Non-point, non-agricultural sources of phosphorus loss: what do we know, and can we manage it?

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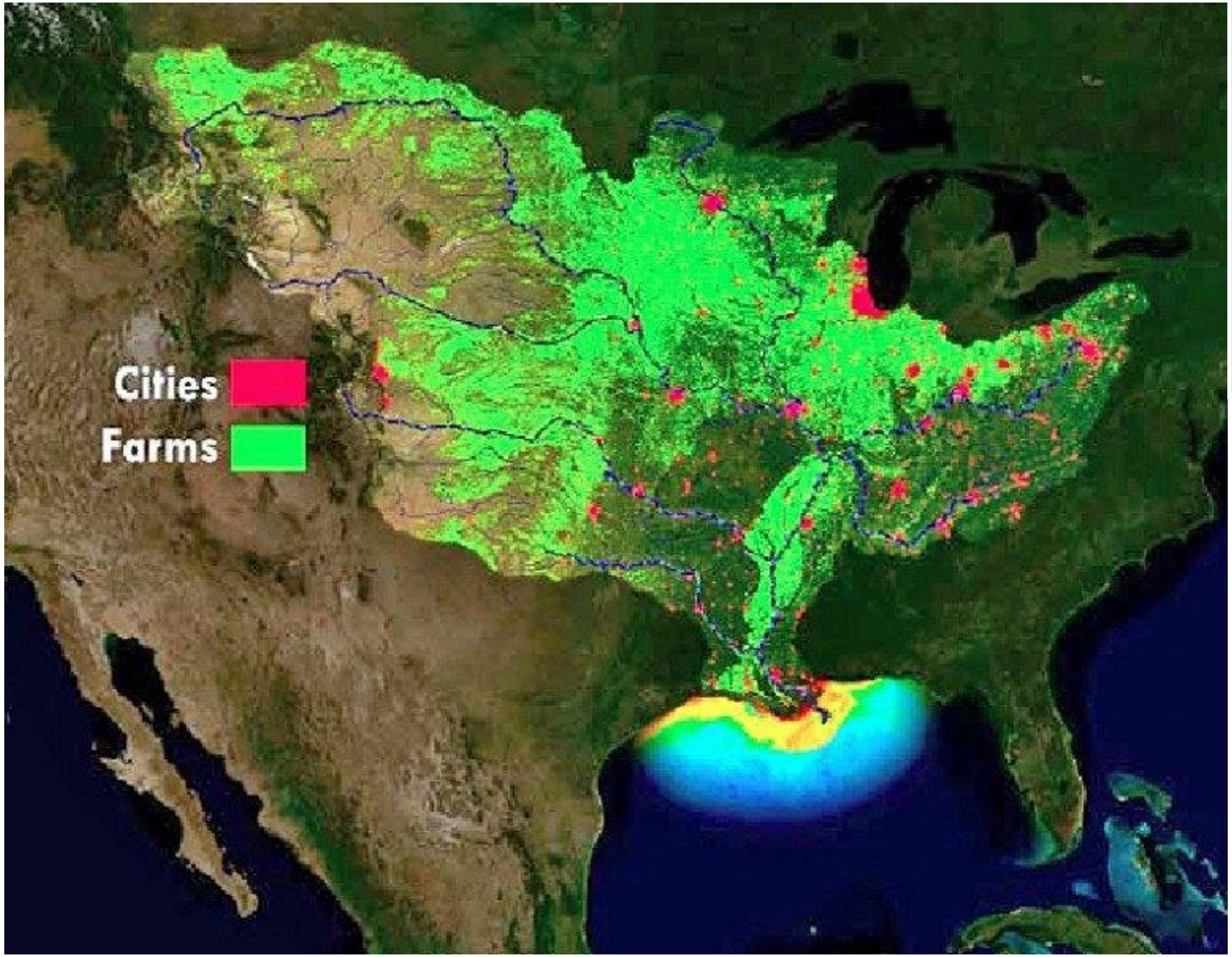
Indiana CCA Annual Meeting
Indianapolis, IN

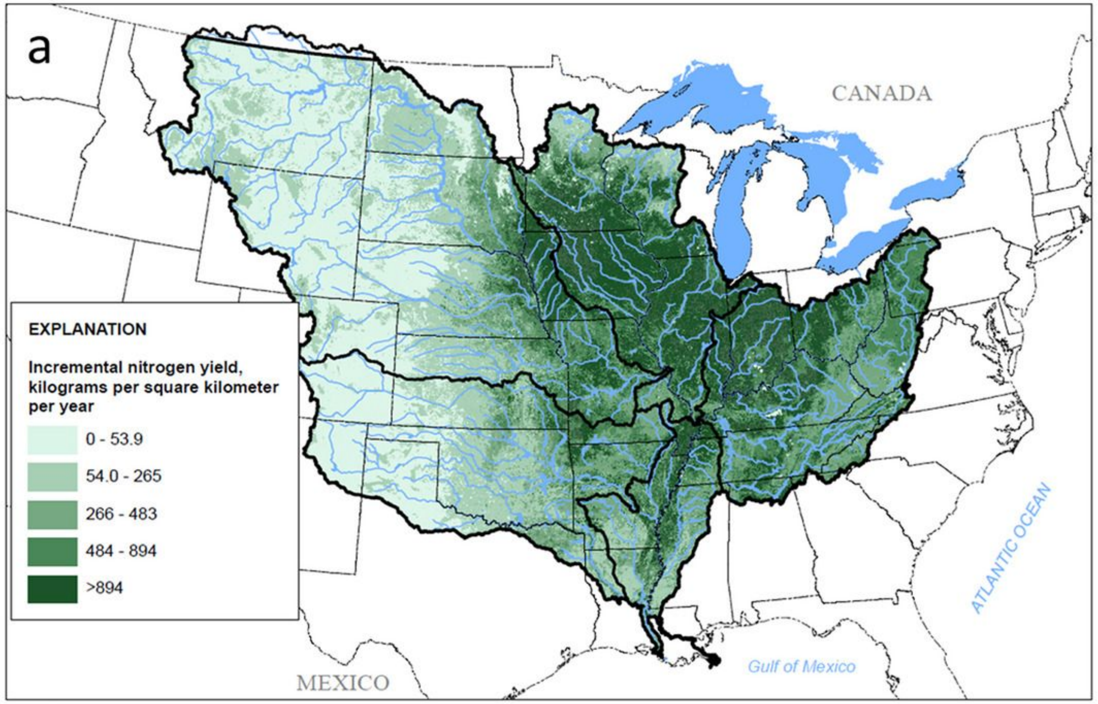
The Mississippi River Basin (MRB)

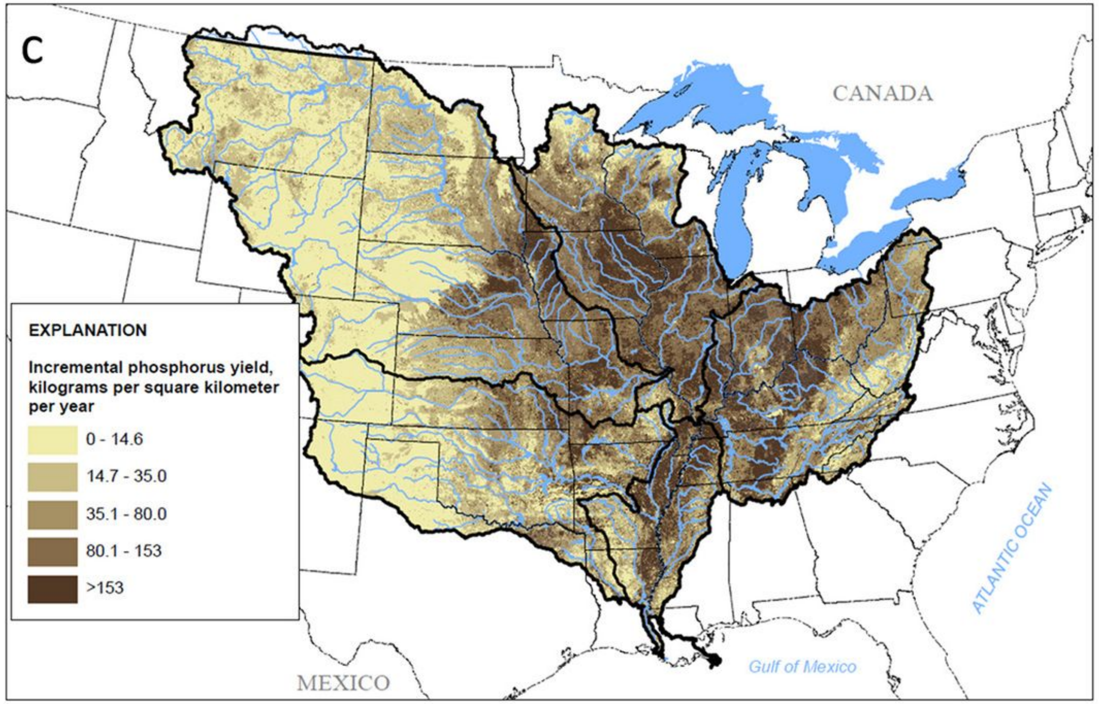
Robertson & Saad 2021 *JAWRA* 57(3): 406

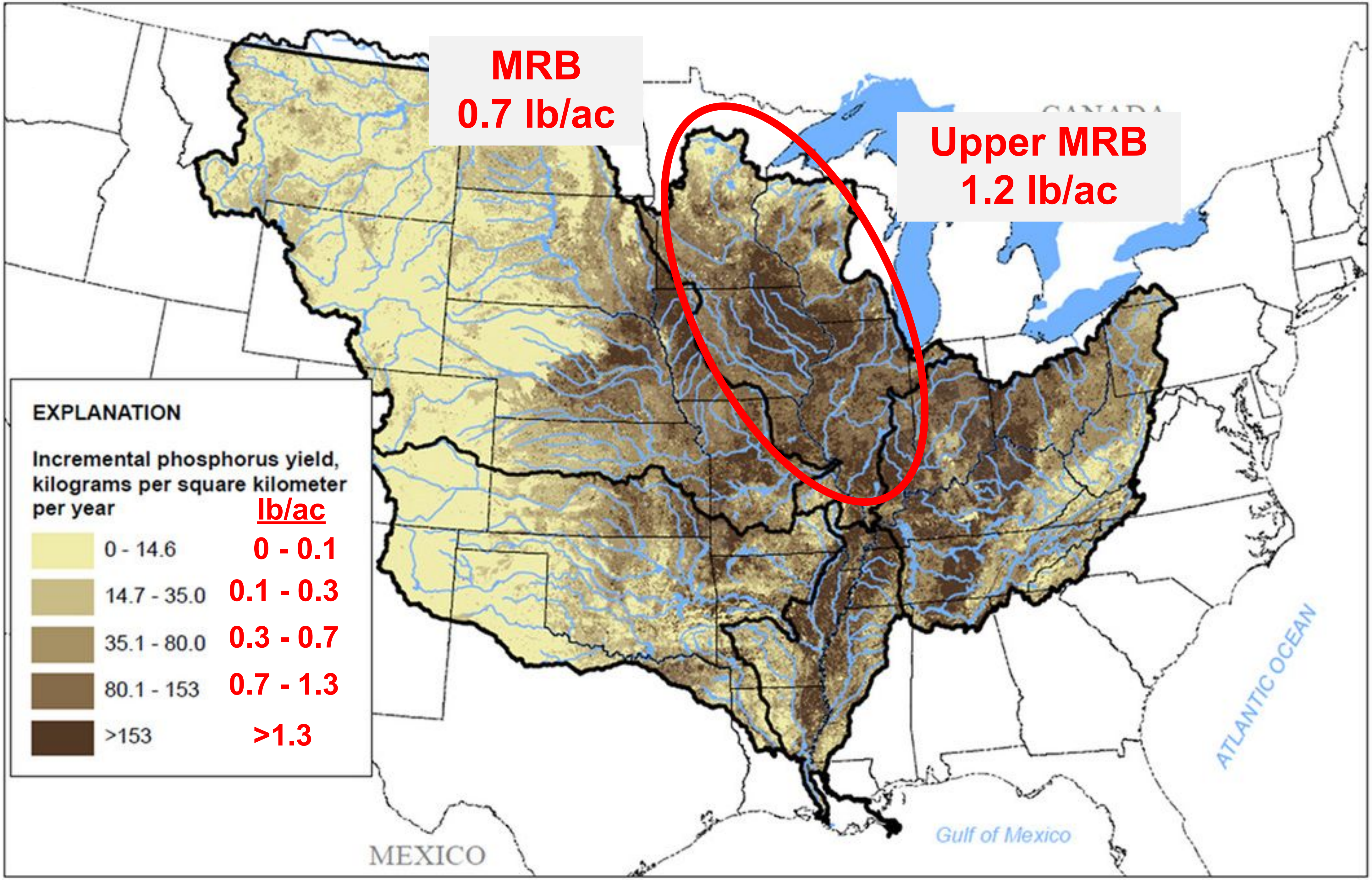
N and P losses in the Mississippi River Basin



Robertson & Saad (2021) *JAWRA*

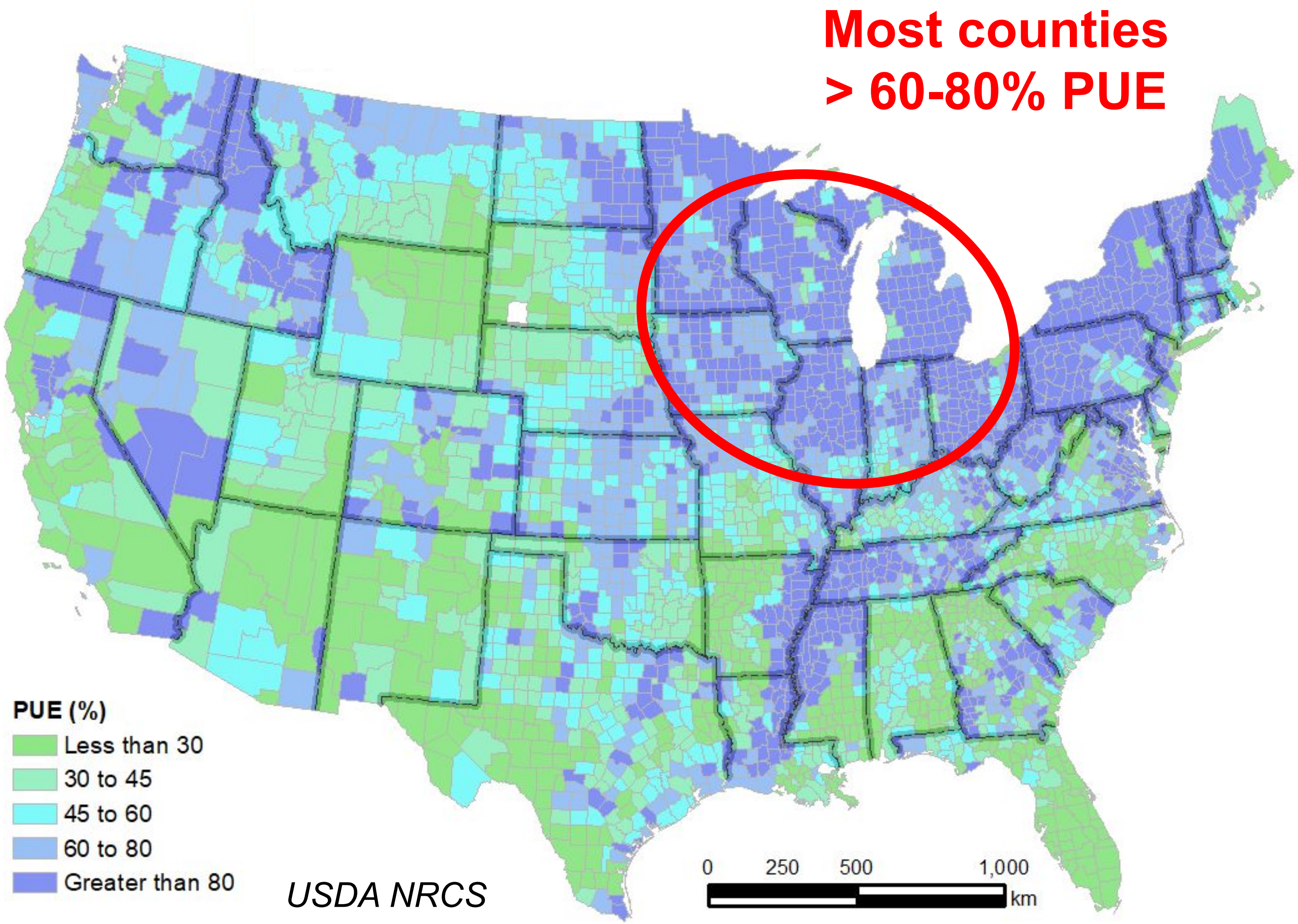






Robertson & Saad 2021 *JAWRA* 57(3): 406

Agronomic P use efficiency (PUE) is high in the MRB



PUE (%) calculated by balance approach:

- County-level
- "same season"
- Grain P ÷ P fertilizer
- Grain harvested ÷ P fertilizer sales

Global PUE (same-season) estimated by difference approach is **≈16%**

Dhillon et al 2017 *Agronomy J* 109(4):1670

Phosphorus paradox?

How can there be such high agronomic PUE in Illinois and Indiana,

but also

high P loading from agricultural fields to surface waters?

Agronomically minor but environmentally significant

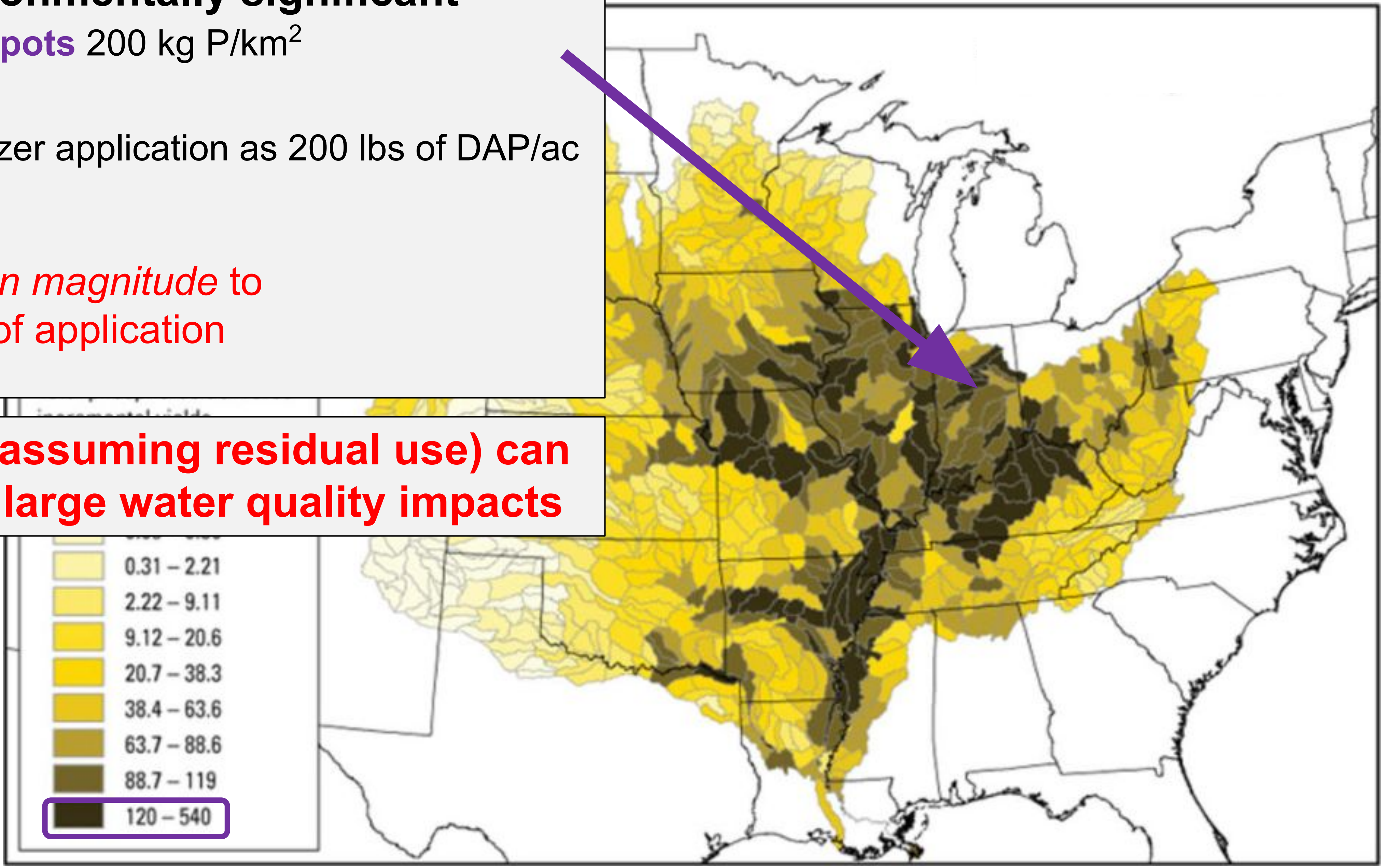
Example: **hotspots** 200 kg P/km^2
= **1.8 lb P/ac**

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

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

95% PUE (assuming residual use) can *still* entail large water quality impacts

Total P losses



USGS Wisconsin Water Science Center

Both legacy P and residual P matter for source apportionment

Environmental Science & Technology

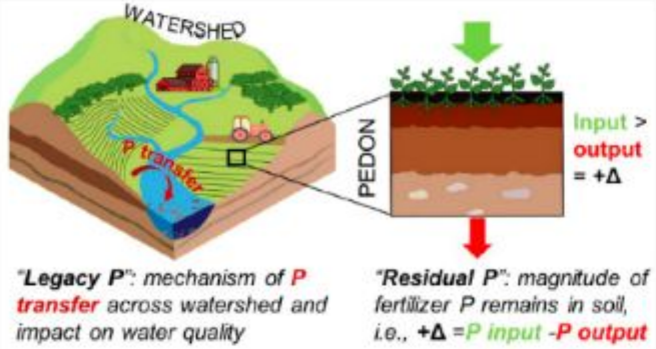
pubs.acs.org/est Perspective

Muddied Waters: The Use of "Residual" And "Legacy" Phosphorus

Shengnan Zhou* and Andrew J. Margenot*

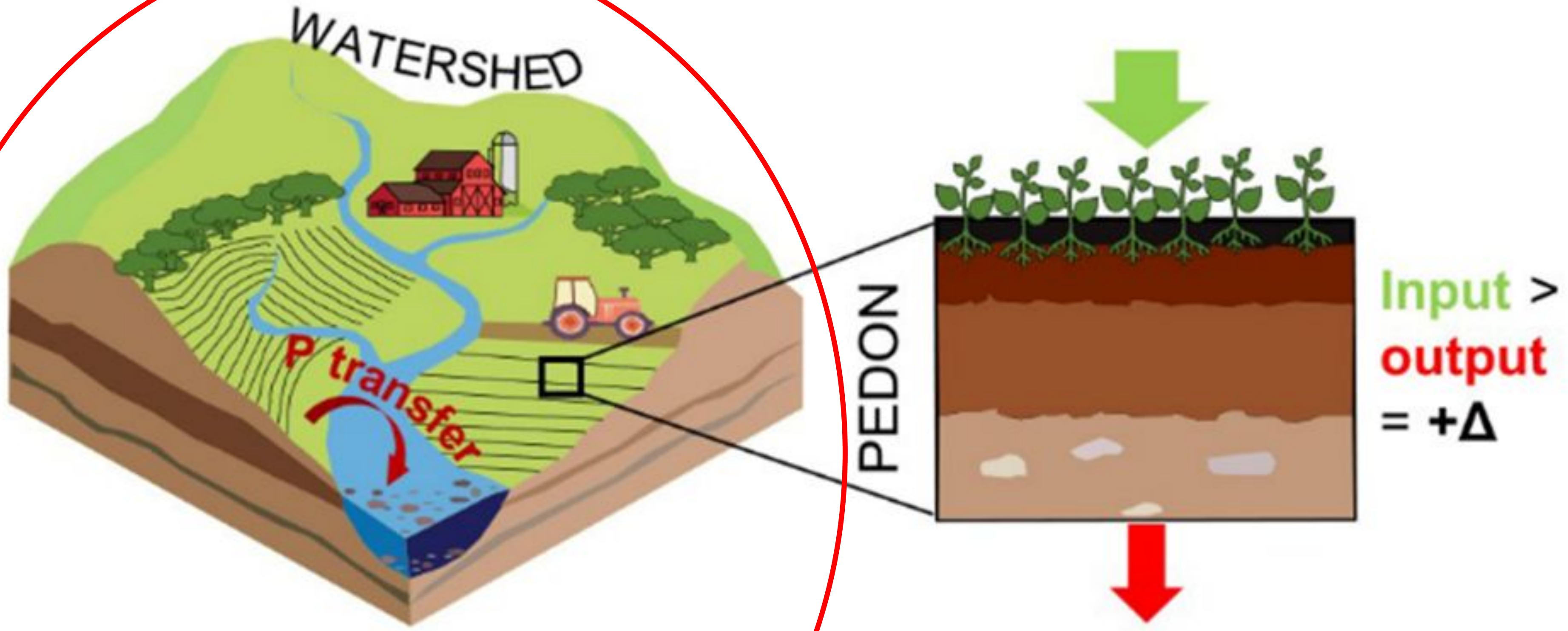
Cite This: https://doi.org/10.1021/acs.est.3c04733 Read Online

ABSTRACT: Phosphorus (P) inputs to the biosphere have quadrupled in less than a century due to intensification of rock phosphate mining and the use of P fertilizers for crop production. Accumulation of P in soils can increase P transfers across the soil-water continuum that impair aquatic ecosystem function and water resource quality for society. However, what this accumulated P is called, and subsequent connotations of magnitude versus mechanism at pedon versus watershed scale, varies in the literature. We argue that the two commonly used terms of "residual" and "legacy" P, though often used interchangeably, hold distinct meanings and connotations. Tracing the historical origins and trajectories of these terms reveals that "residual P" refers to the magnitude of fertilizer P that remains in the soil after crop harvest, whereas "legacy P" refers



Both are sources of non-point P – but not in the traditional or commonly used sense of the term

Both legacy P and residual P matter for source apportionment



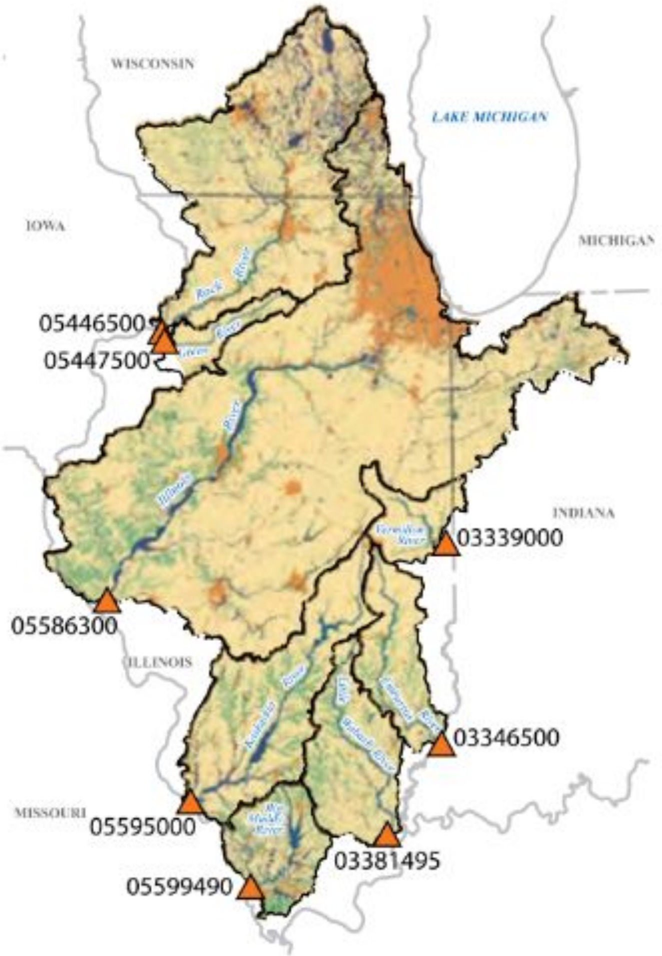
"**Legacy P**": mechanism of ***P transfer*** across watershed and impact on water quality

"**Residual P**": magnitude of fertilizer P remains in soil, i.e., **+Δ** =***P input*** -***P output***

Zhou & Margenot **2023** *Environmental Science & Technology* 57:21535

How are non-point source (NPS) loads calculated?

- Non-point sources are generally measured indirectly, *by difference*
- This makes discrimination among or partitioning of multiple non-point sources challenging, because multiple types are lumped together



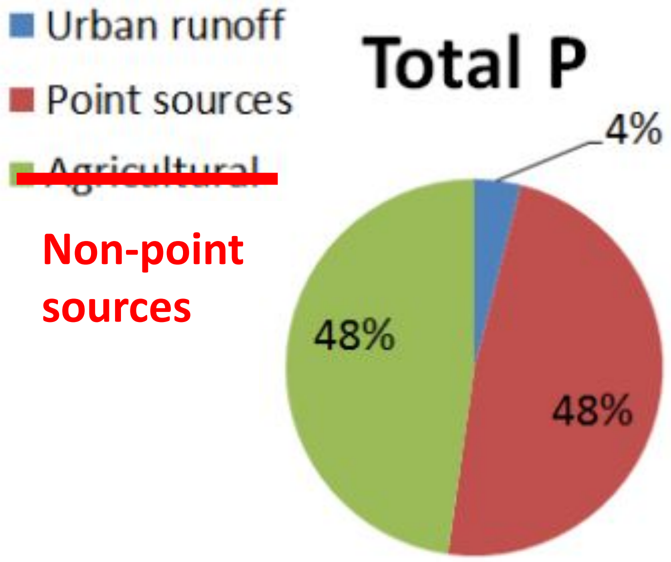
Example of non-point P in Illinois

- Total P export calculated using network of USGS "super gages"
- Point source P calculated based on emissions of ~210 point source facilities

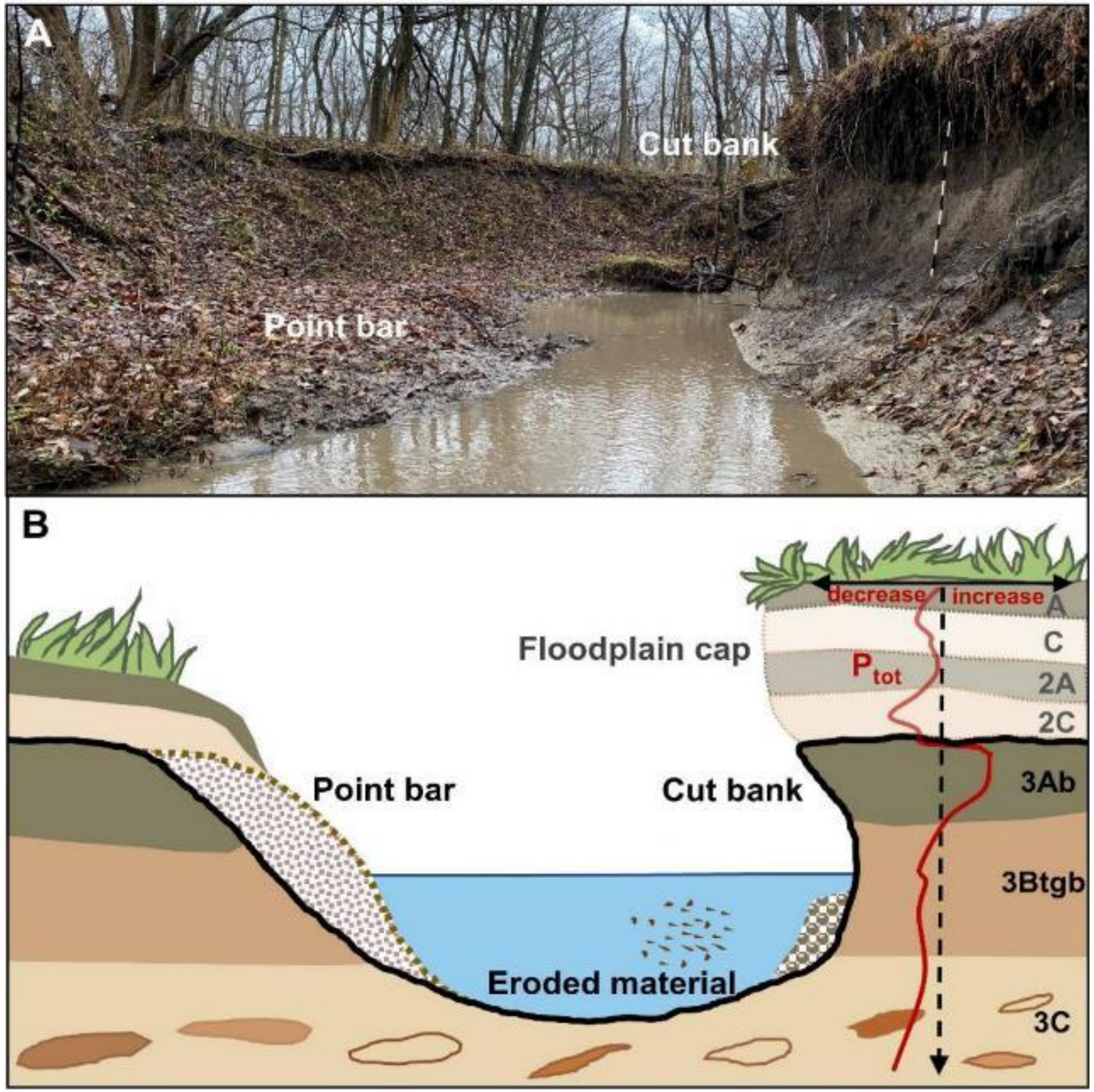
Non-point source
= total export – point source

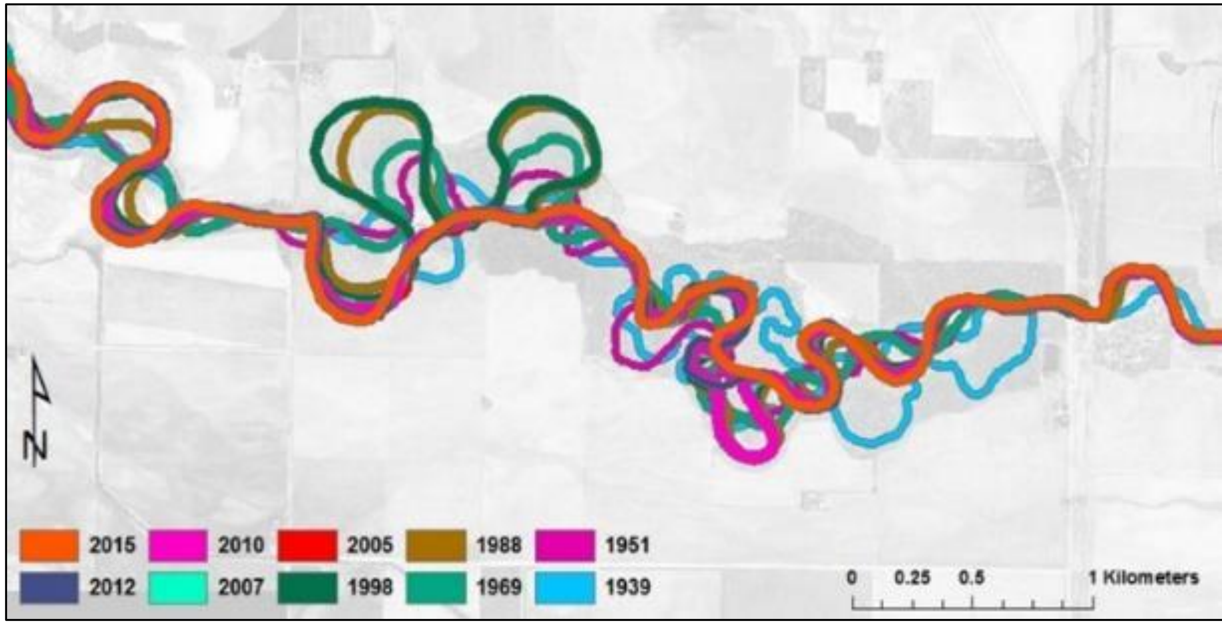
Problem: non-point sources are not further discriminated

Illinois Nutrient Loss Reduction Strategy



Streambank erosion: P transfers from land to water





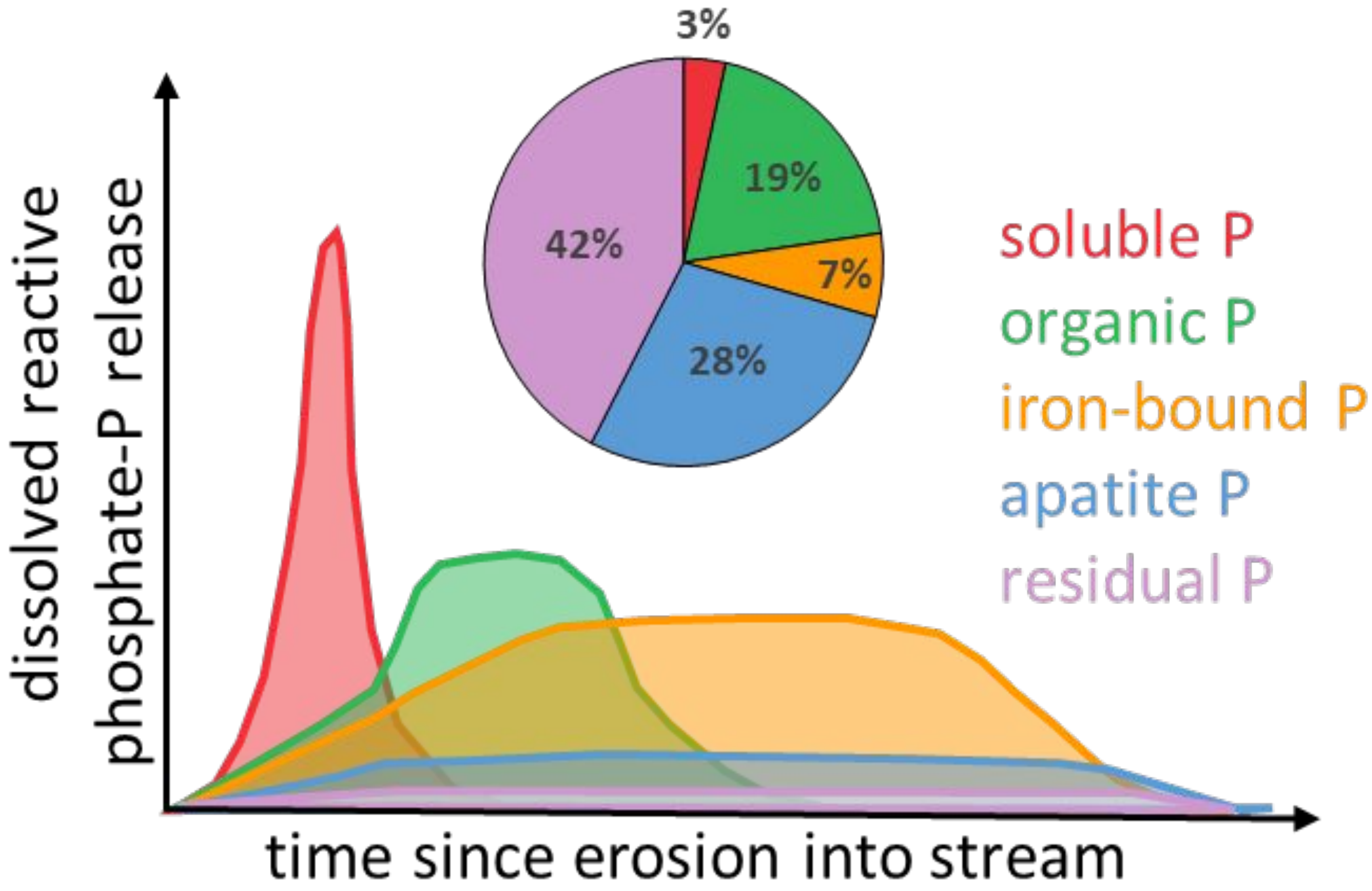
Mackinaw River (Illinois) migration from 1939-2015 identified by rectifying aerial imagery

- Meandering streams in flat topography especially prone to erosion
- Loads sediment as streambank soil
- Soils eroded into the stream contain P – most of it is native, from parent material (i.e., *not* fertilizer)

Zhou, Li & Margenot. *Geoderma* 2022. 424: 115989

The form of P is overlooked but entails lag times

Example of P forms in streambank soils and theoretical release rates

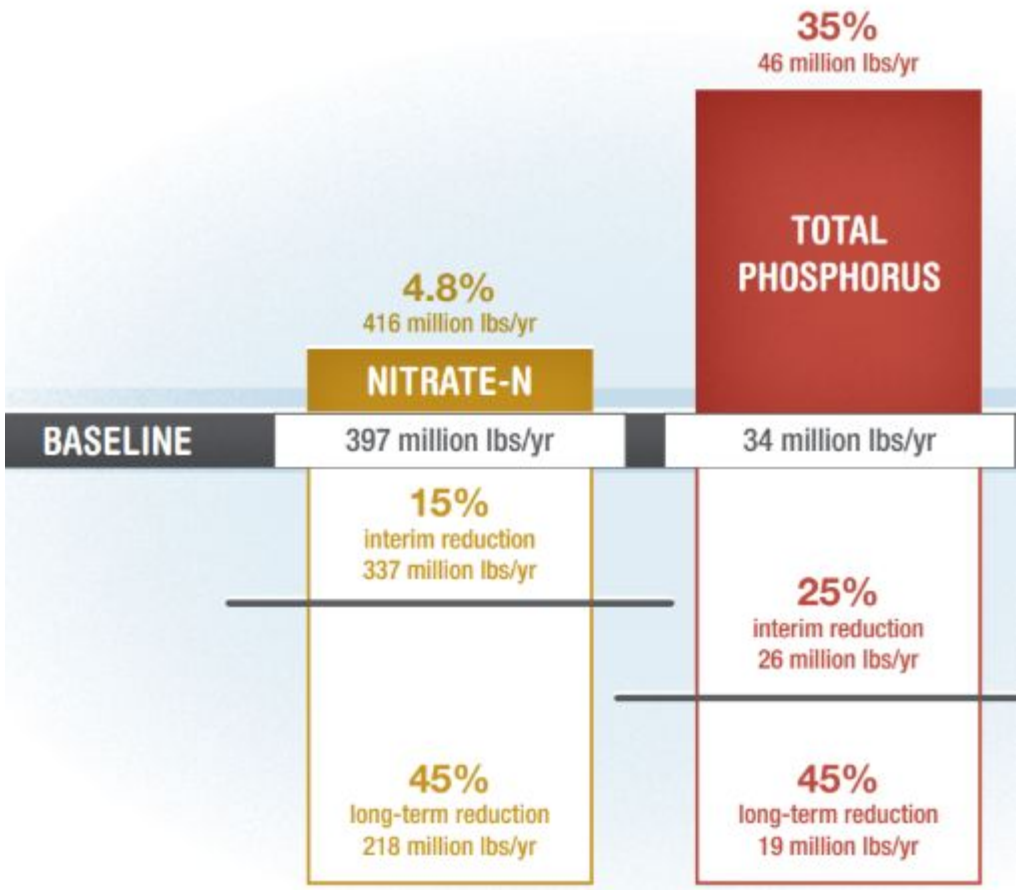


- Only a small % of the P eroded with streambanks will dissolve upon entering the stream
- Majority of P will likely take years to decades to centuries to dissolve
- Allows for DRP losses even with iterative sediment deposition-remobilization down the channel

Zhou, S. & Margenot, A.J. 2023, *CATENA* 231: 107305

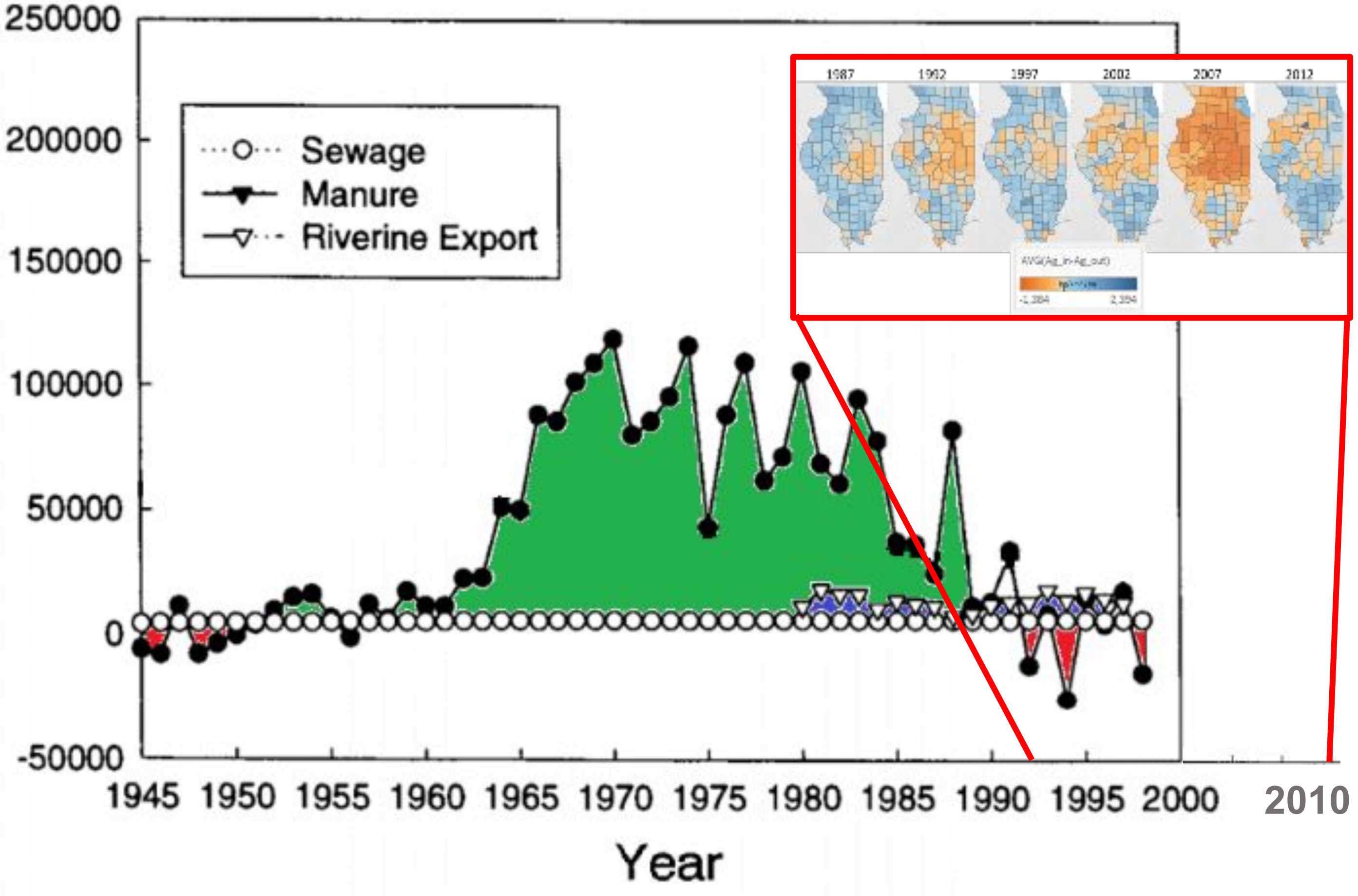
Lag times matter: discrepancies of losses vs balances

- +35% P loss as a 5-year average (2017-2021) for Illinois



2023 Illinois NLRS Biennial Report Summary

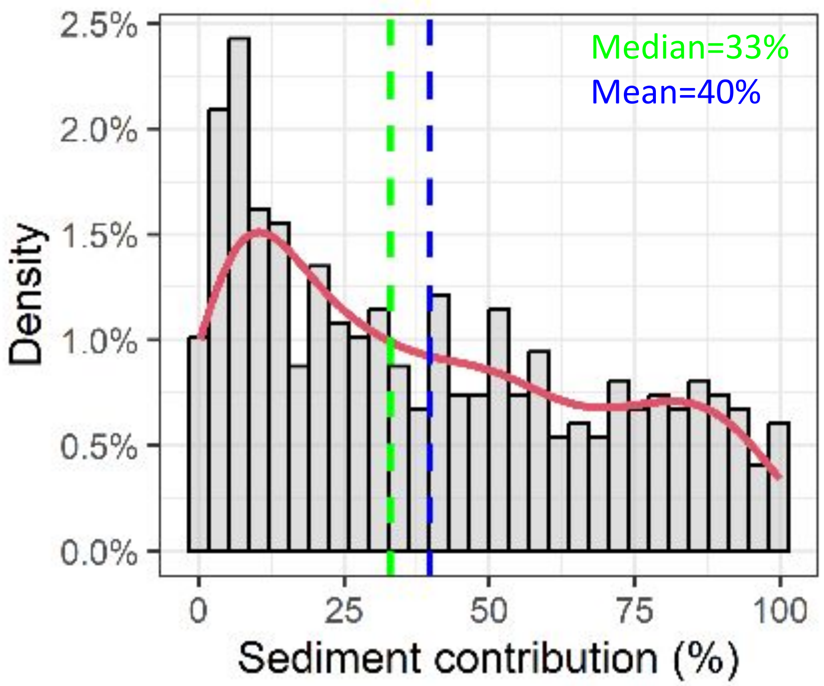
- Yet: Illinois has had a net negative P balance since 1990

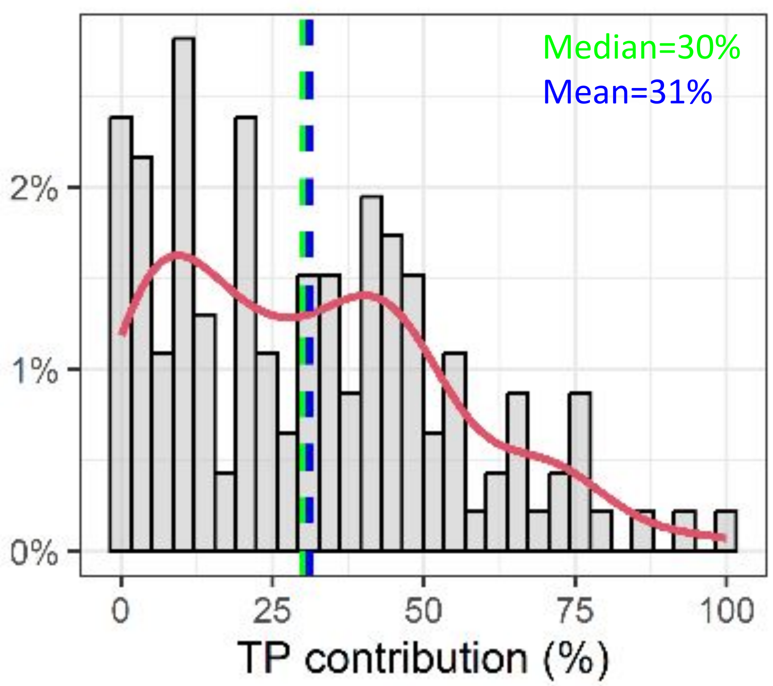


Adapted from David & Gentry 2000 *JEQ* 29:494

Streambank erosion contributes substantial riverine sediment and TP export

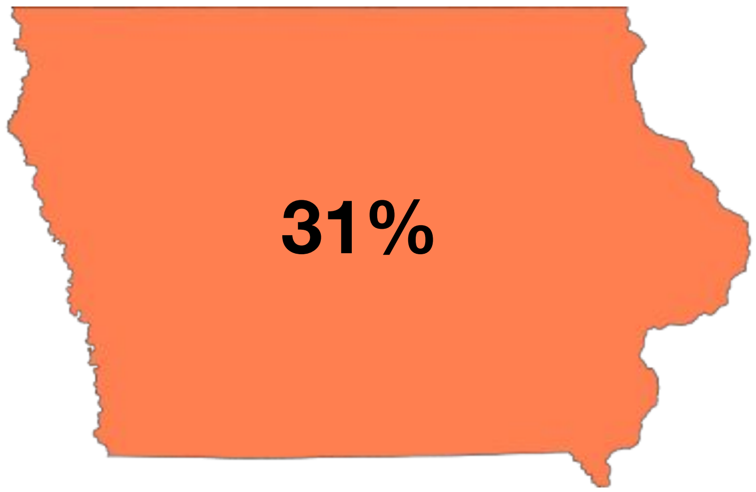
- Globally, bank erosion accounts for an average of
  - 40% riverine suspended sediment export
  - 31% riverine TP export





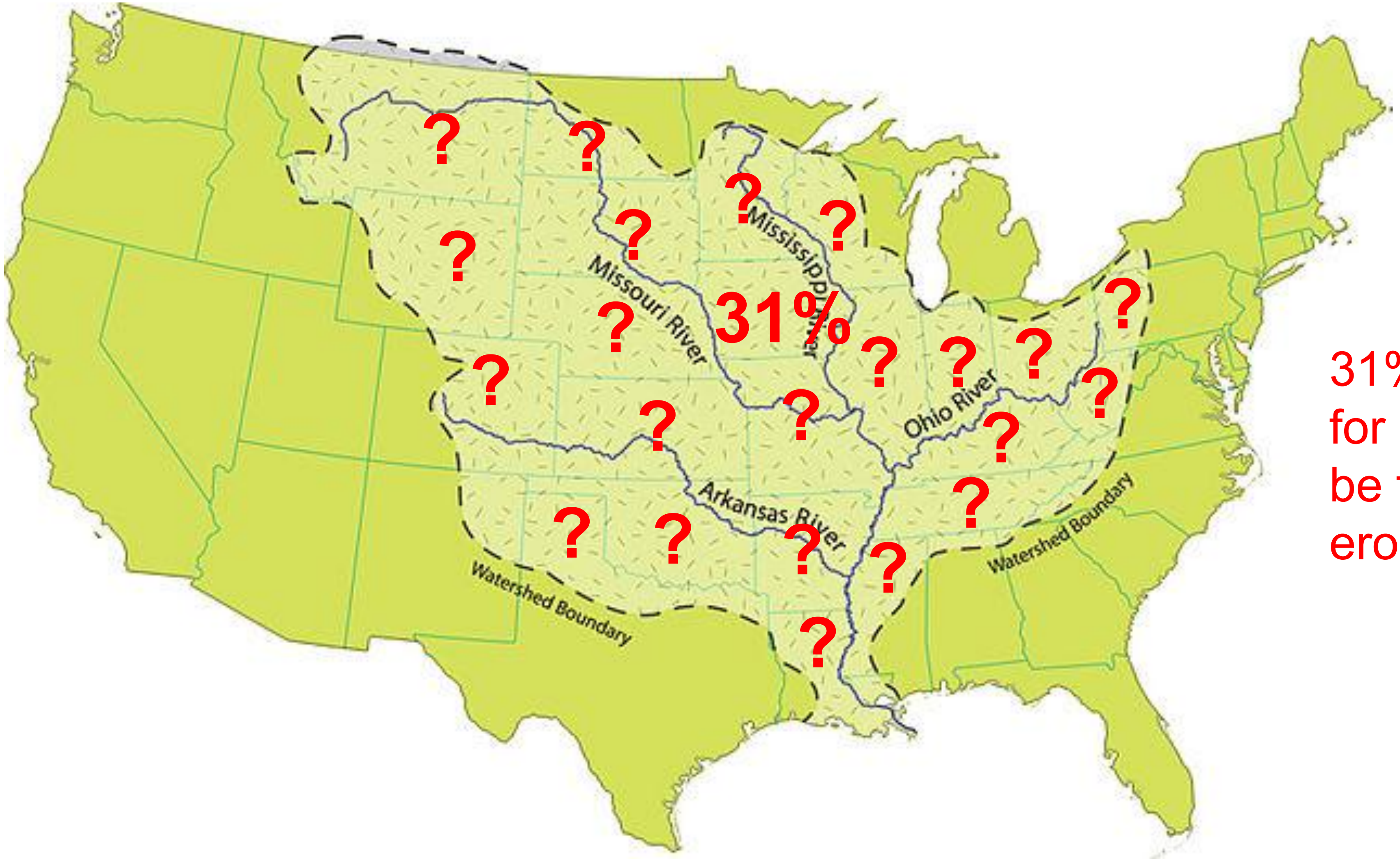
Zhou, S. & Margenot, A.J. In review

- Exactly the 31% conservative estimate for Iowa



Schilling et al. 2022. *JSWC* 77 (2) 103

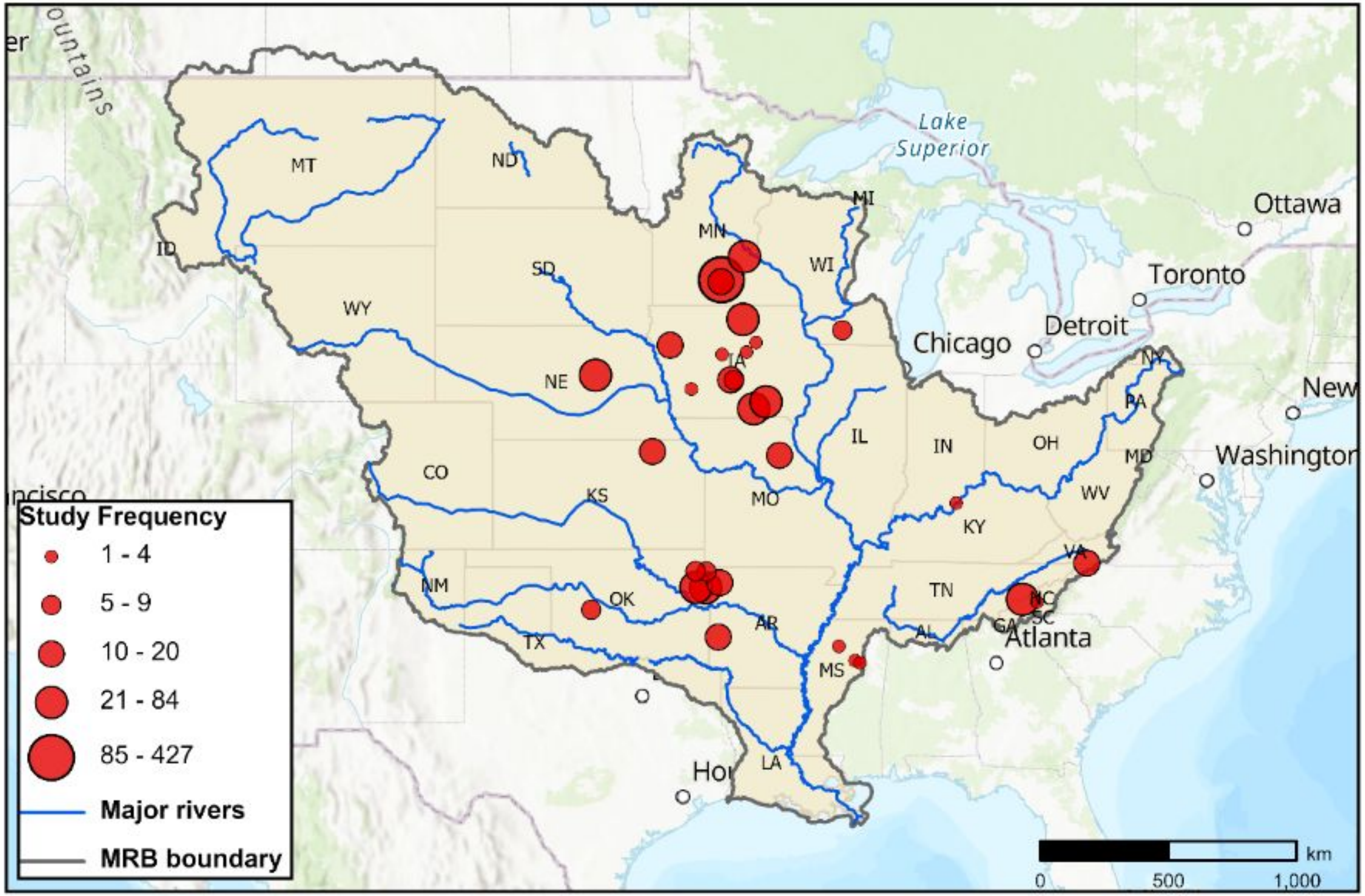
How much does streambank erosion contribute to P export at *the state scale*?



31% of total P loads for **Iowa** estimated to be from streambank erosion

What about streambank erosion in the MRB?

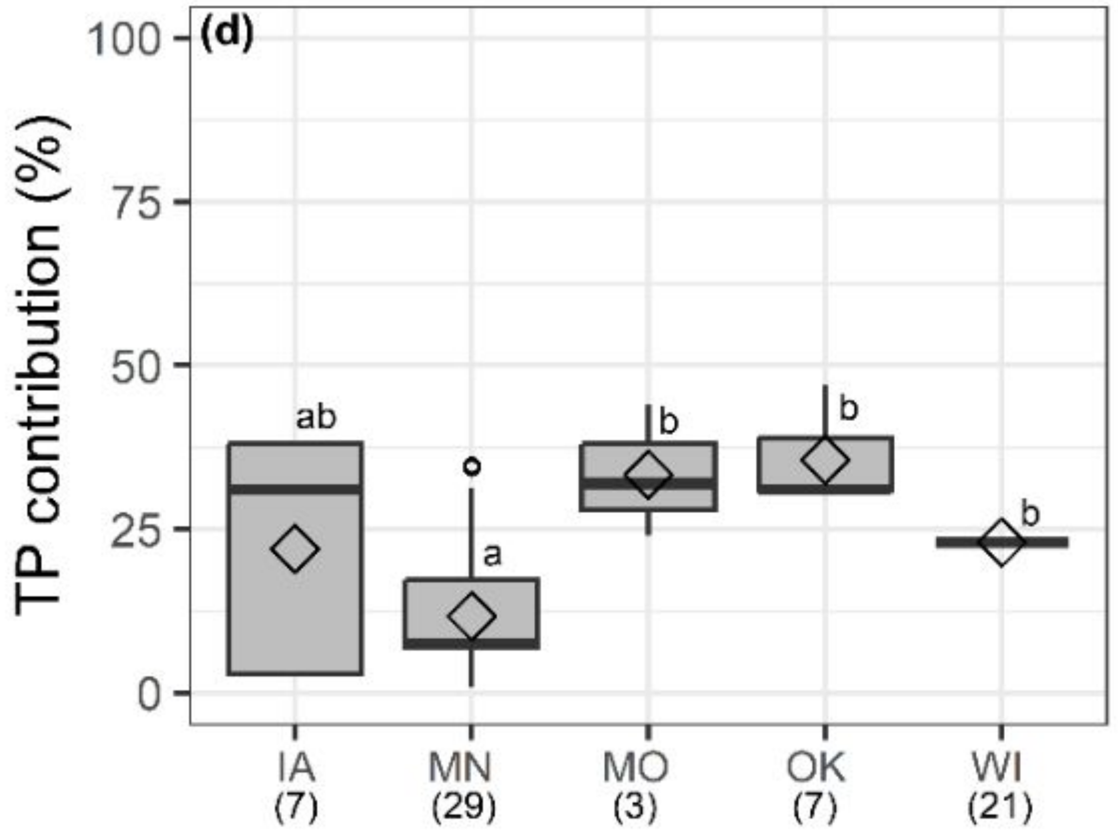
51 peer-reviewed studies, largely <15 years duration



Streambank erosion P is appreciable in the MRB

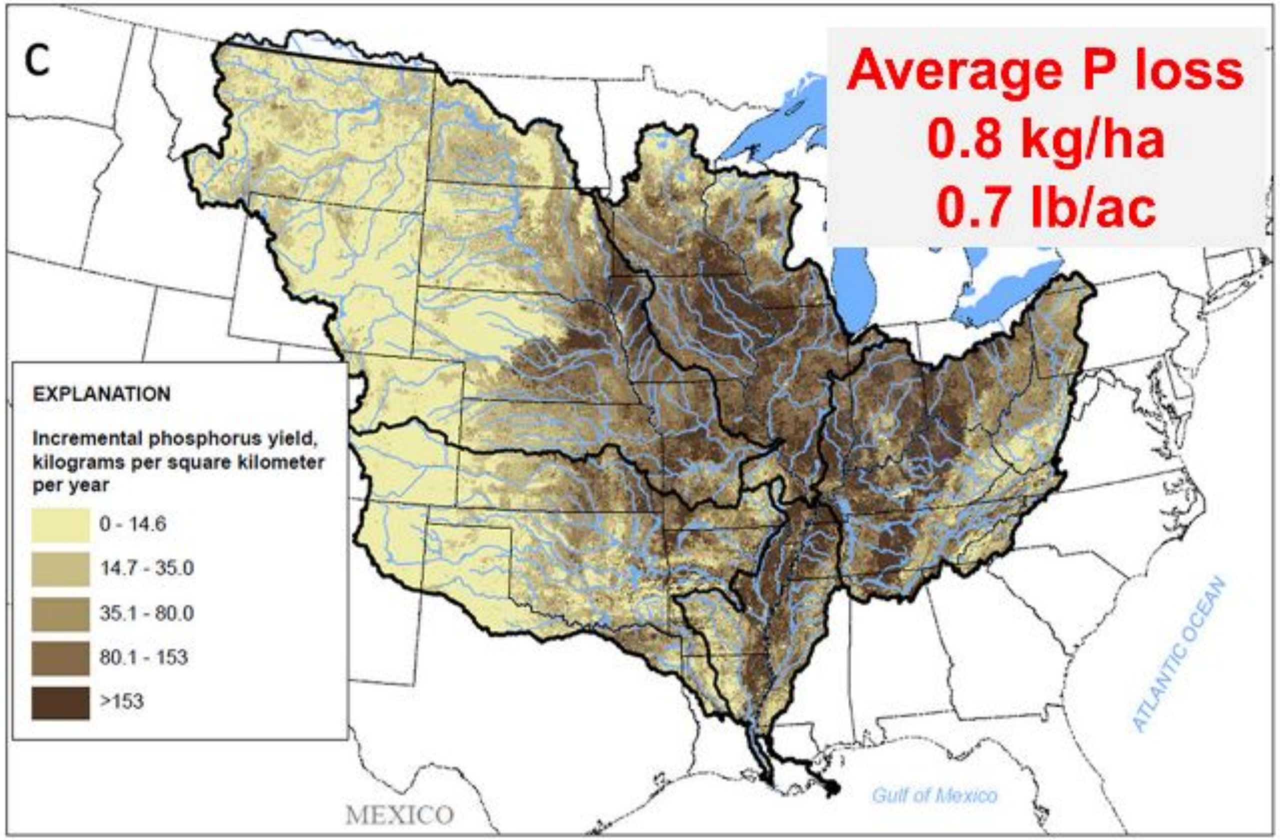
P loaded by bank erosion is 1-100% of watershed P export in magnitude

- 31% of watershed P on average
- 0.7 kg P/ha on average



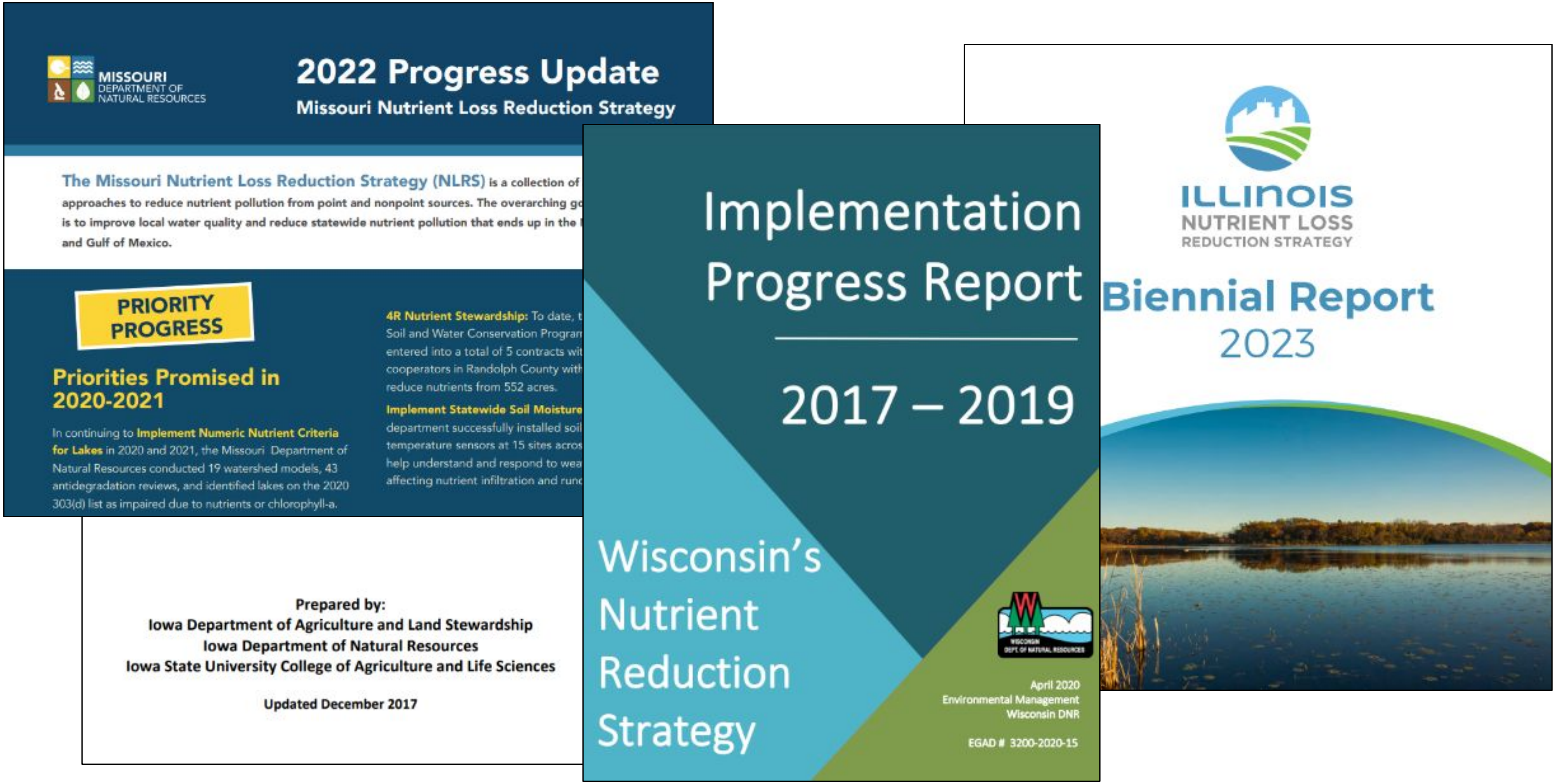
Margenot, A.J., Zhou, S., Wickramarathne, N. In review.

Average TP loads via bank erosion (0.7 kg/ha) align <u>in magnitude</u> with the *average* non-point loss in the MRB



Review of state nutrient loss reduction strategies (NLRS)

Review of *updates to* state NLRS



Most states in the MRB do not account for streambank erosion in original nutrient loss reduction strategies (NLRS)

State	Streambank erosion recognized as a nonpoint P source?	Description from the strategy	Measures taken to reduce P load from streambank erosion	Reference
Illinois	Yes	• Addressed under "urban nonpoint sources". • approximately 40% of NPS P loads are estimated to be derived from overland erosion, dissolved reactive P losses, and streambank erosion. • Severely eroding streambanks estimated to contribute approximately up to 30%–50% of total sediment entering surface waters in IL.	• The Illinois Streambank Stabilization and Restoration Program funds low-cost stabilization of eroding streambanks. • In 2004–2012, 93 km of eroding streambanks was stabilized, reducing loads by an estimated 25.9 Mg P.	(IEPA, 2015)
Iowa	Yes	• Streambank erosion is a relatively high proportion of P loading to Iowa streams. • Accurately accounting for streambank P sources is challenging due to limited methods for measuring beyond a local scale.	• Riparian buffers and streambank stabilization proposed.	(IDALS, 2012)
Minnesota	Yes	• Streambank erosion is described as a major source of P to surface waters and target for reduction effort. • approximately 20% of the total NPS P load from Minnesota to Mississippi River basin likely comes from streambank erosion. • Streambank erosion is the main source of P under wet conditions, but it is not significant during dry periods.	• Implementing watershed BMPs that promotes the retention or detention of surface runoff and tile drainage will aid in managing downstream flows, consequently reducing streambank erosion.	(MPCA, 2014)
Missouri	Yes	• Streambank erosion in Missouri is a significant part of P loading to surface waters.	• Missouri Soil and Water Conservation Program funds streambank stabilization and grazing management to reduce streambank erosion.	(MDNR, 20114)
Wisconsin	Yes	• Streambank erosion is a major nutrient loading source to lakes, streams, and groundwater.	• 0.3 m tillage setback from the top of a channel should be maintained to maintain streambank integrity. • Streambank and shoreline protection are identified as BMPs to manage sediment and nutrient loading and recommended to use.	(WDNR & UWE, 2013)
Arkansas	No			(NRD, 2014)
Indiana	No			(ISDA, 2008)
Kentucky	No			(KDW, 2014)
Louisiana	No			(CPRA et al., 2014)
Mississippi	No			(MDEQ, 2012)
Ohio	No			(OEWA & OEPA, 2014)
Tennessee	No			(TDEC, 2015)

Margenot et al 2023 *JEQ*. 52(6): 1063

Not distinguishing streambank erosion within non-point source will incorrectly count it as an agricultural source

American Society of Agronomy | Crop Science Society of America | Soil Science Society of America

DOI: 10.1002/jeq2.20514

Journal of Environmental Quality

PERSPECTIVE

Streambank erosion and phosphorus loading to surface waters: Knowns, unknowns, and implications for nutrient loss reduction research and policy

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Contributions of streambank erosion to surface water P loads are…

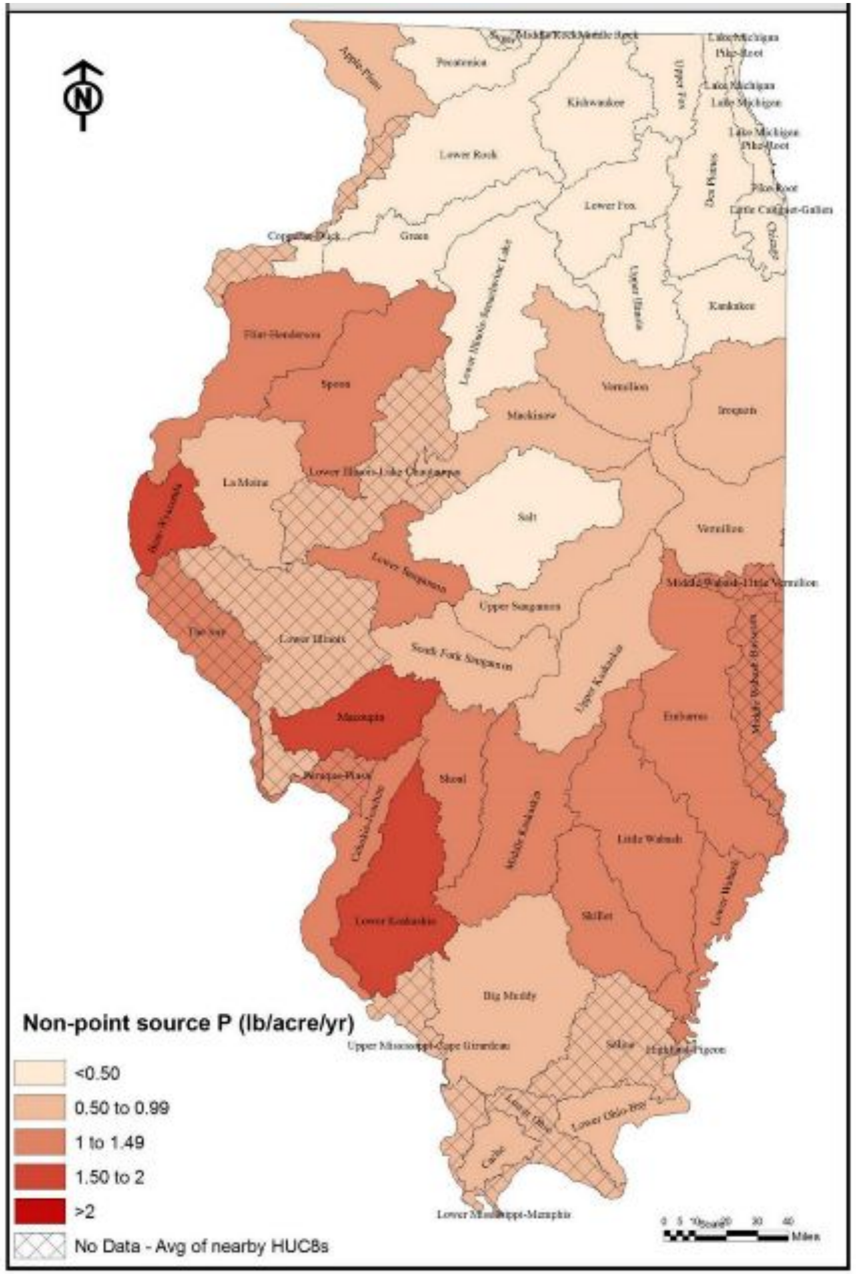
1. …relatively unquantified
2. …typically unaccounted for in many nutrient loading assessments/policies

Consequences:

1. Agricultural P contributions are overestimated
2. Potentially manageable nonpoint source of P is missed in strategies to reduce loads
3. Resources may be misdirected
4. Expectations may not be realistic

(Gulf HTF target: 2035, or 2135?)

Why are streambank erosion P contributions absent?



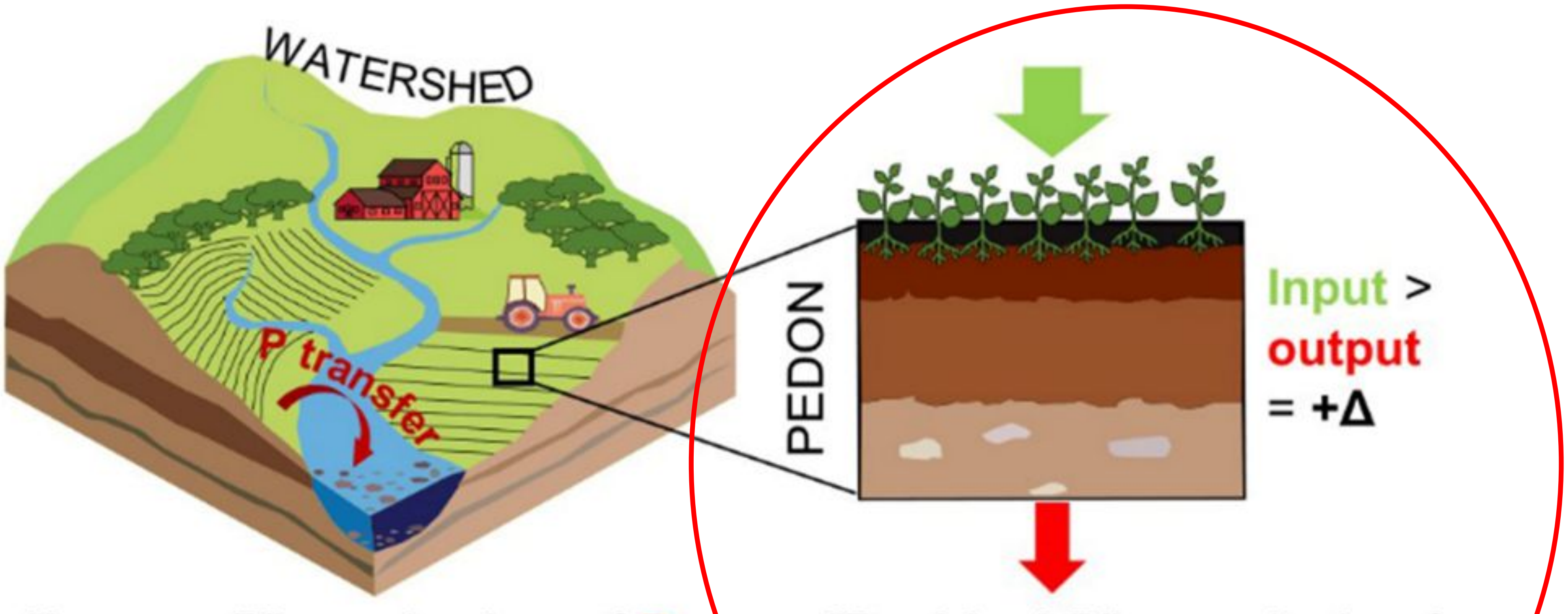
Data is difficult to produce

- Non-point (agricultural) P losses account for approximately half of Illinois riverine P export (**48%**)
- The Illinois Nutrient Loss Reduction Strategy does not currently include streambank erosion estimates in its source partitioning

- 2015 NLRS Biennial assessment:

  "The phosphorus assessment did not include stream bed and bank erosion as sources of phosphorus, nor did we include losses of phosphorus from ephemeral gulley erosion. Data are not currently available to estimate these potential sources of phosphorus throughout Illinois."

Both legacy P and residual P matter for source apportionment

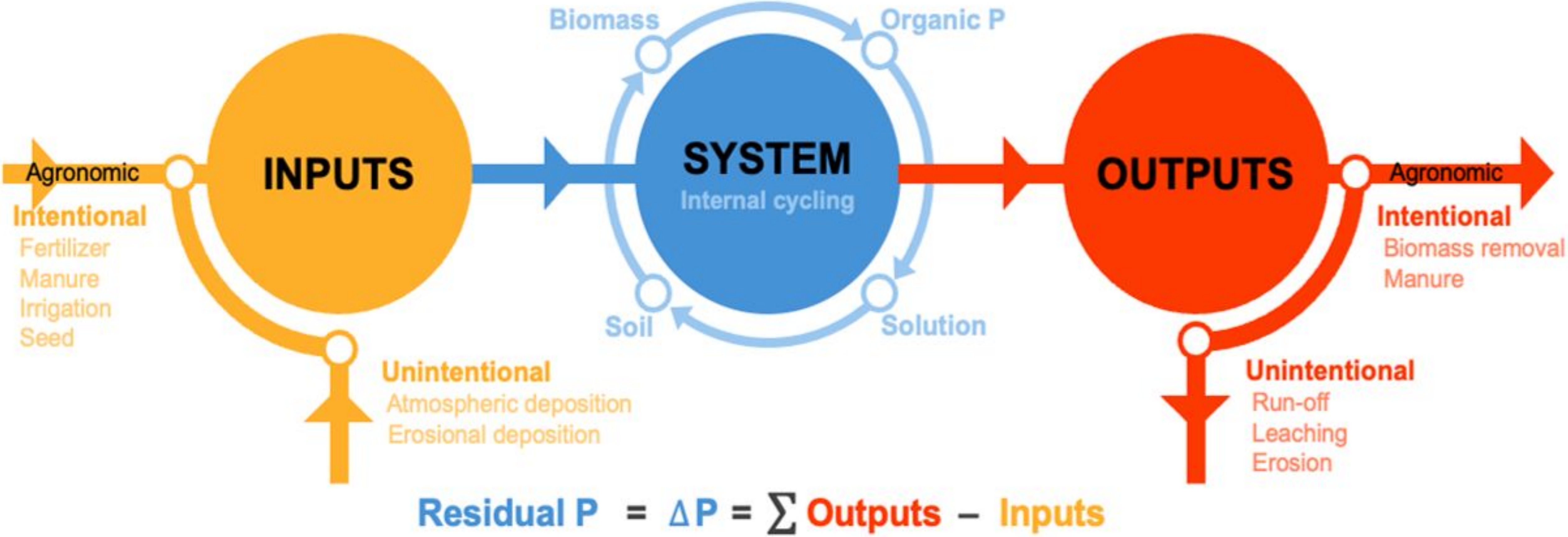


"**Legacy P**": *mechanism of* ***P transfer*** *across watershed and impact on water quality*

"**Residual P**": *magnitude of fertilizer P remains in soil, i.e.,* **+Δ** *=* ***P input*** *-* ***P output***

Zhou & Margenot 2023 *Environmental Science & Technology* 57:21535

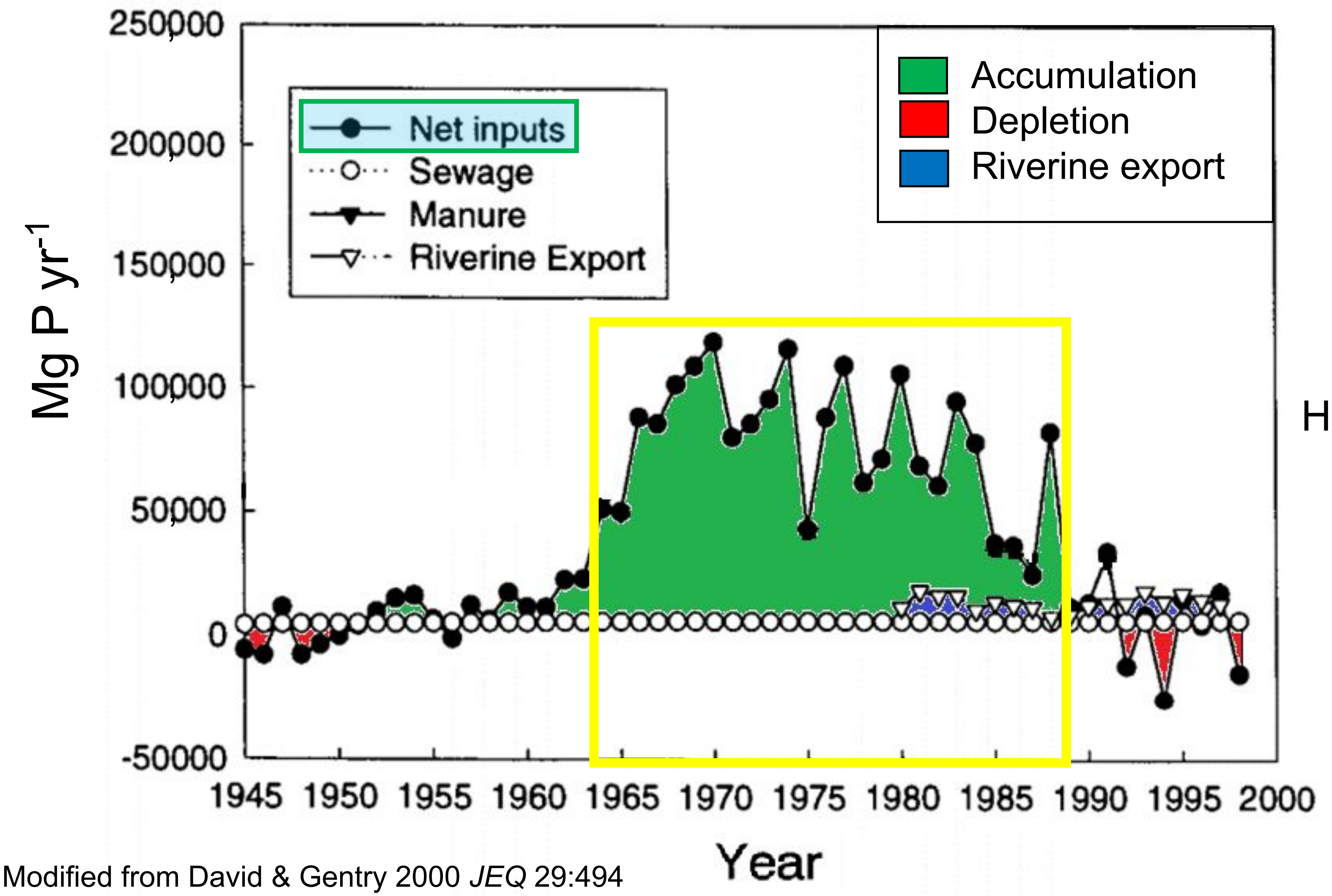
Mass balances: a critical tool to *estimate* residual P



Zhou & Margenot 2023 *Environmental Science & Technology* 57(51): 21535
Margenot et al. 2024 *Global Change Biology*. 30(6): e17376

How much soil residual or legacy P is there in Illinois?

Large positive balance encumbered in ≈ 25 year period



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

≈ +4.85 billion lbs P positive balance

203 lb P/ac across Illinois croplands

How much of a *relative* enrichment?

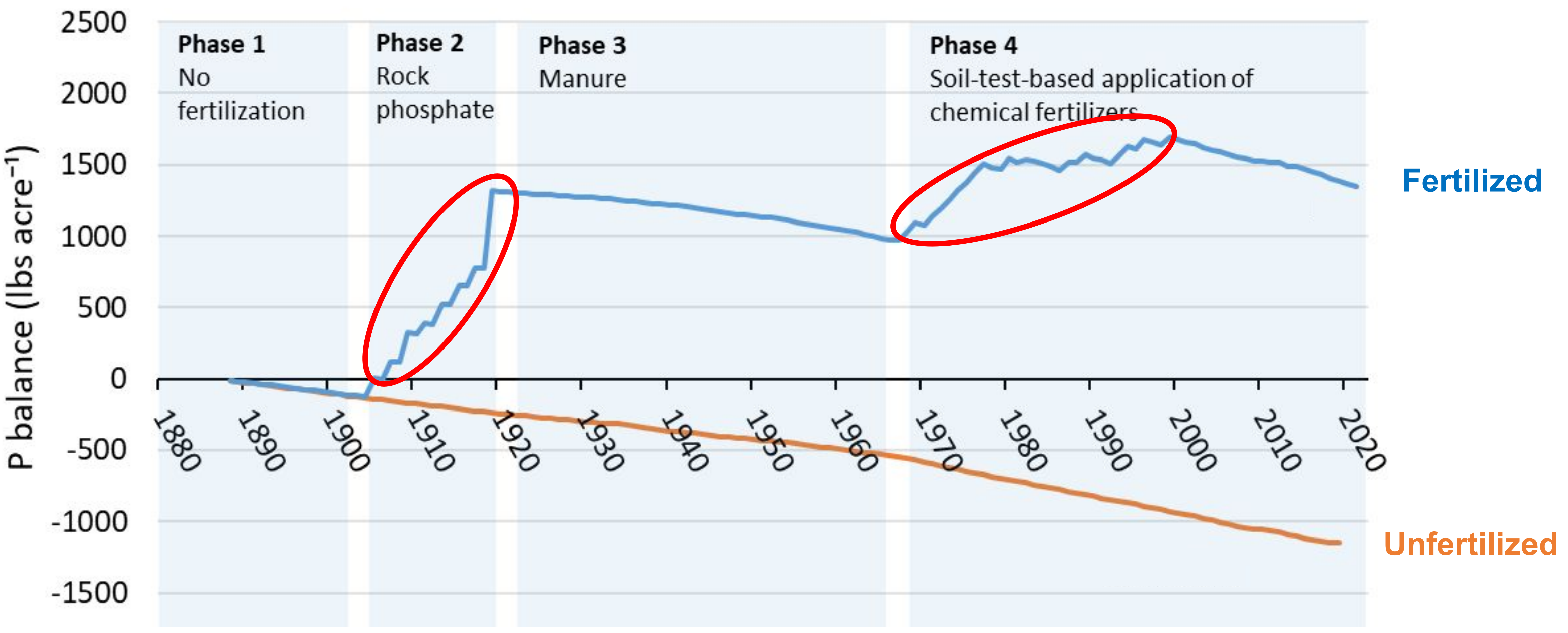
21 million ha of cropland
Assume 4500 lb P/ac to 3' depth
=94.5 billion lbs P

≈ +5% of soil P stocks

What’s the form of residual P? (can we use it via drawdown?)

Soil residual P: past inputs can stick around for a long time

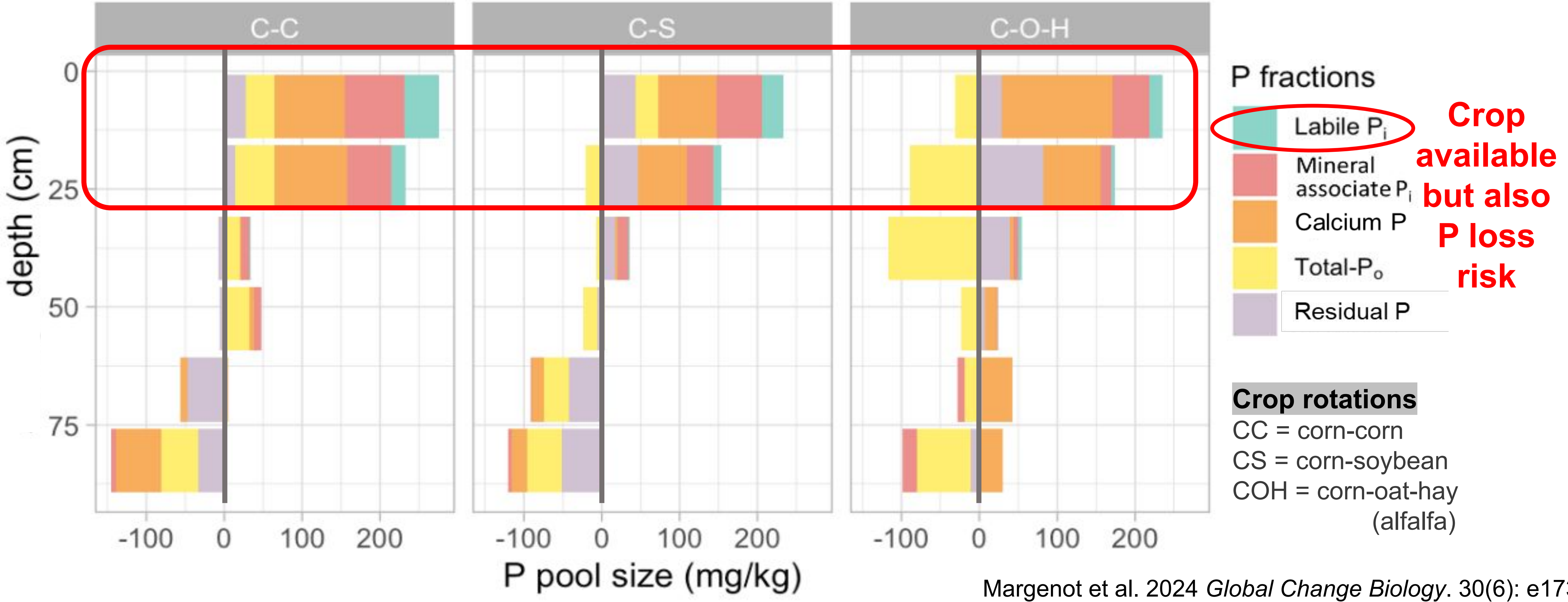
- Morrow Plots: established 1876
- Unique opportunity to evaluate the form of legacy / residual soil P
- Large positive P balances accrued over 145 years – majority within 15 years



Margenot, Xu, Kasmerchak. In prep.

Soil residual P does not build up in a specific form or pool

1. Surplus P found mostly in surface depths (0-12”)
2. Surplus P exists in highly diverse forms – **transformed** from fertilizer inputs
3. <10% of positive P balance ends up as labile forms susceptible to DRP loss



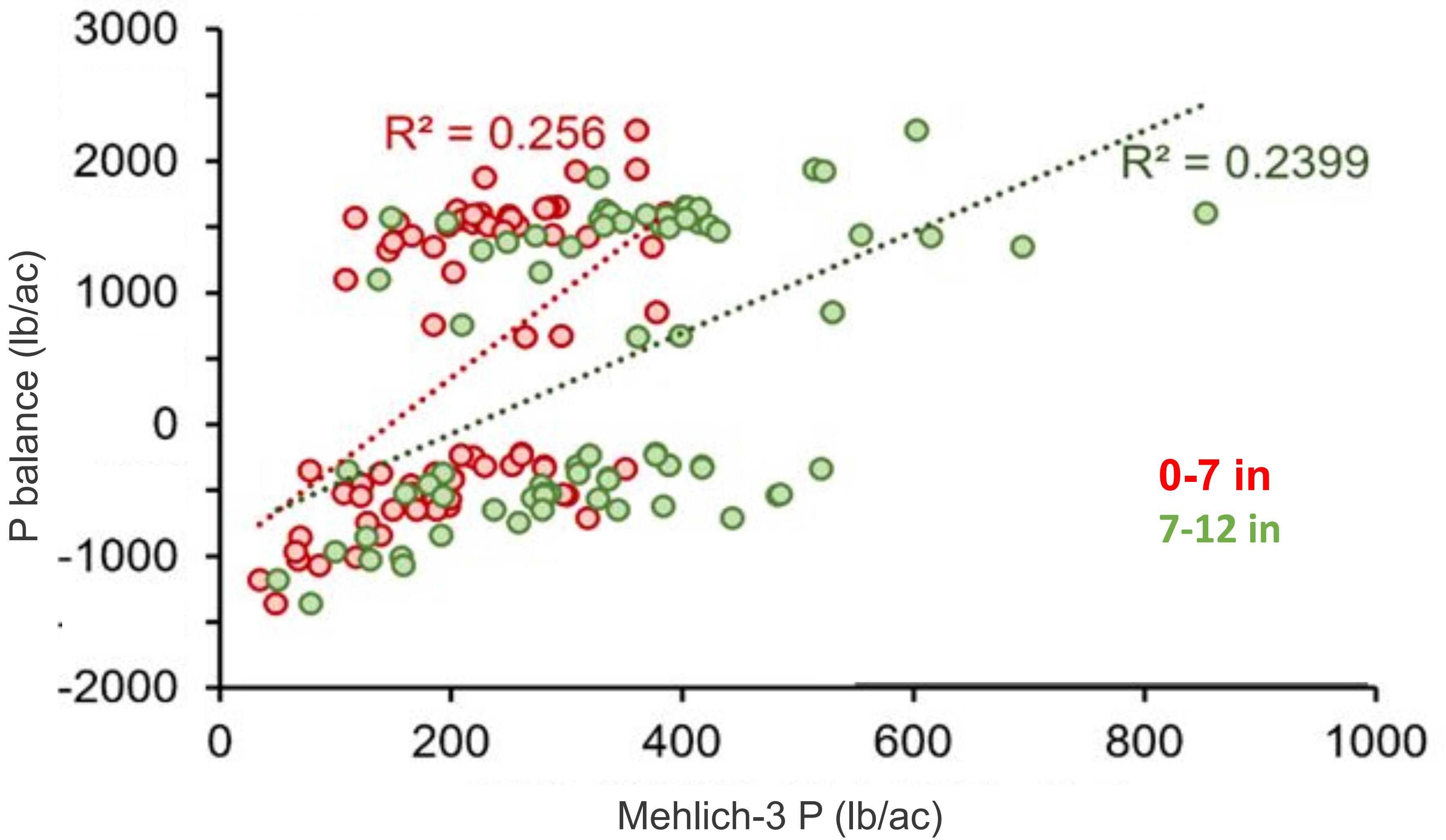
Crop rotations

CC = corn-corn
CS = corn-soybean
COH = corn-oat-hay (alfalfa)

Margenot et al. 2024 *Global Change Biology*. 30(6): e1737

Hard to track residual P using soil test P

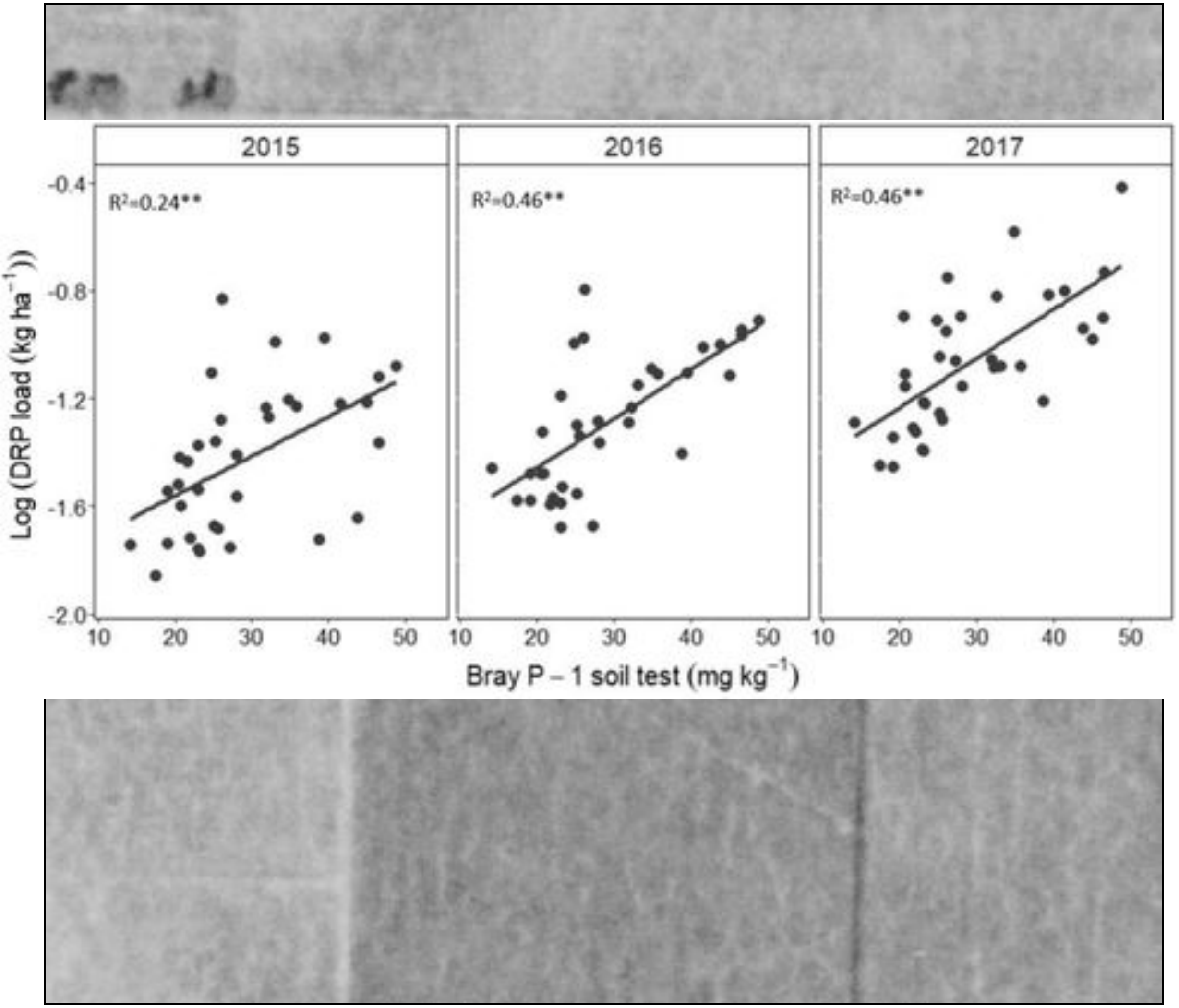
- Not quantitative, but qualitative : more residual/legacy P ~ higher soil test P
- Basis for drawdown that is profitable

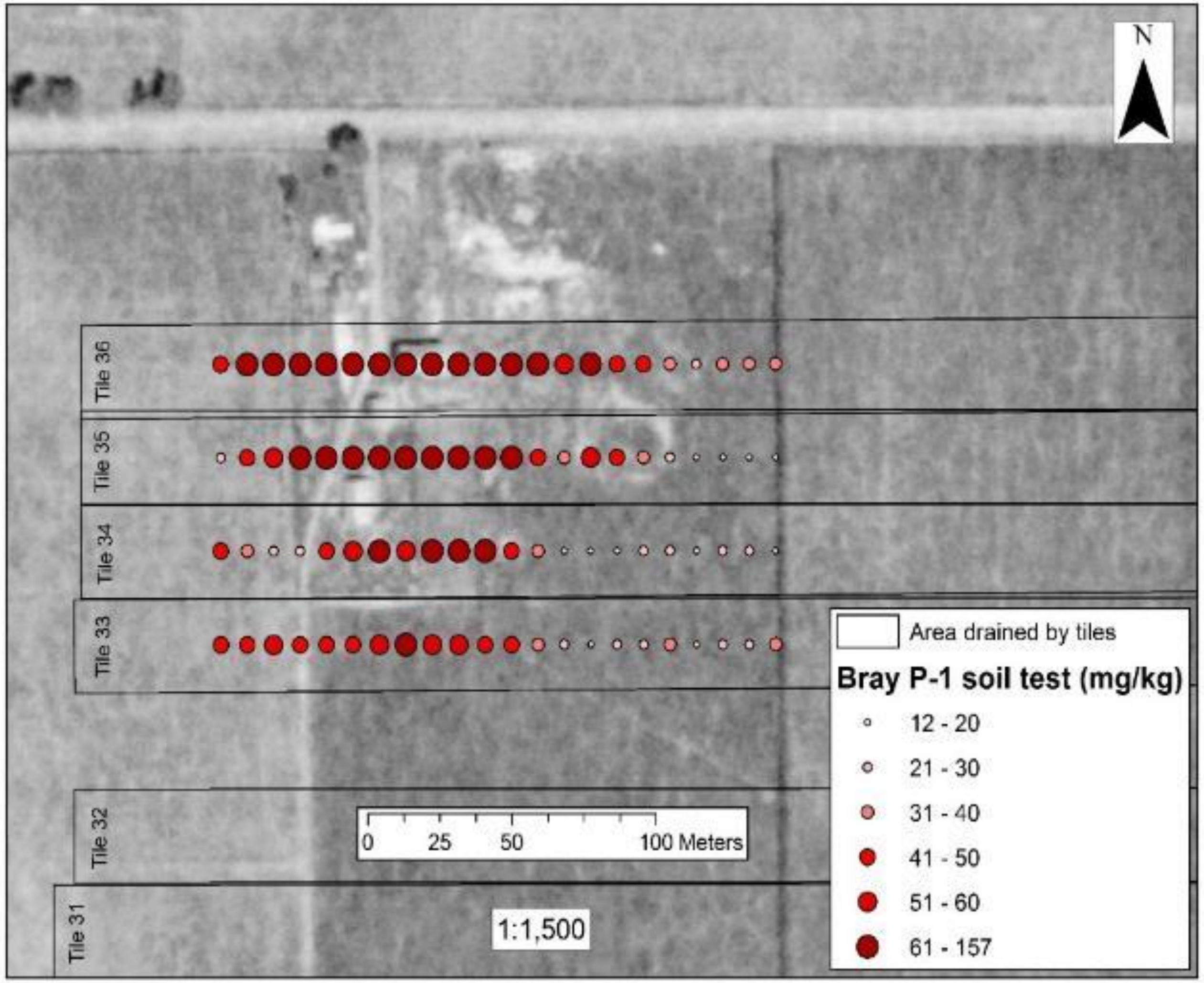


Margenot et al. In review.

Residual P in soils contribute to non-point P losses

Soil P hotspots from former barns *partly* explains (24-46%) higher tile DRP loads

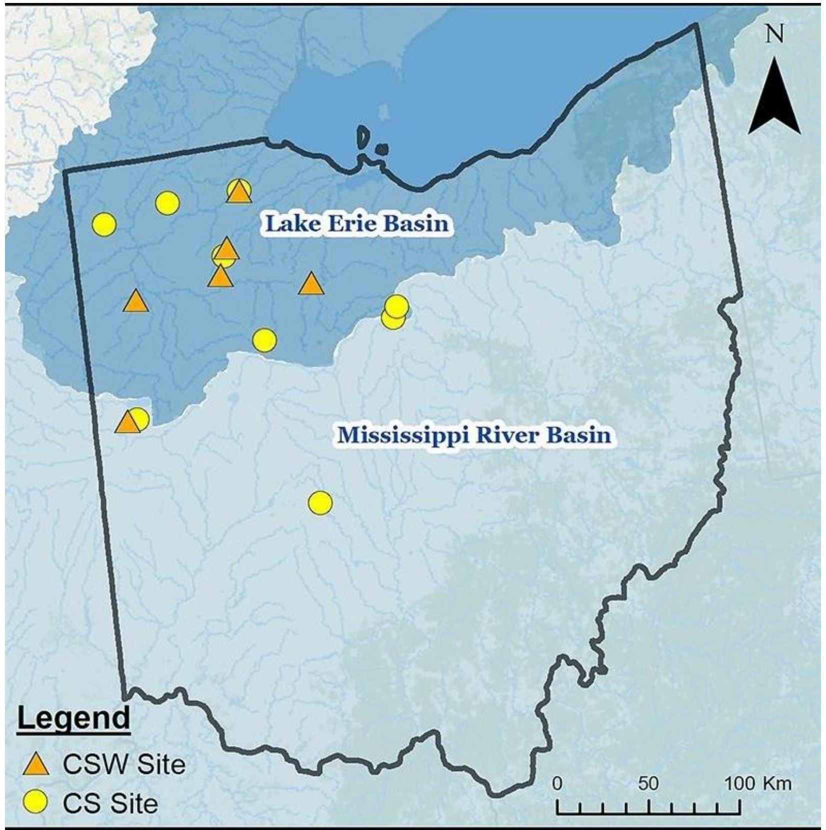


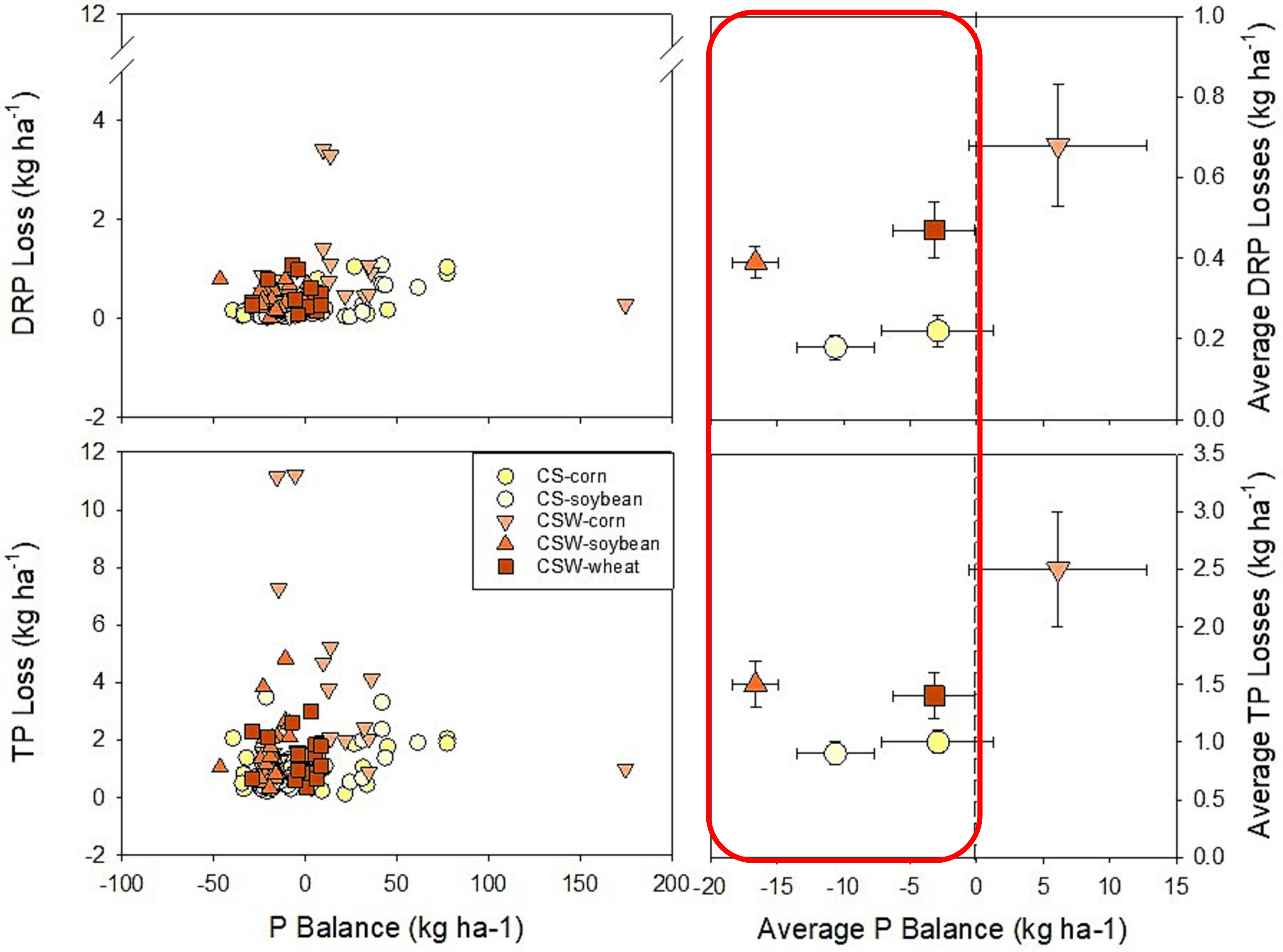


Andino et al 2020 *JEQ* 49(5):1273

Legacy P may explain losses even under negative P balances

- Despite annual P deficits (-5 to -9 kg/ha), losses of P as DRP and were still measured
- In part due to elevated soil test P concentrations





Hanrahan, B., King, K. et al. 2023. *J Great Lakes Res*. 102232

Summary

- Non-point P losses have not well-quantified contributions from non-contemporary, non-fertilizer sources
- Streambank erosion is a key and overlooked non-point source of P
- MRB state nutrient loss reduction plans **do not account for streambank erosion**
- Legacy P in soils ('residual P') and in channels have different origins, but can mute current and future water P load response to BMPs
- Only a fraction of P accumulated in soils is susceptible to DRP loss

- **Legacy P-driven lags in water quality recovery** must be quantified in order to…
    1. Accurately account for direct agricultural P contributions within non-point sector
    2. Potentially manage a nonpoint source of P
    3. Efficient use of NLRS resources
    4. Establish realistic expectations of nutrient loss reduction magnitudes and timeframes

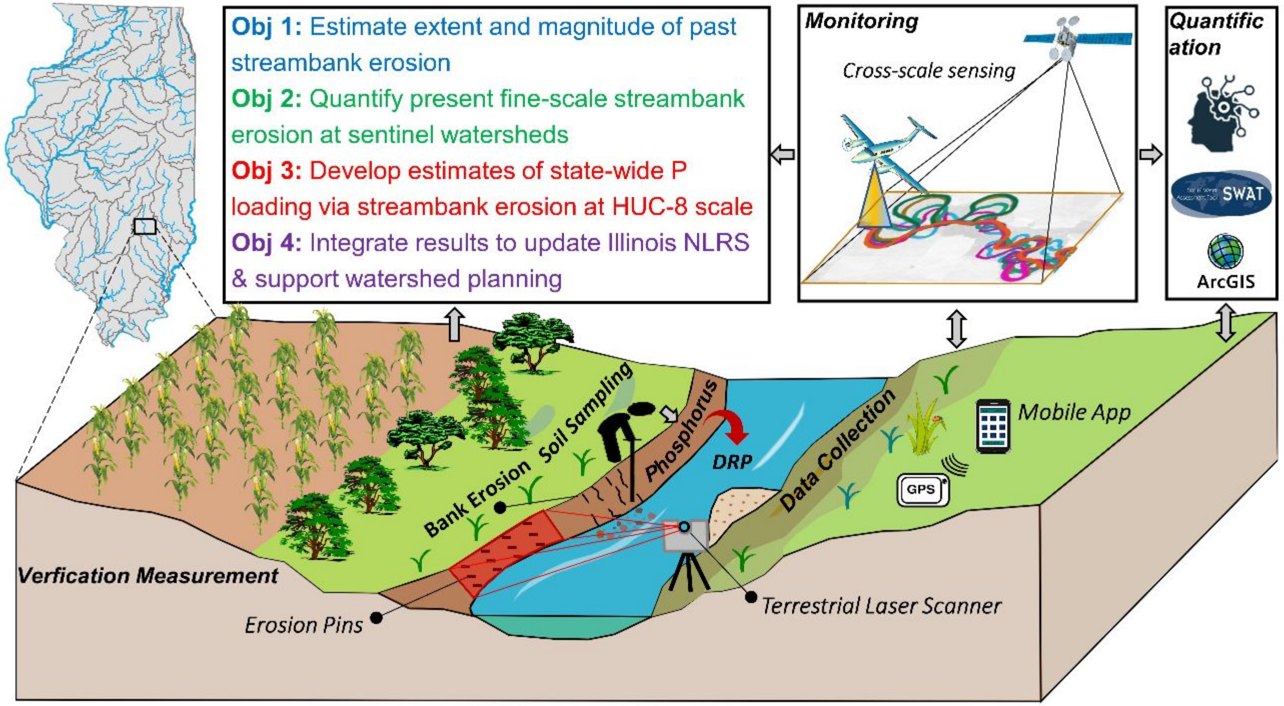
ILLINOIS NREC
Award #2021-4-360731-469
Award #2023-4-360731-642

National Science Foundation
Award #2230180

USB UNITED SOYBEAN BOARD
Award #2311-212-0101

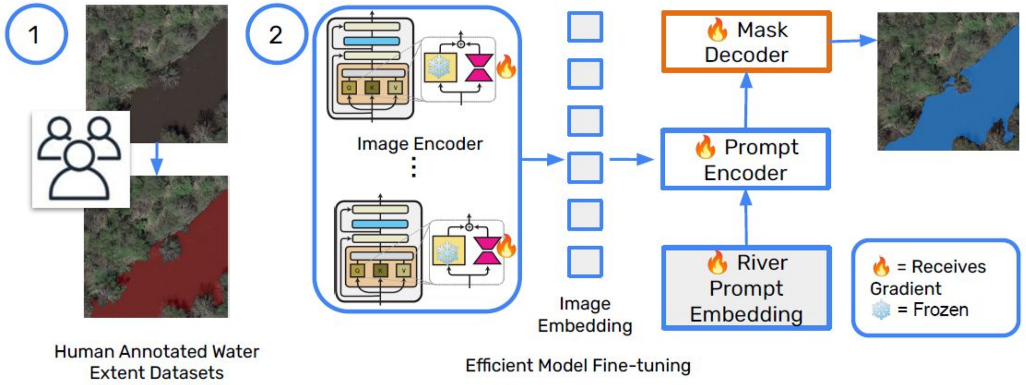
Fill the gap on streambank erosion contributions to P loading for the state of Illinois

Erosion pins

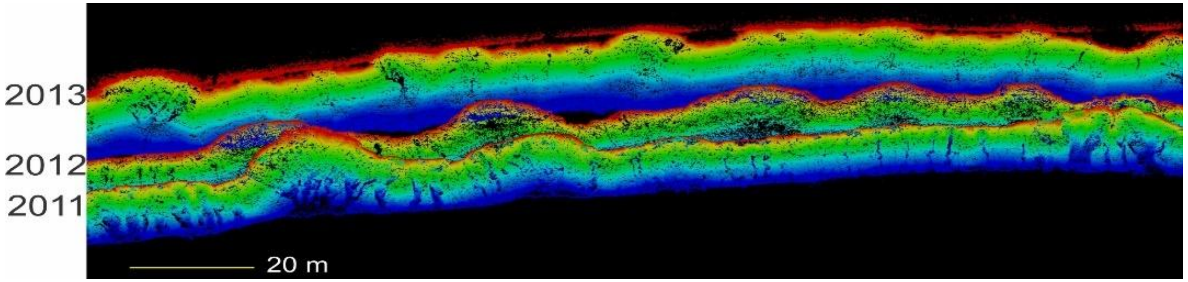


Terrestrial laser scanner

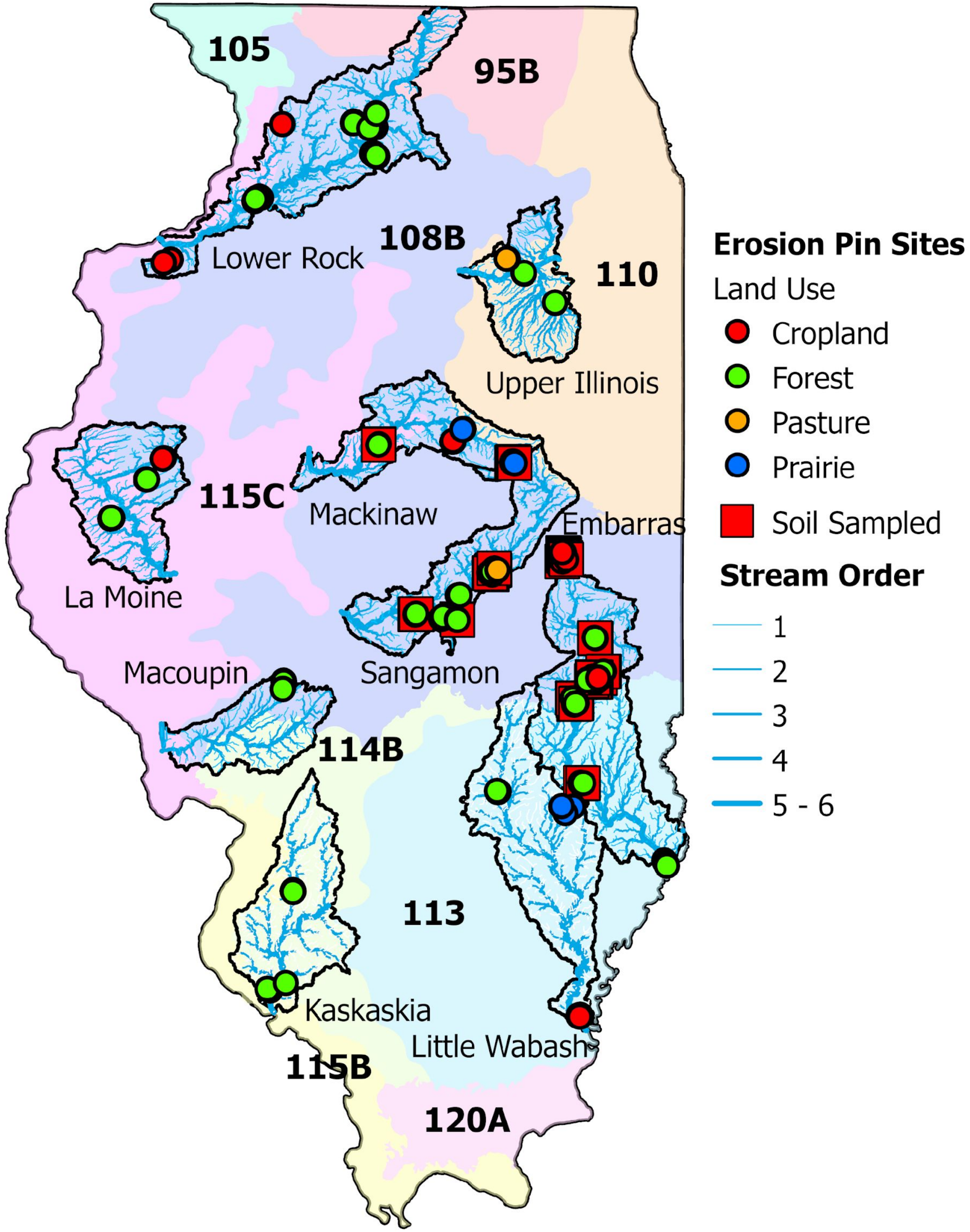
Scaling bank assessments with historical aerial imagery using AI



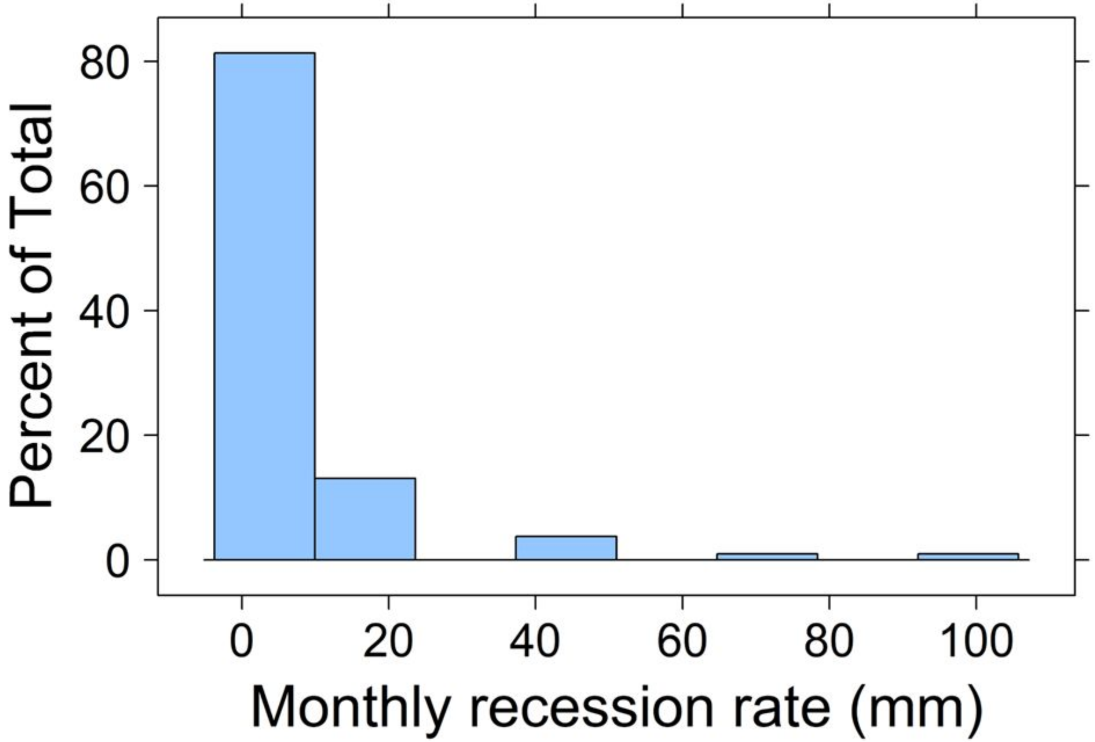
LiDAR scans to reveal channel bank migration



Any streams in the area for which we could measure bank erosion?



- ~30% of total P loads from a watershed may (on average) be from streambank erosion
- This is largely native soil P, not fertilizer



What and Why

What is involved:

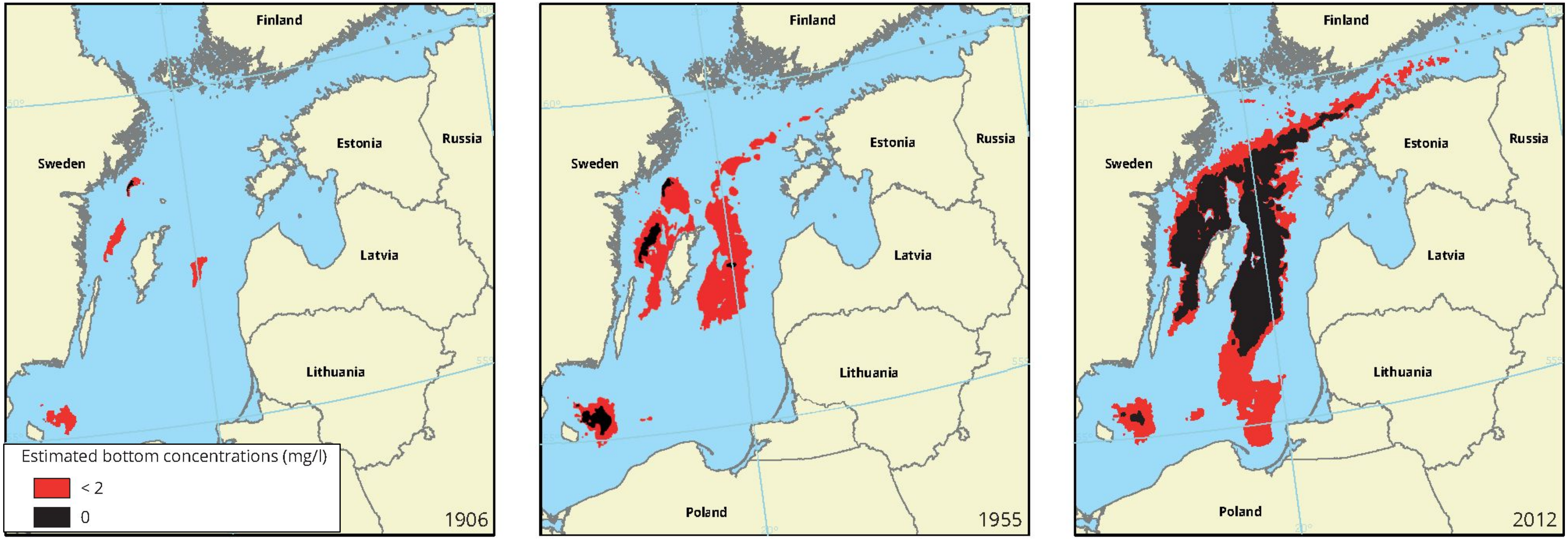
1. 24" rebar insert horizontally into the streambank in 3x3 grid
2. Site visits every 6 months for at least 2 years (4x)
3. Streambank soils sampled for P analyses
   - Data shared with landowner

Outcomes (why)

1. Provide field data to demonstrate the % of P losses <u>not</u> from agriculture but *currently being counted as agriculture*
2. Update the Illinois NLRS
3. Proposal to US EPA that their P reduction timelines are impossible – science suggests the timeline should be 50-100 years later from now

Lags in P loading to surface water: the Baltic case

- Since early 1900s, an estimated 60 million lbs P accumulated in the Baltic Sea basin
- Losses from streambank erosion and legacy pool contributed nearly half of P loads
- Despite point source and agricultural reductions, total P loads still high



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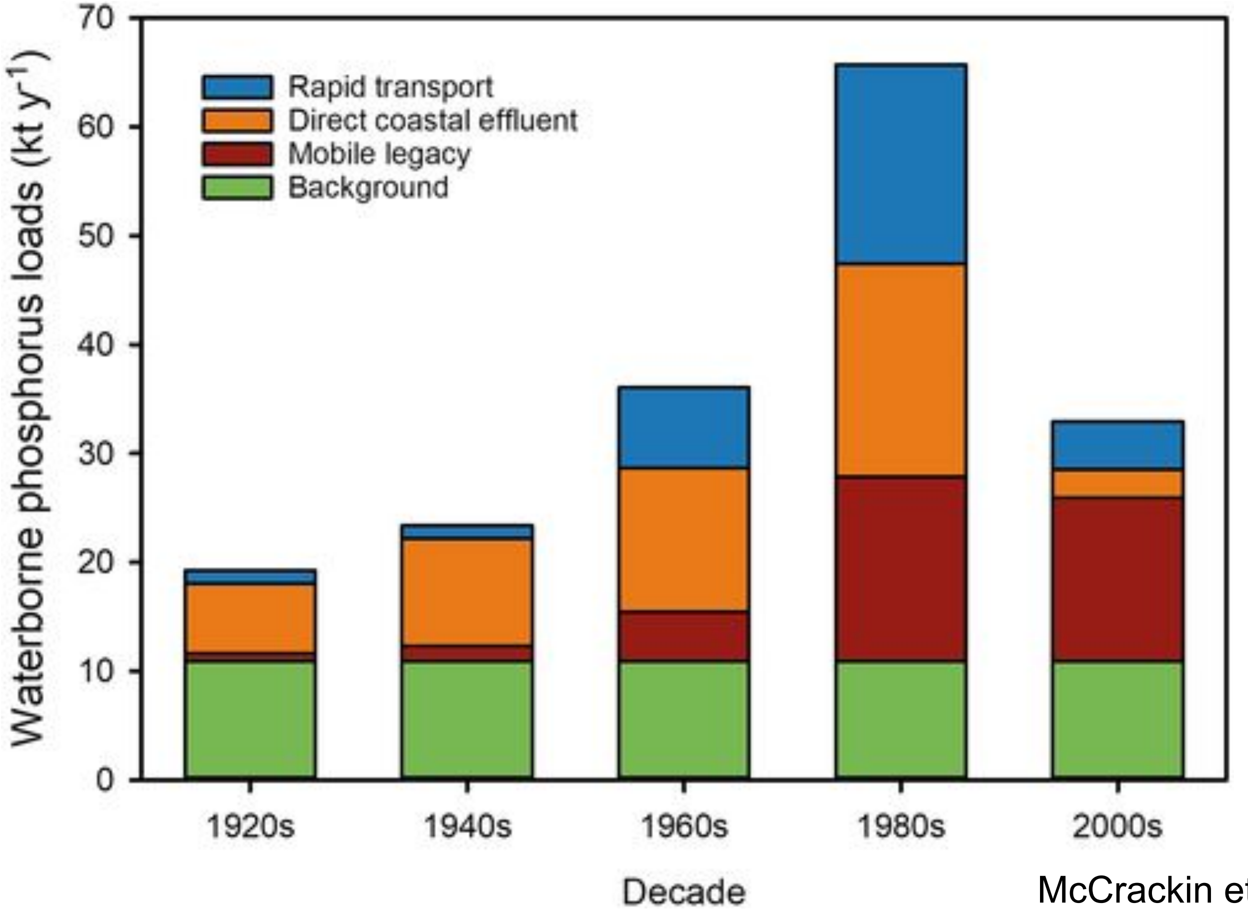
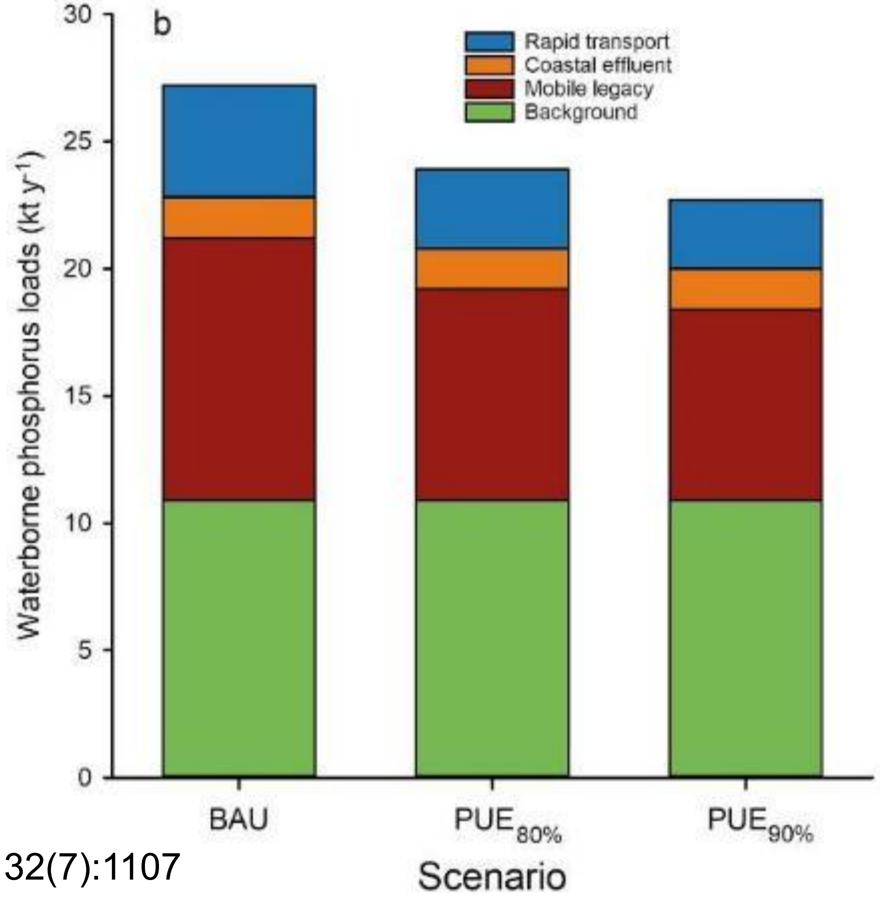
Lag of legacy P loading to surface water: the Baltic case

- **Streambank erosion** and **legacy P** key contributors to lag effect in Baltic Sea basin
- Reductions in point sources and agricultural losses alone will not stop P loading in the near-term

*Contribution of **legacy P** has increased in absolute and relative terms*



*Slower response of **legacy P** = lag in P reductions*



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