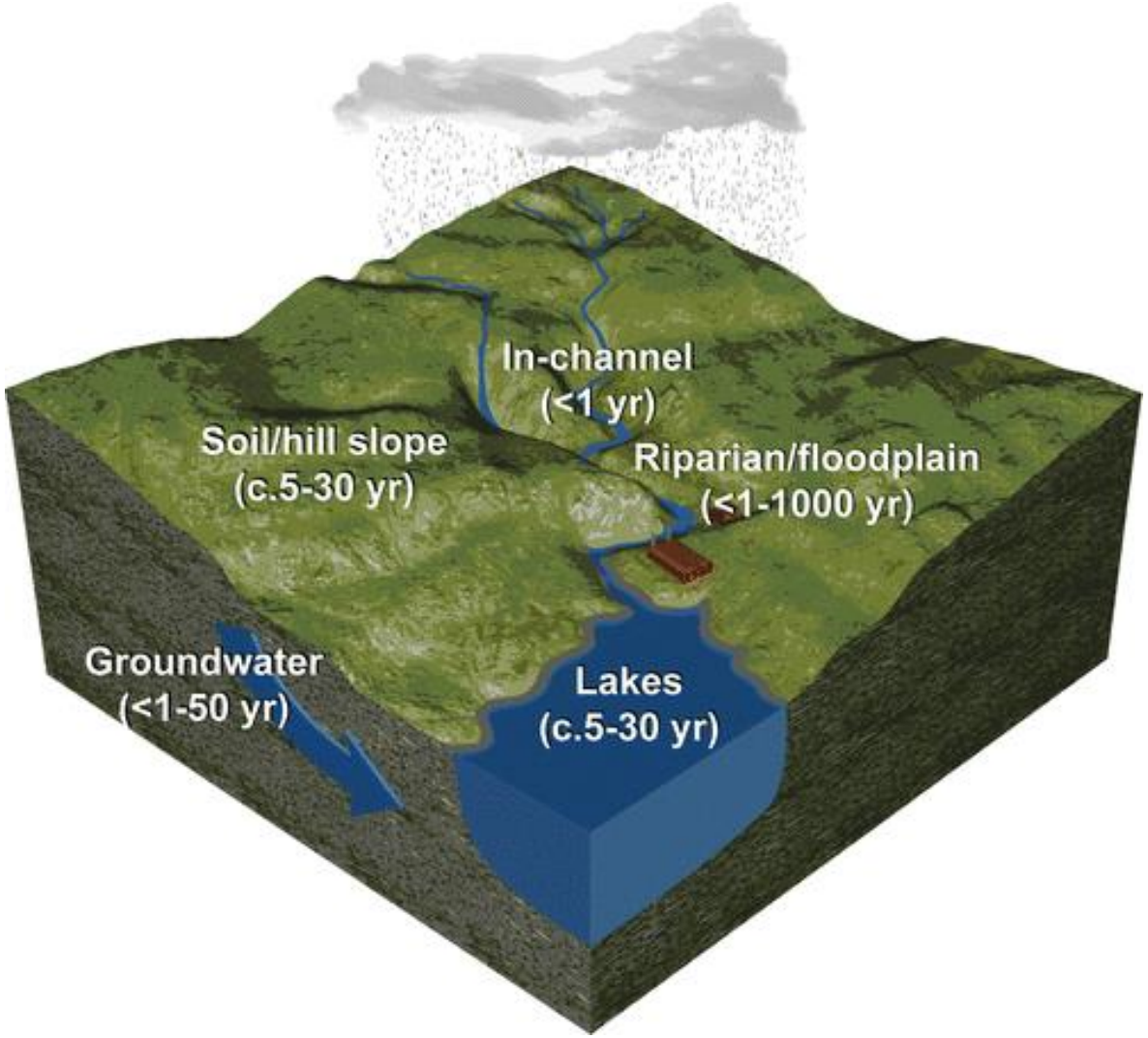
- P stored in streambed sediment may be a missing link between non-point P sources and riverine export loads

- Sediments <u>can switch from net sinks to net sources</u> of dissolved reactive P
  - P release when streamwater is lower P conc than in streambed
  - The “off-on” dynamics of sediment P can contribute to variation in year-to-year P export



Inamdar et al 2020 *Soil Systems* 4(2): 30

Typical time scales in soils and water of a watershed entail a chronic release of “legacy P” that will impair downstream water quality over timescales of years to centuries



Implications

1. Constant loading of legacy P can create lag times between the implementation of nutrient abatement measures on land and the reduction in nutrient loads
2. Legacy P-based **lags in water quality recovery** must be quantified so that need-based evaluation of P loss reduction goals at longer time scales of recovery

Jarvie et al 2013 *ES&T* 47(16): 8997

How to manage legacy sediment P? Case study: Dane Co., Wisconsin

- In 2014, Dane Co and WI Dept. Natural Resources discovered that 7x greater P concentrations in the stream sediments of Dorn Creek than in crop fields
- Sediment in Dorn Creek has existed since the late 1800s
- If the accrued legacy sediment remains at the bottom of the streams, it would take ~ 100 years for P to continue to leach out of the sediments and enter the lake.
- Dane Co. selectively dredging streams that are (1) smaller and (2) have higher P loads, costing **$14/lb P**

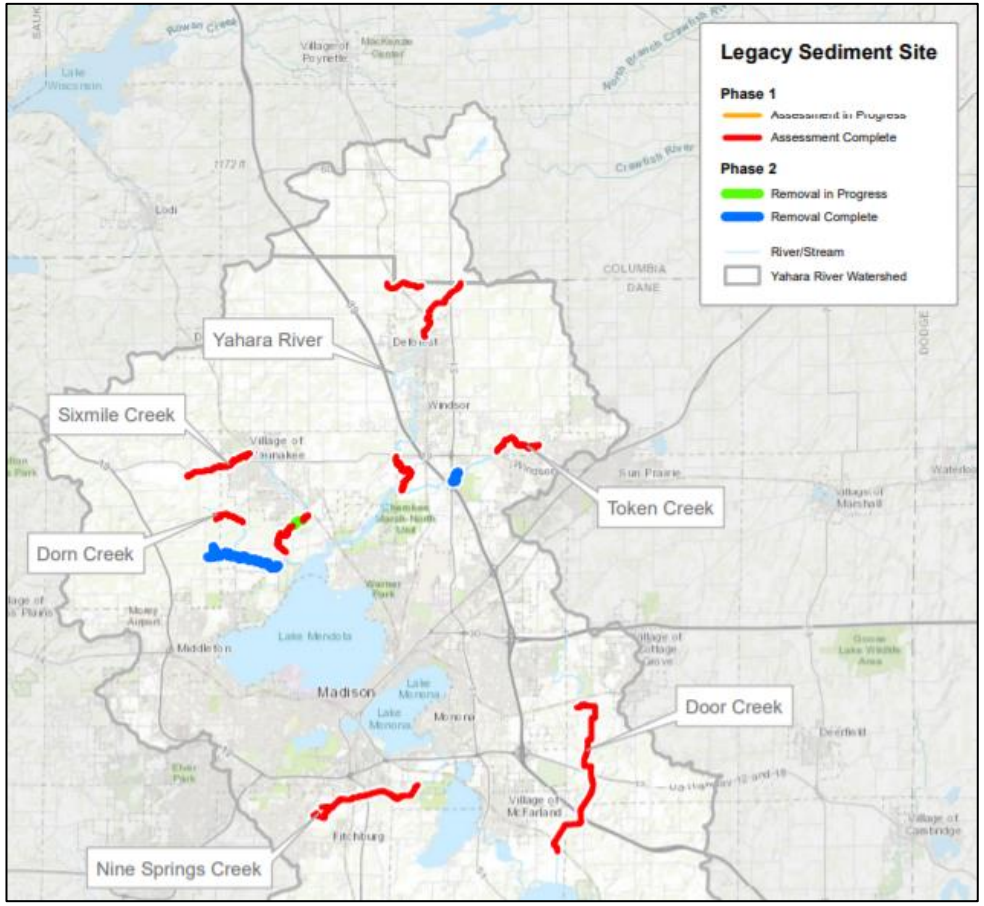


Table 3.7. Conservation practice costs included in the Illinois NLRS

Practice	Cost ($/ac)	Other Economic Concerns, as Noted in Illinois NLRS
Reduced tillage	-$17.00	Potential yield reductions
Phosphorus rate reduction	-$7.50	—
Stream buffer	$294.00	Cost is per acre of buffer; negative impacts on farmland
N rates reduced from background to MRTN	-$8.00	—
N inhibitor with fall-only fertilizer application	$7.00	—
Split N fertilizer application on tiled soils (50% fall and 50% spring)	$17.00	—
Spring-only N fertilizer application on tiled acres	$18.00	Timeliness
Cover crops	$29.00	Planting difficulty; potential impact on yields
Bioreactors	$17.00	Large investment costs; increasing costs with large adoption
Wetlands	$60.63	Large investment costs
Perennial crops	$86.00	Lower forage prices due to large shifts

NLRS 2021 Biennial Report

Summary

- Legacy P in soils is accumulated P from past inputs
  - Typically inferred by balances
  - Challenging to measure with decreasing spatial scale (state to field)
- Large magnitude of soil-based P transfers to surface waters via streambank erosion
  - Potentially large contribution to total P export
- Legacy P as sediment in stream channels entails major lags
  - Constant loading of legacy P can create lag times between the implementation of nutrient abatement measures on land and the reduction in nutrient loads
  - Legacy P-based **lags in water quality recovery** must be quantified so that need-based evaluation of P loss reduction goals at longer time scales of recovery are not dismissed as ‘buying more time’

Questions?

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