

EPA's National Nutrient Inventory

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US Environmental Protection Agency, Office of Research and Development

*CWA Cross-Program Coordination to Improve
Nutrient Management and Address Nutrient Pollution*

July 22, 2025

National Nutrient Inventory Team

Presenting Today



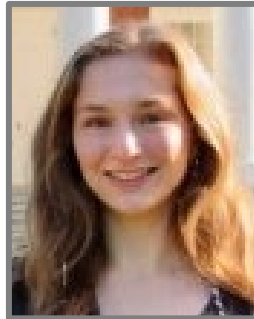
Robert Sabo



Jana Compton



Meredith Brehob



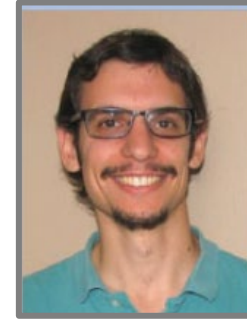
Selia Markley



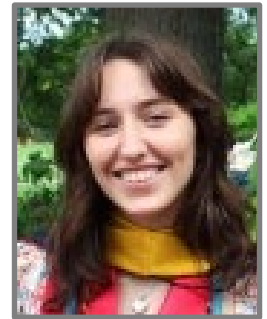
Ryan Hill



Marc Weber



Michael Pennino



Melanie Reynolds



Chris Clark



Anne Rea



Renée Brooks



Scott Alford



Qian Zhang



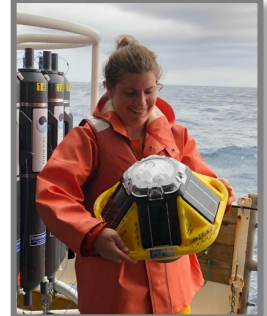
Sarah Stackpoole



Jiajia Lin



Amalia Handler



Catrina Nowakowski

Meeting Objectives

- **Clearly communicate the National Nutrient Inventory information and availability**
- **Present examples of how we connect the inventory to water quality response**
- **Answer questions you have**
- **Identify potential use cases with state CWA partners**
 - What can we do together to help with nutrient issues in your work?

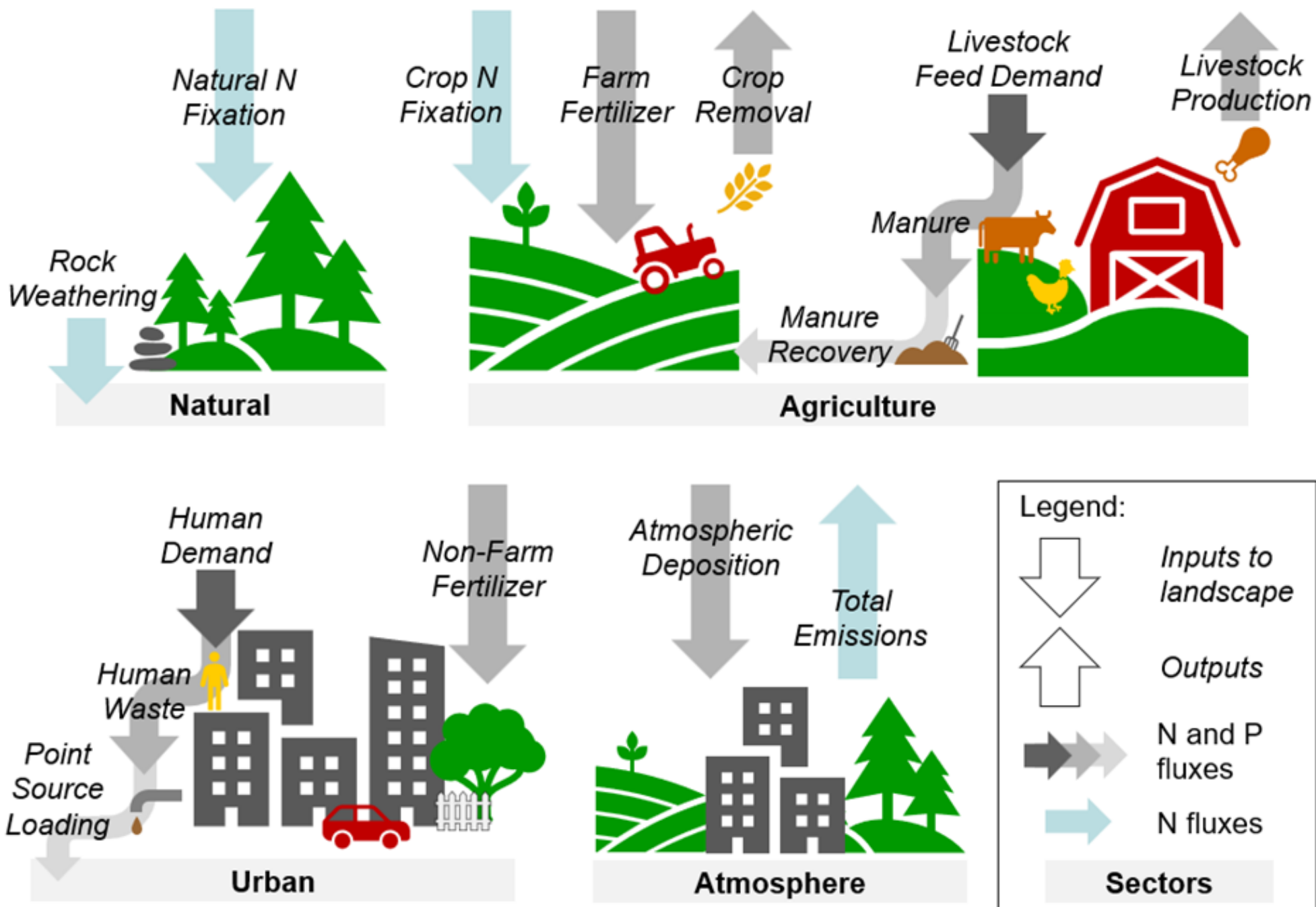
Presentation Outline

- **Introducing EPA's National Nutrient Inventory (NNI)**
 - What's in the inventory? How is it assembled?
 - Source, Extent and Trajectory of nutrient data
 - Precision and accuracy
- **Applying NNI to national, regional and local water quality**
 - River, stream and lake nutrient predictions – national
 - Drinking water nitrate risk – national and local (Oregon)
 - Big data, deep learning models
- **Making NNI actionable for decision makers**
 - Targeting nutrient reductions – strategic approaches to inform implementation
 - National Nutrient Inventory Explorer
 - Custom reports and analyses, publicly available papers and datasets
- **Answering questions and discussion of potential uses**

National Nutrient Inventory to inform air and water quality restoration efforts

What we offer:

- Integrated mass balance with management relevant metrics
- Empirical, interpretable, and predictive models of water quality
- Web-based tools, prioritization schemes, and tailored products
- Robust stakeholder engagement
- Operational flexibility to meet evolving information needs

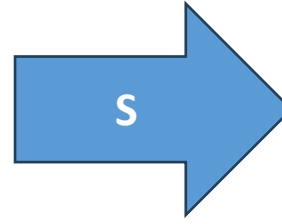


Conceptual figure of National Nutrient Inventory from Brehob et al. (in prep)

Highlight→ Inventory Data are largely **empirical** and often tied to localized data collection efforts like US Census and USDA Census of Agriculture

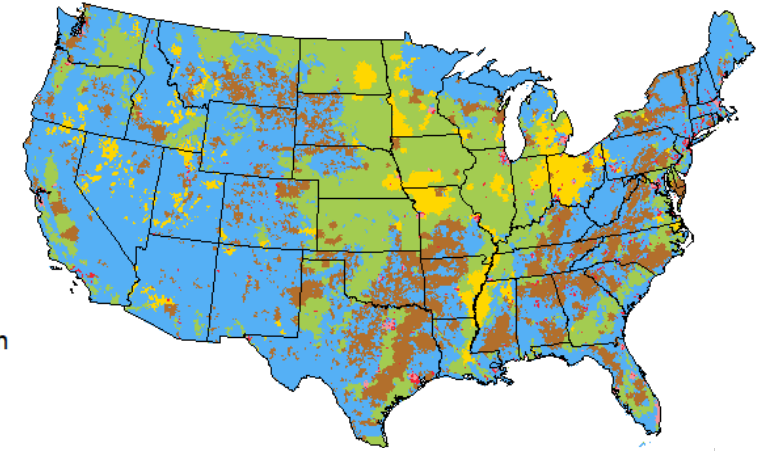
Inventories provide actionable “SET” information about nutrient pollution sources

Source: Identify largest source of nutrient inputs into a watershed or other spatially defined unit

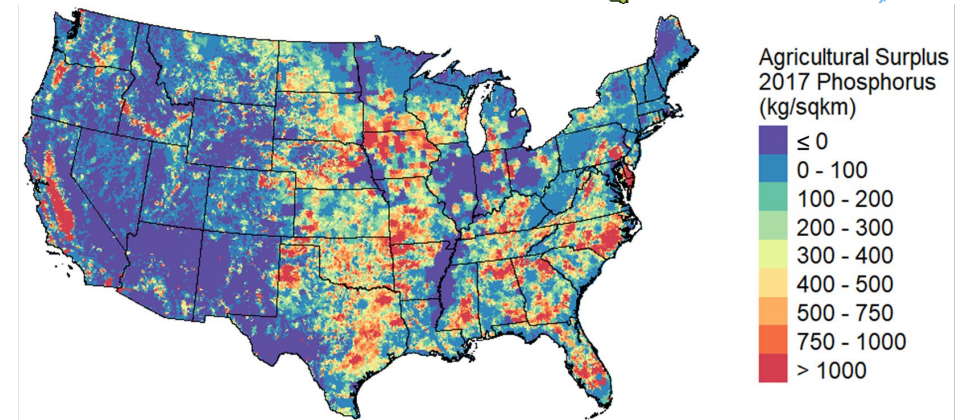
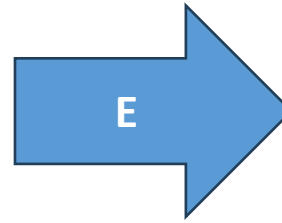


Largest Anthropogenic N Input
2007 to 2017

- Farm Fertilizer
- Livestock Waste
- Crop N Fixation
- Non-Farm Fertilizer
- Point Source
- Atmospheric Deposition



Extent/Magnitude: Communicate 1) the magnitude of pollution sources using management relevant metrics and 2) the feasibility of improving those metrics



Trajectory: Illustrate how pollution sources are evolving through time

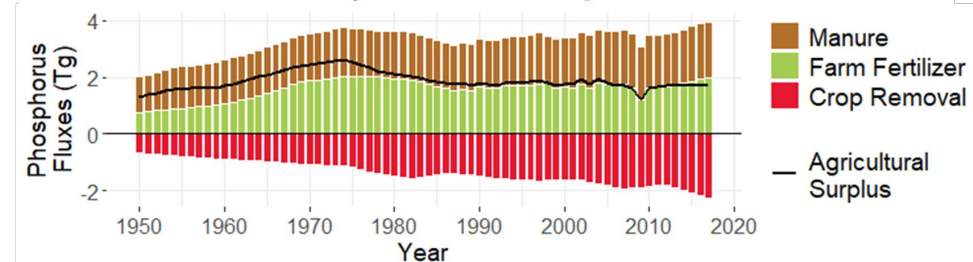
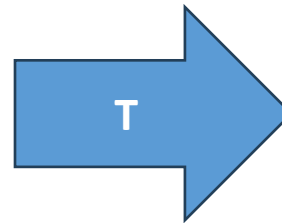
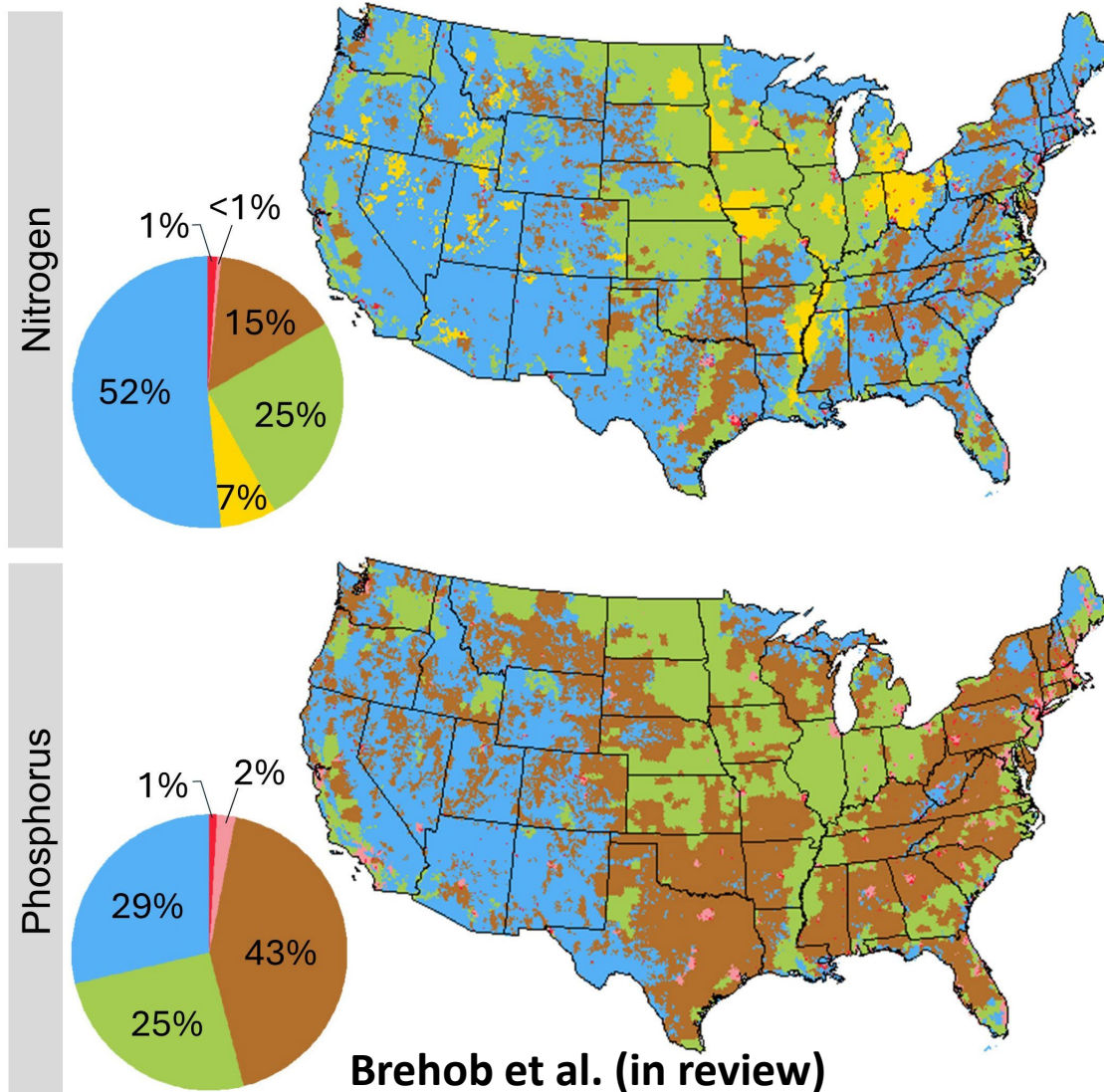
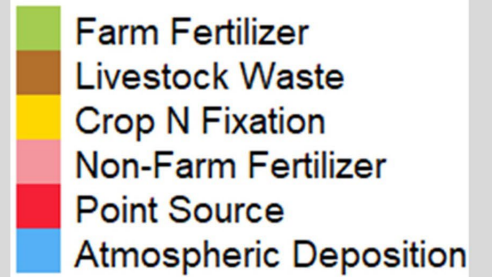


Figure from Brehob et al. (in review)

How do inputs vary spatially?

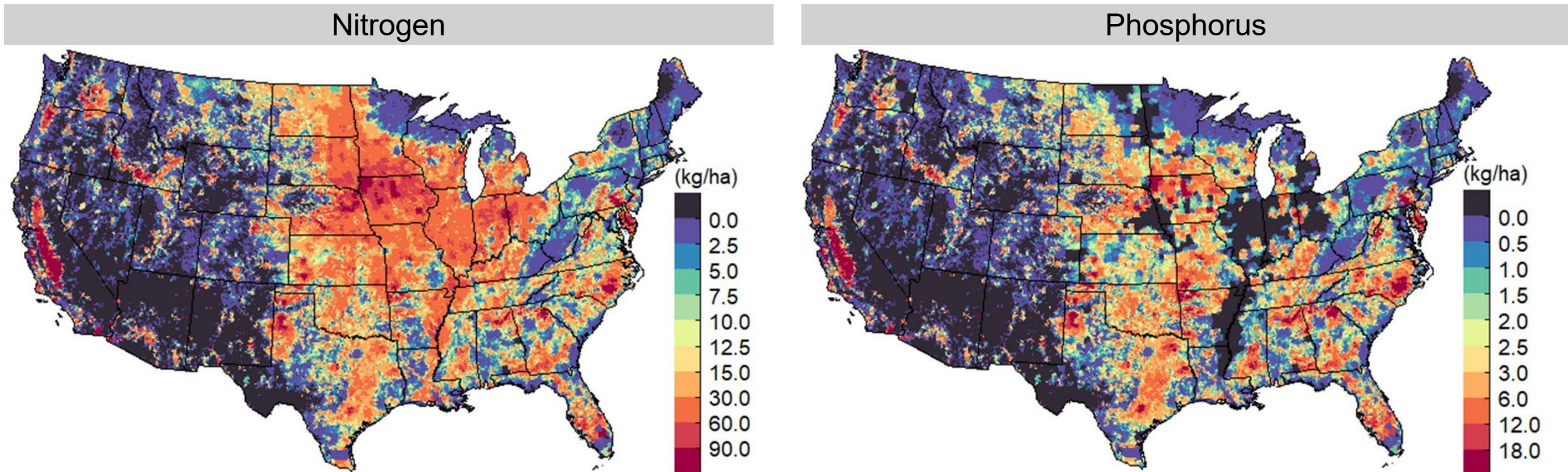
- High **fertilizer** and **crop N fixation** in agricultural regions
 - See Midwest and Mississippi River Alluvial Plain
- **Atmospheric deposition** larger for N than P; **manure** larger for P than N
 - See eastern and south-central US
- **Urban inputs** are regionally important

**Largest anthropogenic
N and P input**
in each HUC12 for an
average from 2007 to
2017.



How do inputs vary spatially?

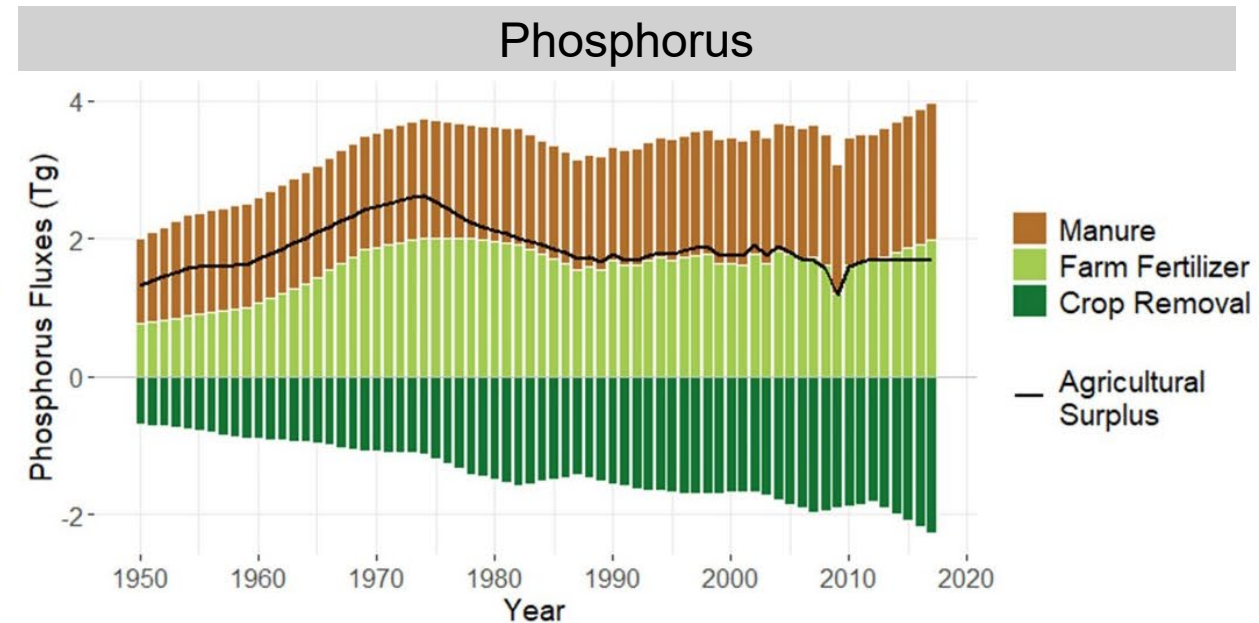
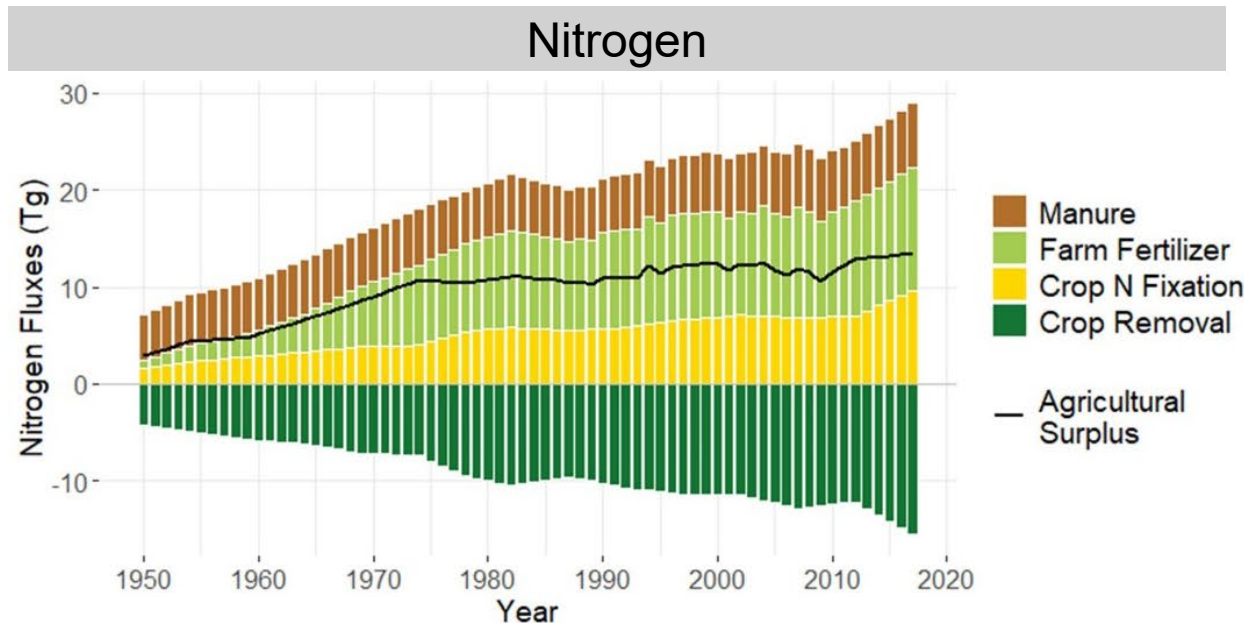
- Spatial extent of N and P agricultural surplus differs
 - See eastern Midwest and Mississippi River Alluvial Plain



Maps of 2017 N and P agricultural surplus (kg/ha).

How have fluxes changed over time?

- Crop removal has increased over 3x since 1950
- Agricultural surplus has plateaued
 - Plateau hasn't manifested equally across the US...

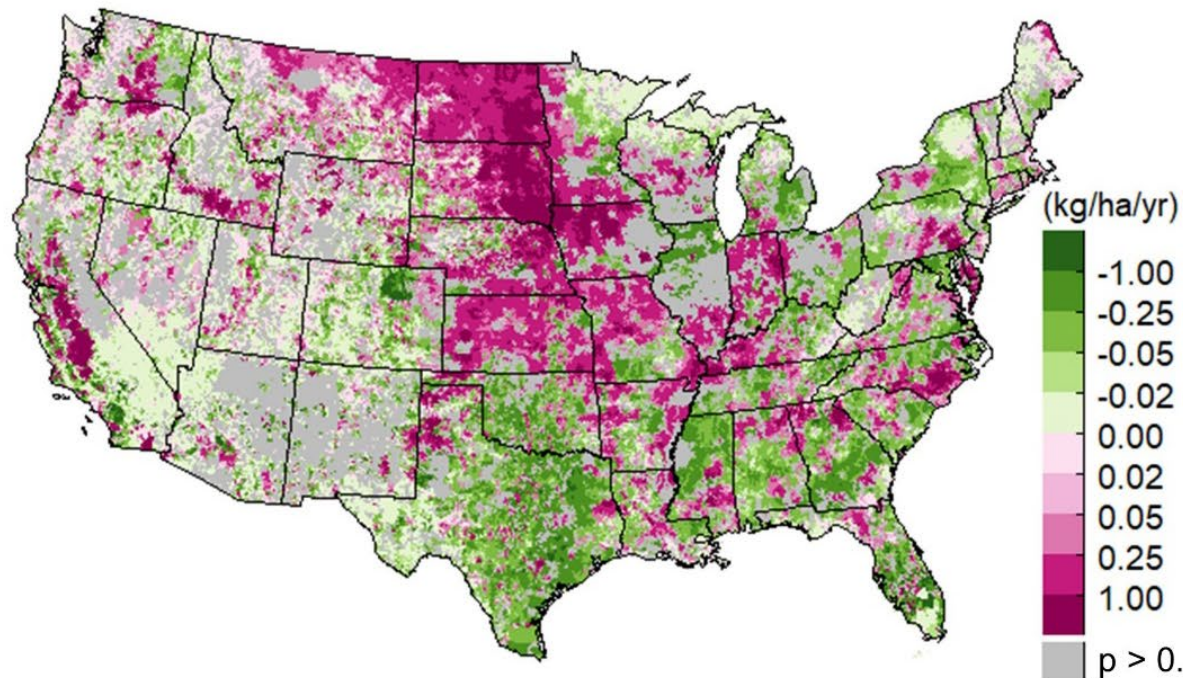


Annual time series of N and P agricultural surplus and relevant fluxes (Tg) from 1950 to 2017.

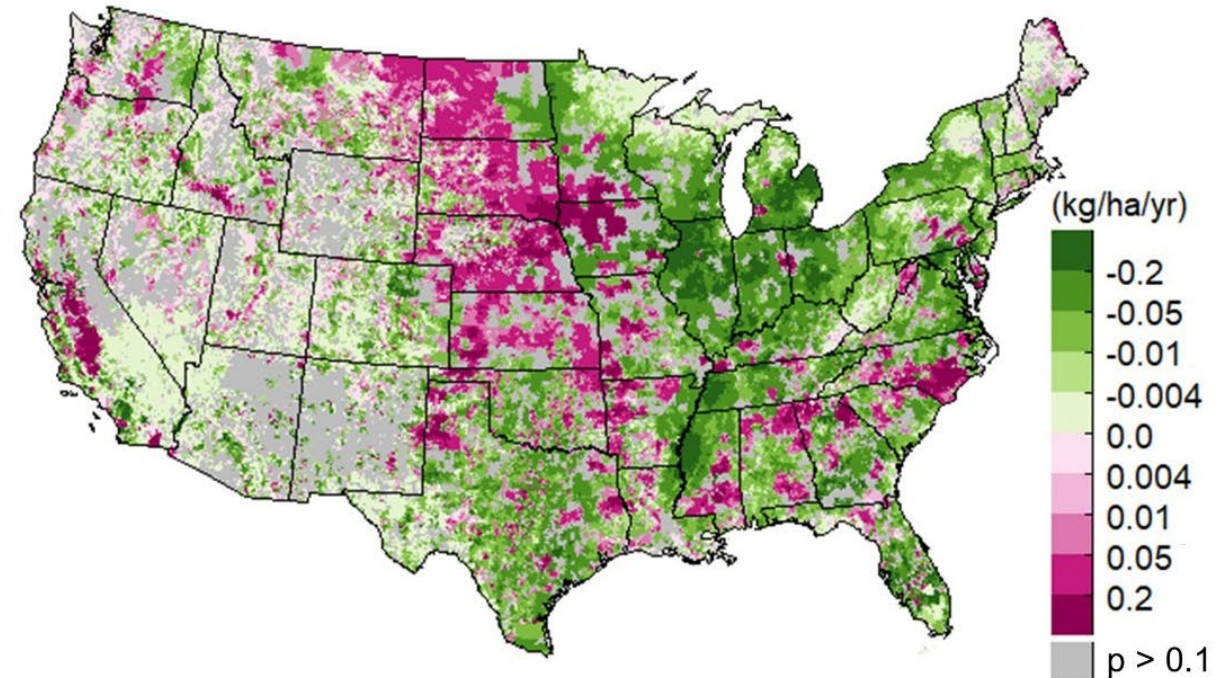
How have fluxes changed over time & space?

- From 1987 to 2017, agricultural surplus
 - Increased across Great Plains, Snake River Valley, Central Valley of CA
 - Decreased across parts of the eastern Midwest and Mississippi River Alluvial Plain, more for P than N

Nitrogen



Phosphorus



Maps of annual change in N and P agricultural surplus from 1987 to 2017 (kg/ha/yr; calculated as Theil-Sen slope).

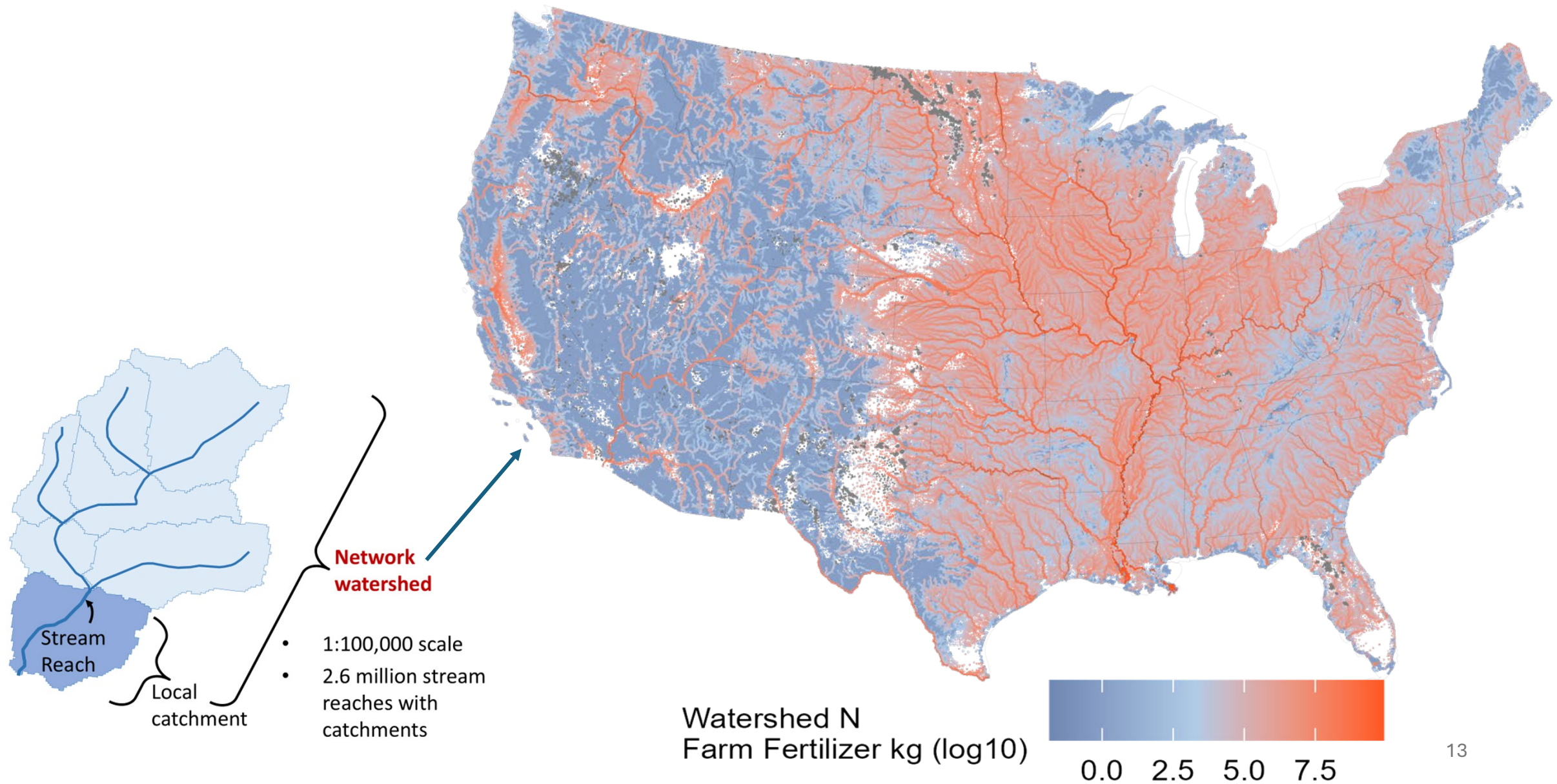
StreamCat^{NNI} - Downscaled and Accumulated Values Across CONUS

High resolution catchment and cumulative watershed nutrient data for any stream segment in the US

- Inform nutrient management needs and increase effective conservation funding efforts.
- Can be applied to predictive AI deep learning models for water quality management.

StreamCat^{NNI} Accumulates Upstream Watershed Metrics for Every Local Stream Reach Across CONUS

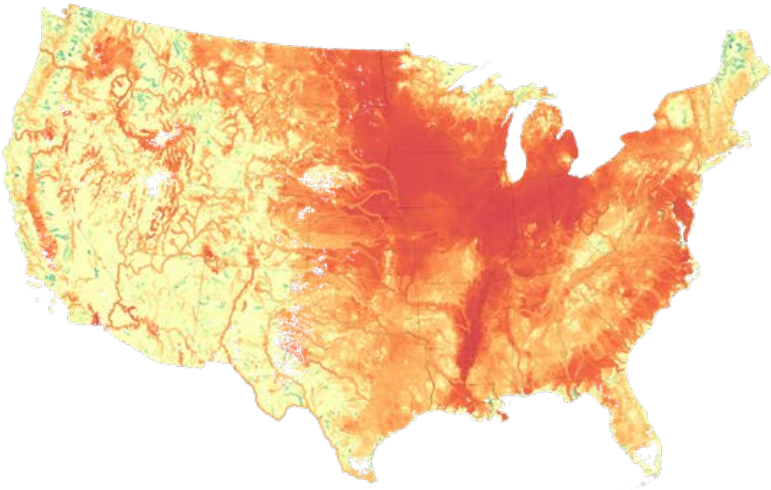
Selia Markley
ORISE - ORD



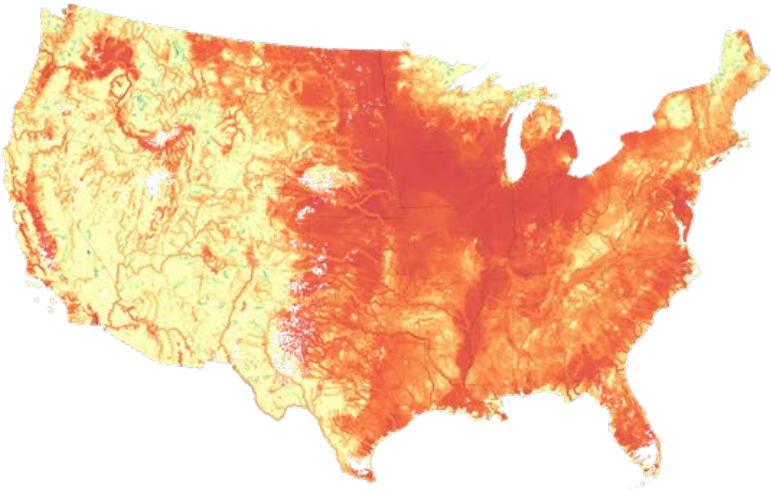
30 Years of Watershed Nutrient Budget Data

Selia Markley
ORISE - ORD

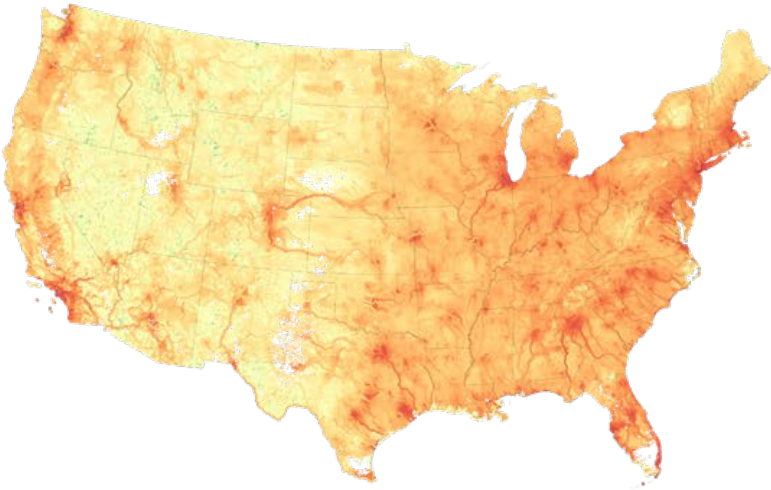
Crop N-Fixation



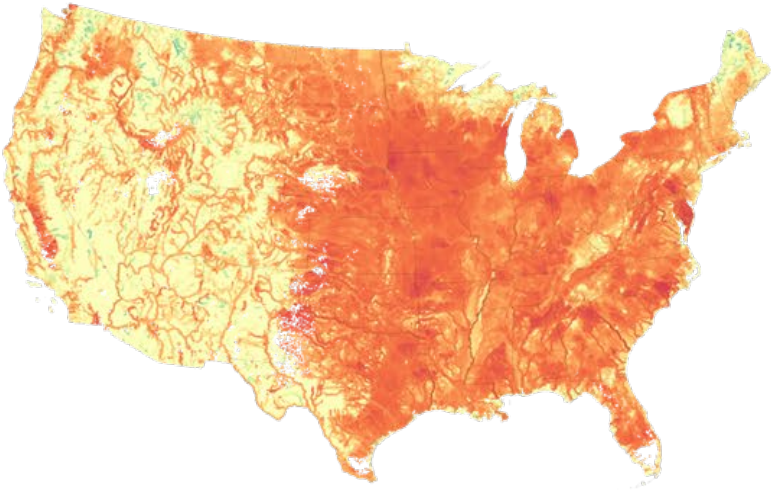
Farm Fertilizer



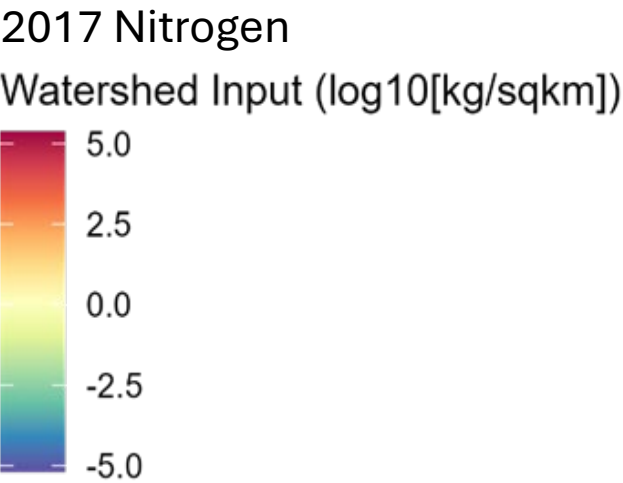
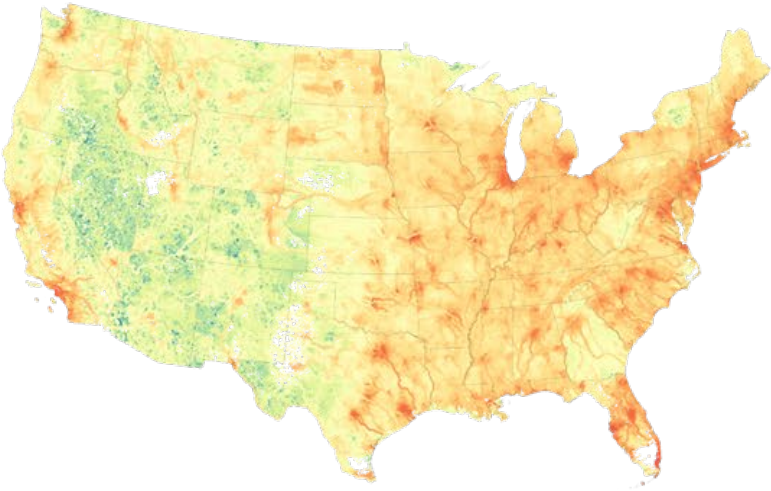
Human Waste



Livestock Waste

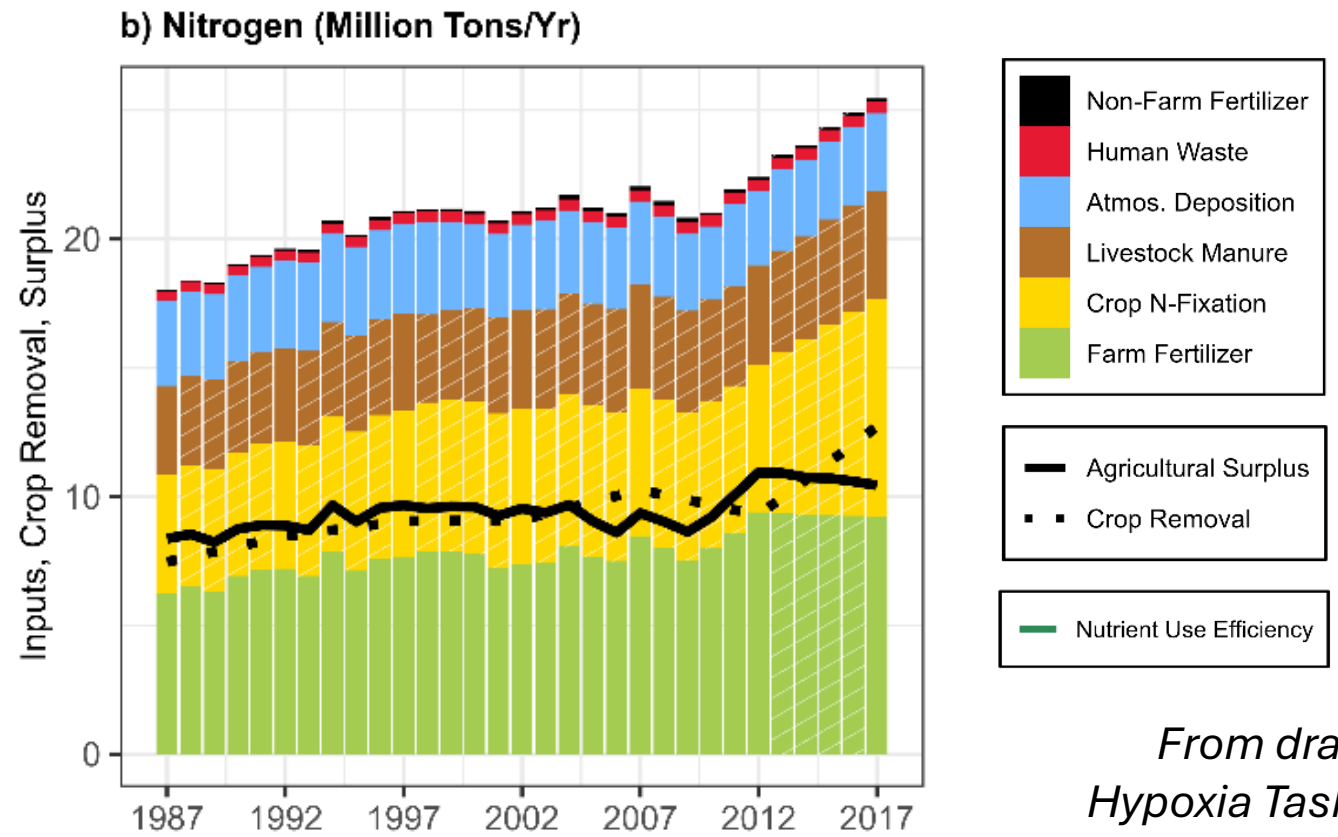
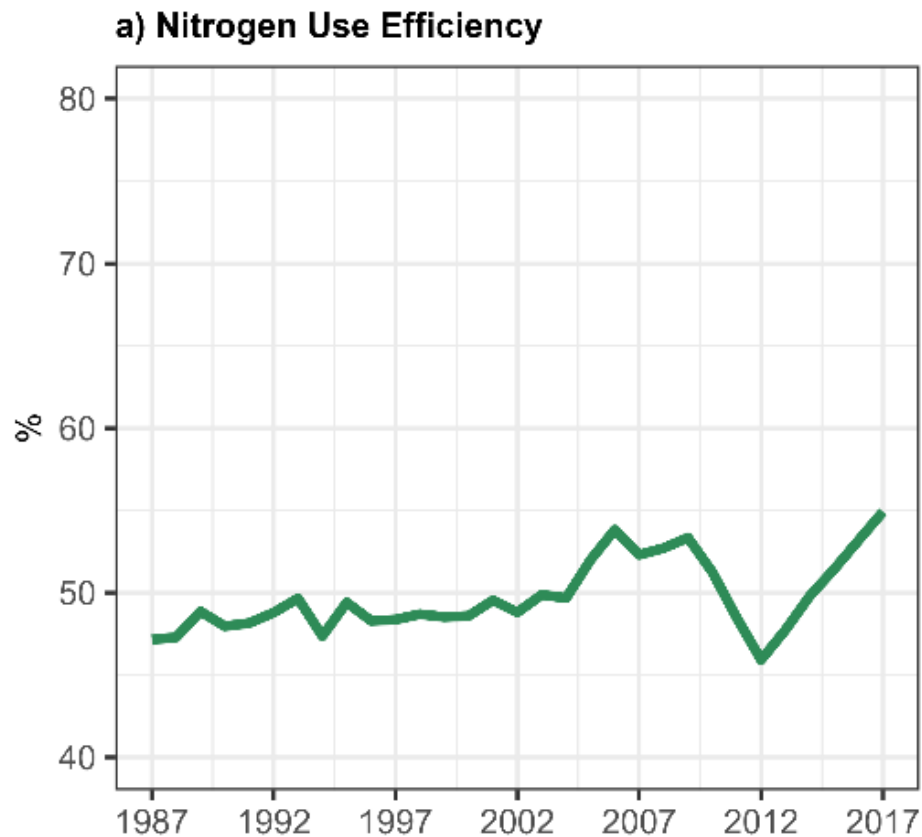


Non-Farm Fertilizer



Stats for any catchment or watershed: Nitrogen in the MARB over time

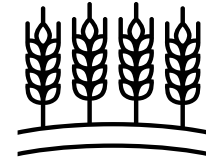
- Deposition declining by almost 9%
- Substantial increase in nutrient use efficiency (7%)



Hatched bars indicate extrapolations between census years

*From draft 2025
Hypoxia Task Force
Report to Congress*

- Inform TMDLs and watershed planning
- Assess nutrient conservation practice effectiveness at refined scale
- Driver for nutrient and water quality modeling (Neural Network, AI)
- Assist with nutrient related drinking water contamination
- Inform priority areas for SRF programs

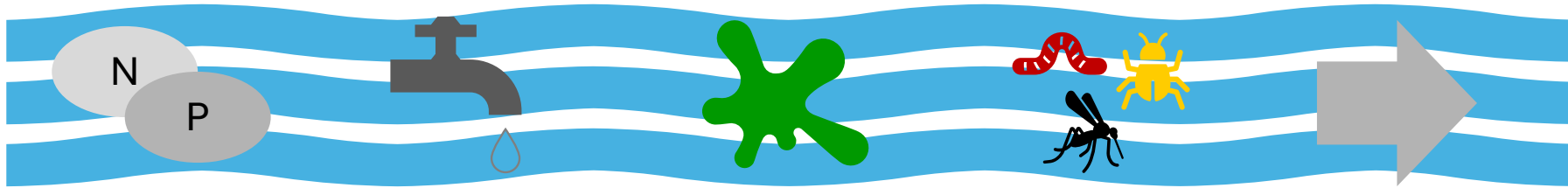
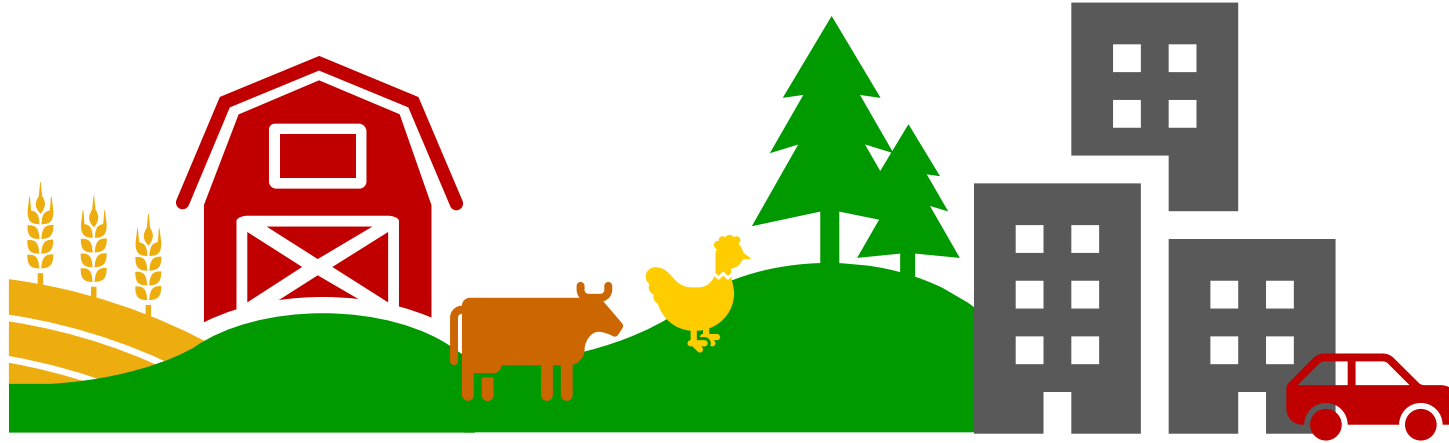


Using the NNI to develop predictive models

Nutrient Inputs to Landscape (National Nutrient Inventory)

SET

(Source, Extent,
Trends)



Predictive
Models and
Technical
Analyses

Data-driven modeling projects

Growing Season
Nutrient
Concentrations

Drinking Water
Conditions
(NO₃ and HABs Risk)

Harmful Algal
Blooms
(Chl-a and Toxins)

Biotic
Assemblages
(Macroinvertebrates)

Nutrient Export
and
Concentration

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National Aquatic Resource Surveys (NARS)

Federal, State and Tribal Partnership to Track Progress on CWA Objectives



Lakes

2007, 2012, 2017, 2022



Rivers

2008-2009, 2013-2014, 2018-2019, 2023-2024



Streams



Coastal

2010, 2015, 2020, 2025



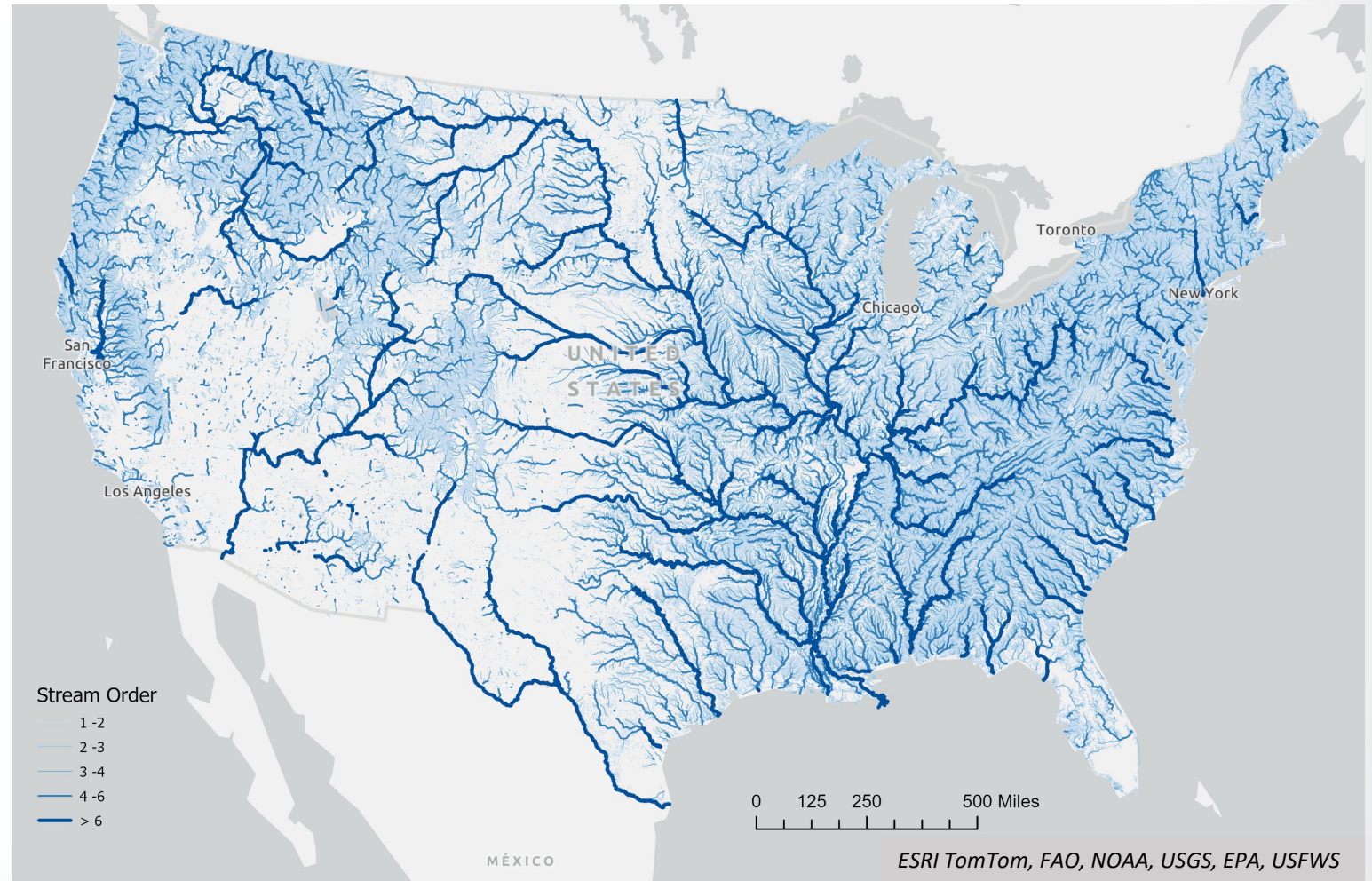
Wetlands

2011, 2016, 2021, 2026



National Rivers and Streams Assessment (NRSA)

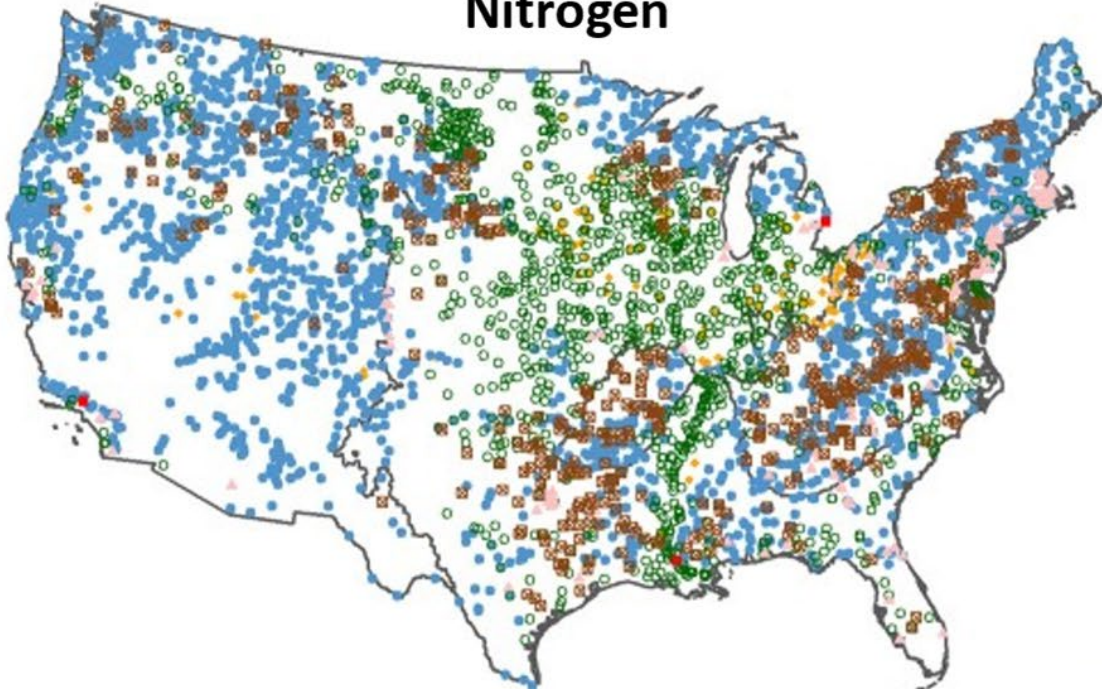
- ~2,000 samples every 5 years
- Perennial streams
- Field visits measure
 - Physical Habitat, Streamflow
 - Human disturbance
 - Insect, fish, algae
 - Water chemistry
- Probability design allows estimates of lower 48 stream length (1.4 million miles)
- Classification of sites into **good**, **fair**, & **poor** condition based on ecoregional thresholds



Credit: Marc Weber, EPA Corvallis

Use NNI to categorize NRSA sites by largest input source

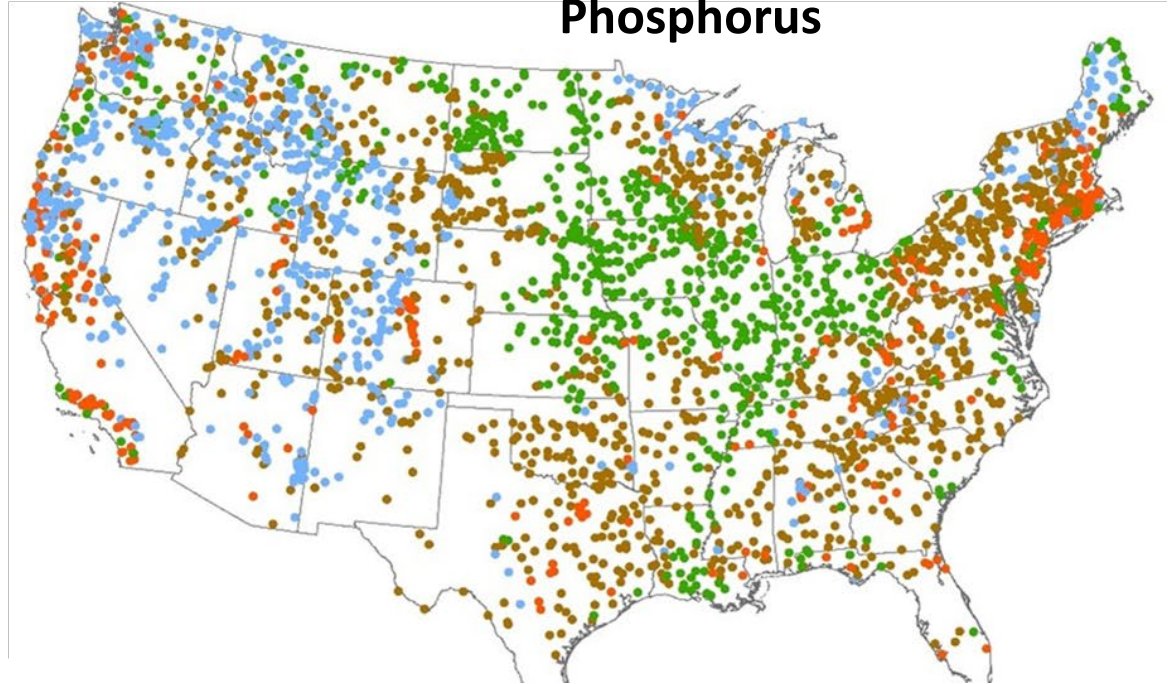
Nitrogen



Largest Watershed N inputs

- Human Waste
- Atmospheric Deposition
- Farm Fertilizer
- Crop N fixation
- Livestock waste
- Urban fertilizer

Phosphorus

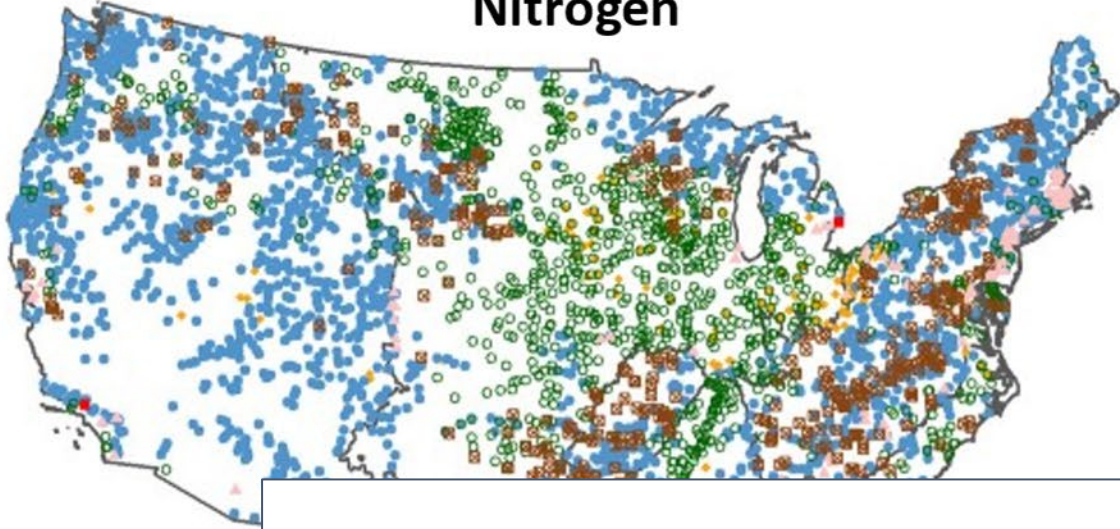


Largest Watershed P Input

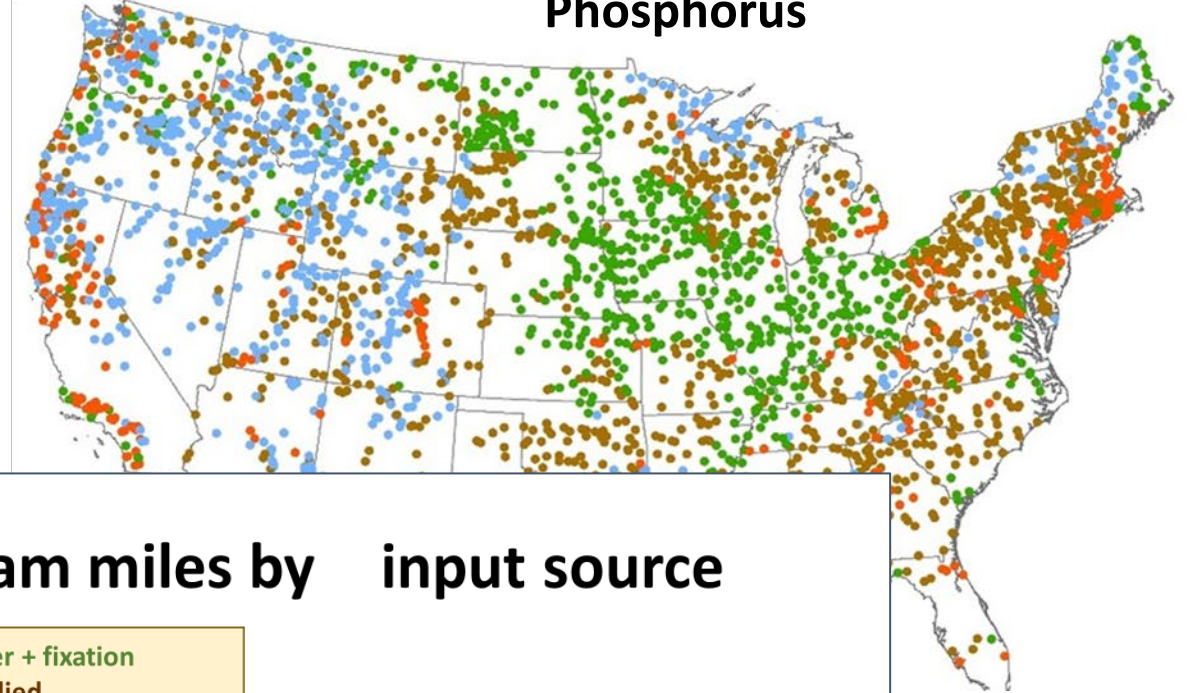
- Human Waste
- Atmospheric Deposition
- Farm Fertilizer
- Livestock Waste

Relative importance of each input source

Nitrogen



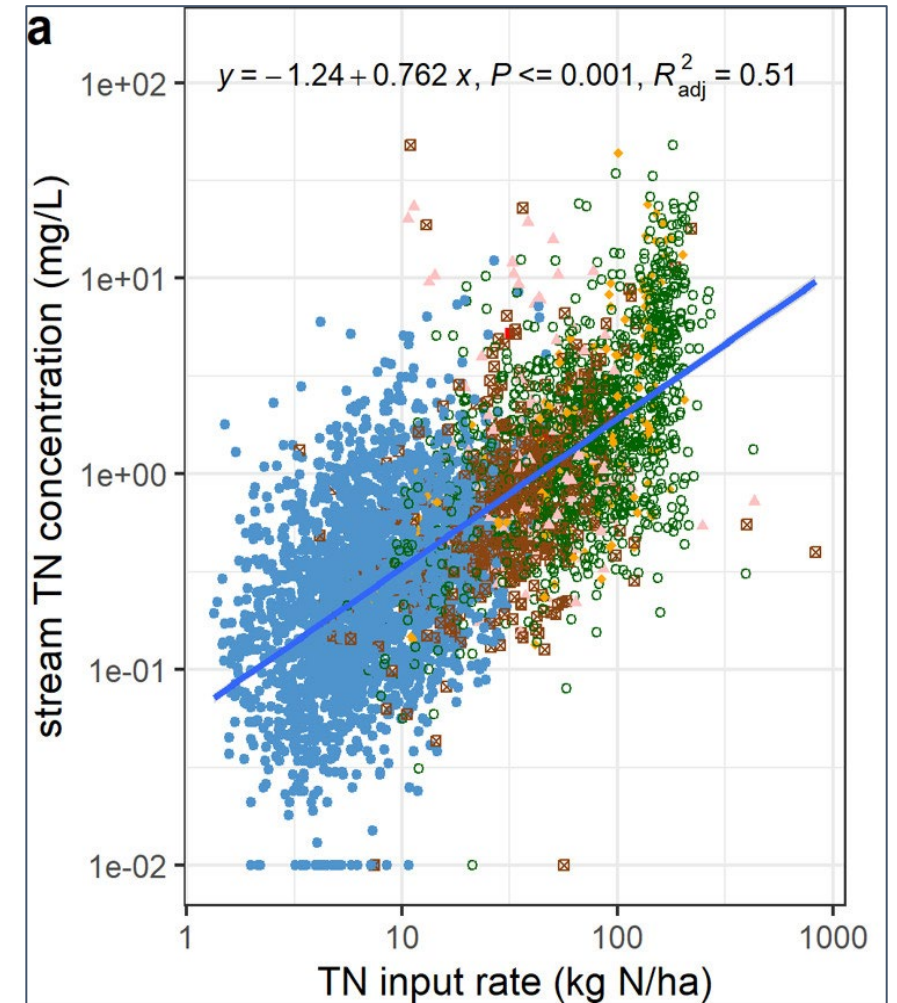
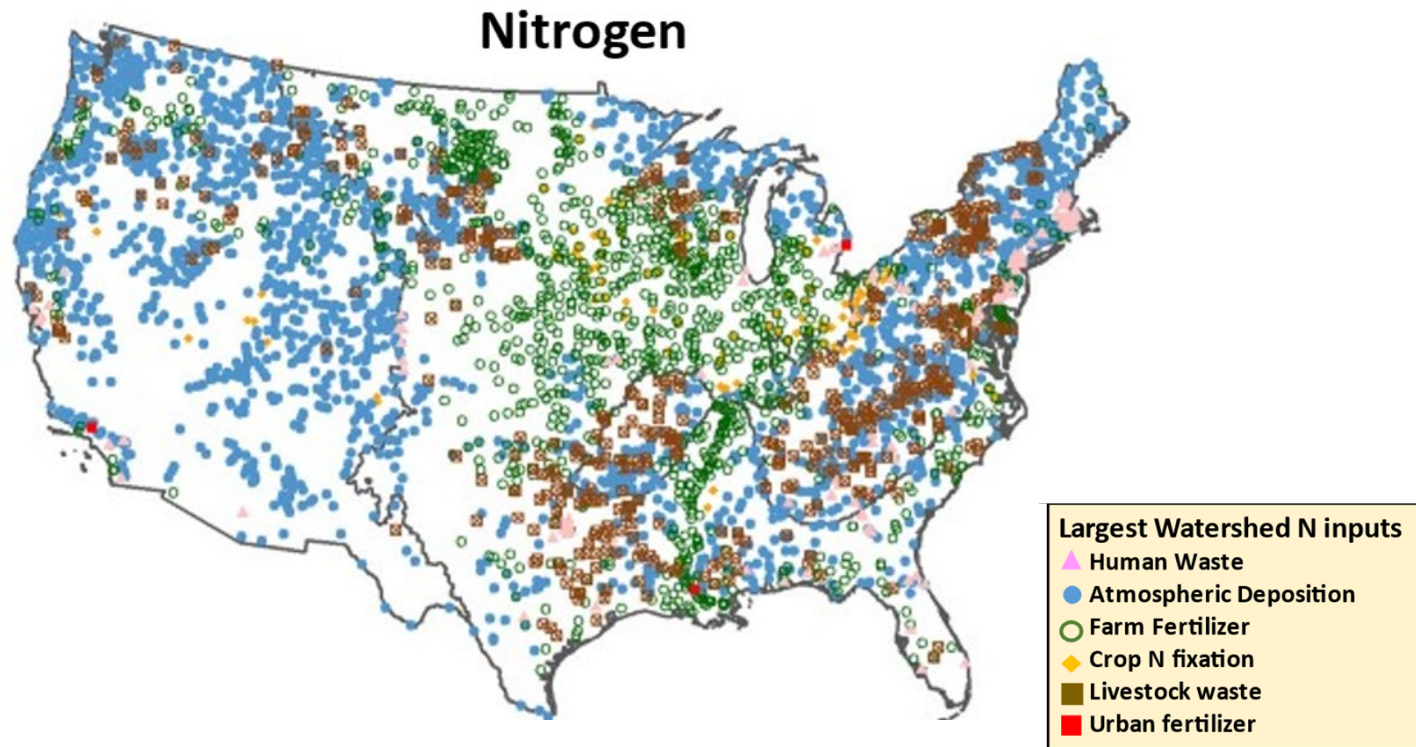
Phosphorus



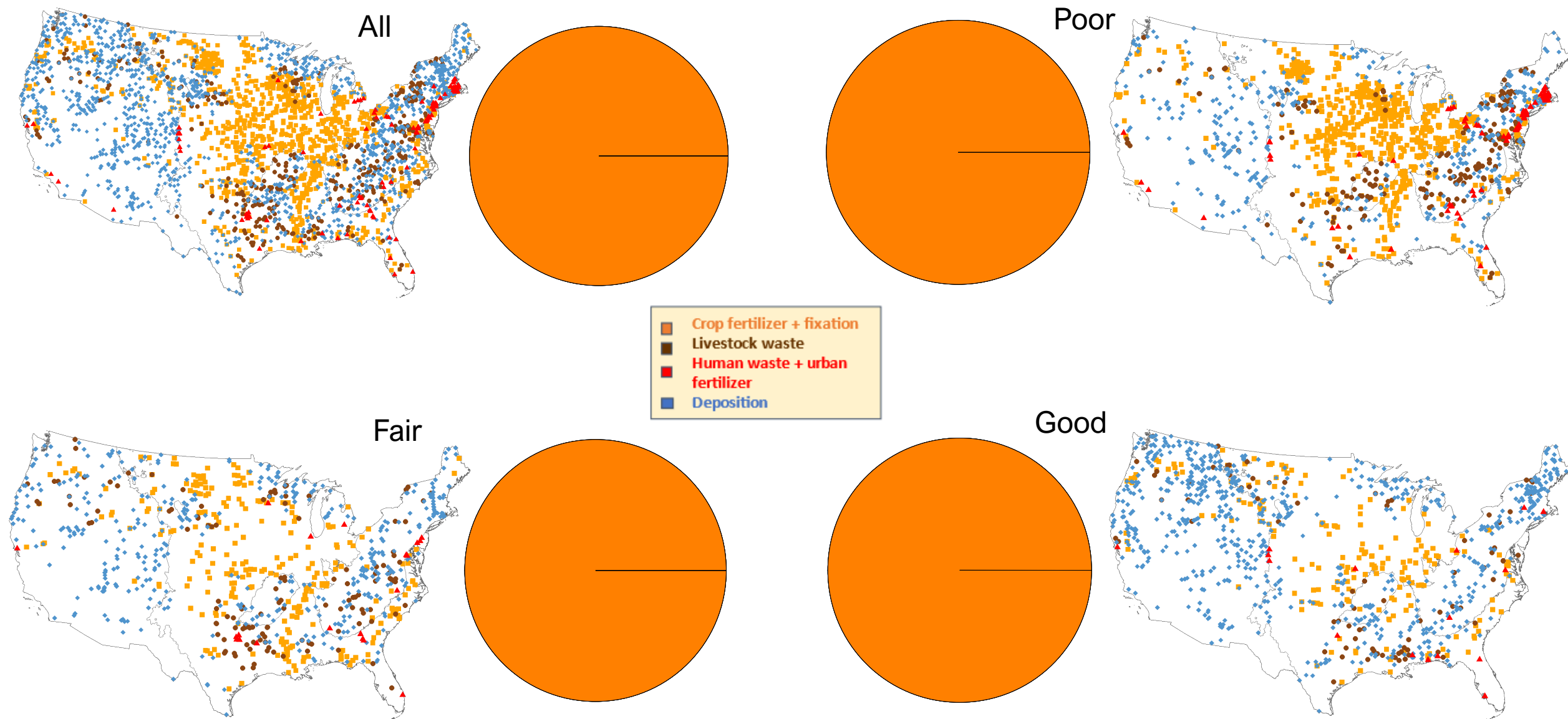
Proportion of CONUS stream miles by input source



Connecting source and stream/river concentrations

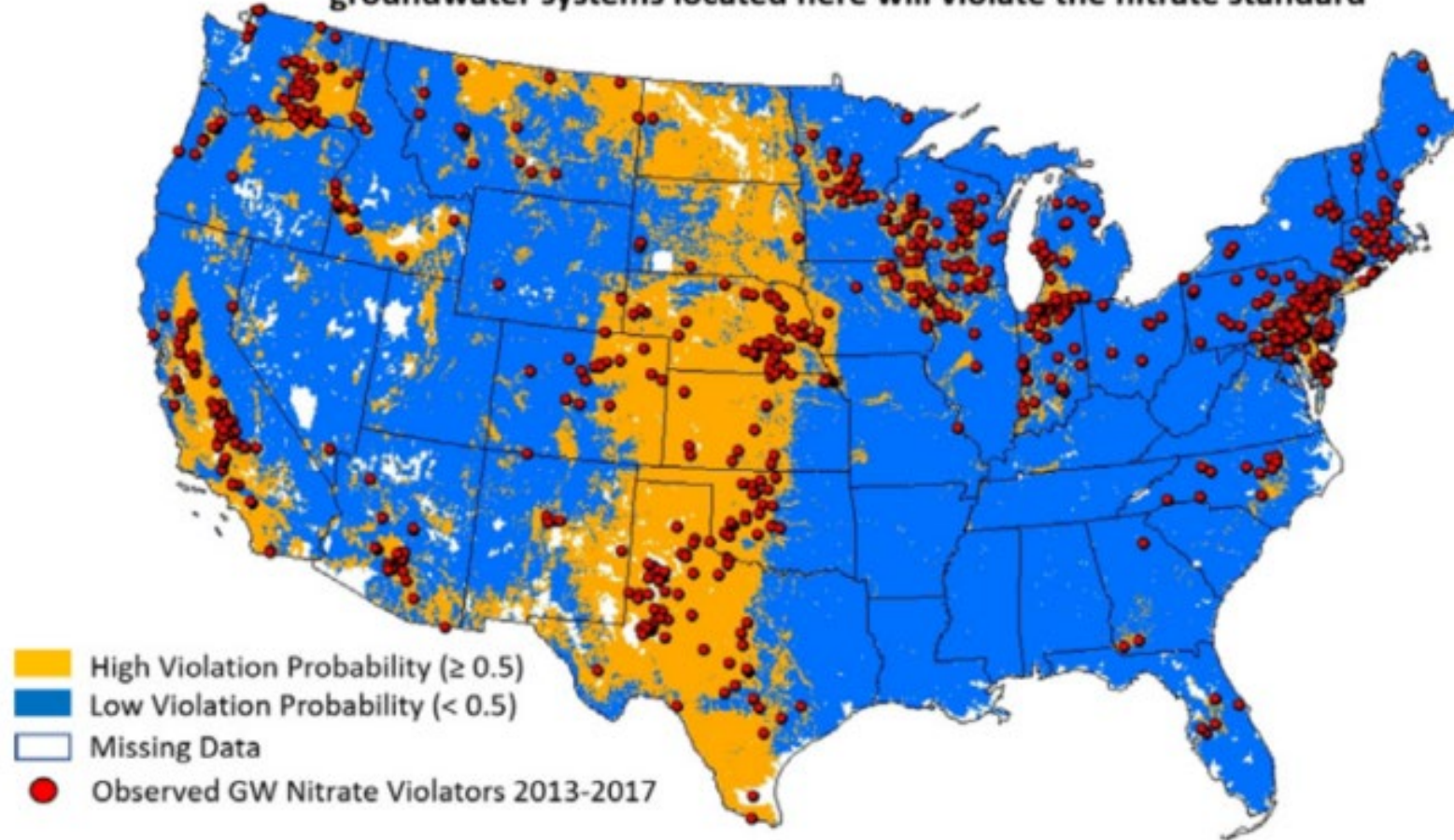


Largest Nitrogen Source by NRSA Nutrient Condition



Connections to Drinking Water

Probability that groundwater sourced Public Water Systems or private groundwater systems located here will violate the nitrate standard

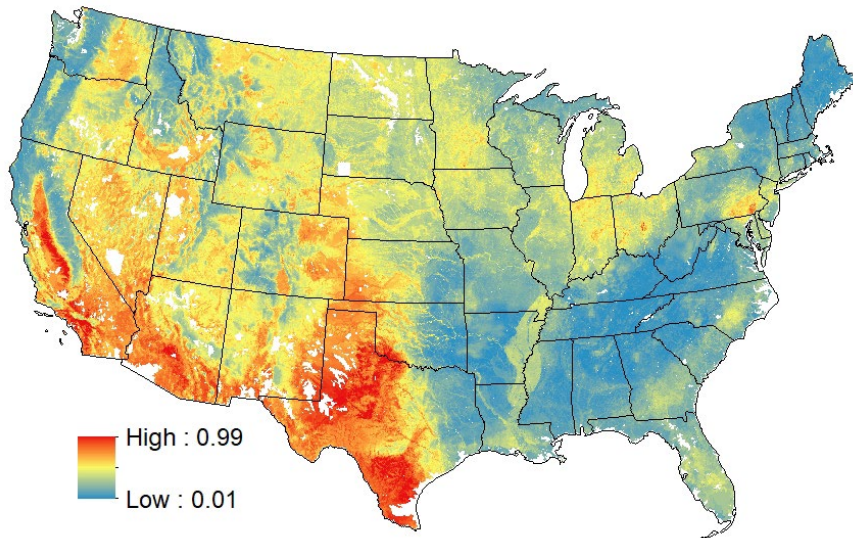


Public Water Supply Nitrate Violations

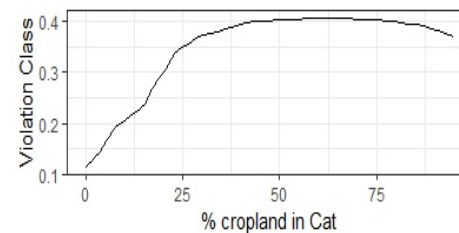
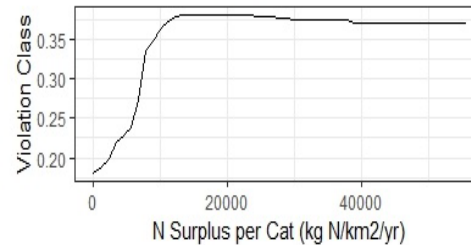
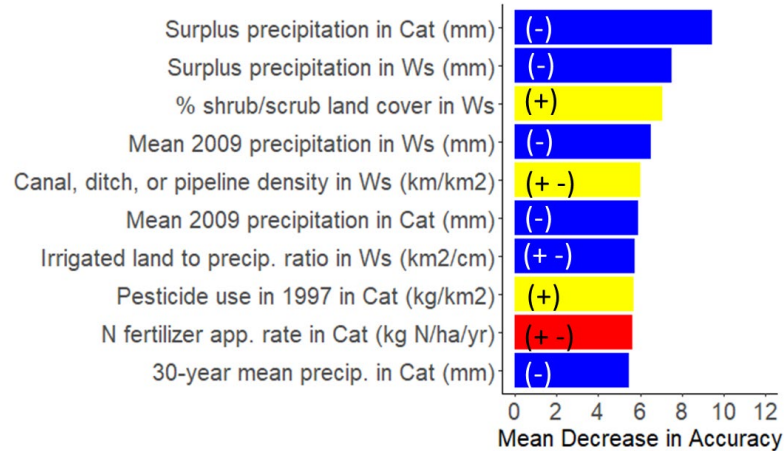
Used nutrient data to predict the probability of nitrate violations in groundwater sourced drinking water

Drinking Water Nitrate Violation Risk Predictions

Surface Water



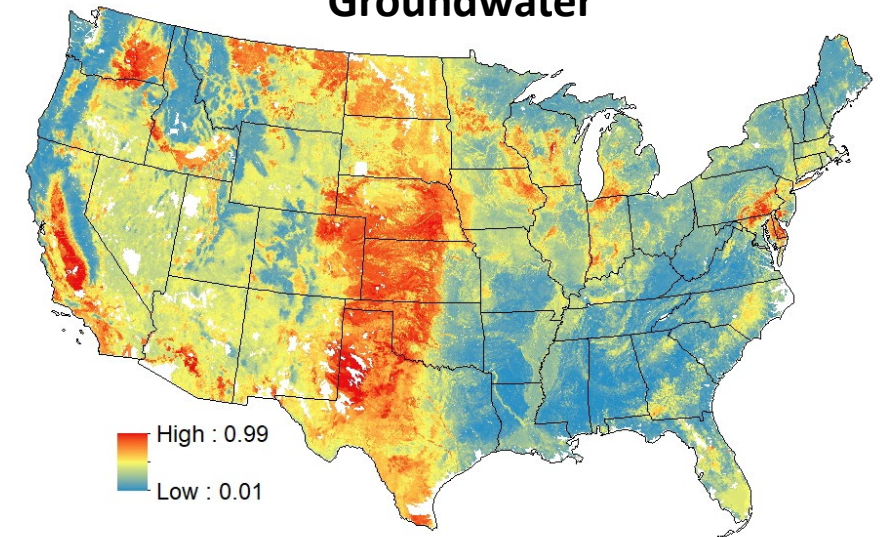
Dominant Drivers of Surface Water NO₃⁻



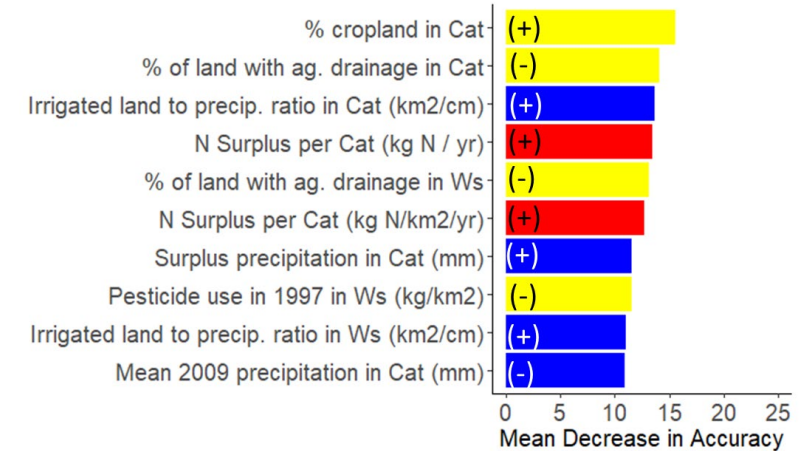
Categories: **N Inputs;**
Human Land Use; **Deposition;**
Natural Watershed/Geologic;
Climate/Hydrologic

Cat = Catchment scale
 Ws = Watershed scale

Groundwater



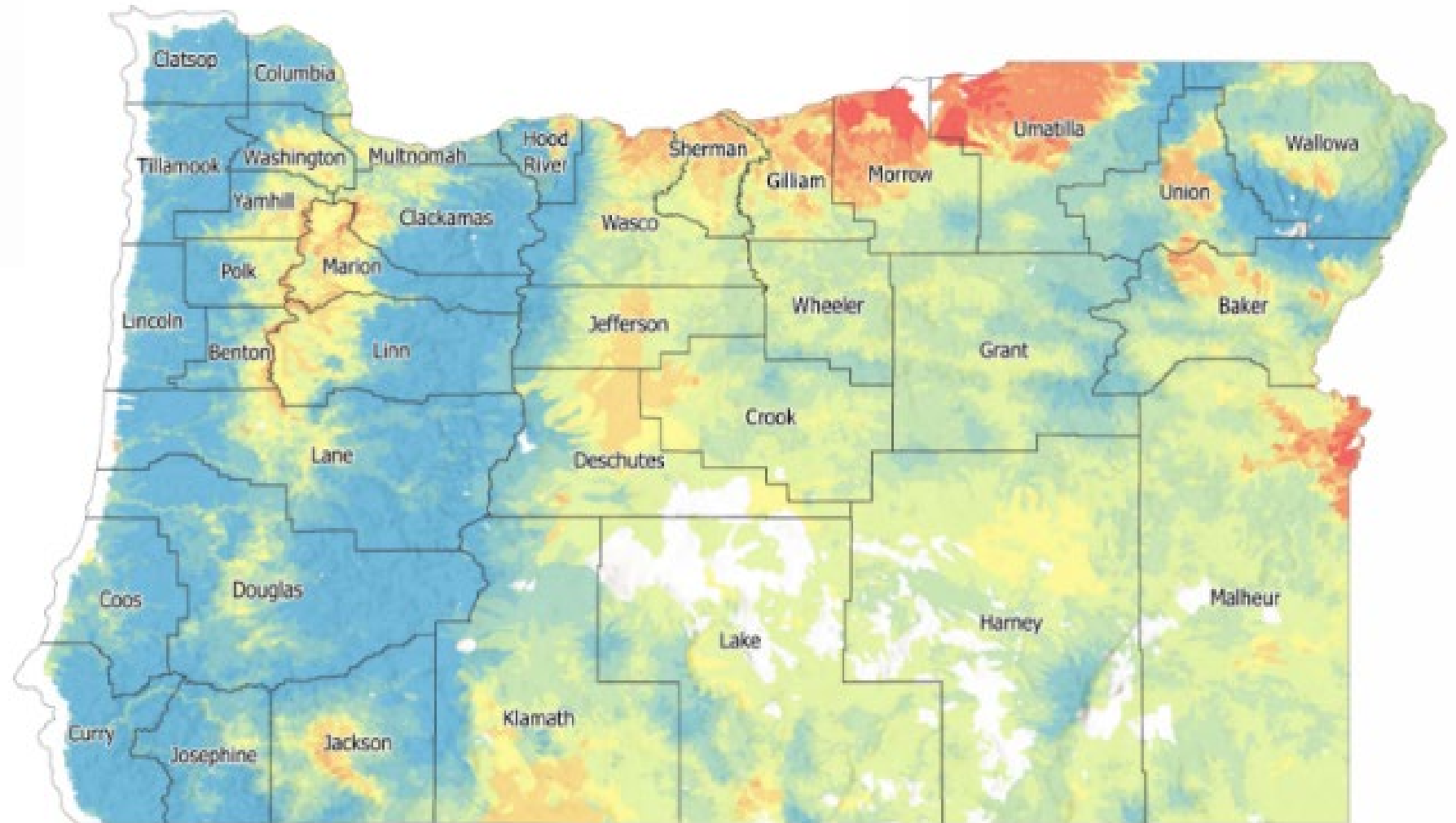
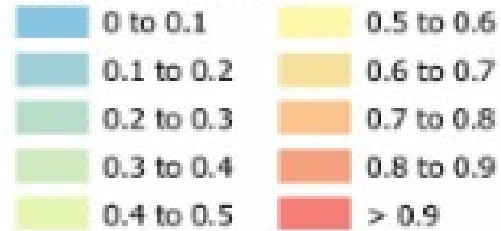
Dominant Drivers of Groundwater NO₃⁻





Probability of GW nitrate violations - OR

Model-Predicted Probability of Nitrate > 10 mg/L



Wenzlick et al.,
based on
[Pennino et al. 2020](#)
[STOTEN](#)

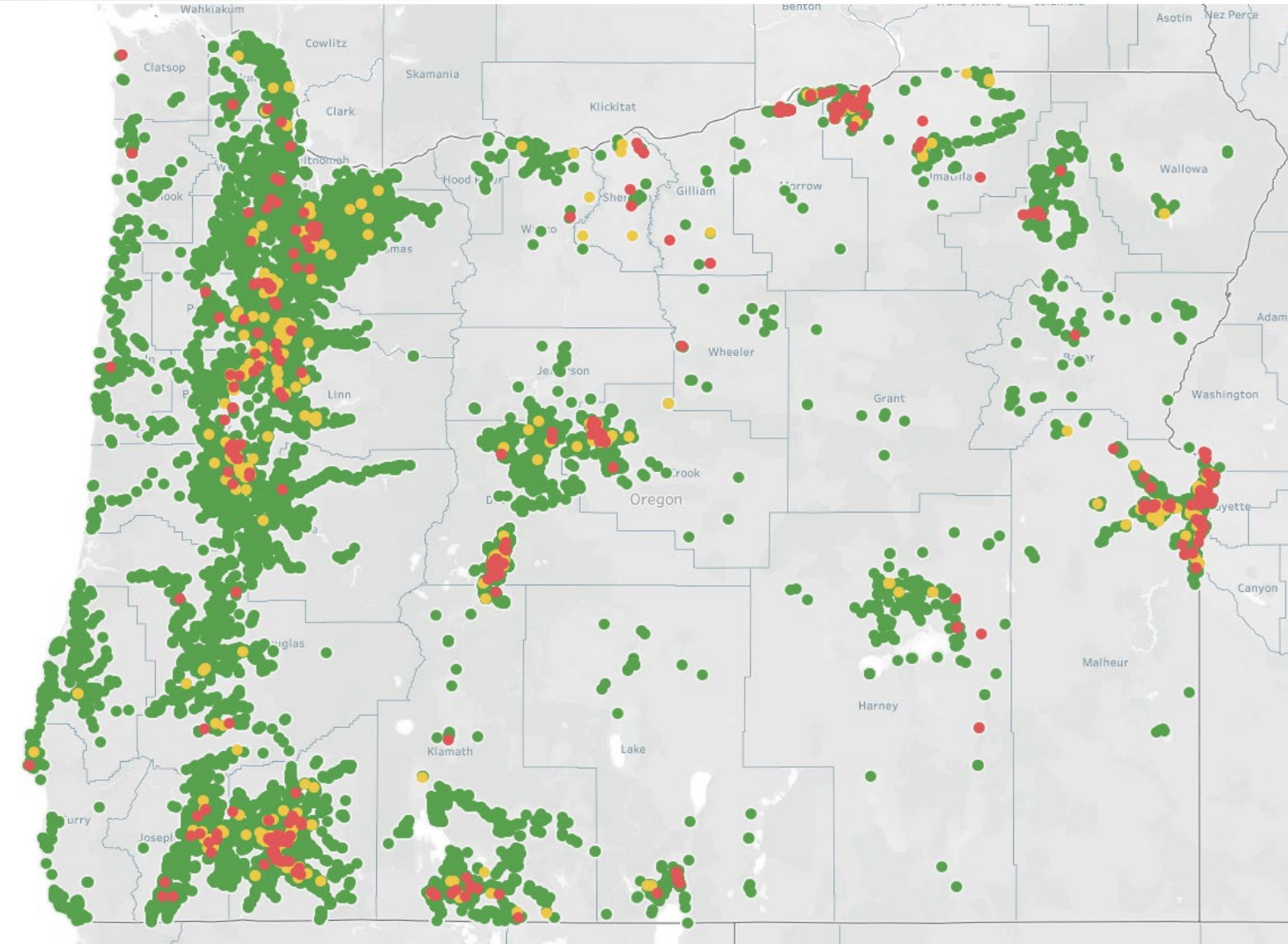


Testing national model with local data

Data from the Real Estate Transaction (RET) database for domestic wells (1987-2020, n=26,298)

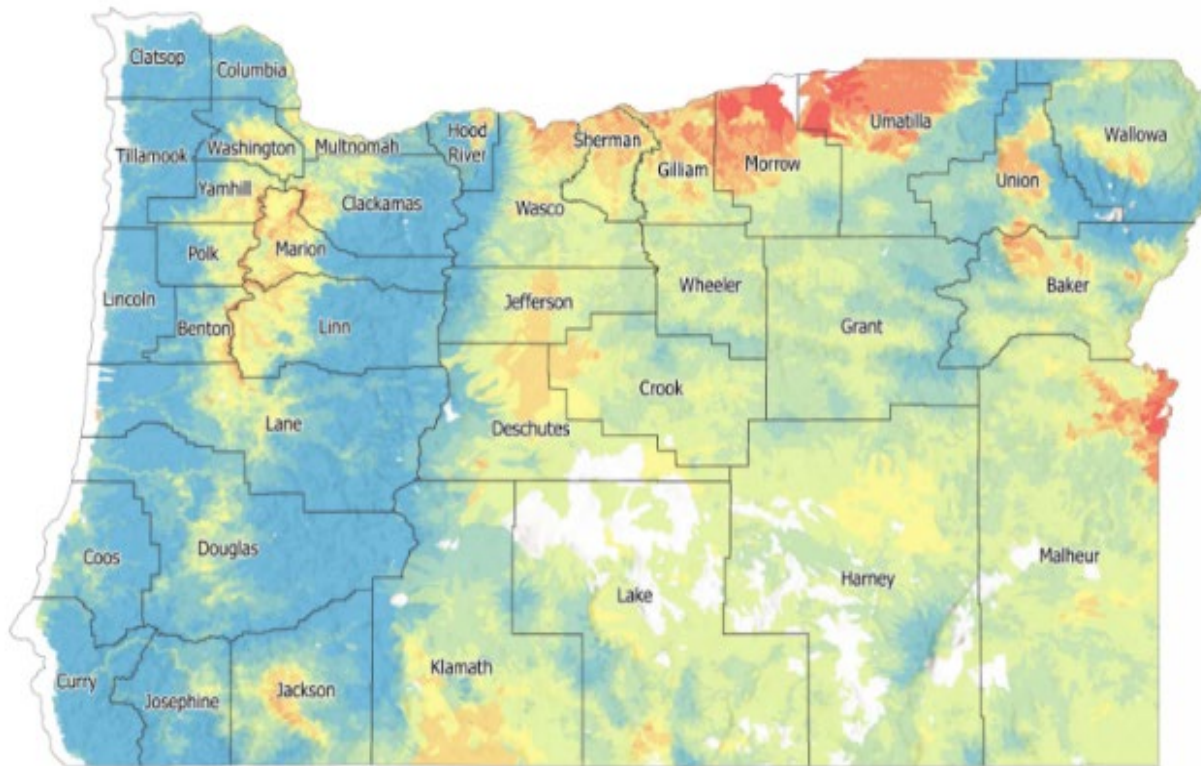
Color Scale

- >10 mg/l Nitrate-N
- 7-10 mg/l Nitrate-N
- <7 mg/l Nitrate-N





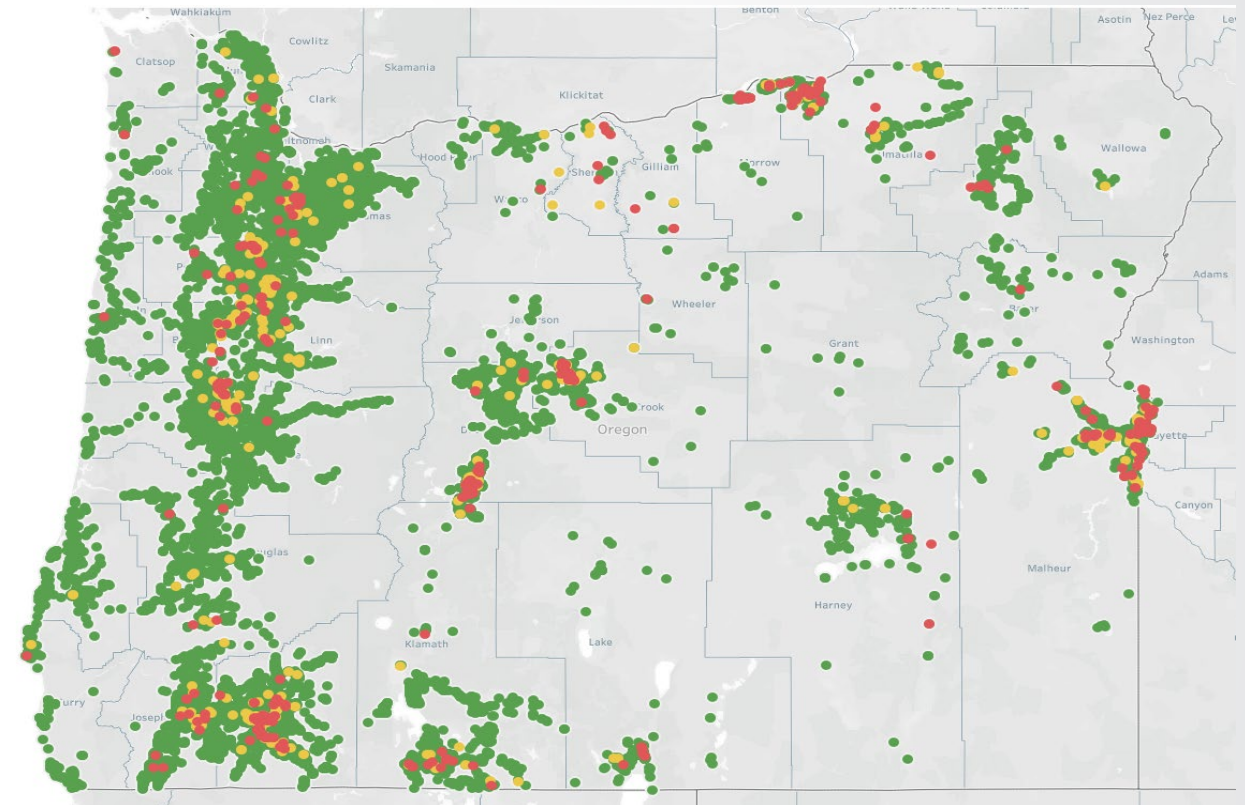
Comparing GW predictions with Real Estate Transaction data



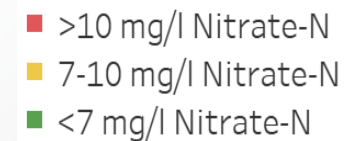
Model-Predicted Probability of Nitrate > 10 mg/L



Esri, USGS



Color Scale



Wenzlick et al. In prep., based on [Pennino et al. 2020 STOTEN](#)



Good agreement with national model

Dataset	Number of RET observations	Number of observed violations	Percent Correctly Classified	Sensitivity	Specificity
Nationwide (Pennino et al., 2020)	N/A	N/A	78.1	100	77.8
Statewide	25,982	378	61.8	83.9	61.5

Percent correctly classified = % correct for both violators and non-violators

Sensitivity = percent of violators correctly classified

Specificity = percent of non-violators correctly classified

Modeling Harmful Algal Blooms (HABs)

“HABs/Hypoxia/Excess Nutrients. Expand the ability of the Cyanobacterial Harmful Algal Bloom model to detect blooms in 99 percent of lakes (>270,000) and almost all estuaries across the lower 48 states.”

(FY26 EPA Congressional Justification)

Here, we use NNI data to make unprecedented insights about HAB occurrence in lakes and rivers across the CONUS



What are the Drivers of Algal Blooms?

Covariates

In-Lake Conditions

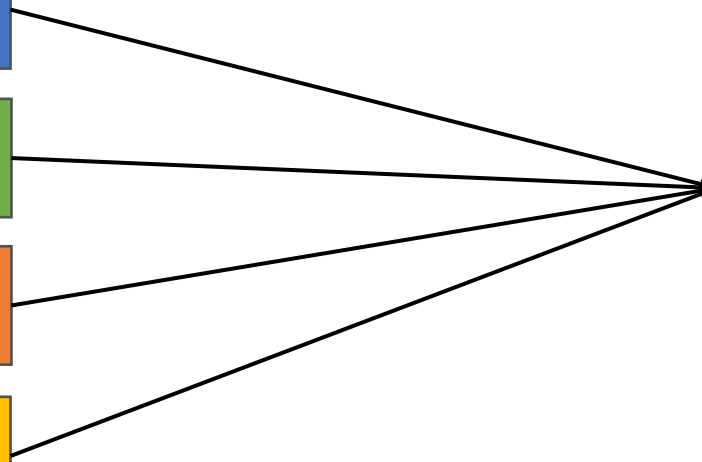
Nutrient Inputs

Climate & Setting

Lake Morphology

Response

Chlorophyll a
CyanoHABs

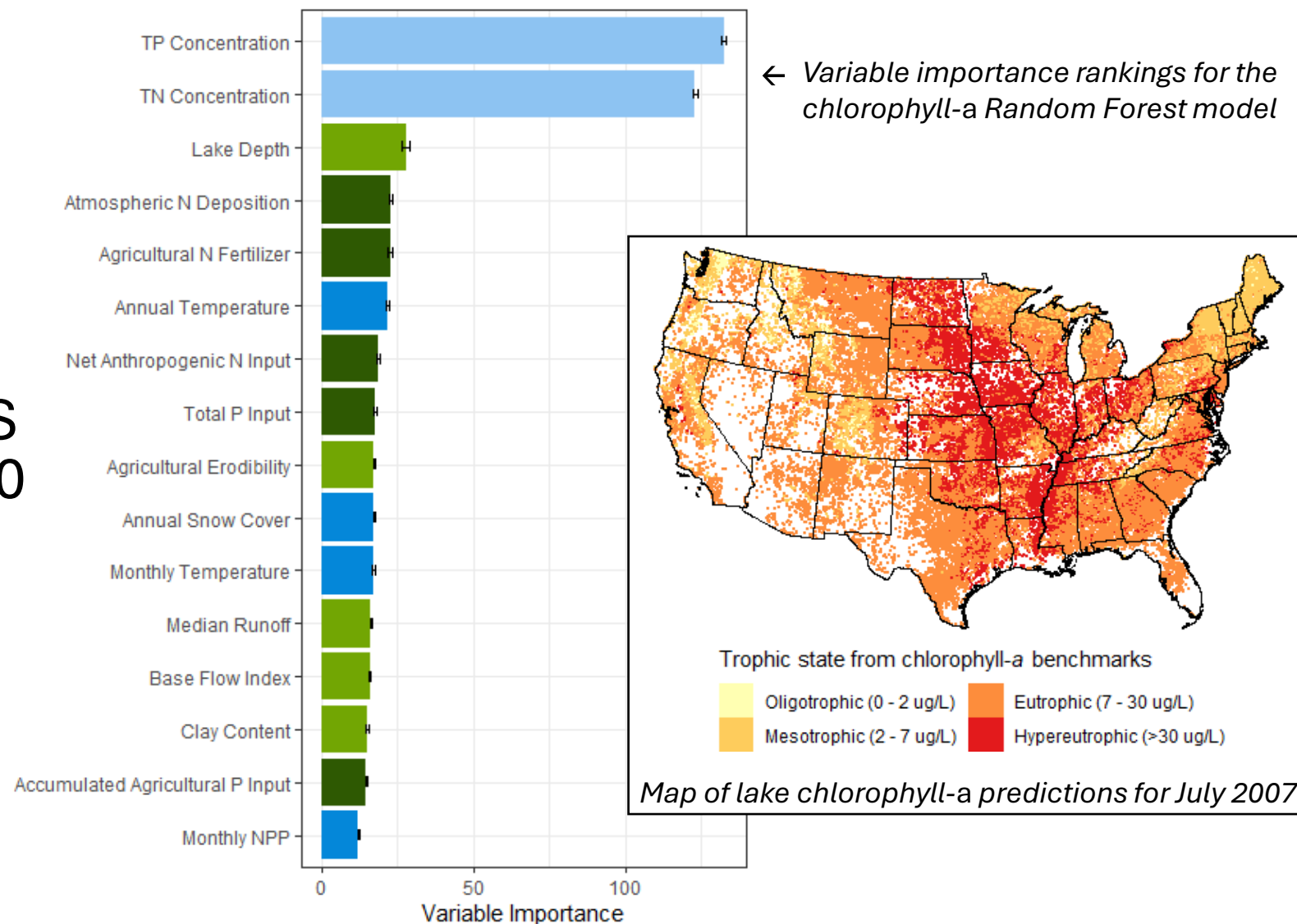


Lake Chlorophyll-*a*

- Trained Random Forest models using NLA observations
- Used nested modeling strategy to make predictions for all CONUS catchments and ~112,000 on-network lakes
 - Total nitrogen (TN)
 - Total phosphorus (TP)
 - Chlorophyll-*a*

Estimates of Lake Nitrogen, Phosphorus, and Chlorophyll-*a* Concentrations to Characterize Harmful Algal Bloom Risk Across the United States (2024)

Meredith M. Brehob, Michael J. Pennino, Amalia M. Handler, Jana E. Compton, Sylvia S. Lee, and Robert D. Sabo





What are the Drivers of Algal Blooms?

Covariates

In-Lake Conditions

Nutrient Inputs

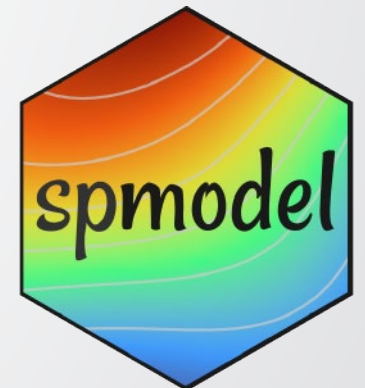
Climate & Setting

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Chlorophyll a
CyanoHABs

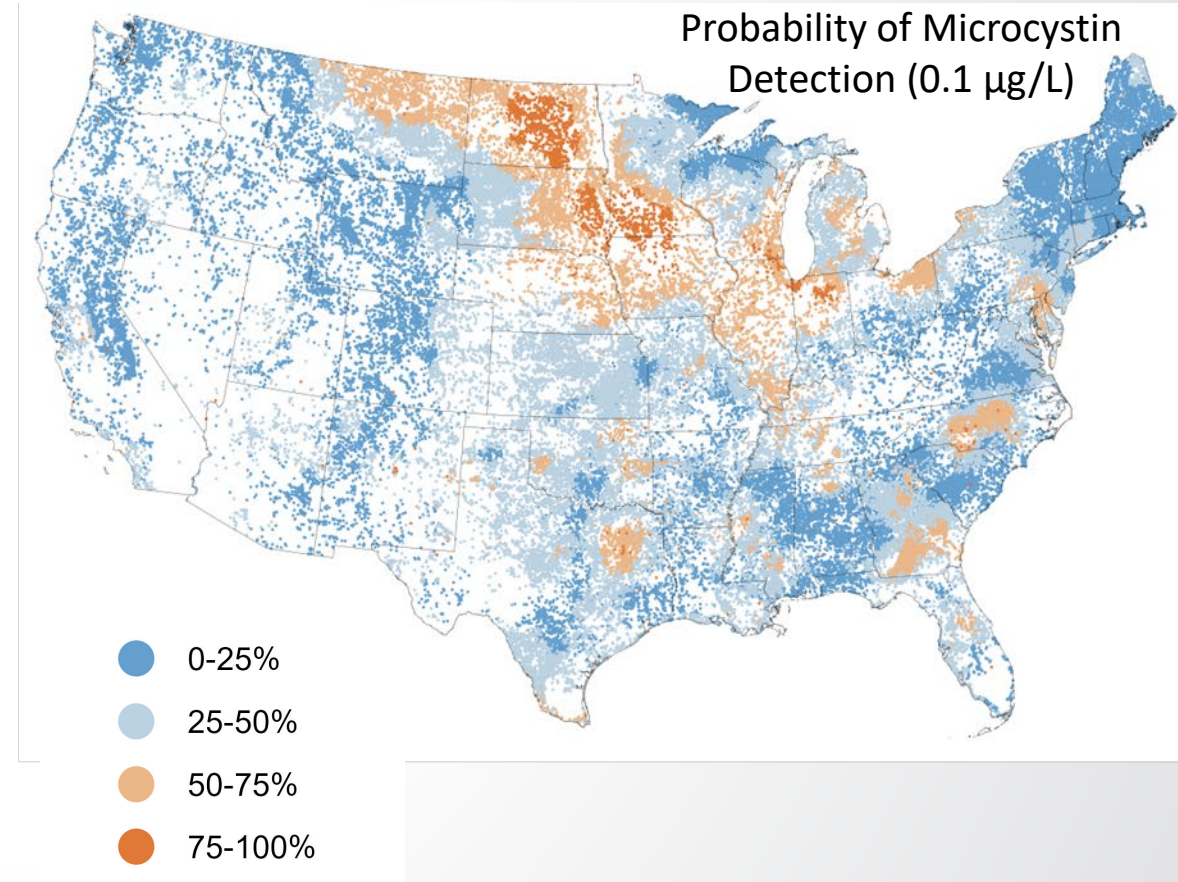
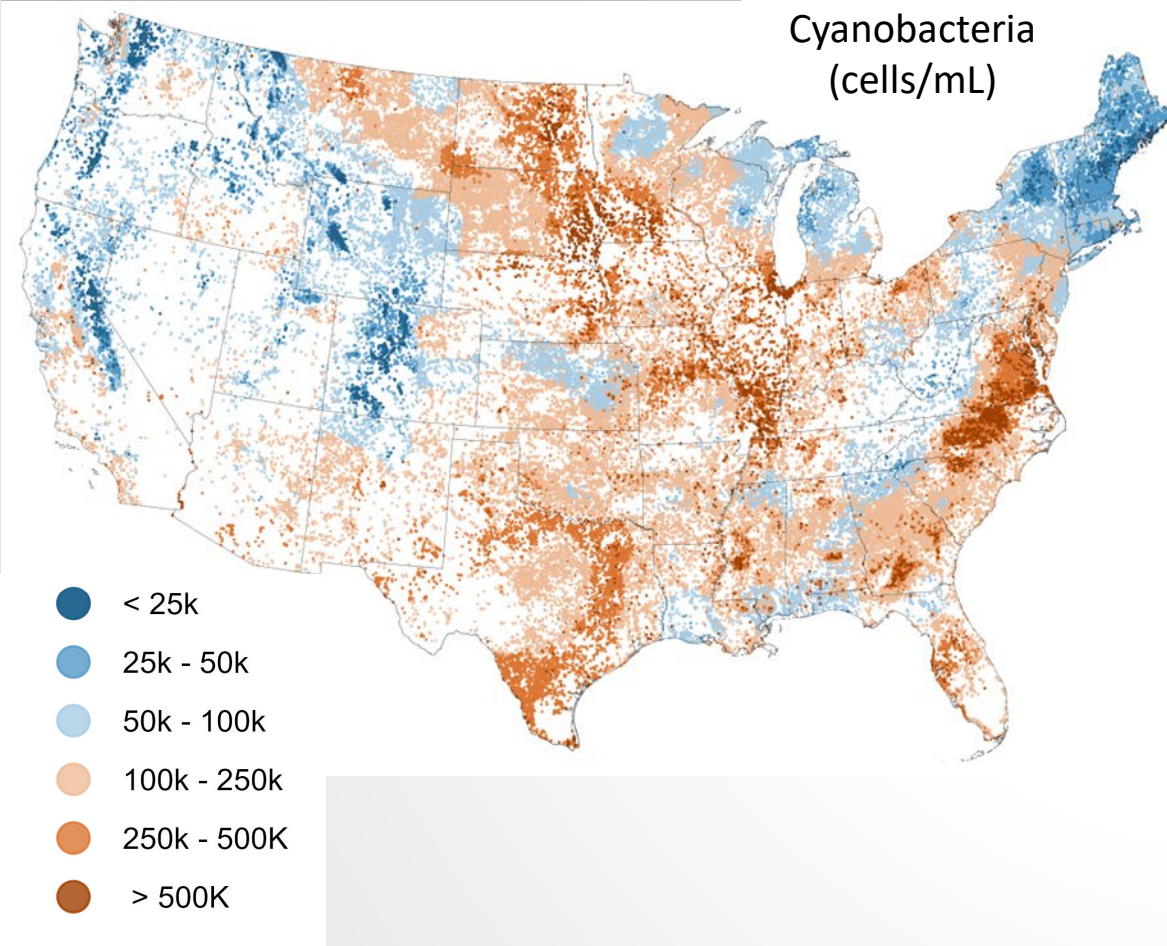
In-Lake Conditions	Cyanobacteria (R^2)	Microcystin Detection (AUC)
Included	0.52	0.87
Excluded	0.46	0.87





Predicted Cyanobacteria Abundance and Microcystin Detection for on-network lakes

127,000 lakes





Drivers and Predictions of CyanoHABs

- Models driven by nutrient inputs, geographic context, and lake morphology
- Human nutrient inputs important to cyanoHAB risk patterns at national scale
- Other non-nutrient drivers can refine understanding of risk
- Future work will expand to off-network lakes



Credit: US EPA

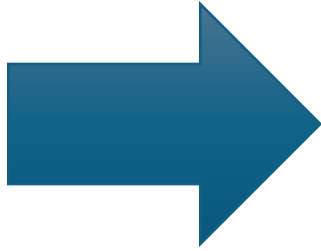
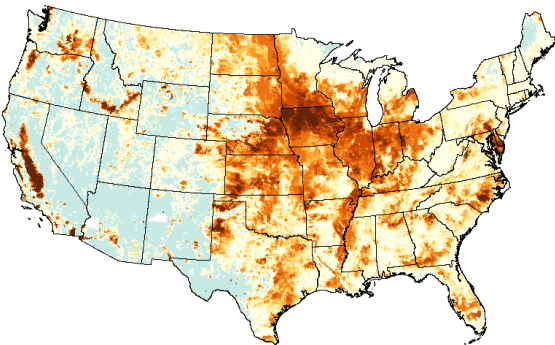
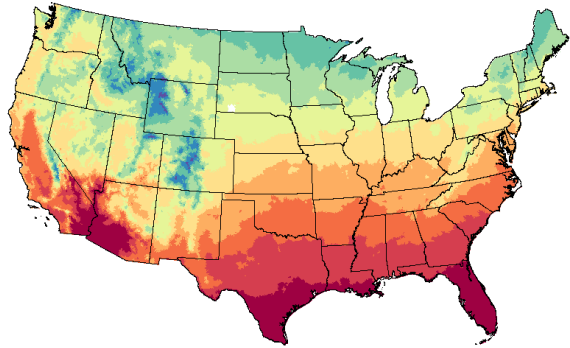
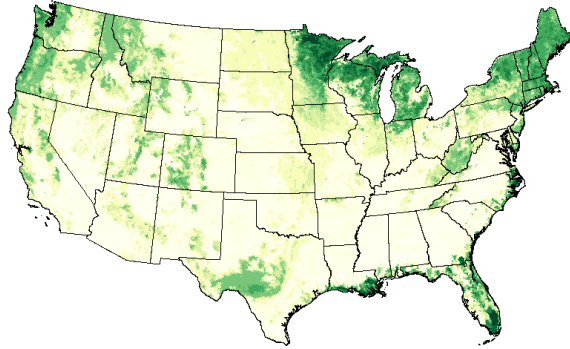
Modeling Watershed Nutrient Export and Trends

Goals

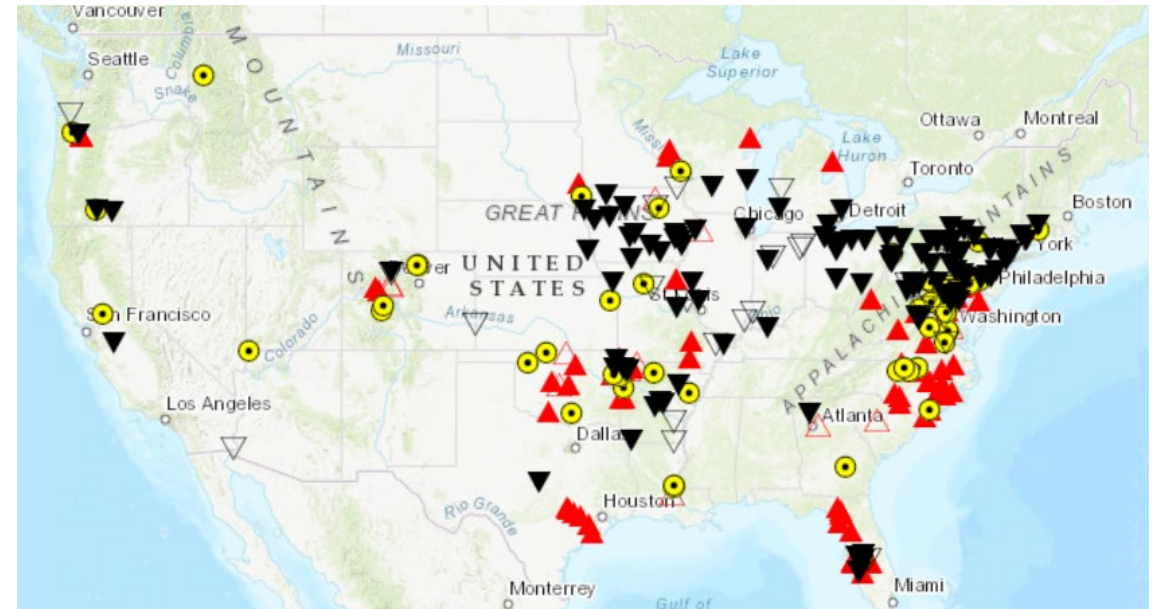
1. Directly supports nutrient reduction strategies being developed and implemented for the *Geographic Programs (FY26 EPA Congressional Justification)* and state partners.
2. Calibrate most advanced, predictive, and explainable deep learning models for a variety water quality endpoints

Please note, this work highlights our “big data” data and AI/deep learning model transition. Other water quality endpoints will be integrated into multi-response neural networks with the latest explainable AI features accessible via automated reports.

Link the NNI to USGS annual nutrient loads



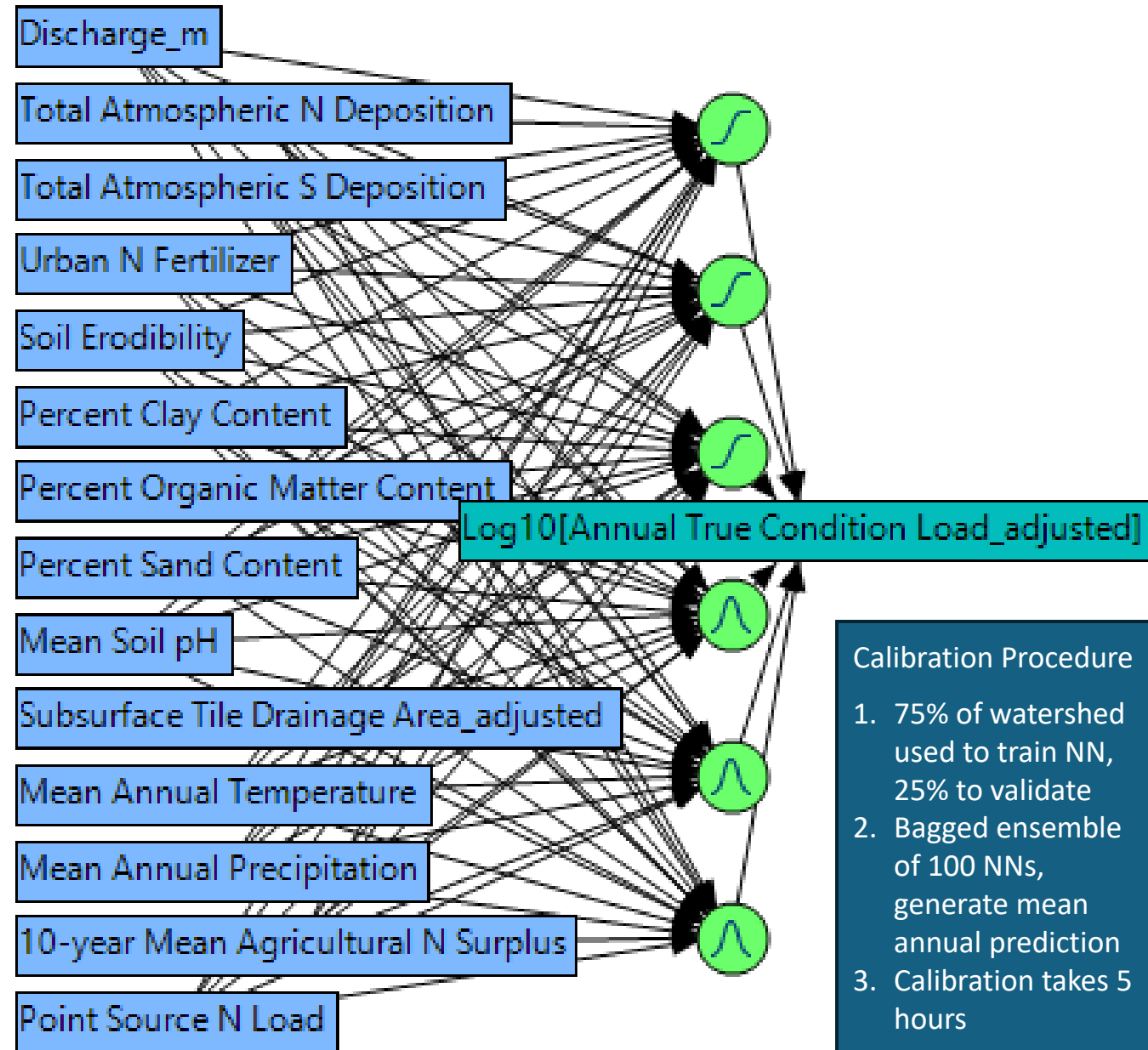
USGS “Water-Quality Changes” Stations (for Total Nitrogen)



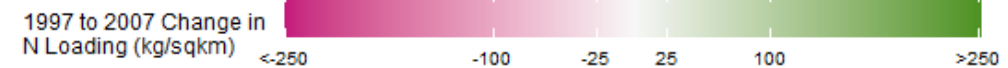
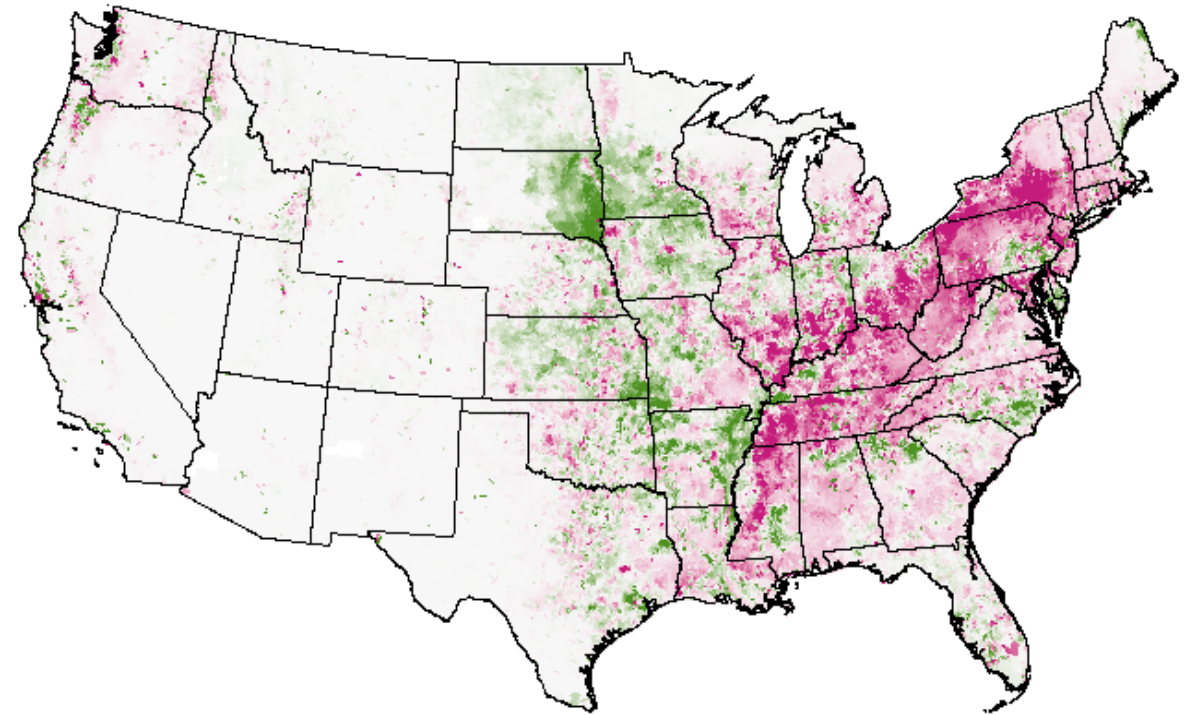
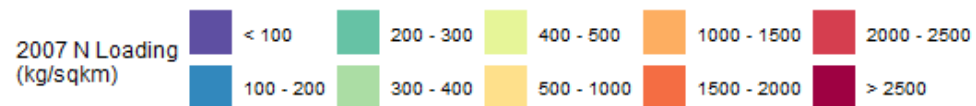
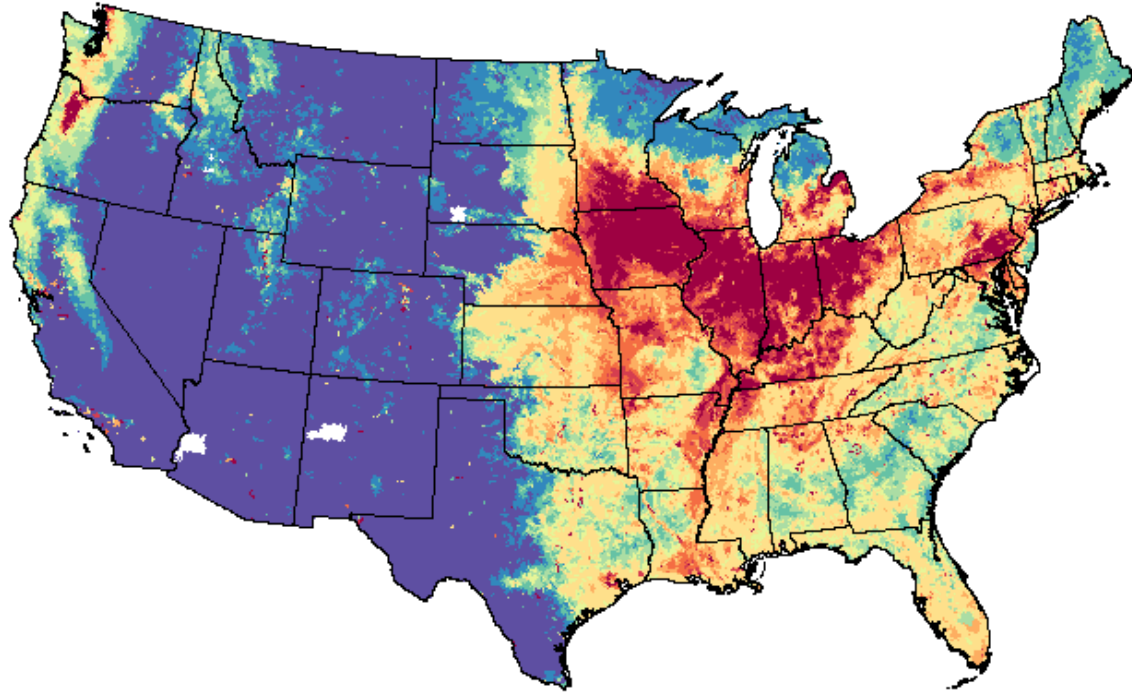
National Nutrient Inventory, climatic, and soil characteristic variables were matched to hundreds of watersheds with annual nitrogen and phosphorus loading estimates across the United States.

What is a neural net (NN)?

- A type of deep learning model
 - **Driven by data, not model assumptions/parameterizations**
- Function of a set of derived inputs, called hidden nodes (green circles)
 - Hidden nodes are nonlinear functions of the predictors
 - Predicted Y variable is a linear function of the nodes
- Efficiently model different response surfaces
- Results are sometimes not easily interpretable
 - Layers obfuscate the direct relationship between X and Y variables

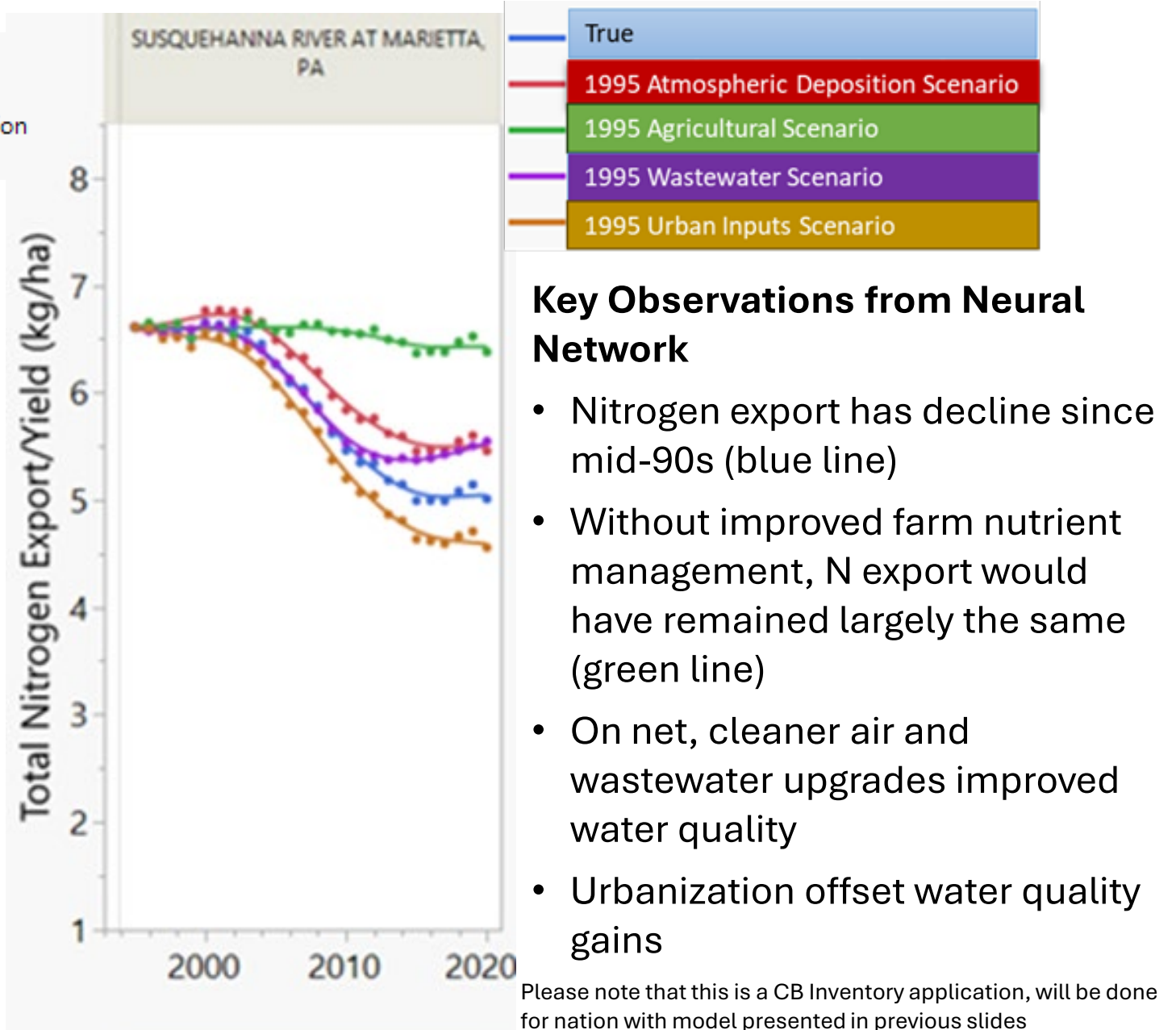
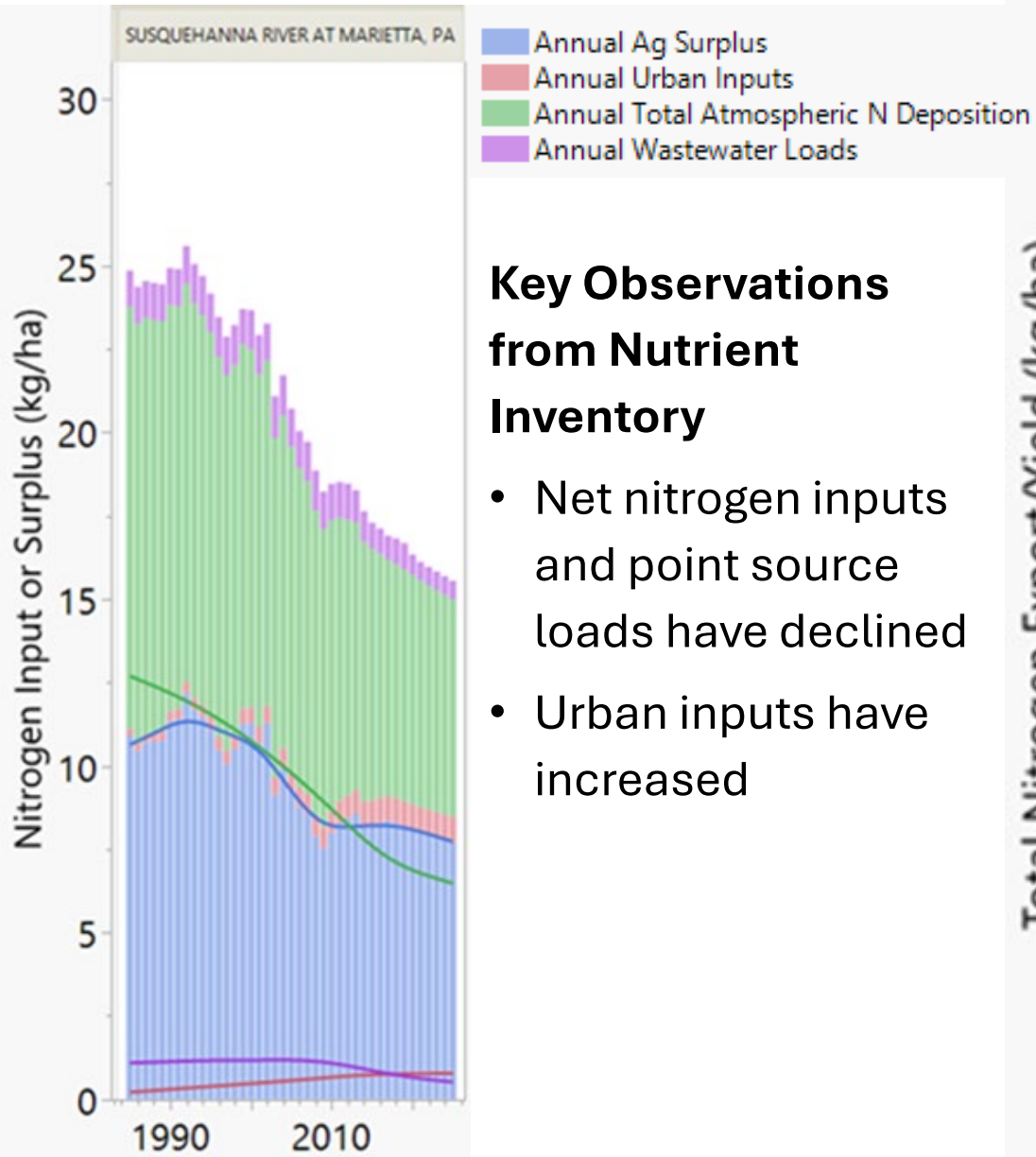


Counterfactual 1: Major urban and agricultural nitrogen pollution hotspots identified by NN and NNI



Note that these predictions rely on water yield maps that essentially describe “natural water yields” at HUC12 scale; thus, highly irrigated agricultural areas like the Central Valley of California and Southern Idaho will have low TN loading rates due to low precipitation rates. We plan to generate additional prediction maps of nitrogen loading that account for water yields greatly enhanced by irrigation.

Zoom into jurisdictions or watersheds



Conclusion and Next Steps

- NNI, STREAMCAT, and other environmental datasets are being paired and linked with water quality observations via powerful statistical and deep learning models
- Models are being applied to characterize likely water quality conditions across space and time as well as other novel applications
- NNI Team will continue to develop custom models for novel insights, **but a “master” multi-response neural network model is being developed to simultaneously explain multiple water quality endpoints**
- Conservation data can be rapidly integrated once a dataset is acquired
- Modeling results will be integrated into the [National Nutrient Inventory Explorer](#), automated report features, and various other prioritization schemes and tools

Example

Example

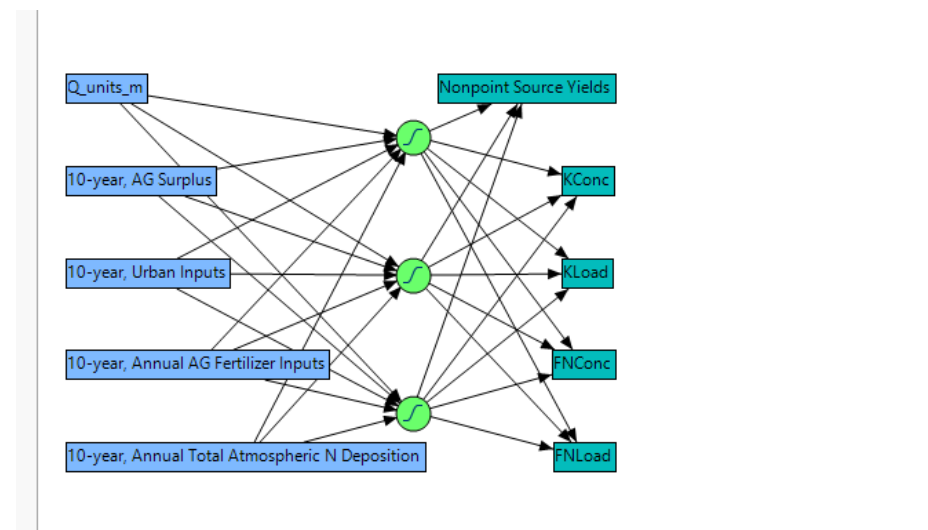


Figure 1. Schematic of simple multi-response NN, will work with partners on predictors and response variables to include.

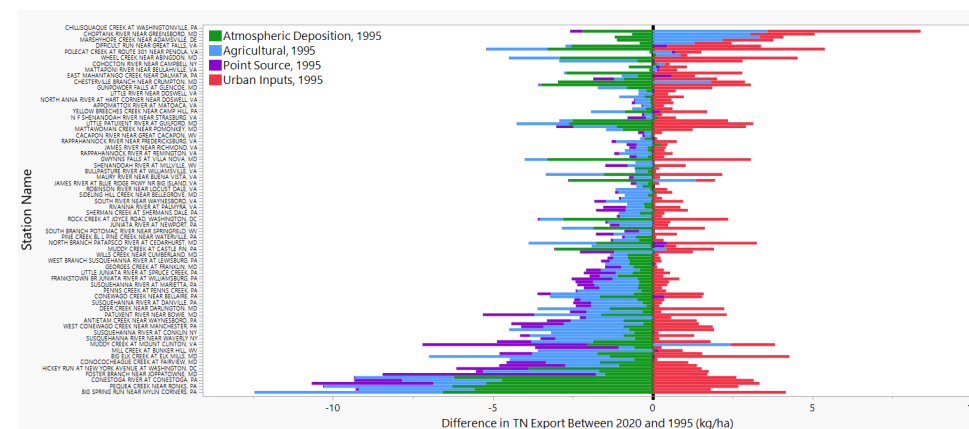


Figure 2. NN inference into net impact of specific nutrient source drivers for monitoring stations throughout Chesapeake Bay. These results/reports can be generated at multiple scales.

Presentation Outline

- **Introducing EPA's National Nutrient Inventory (NNI)**
 - What's in the inventory? How is it assembled?
 - Source, Extent and Trajectory of nutrient data
 - Precision and accuracy
- **Applying NNI to national, regional and local water quality**
 - River, stream and lake nutrient predictions – national
 - Drinking water nitrate risk – national and local (Oregon)
 - Big data, deep learning models
- **Making NNI actionable for decision makers**
 - Targeting nutrient reductions – strategic approaches to inform implementation
 - National Nutrient Inventory Explorer
 - Custom reports and analyses, publicly available papers and datasets
- **Answering questions and discussion of potential uses**

Making NNI Actionable for Decision Makers



Journal of Environmental
Management

Volume 351, February 2024, 119758



Research article

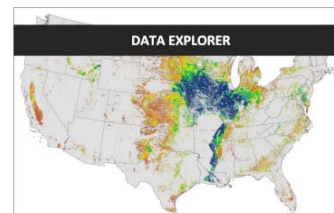
Our national nutrient reduction needs: Applying a conservation prioritization framework to US agricultural lands

Lily Kirk^a  , Jana E. Compton^b, Anne Neale^c, Robert D. Sabo^d, Jay Christensen^e

Nutrient Inventory Explorer



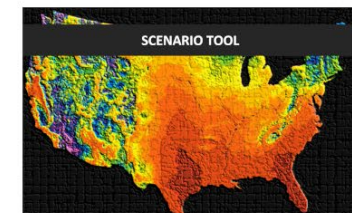
The nutrient inventory tool is a web tool to visualize nitrogen and phosphorus inventories as well as modeled changes annual export for drinking water across the contiguous United States.



Dive deep into the existing dataset and look at nutrient fluxes related to agriculture, the atmosphere, urban areas, and natural processes



See how the National Nutrient Inventory is used to predict the export of nutrients to waterways and the contamination of drinking water

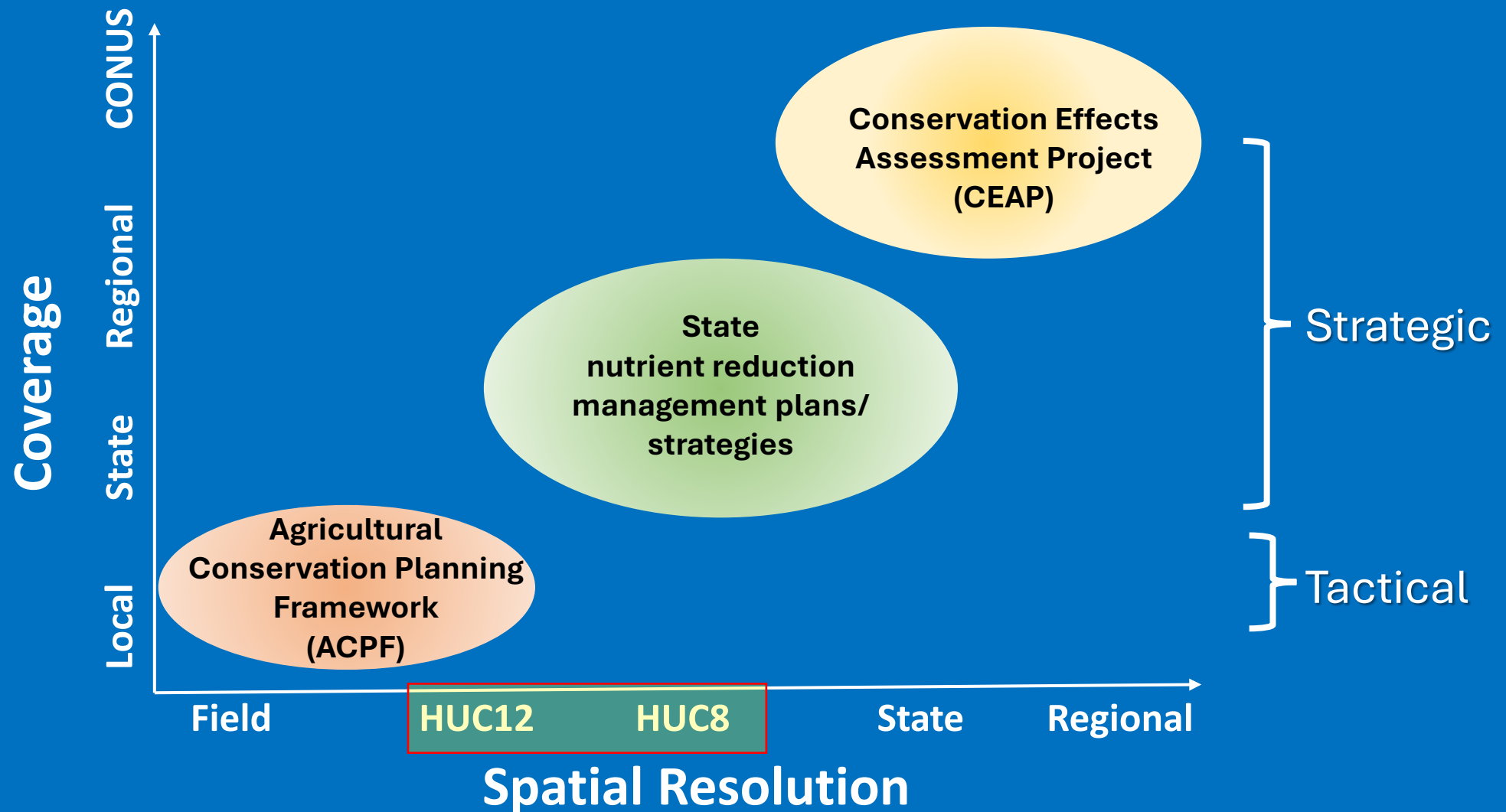


Investigate how alternative choices could change the future of nutrient pollution

Developing a conservation prioritization framework for agricultural lands



What are conservation approaches that lead to nutrient reduction?

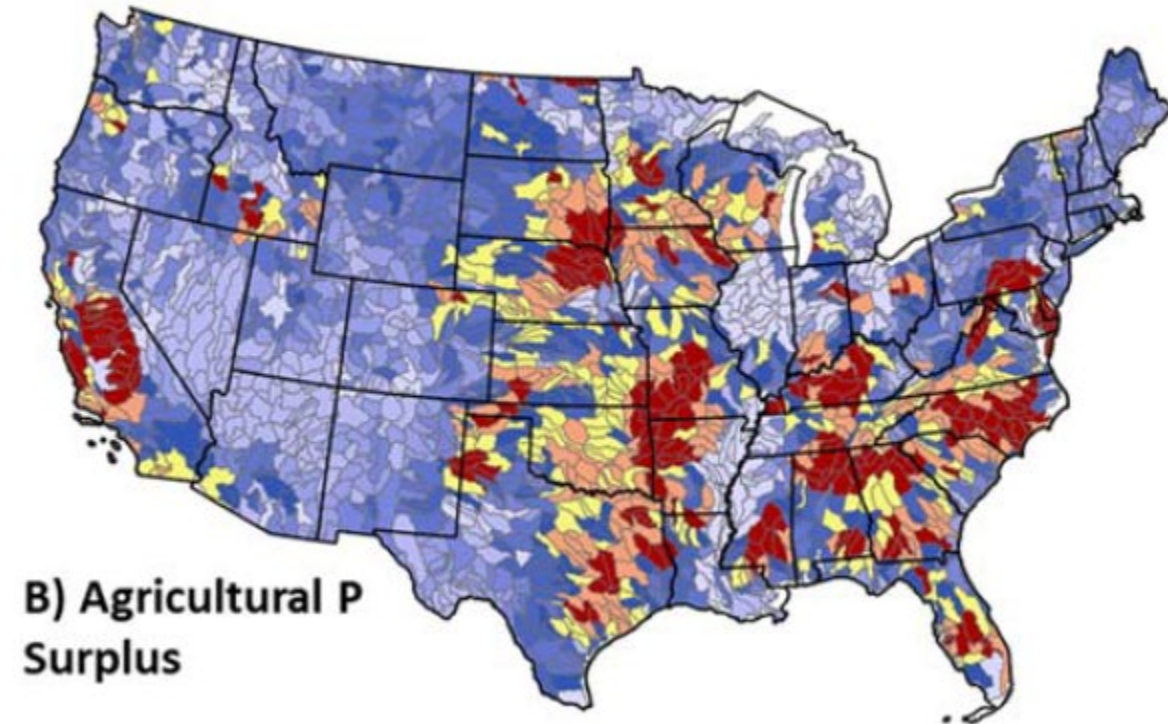
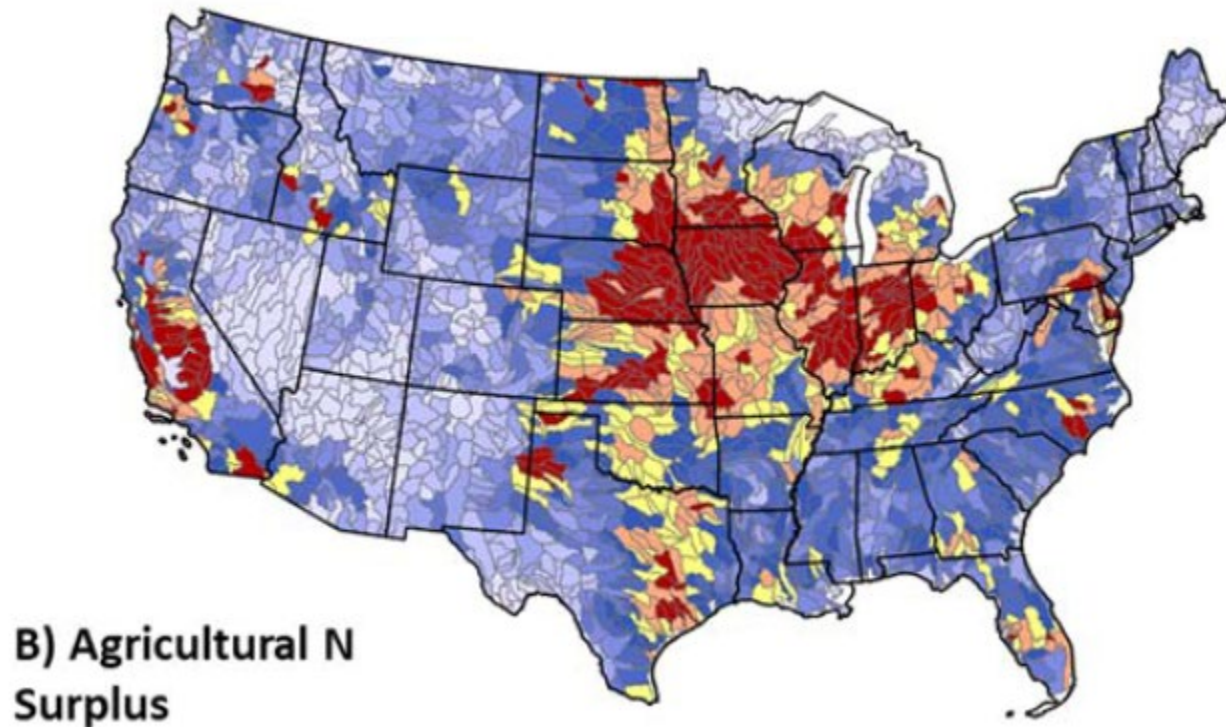


Prioritization: **Where?** How?

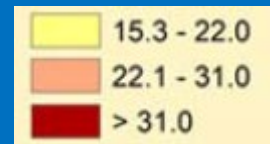
National Nutrient
Inventory (NNI)

Surplus = Inputs – Outputs

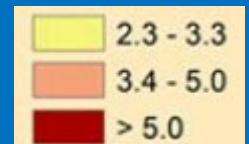
Surplus = Fertilizer + NFix + AtmDep + LivestockWaste – Crop



Sabo et al. (2021) ERC

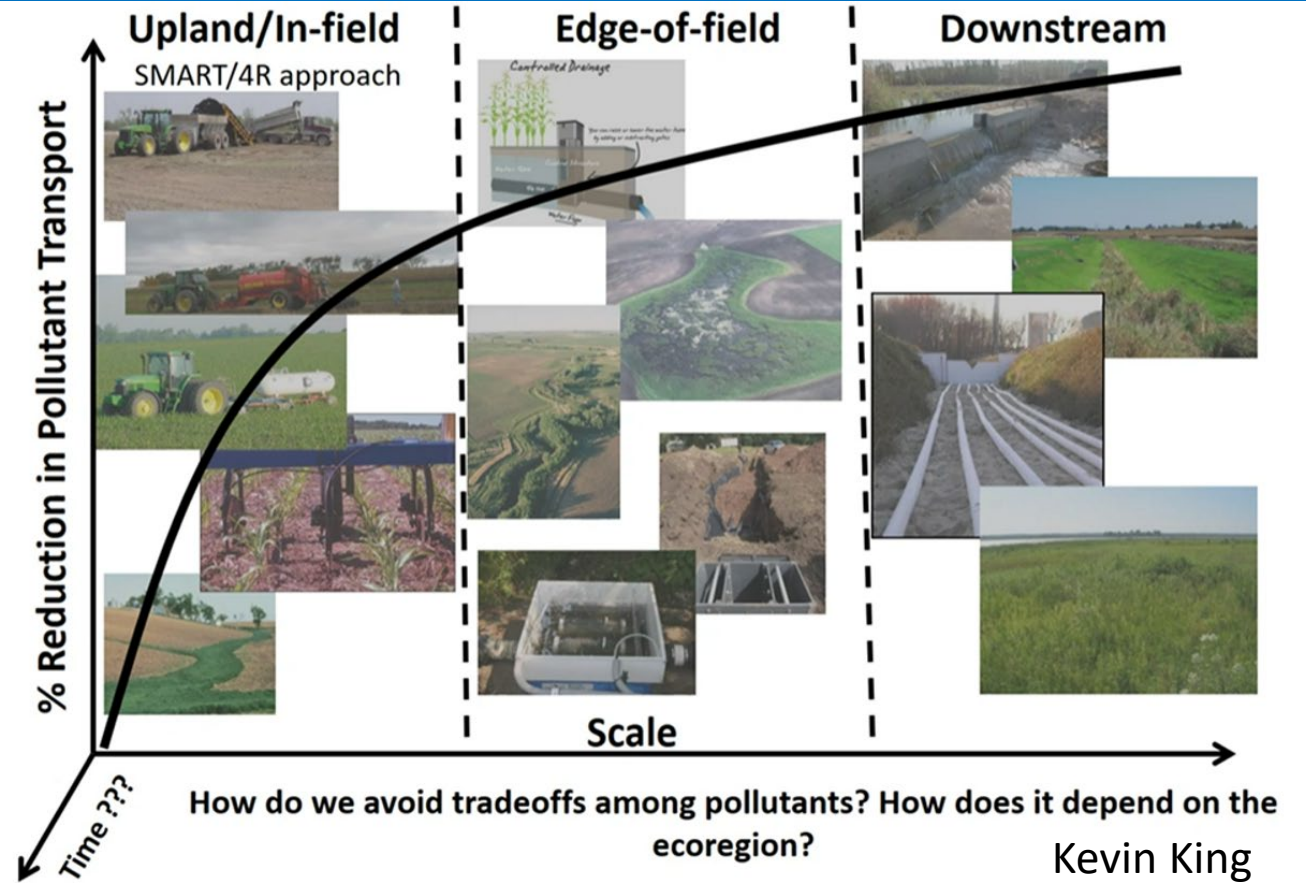
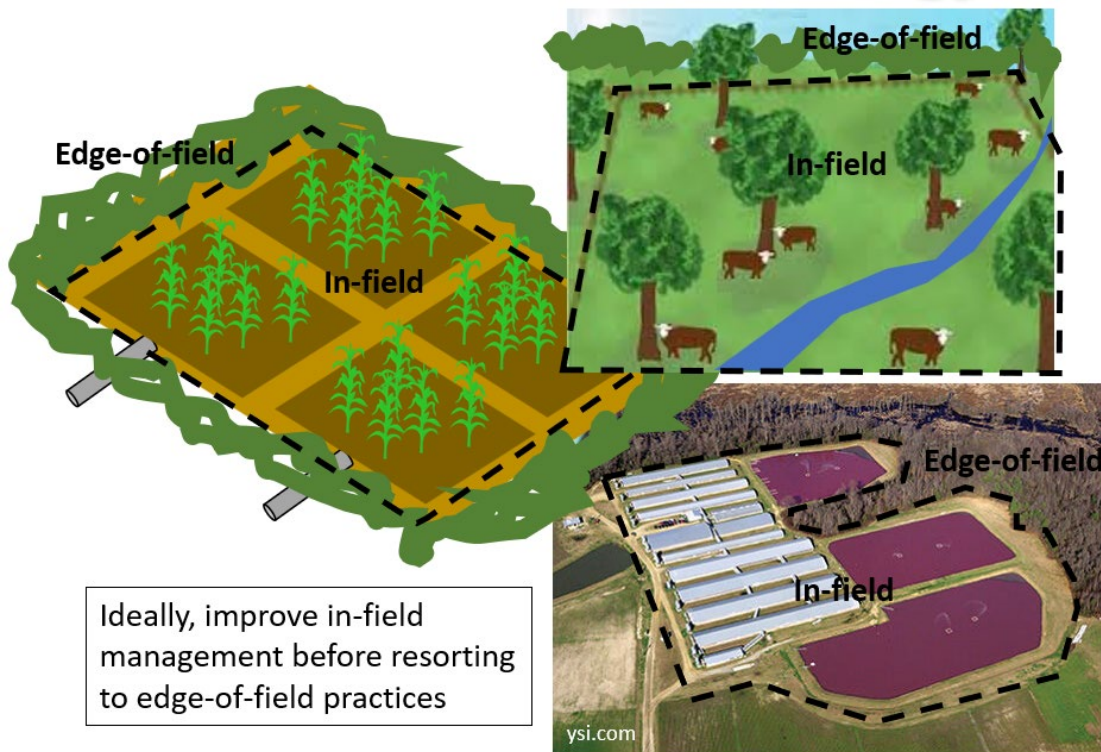


kg-N ha⁻¹ y⁻¹

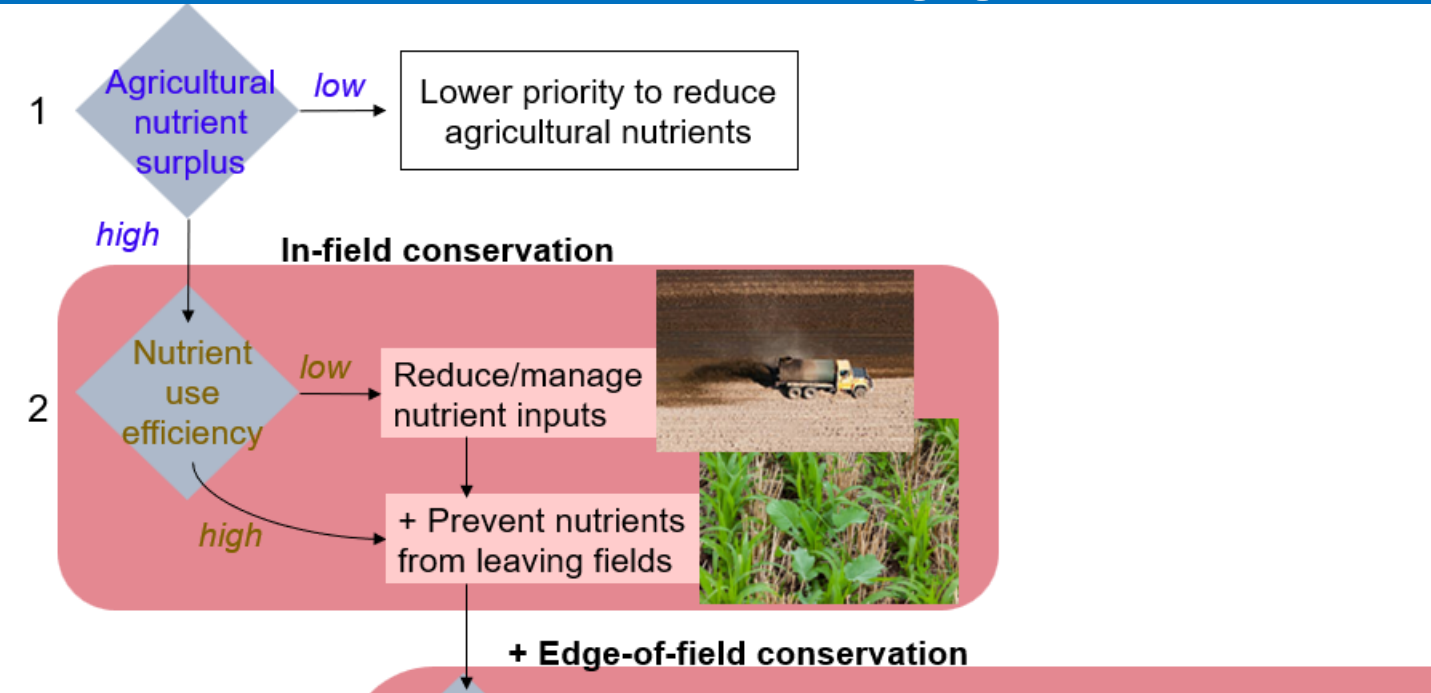


kg-P ha⁻¹ y⁻¹

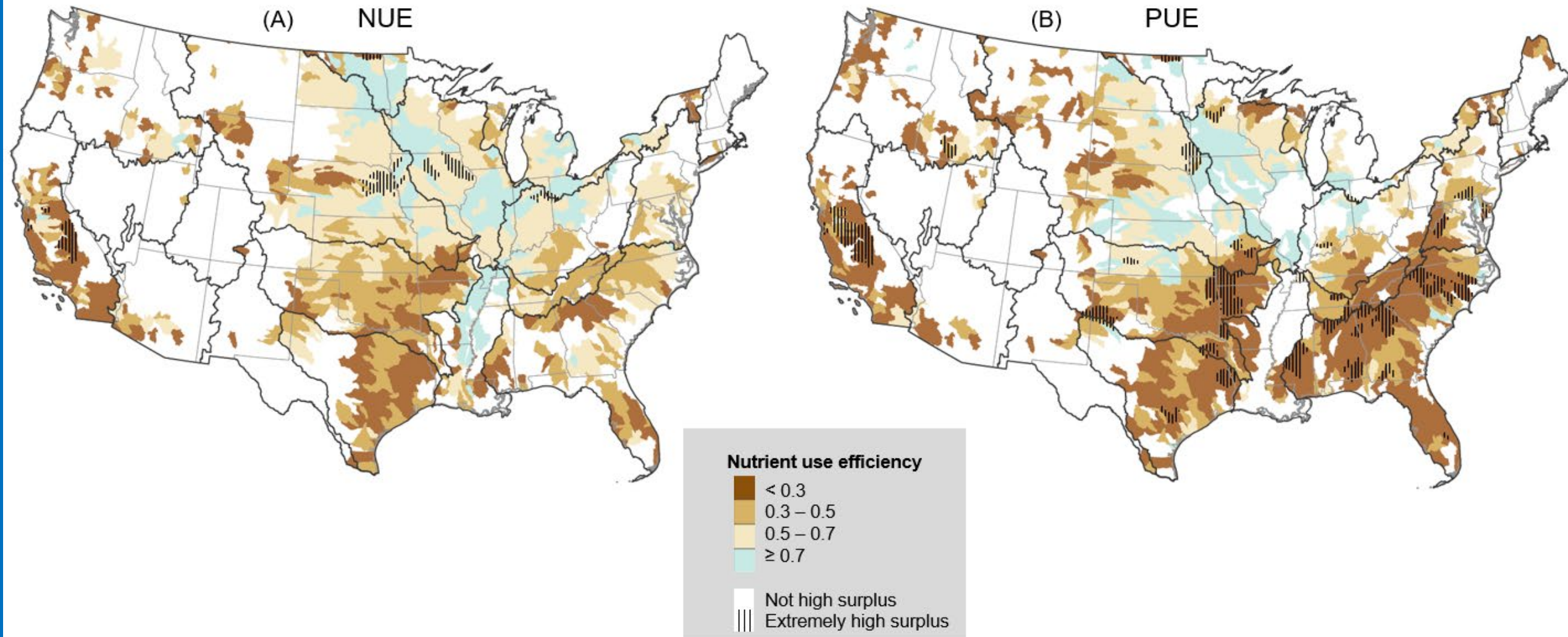
Prioritization: Where? **How?**



Prioritization Approach



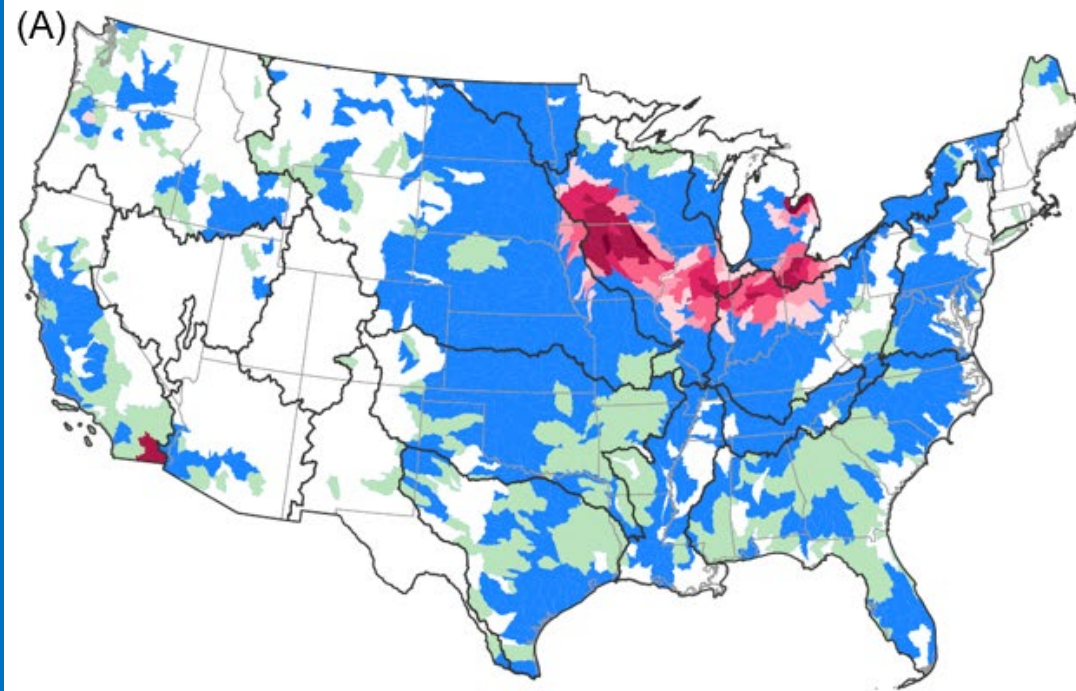
Agricultural Nutrient Use Efficiency



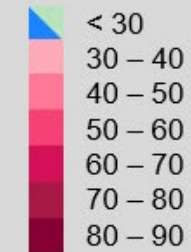
Agricultural landscape metrics

EnviroAtlas

www.epa.gov/enviroatlas



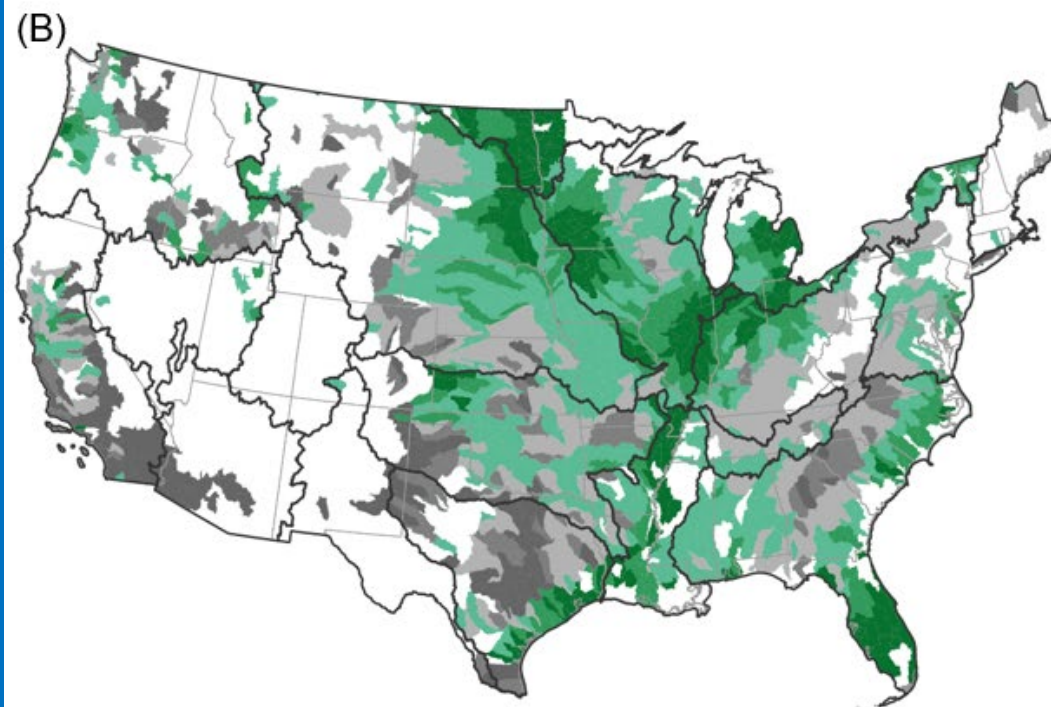
Tile drainage
(% of agricultural land)



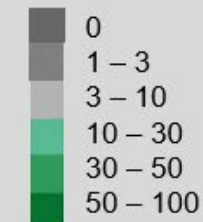
Light Green
Additional buffers
probably not priority

Blue/Red
Could benefit from natural
buffers between agricultural
fields and streams

White
Not high surplus



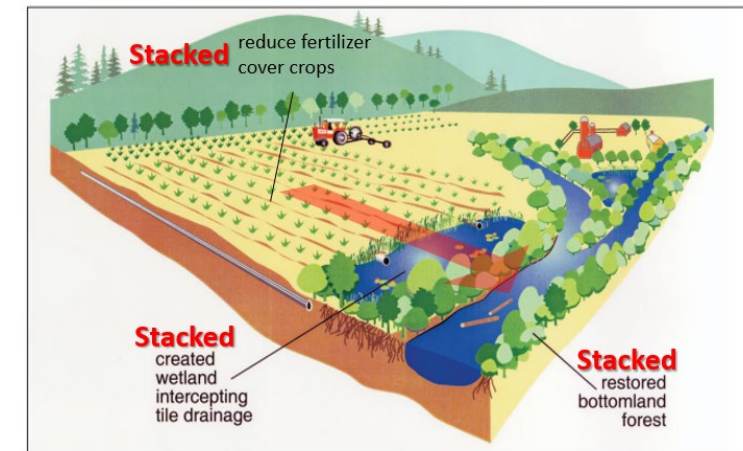
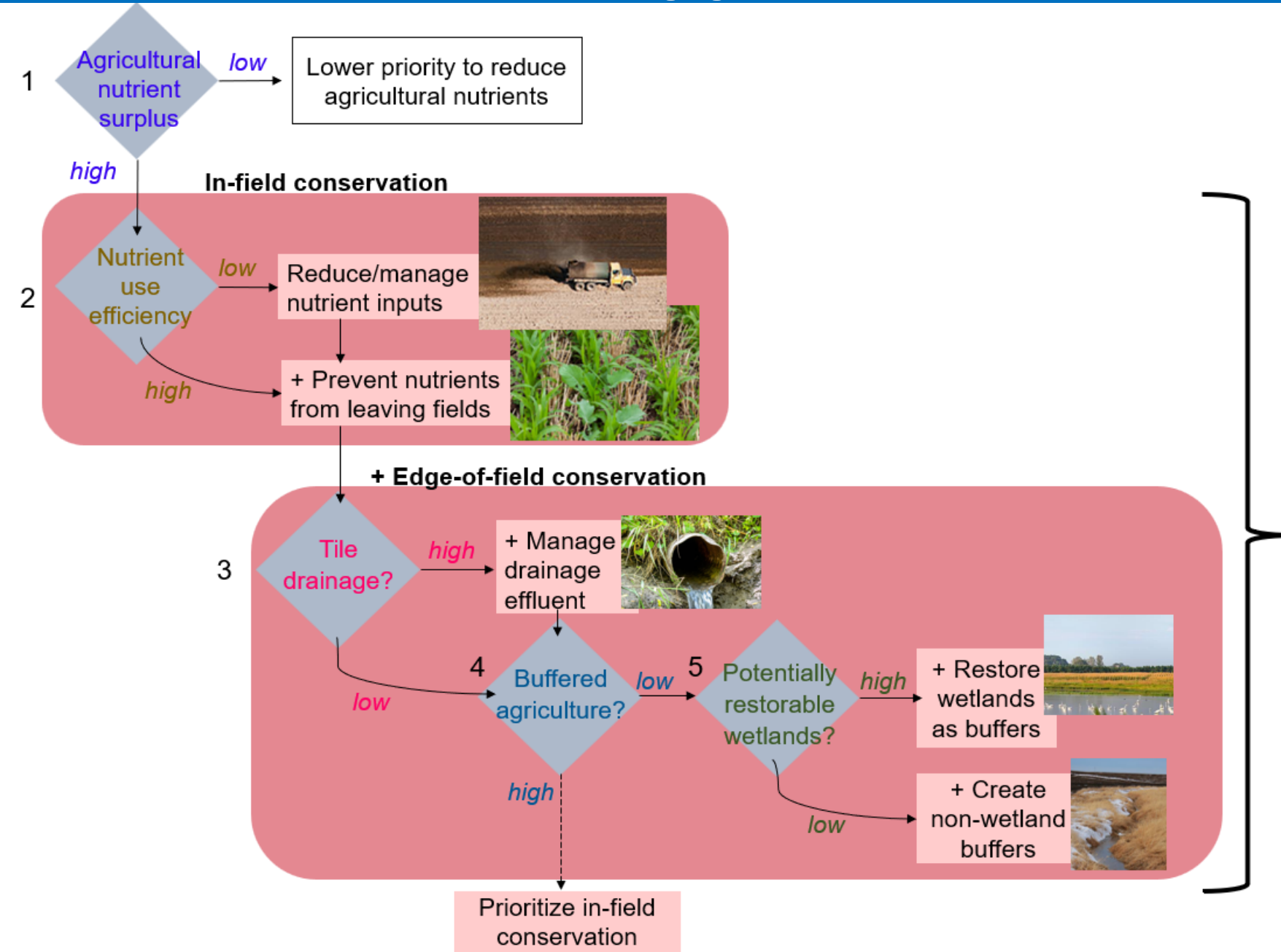
Potentially restorable wetlands
(% of agricultural land)



White
Not high surplus

Lily Kirk et al. 2024 JEM

Prioritization Approach



Mitsch et al (2001)

CONUS results

Conservation strategies

Prioritize in-field conservation

- Reduce nutrient sources + Prevent nutrients from leaving fields
- + Manage drainage + Restore wetlands
- + Manage drainage + Create non-wetland buffers
- + Restore wetlands
- + Create non-wetland buffers

Prioritize edge-of-field conservation

- Prevent nutrients from leaving fields
- + Restore wetlands
- + Manage drainage + Restore wetlands
- + Create non-wetland buffers

Not high surplus

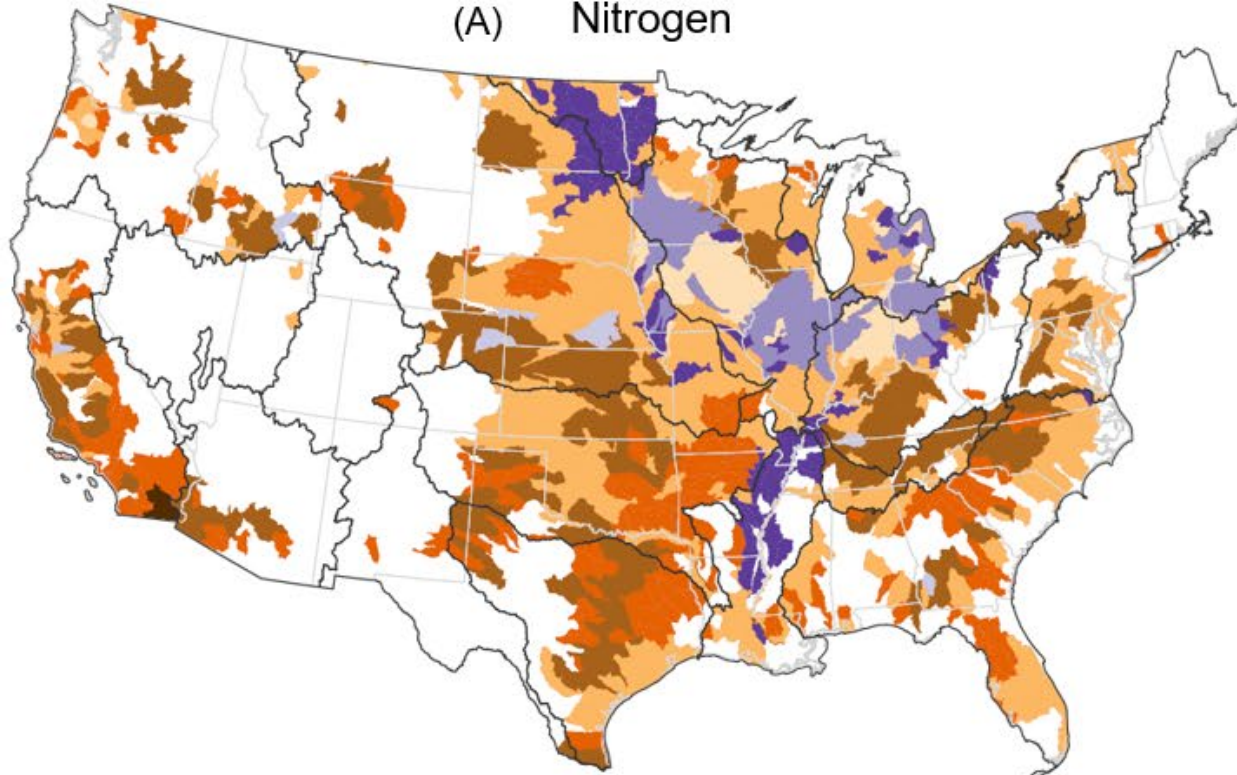
Low Nutrient
Use Efficiency

High Nutrient
Use Efficiency

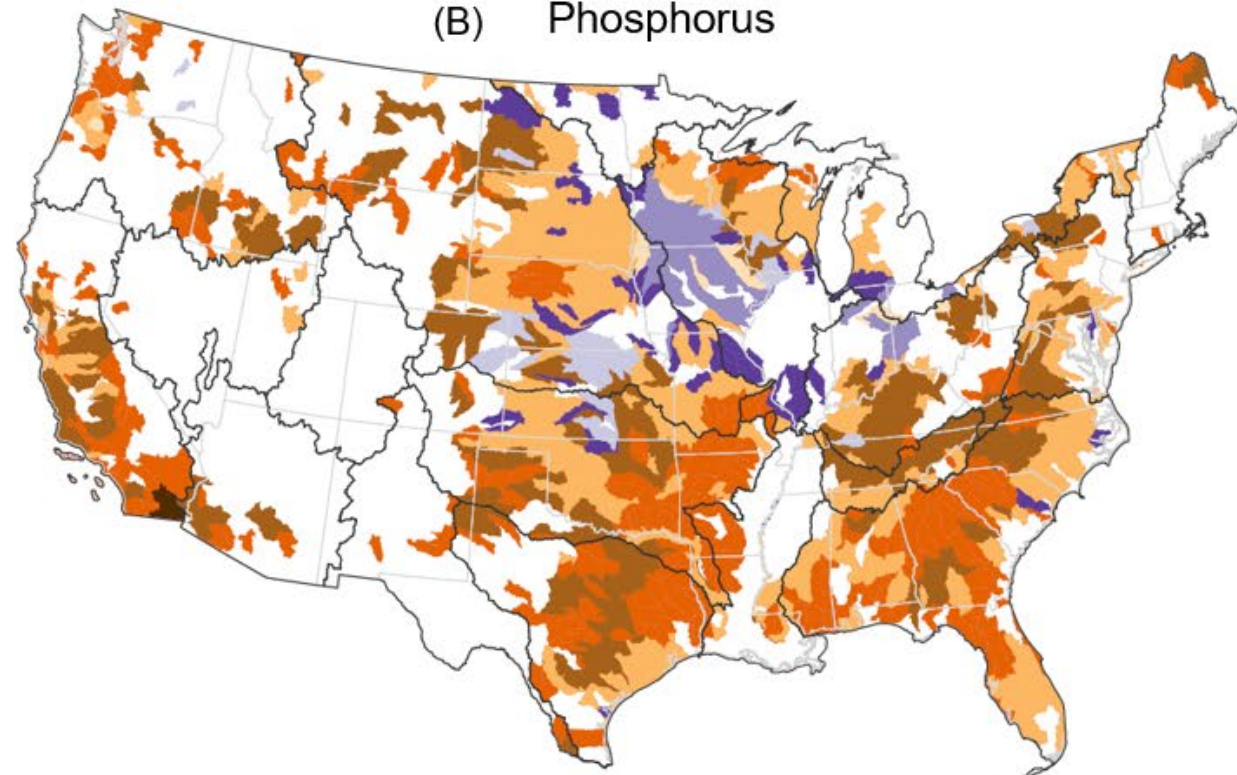
High
Surplus

Lily Kirk et al. 2024 JEM

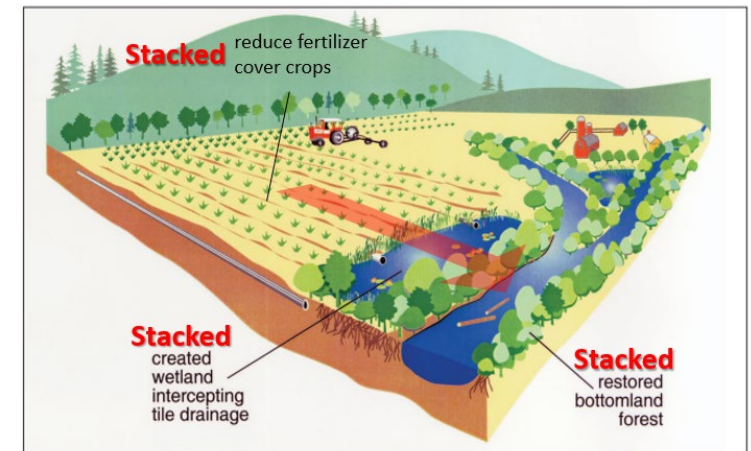
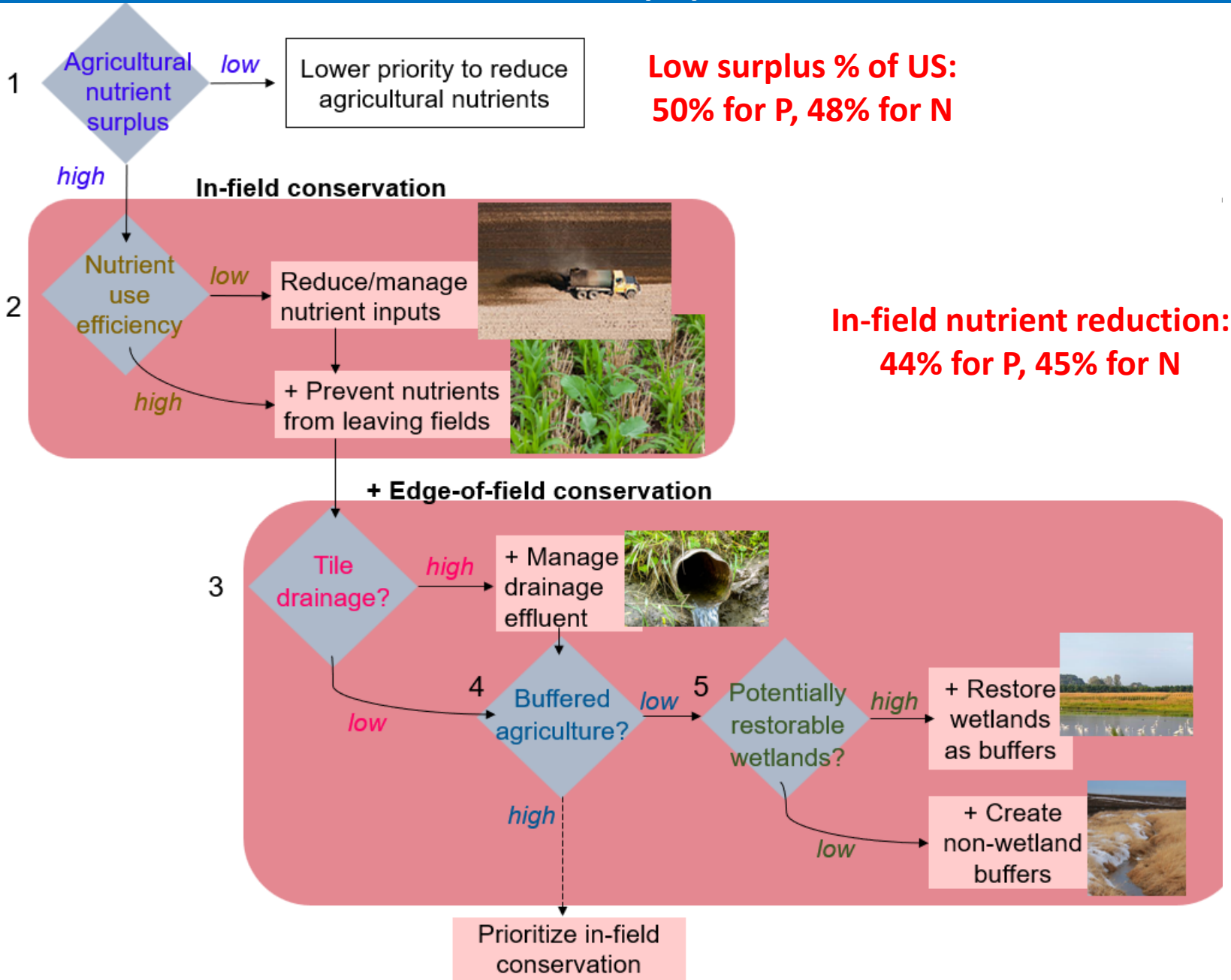
(A) Nitrogen



(B) Phosphorus



Prioritization Approach



Mitsch et al (2001)

Stacking in-field and edge-of-field:
29% for P, 35% for N

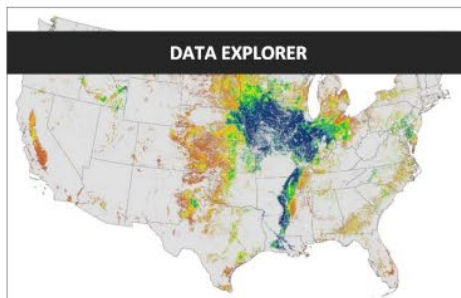
Lily Kirk et al. 2024 JEM

Making NNI Actionable for Decision Makers

Nutrient Inventory Explorer



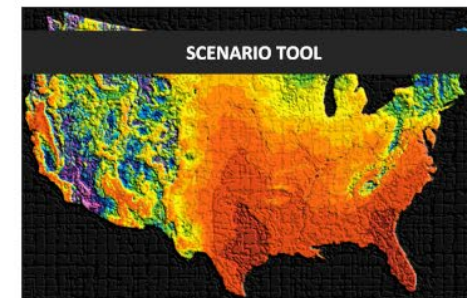
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See how the National Nutrient Inventory is used to predict the export of nutrients to waterways and the contamination of drinking water



Investigate how alternative choices could change the future of nutrient pollution

Meeting Objectives

- **Clearly communicate the National Nutrient Inventory information and availability**
- **Present examples of how we connect the inventory to water quality response**
- **Answer questions you have**
- **Identify potential use cases with state CWA partners**
 - What can we do together to help with nutrient issues in your work?

Contact us with questions and opportunities to work together

Robert Sabo sabo.robert@epa.gov

Jana Compton compton.jana@epa.gov

US Environmental Protection Agency, Office of Research and Development

*CWA Cross-Program Coordination to Improve
Nutrient Management and Address Nutrient Pollution*

July 22, 2025