EPA Tools & Resources Training Webinar: Enhancing Nutrient Reduction Efforts with the National Nutrient Inventory

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Webinar Objectives

After this webinar, participants will be able to:

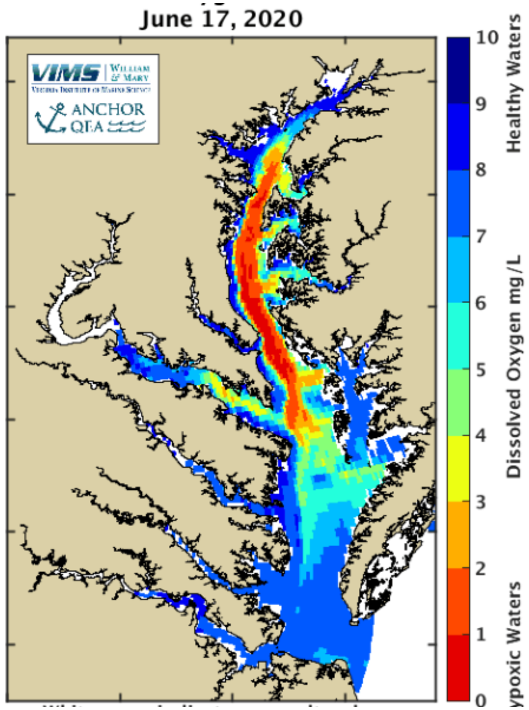
1. Understand the basic premise of a nutrient inventory and its integration into predictive water quality models and tools

2. Identify what products from the National Nutrient Inventory Research portfolio (NNI) can be used to enhance states' and tribes' nutrient reduction strategies to efficiently achieve safe drinking water and surface water quality goals

3. Anticipate and provide critical feedback on reports, databases, and web-based visualization tools that highlight NNI's big data and deep learning/AI transition

Excess nutrients lead to challenges

- We need nutrients to feed, power, and clothe our nation and the world, BUT…
- Excess **nitrogen** and **phosphorus** pollution to waterways drives:
  - Dead zones (oxygen deprived waters)
  - Harmful algal blooms
  - Drinking water contamination
  - Ecological impacts
- Is costly due to annual direct cost for mitigation and indirect cost (e.g., lost revenues)—billions of dollars
- Endangers human health



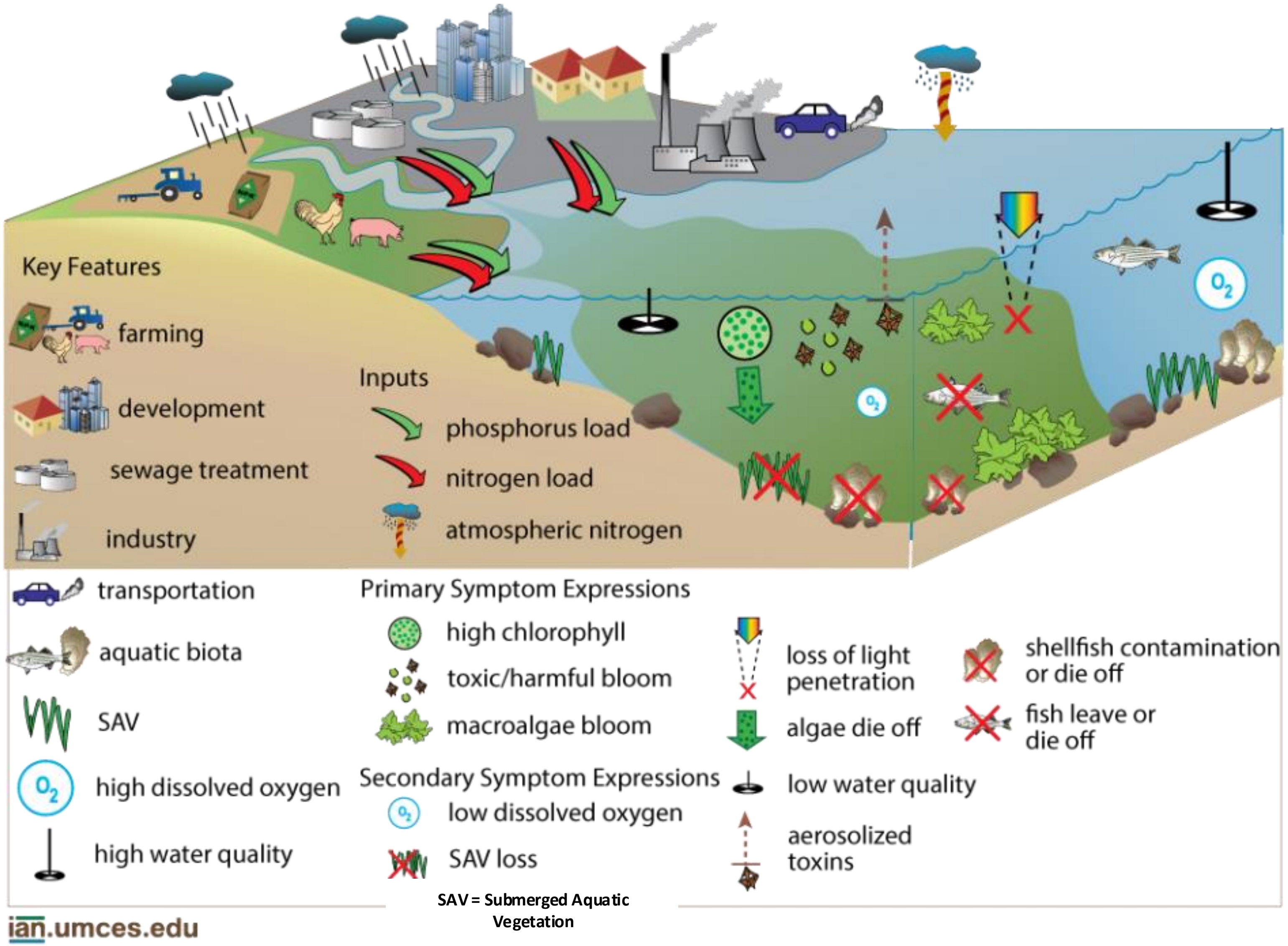
VIMS. Recurrent hypoxia in Chesapeake Bay and Gulf of America compromises fisheries.

USEPA. A satellite image of a cyanohab event occurring Lake Erie in the fall of 2022.

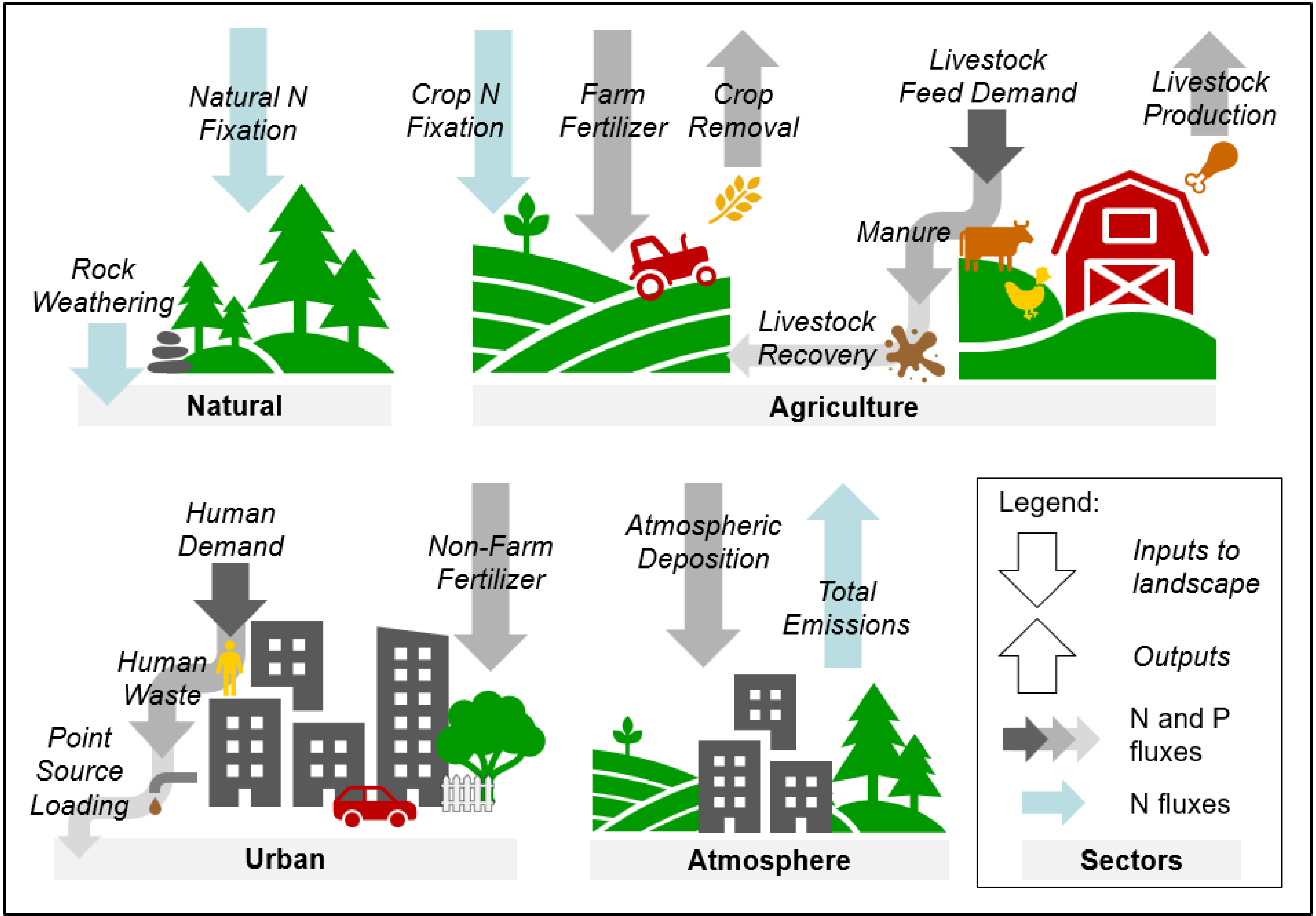
USEPA. Excess nutrient loading contributes to formation of harmful algal blooms (HABs) that are sometimes toxic. HABs directly compromise recreational opportunities, drinking water resources, and fisheries and indirectly impact tourism, property values, and other sources of revenue.

Nutrient Inventories can help efficiently tackle nutrient pollution

- EPA's National Nutrient Inventory (NNI) tracks inputs and outputs at multiple watershed and jurisdictional scales
- Allows users to look upstream
- Compares the magnitude of agricultural, urban, atmospheric, and natural background sources of nutrients



Eutrophication is one of the major factors contributing to the increase in harmful algal blooms in the Chesapeake Bay.



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

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

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

<u>Trajectory</u>: Illustrate how pollution sources are evolving through time

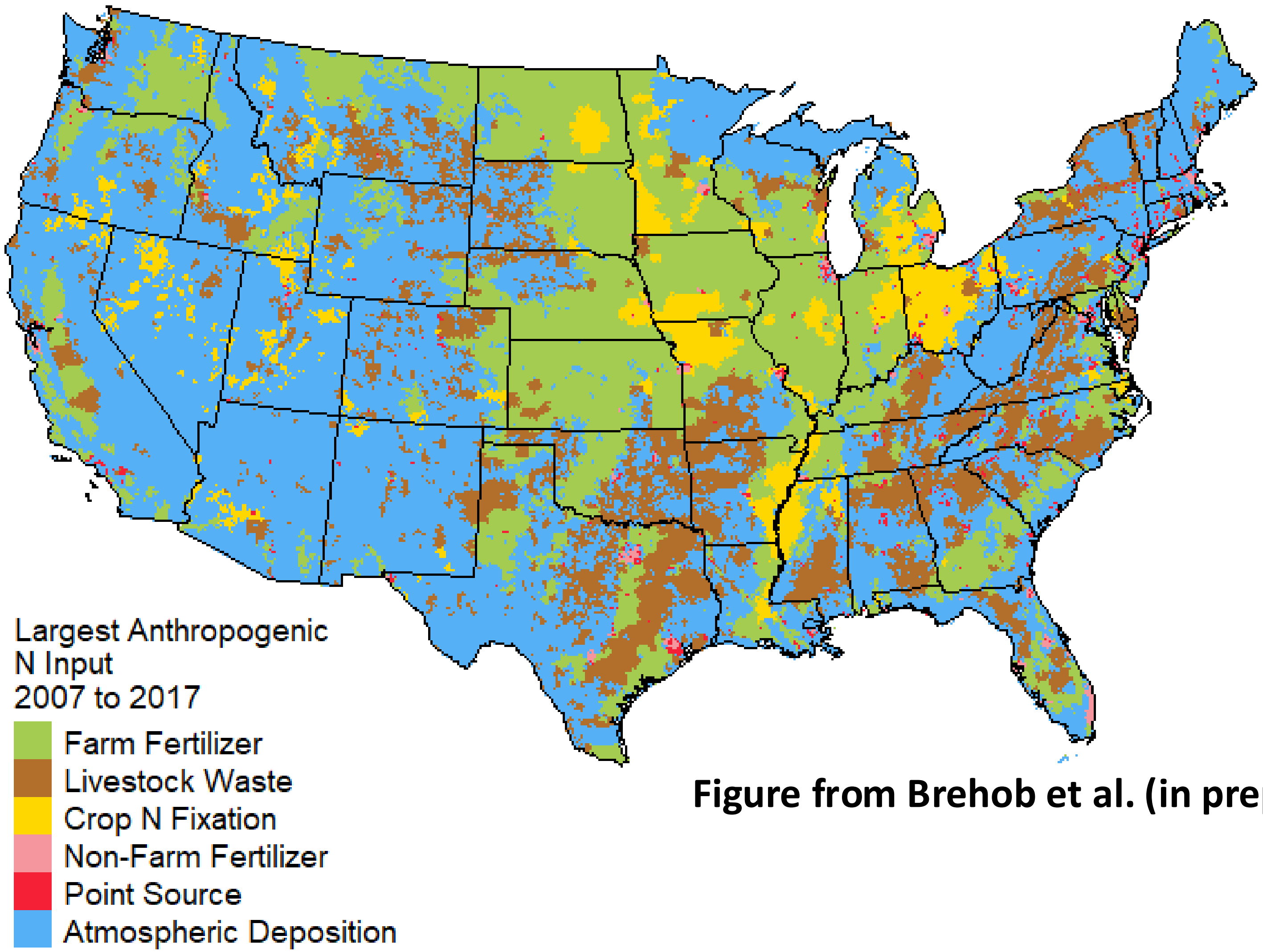
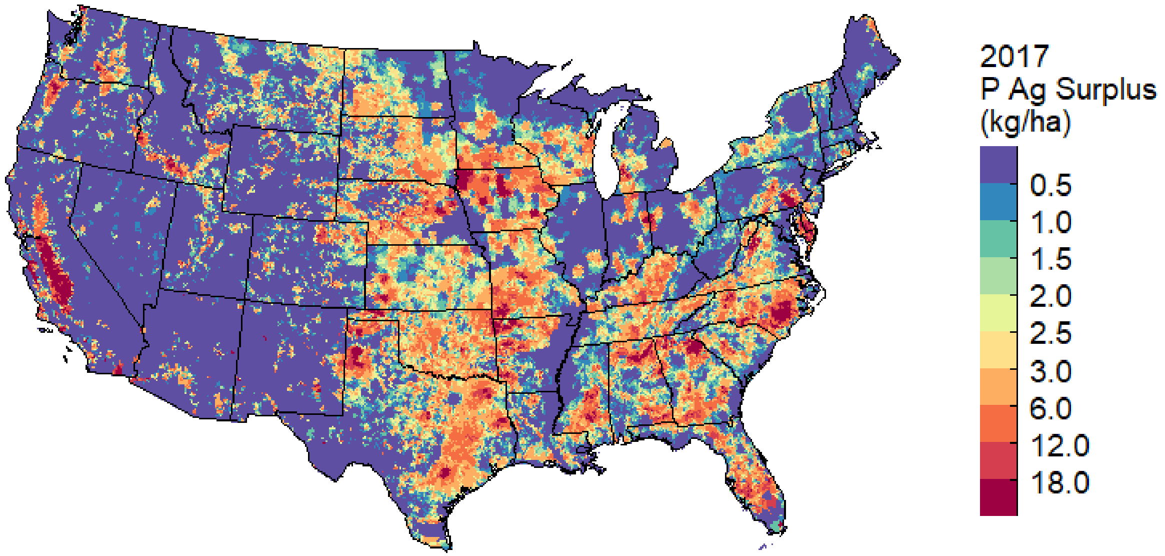


Figure from Brehob et al. (in prep)

Agricultural phosphorus surplus has declined in many major agricultural regions across the US

Agricultural Phosphorus Surplus

2017 Snapshot



Change from 1997 to 2017 (11-year rolling averages)

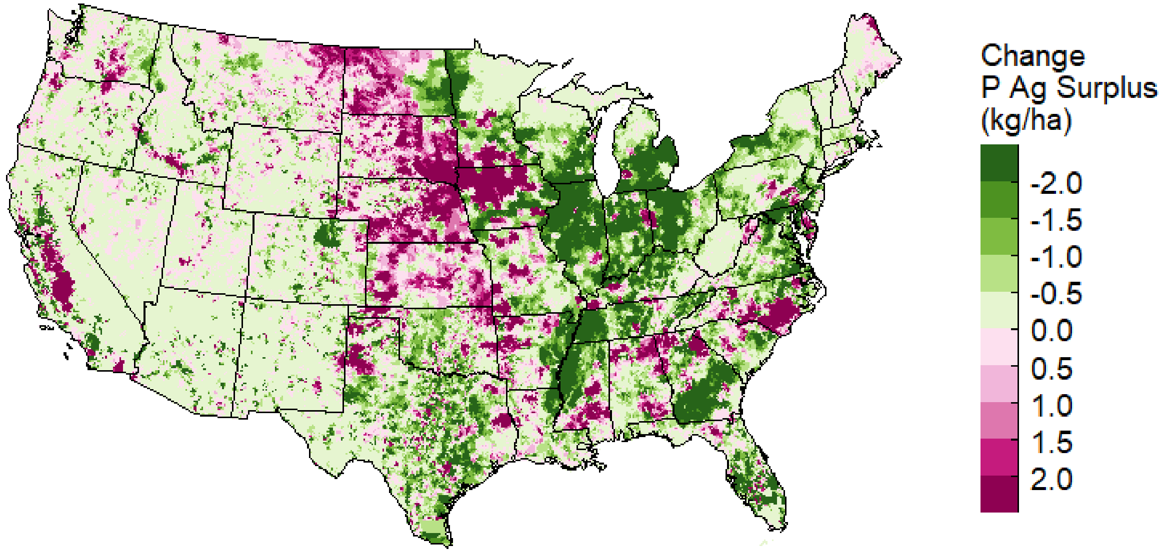


Figure from Brehob et al. (in prep)

How can I access over 20 current National Nutrient Inventory papers and datasets?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National Nutrient Inventory Portfolio

On this page:

- Project Overview
- Contact Us
- Publications
- Related Resources

The National Nutrient Inventory Portfolio is a multi-agency project that offers tools and datasets to help decision makers identify point and non-point source nitrogen and phosphorus pollution hotspots and link them to water quality conditions across the country. This portfolio supports federal, state, tribal, and local partners in their efforts to assess and improve water quality to benefit aquatic and human health.

Project Overview

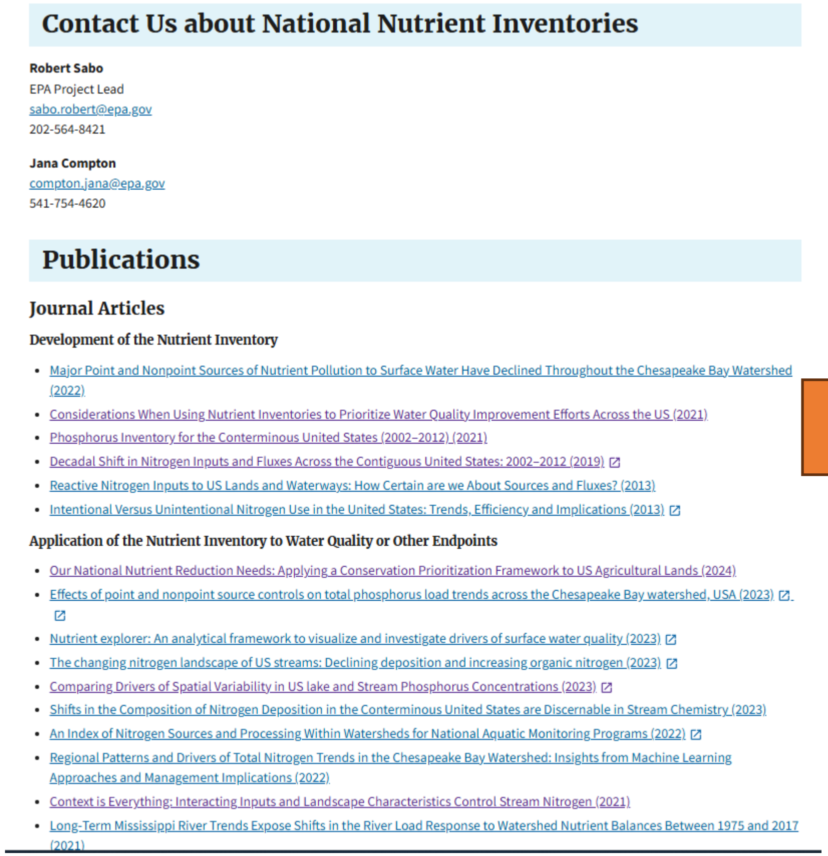
The mission of the nutrient inventories project is to assist with tracking major fluxes of nutrients across agricultural, natural, and urban environments. These inventories provide users with databases to help them identify the potential types and sizes of nutrient pollution sources in their locality, and how these nutrient pollution sources are influencing local and downstream water quality conditions.

Goals

- Develop nationwide, region-specific, and locally downscaled nutrient inventories based on client/partner feedback and guidance.
- Determine metrics that best approximate point and non-point source pollution and are effective components of watershed restoration plans.
- Relate shifts in nutrient sources to observed water quality conditions to highlight success stories and ongoing/emerging challenges in reducing nitrogen and phosphorus pollution to waterways.

Outcomes

- Inventories are used to track how nutrient pollution sources are evolving across the landscape and explain nutrient concentrations in surface and ground water through models. These models can be used to predict aquatic ecosystem condition in other unmonitored areas.
- Inventories can be incorporated into existing models and restoration planning schemes to provide current data on nutrient input and management conditions.
- The National Nutrient Inventory Explorer (NNIE) tool, an online visualization and data download platform, is anticipated to be


Contact Us about National Nutrient Inventories

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Publications

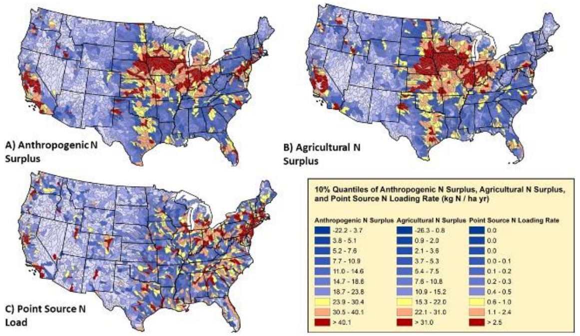
Journal Articles

Development of the Nutrient Inventory

- Major Point and Nonpoint Sources of Nutrient Pollution to Surface Water Have Declined Throughout the Chesapeake Bay Watershed (2022)
- Considerations When Using Nutrient Inventories to Prioritize Water Quality Improvement Efforts Across the US (2021)
- Phosphorus Inventory for the Conterminous United States (2002–2012) (2021)
- Decadal Shift in Nitrogen Inputs and Fluxes Across the Contiguous United States: 2002–2012 (2019)
- Reactive Nitrogen Inputs to US Lands and Waterways: How Certain are we About Sources and Fluxes? (2013)
- Intentional Versus Unintentional Nitrogen Use in the United States: Trends, Efficiency and Implications (2013)

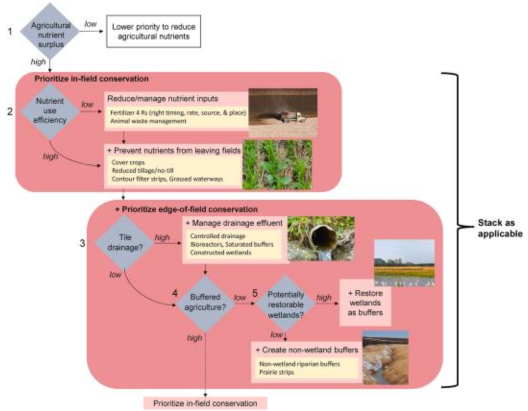
Application of the Nutrient Inventory to Water Quality or Other Endpoints

- Our National Nutrient Reduction Needs: Applying a Conservation Prioritization Framework to US Agricultural Lands (2024)
- Effects of point and nonpoint source controls on total phosphorus load trends across the Chesapeake Bay watershed, USA (2023)
- Nutrient explorer: An analytical framework to visualize and investigate drivers of surface water quality (2023)
- The changing nitrogen landscape of US streams: Declining deposition and increasing organic nitrogen (2023)
- Comparing Drivers of Spatial Variability in US lake and Stream Phosphorus Concentrations (2023)
- Shifts in the Composition of Nitrogen Deposition in the Conterminous United States are Discernable in Stream Chemistry (2023)
- An Index of Nitrogen Sources and Processing Within Watersheds for National Aquatic Monitoring Programs (2022)
- Regional Patterns and Drivers of Total Nitrogen Trends in the Chesapeake Bay Watershed: Insights from Machine Learning Approaches and Management Implications (2022)
- Context is Everything: Interacting Inputs and Landscape Characteristics Control Stream Nitrogen (2021)
- Long-Term Mississippi River Trends Expose Shifts in the River Load Response to Watershed Nutrient Balances Between 1975 and 2017 (2021)



U6 | 1882

	A	B	C	D	E	F	G
1	HUC_8	area_km2	STUSPS	NAME	P_human_	P_human_food_demand	P_nf_fertilizer
2	1010002	3198.1	ME	Maine	5.3E-05	6.81996E-05	0.027523
3	1010003	2304.01	ME	Maine	0.01218	0.015589114	0.037437667
4	1010004	6221.51	ME	Maine	0.02584	0.033081308	0.042830333
5	1010005	1101.14	ME	Maine	0.05106	0.065356398	0.037437667
6	1010006	1724.33	ME	Maine	0	0	0.045965667
7	1010007	2394.88	ME	Maine	0.00014	0.000182037	0.037573
8	1010008	955.865	ME	Maine	0.03204	0.041012188	0.037437667
9	1010009	464.458	ME	Maine	0.05278	0.067561925	0.037437667
10	1010010	495.064	ME	Maine	0.04945	0.063295717	0.037437667
11	1010011	47.086	ME	Maine	0.02006	0.025676205	0.037437666
12	1020001	5518.67	ME	Maine	0.0064	0.008185739	0.047198333
13	1020002	2899.62	ME	Maine	0.00106	0.001352213	0.120733667
14	1020003	3907.82	ME	Maine	0.01036	0.013258322	0.083023667



Via our website, access foundational HUC8 scale National Nutrient Inventory data, as well as management relevant metrics and prioritization schemes that make the inventories actionable for your nutrient reduction strategies. A custom regional nutrient inventory for the Chesapeake Bay watershed is also available.

United States Environmental Protection Agency

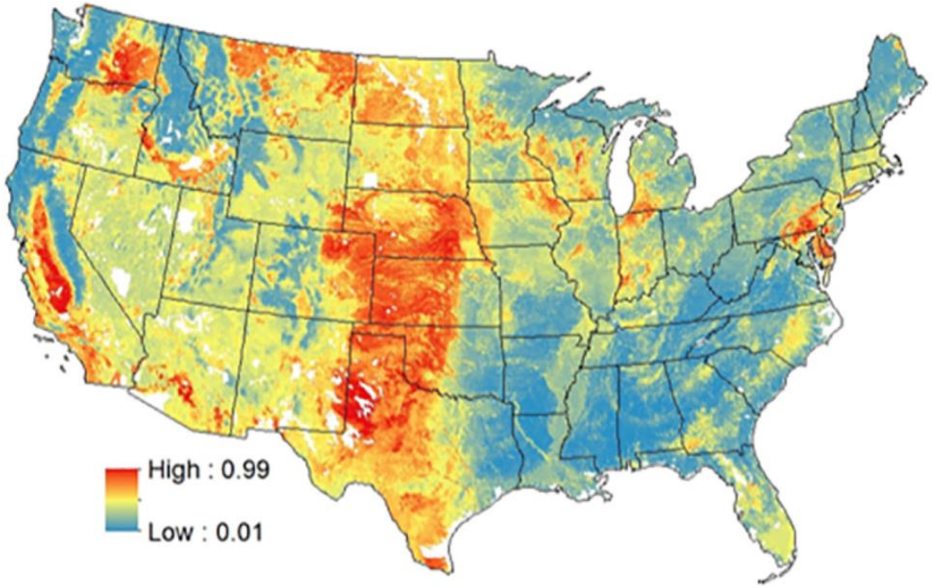
The NNI's Predictive Water Quality Models and Big Data Initiatives

Nutrient inventories communicate the magnitude and trajectories of sector-specific pollution sources, but other environmental factors influence the loss of nutrients to groundwater and surface water.

National Nutrient Inventory (NNI) Portfolio offers a strong suite of predictive water quality models & management tools

- Using the EPA's National Nutrient Inventory and StreamCat, NNI scientists continue to develop powerful statistical, machine, and deep learning models
- **Identify nutrient pollution hotspots based on multiple water quality endpoints**
  - Nutrient concentrations (e.g., Sabo et al., 2023; Lin et al., 2021)
  - HABs and cyanoHABs risk (e.g., Brehob et al., 2024; Handler et al., in prep)
  - Macroinvertebrate assemblages (Kopp et al., in review)
  - Annual nutrient export (Sabo et al., in prep)
  - Drinking water nitrate contamination (e.g., Pennino et al., 2020)
  - Wetland processing (Brooks et al. 2022, Nowakowski et al., in prep)
- **Determine effective management strategies to mitigate nutrient pollution**
  - Techno-economic efforts to optimize nutrient removal and treatment at POTWs and CAFOs (e.g., Martin-Hernandez et al., 2024)
  - Optimization of wetland protection and placement (Kirk et al., 2024; Alford et al. in prep)

Map of predicted probability for groundwater sourced drinking water violations



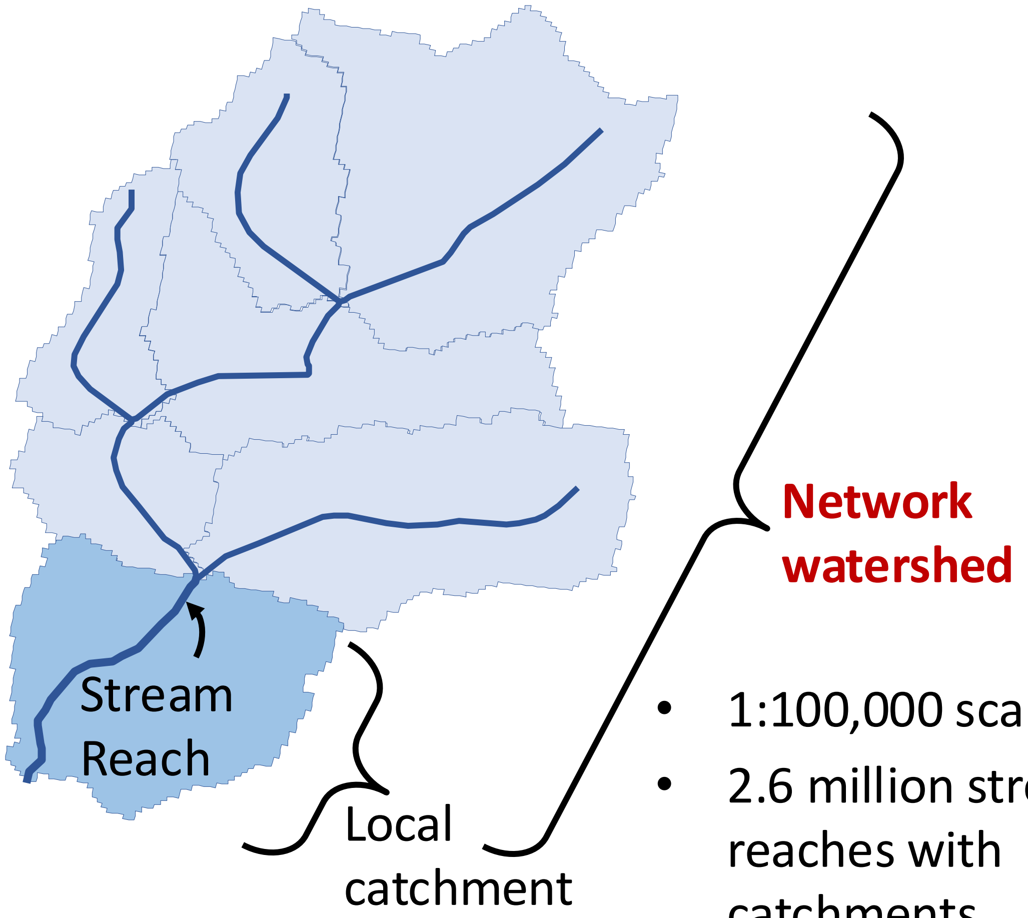
Pennino et al. (2020)

Highlight→ The inventory and these models can supplement state efforts in implementing plans to meet total maximum daily loads, evaluating water quality risk, and setting nutrient criteria.

Markley et al., in prep
Alford et al., in prep

Adjusting spatial scales to meet management and research needs

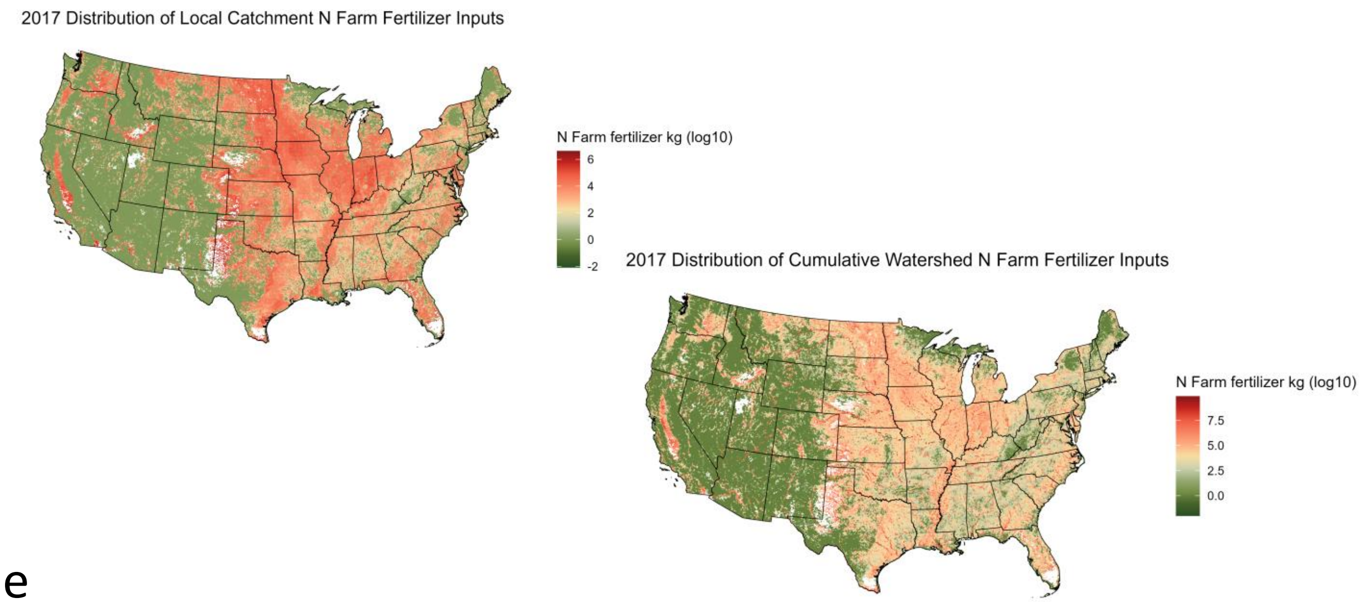
Downscaling nutrient inventory to NHD+ and generating watershed accumulated statistics



- 1:100,000 scale
- 2.6 million stream reaches with catchments

Markley et al., in prep

Catchment and Cumulative Watershed Maps of Nitrogen Farm Fertilizer



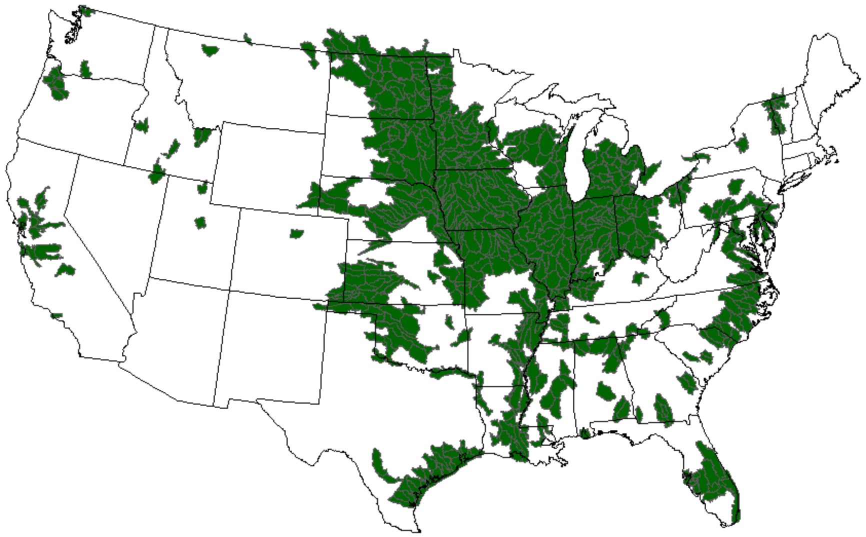
https://github.com/NelsonMinar/vector-river-map

Integration of the NNI into StreamCat will allow users to generate custom watershed mass balances ranging in scale ~4 km^2 to the scale of Mississippi River basin

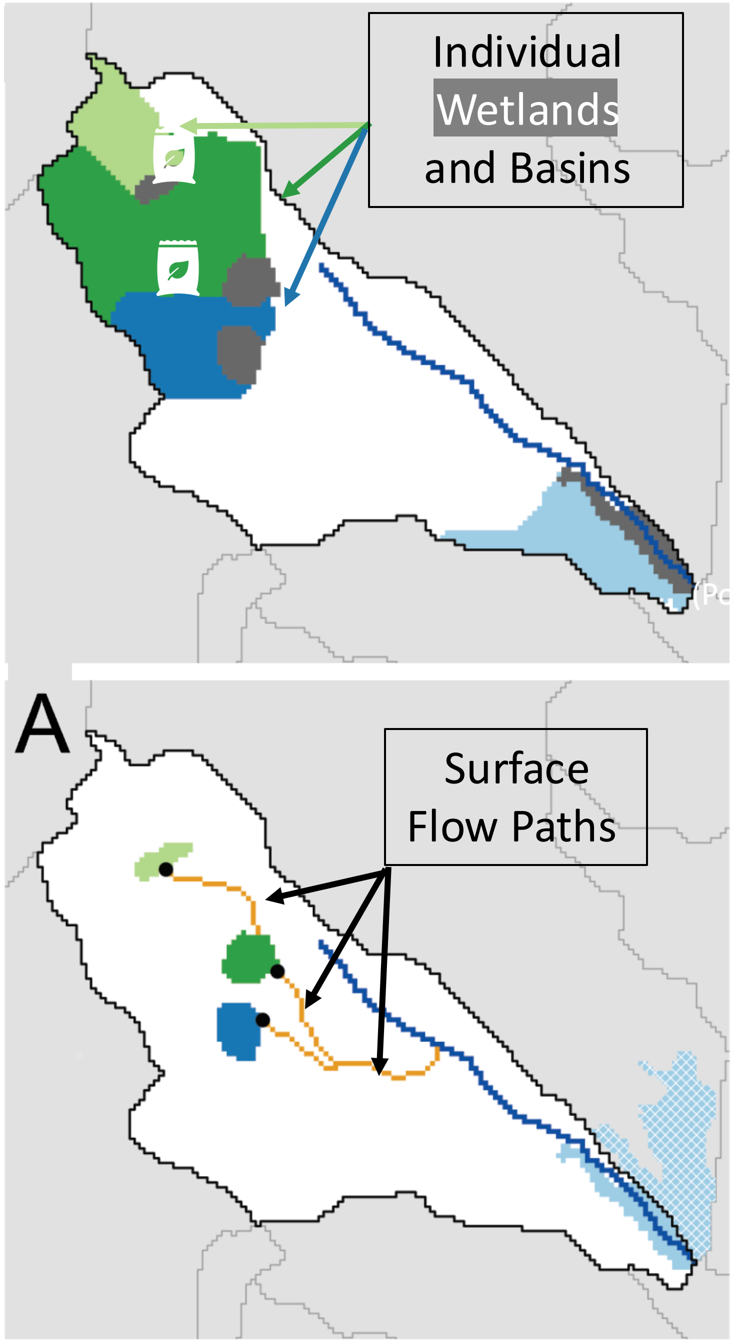
Targeted wetland conservation for localized water quality strategies

- Map existing and potential wetlands
  - Examine change in wetland area through time
  - Apply NNI data to calculate basin loads
- Use surface flow paths to link nutrient inputs to water resources
  - Identify wetlands critical for landscape nutrient interception

Data from Kirk et al. (2024)



HUC8s where wetland conservation could benefit water quality



Alford et al., in prep

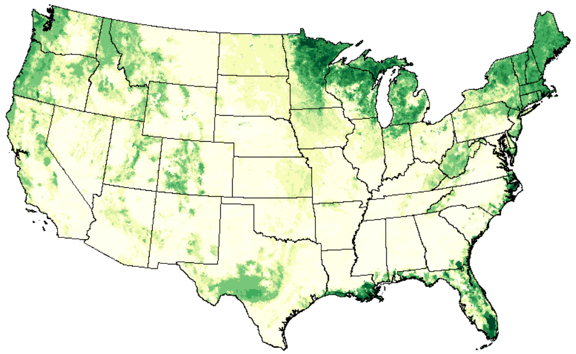
Brehob et al., 2024
Handler et al., in prep

Predicting HABs and cyanoHABs risk to lakes across the United States

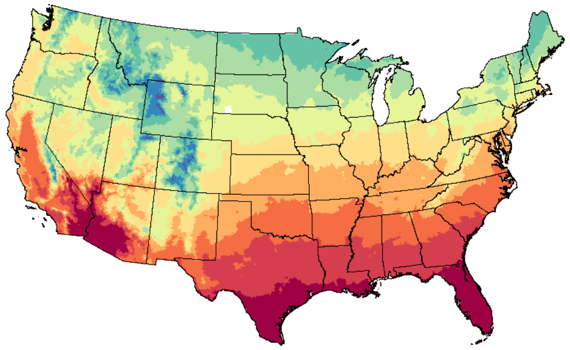
United States Environmental Protection Agency

BIG DATA EXAMPLE: Link the NNI and other environmental factors to a priority water quality endpoint

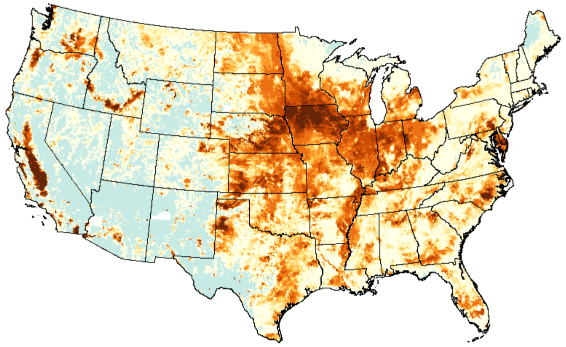
Soil and Lake Characteristics



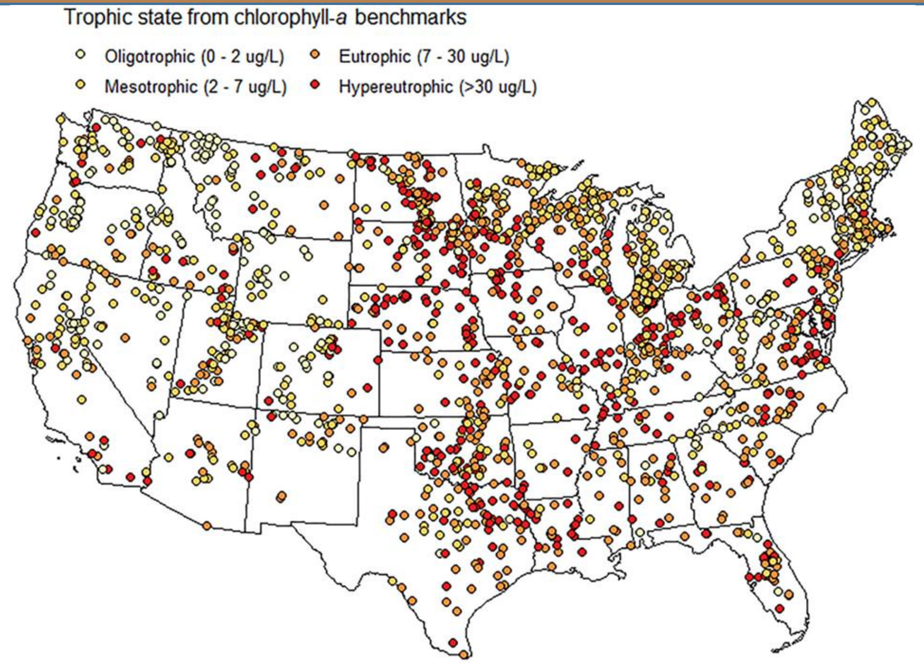
Weather Variables



Nutrient Inventory

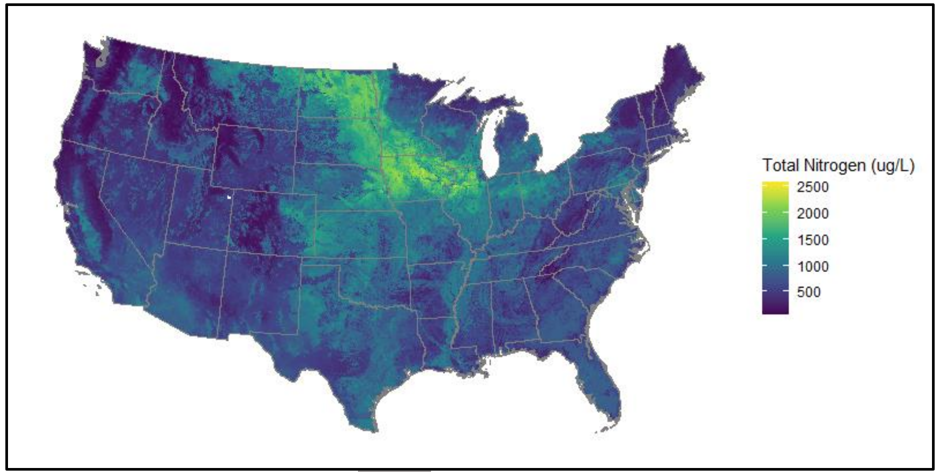


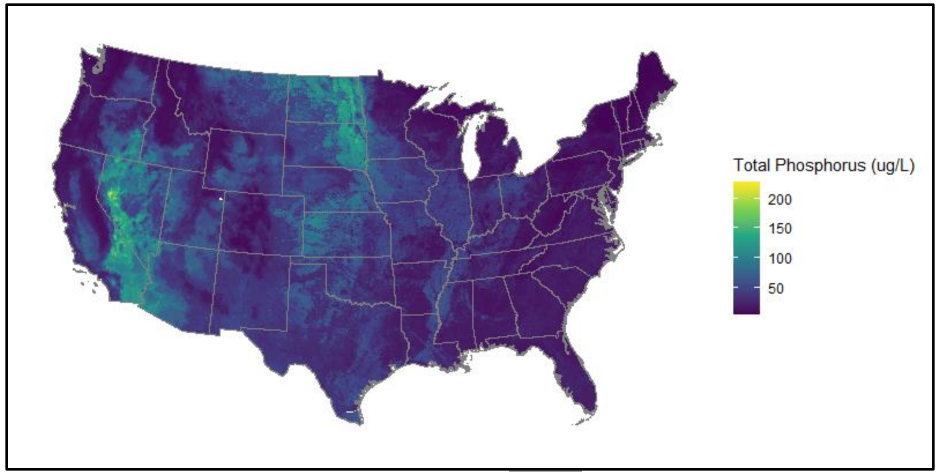
EPA NATIONAL LAKE ASSESSMENT

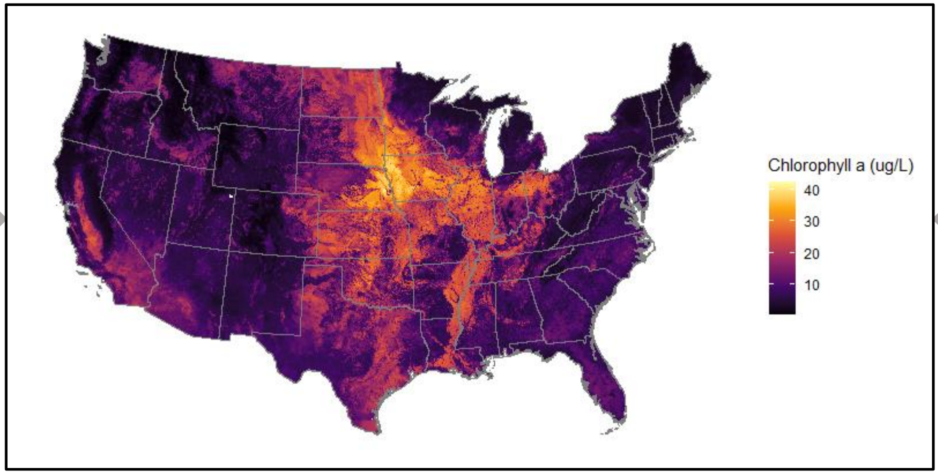


National Nutrient Inventory, climatic, and soil characteristic variables were matched to thousands of lake TN, TP, and Chl-*a* concentrations

Calibrate machine learning models and generate nutrient and chlorophyll-*a* predictions







Brehob et al., 2024 Earth's Future

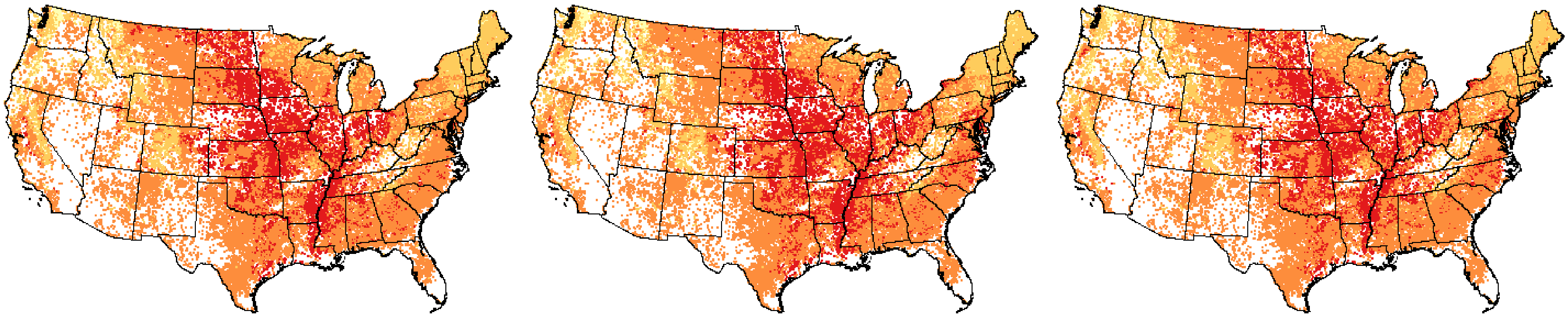
Chlorophyll-*a* predictions for ~112,000 lakes

Watershed-scale prediction maps - 2007

Trophic state from chlorophyll-a benchmarks

Oligotrophic (0 - 2 ug/L)
Mesotrophic (2 - 7 ug/L)
Eutrophic (7 - 30 ug/L)
Hypereutrophic (>30 ug/L)

May | July | October



[Specific lake and headwater prediction data accessible at Brehob et al., 2024]()

EPA United States Environmental Protection Agency

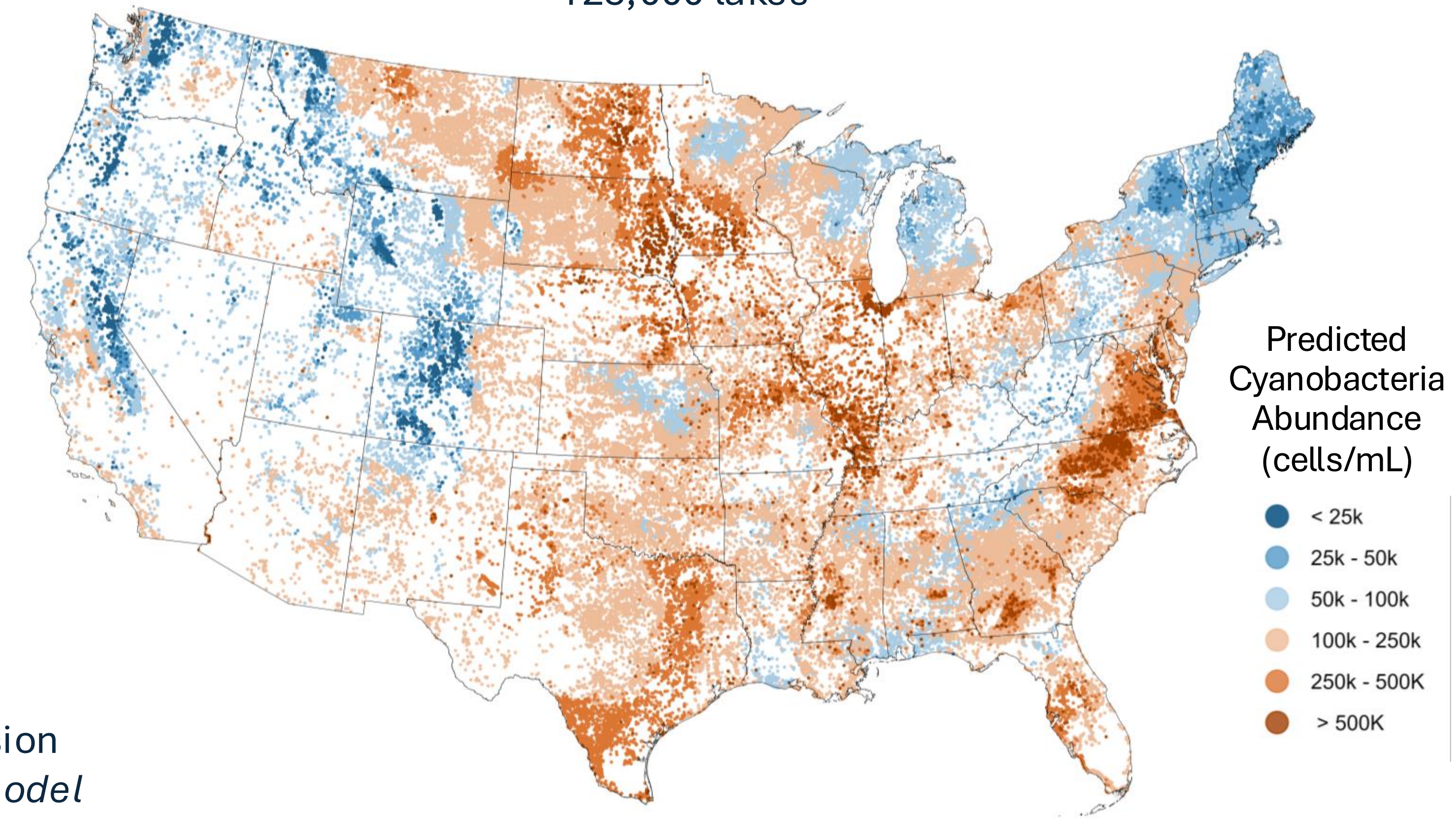
Leveraging the NNI to predict cyanoHABs

Model Inputs
~3,000 observations

- National Nutrient Inventory
- NLDC Land Cover
- PRISM Climate
- Lakemorpho Lake Morphology
- PRISM Climate
- NLA Cyanobacteria

Spatial regression model with *spmodel*

Lake Cyanobacteria Predictions
~125,000 lakes



Handler et al. (in prep)

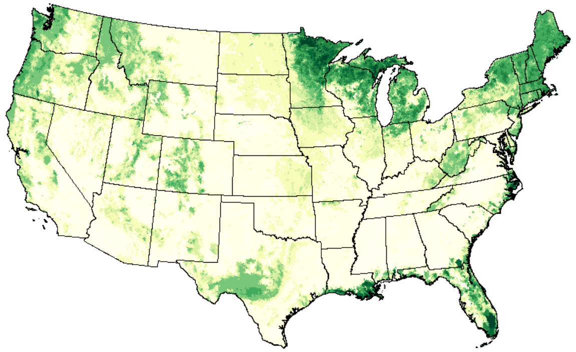
Sabo et al., in prep
Zhang et al., in prep

Predicting annual nitrogen and phosphorus export with deep learning models

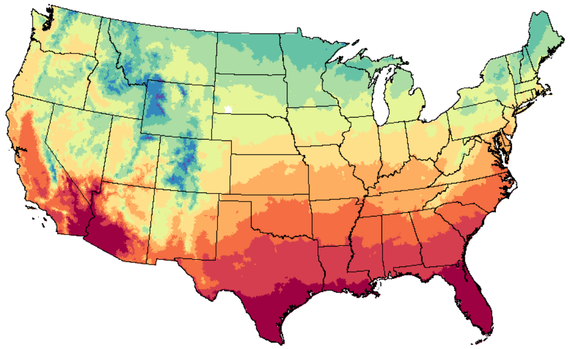
United States Environmental Protection Agency

Link the NNI to USGS annual nutrient loads

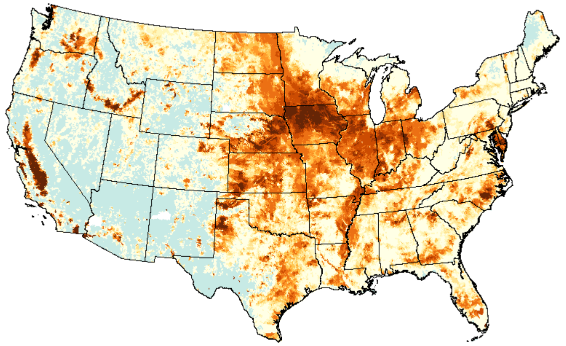
Soil Characteristics (n=4)



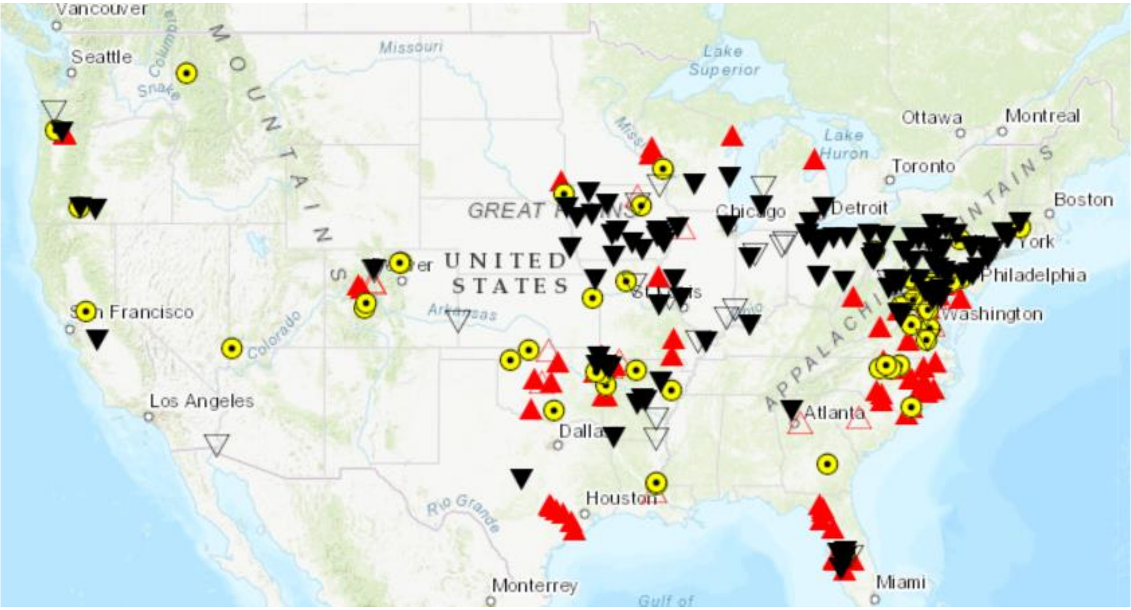
Annual Climatic Variables (n=2)



Nutrient Inventory (n=4)



USGS "Water-Quality Changes" Stations
(for Total Nitrogen)

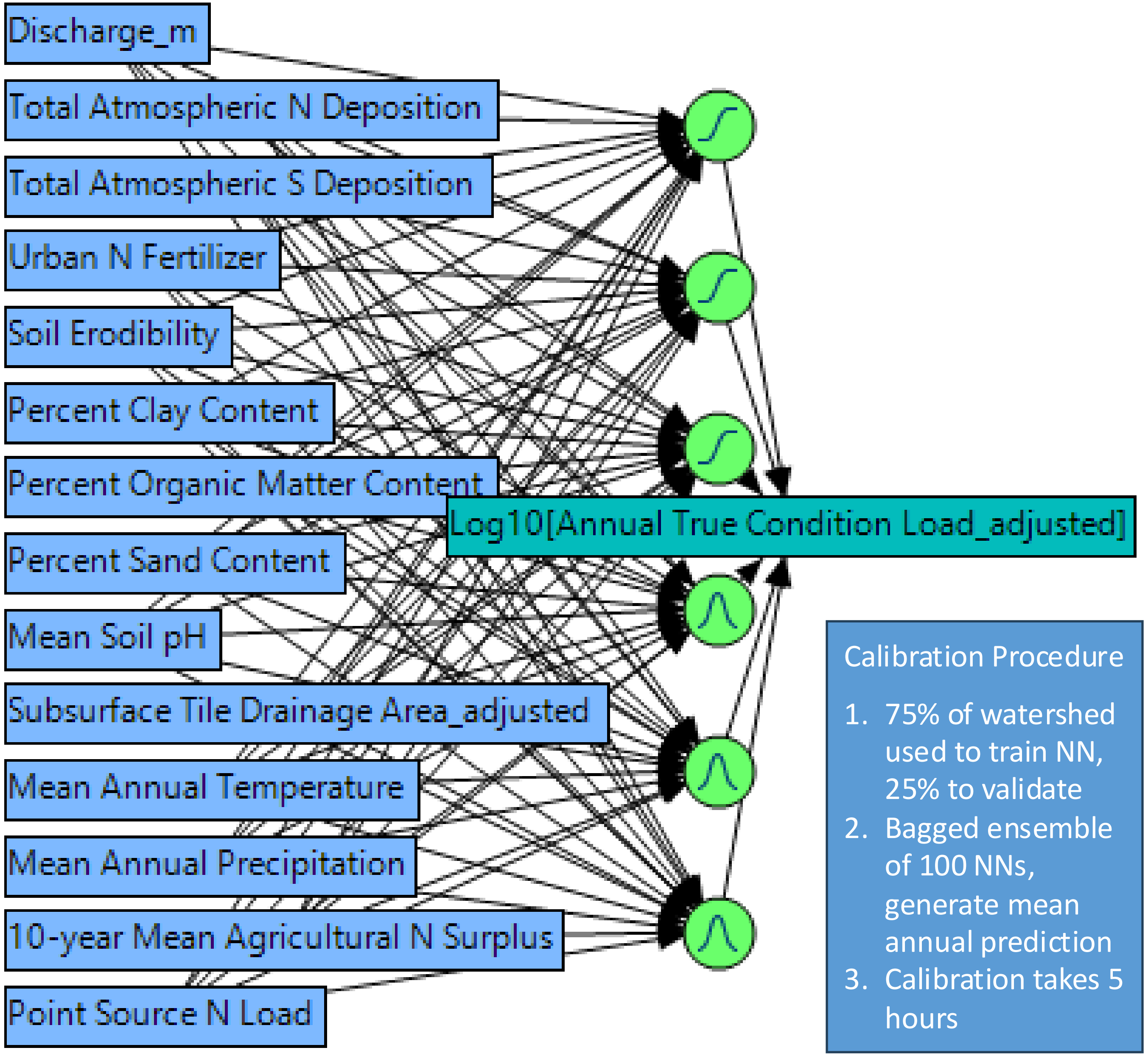


National Nutrient Inventory, climatic, and soil characteristic variables were matched to hundreds of watersheds with annual nitrogen and phosphorus loading estimates across the United States.

21

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



Calibration Procedure

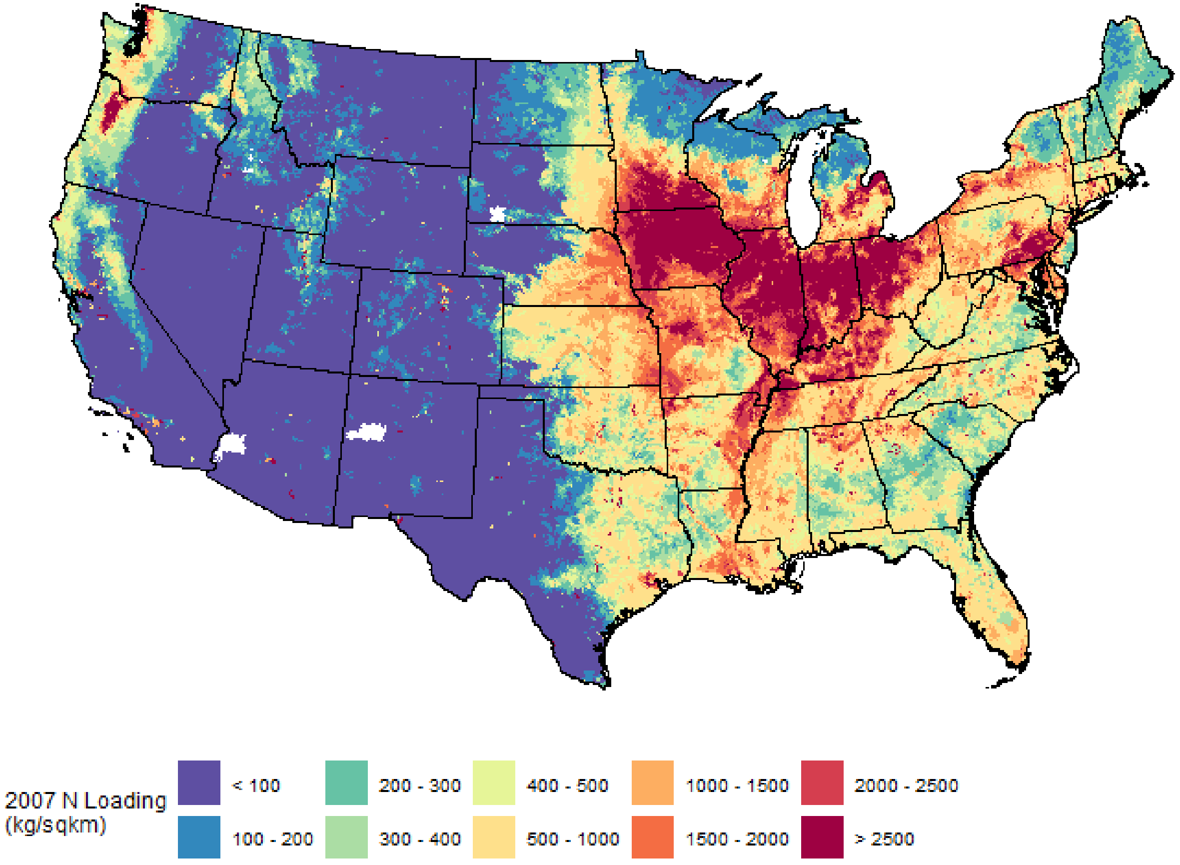
1. 75% of watershed used to train NN, 25% to validate
2. Bagged ensemble of 100 NNs, generate mean annual prediction
3. Calibration takes 5 hours

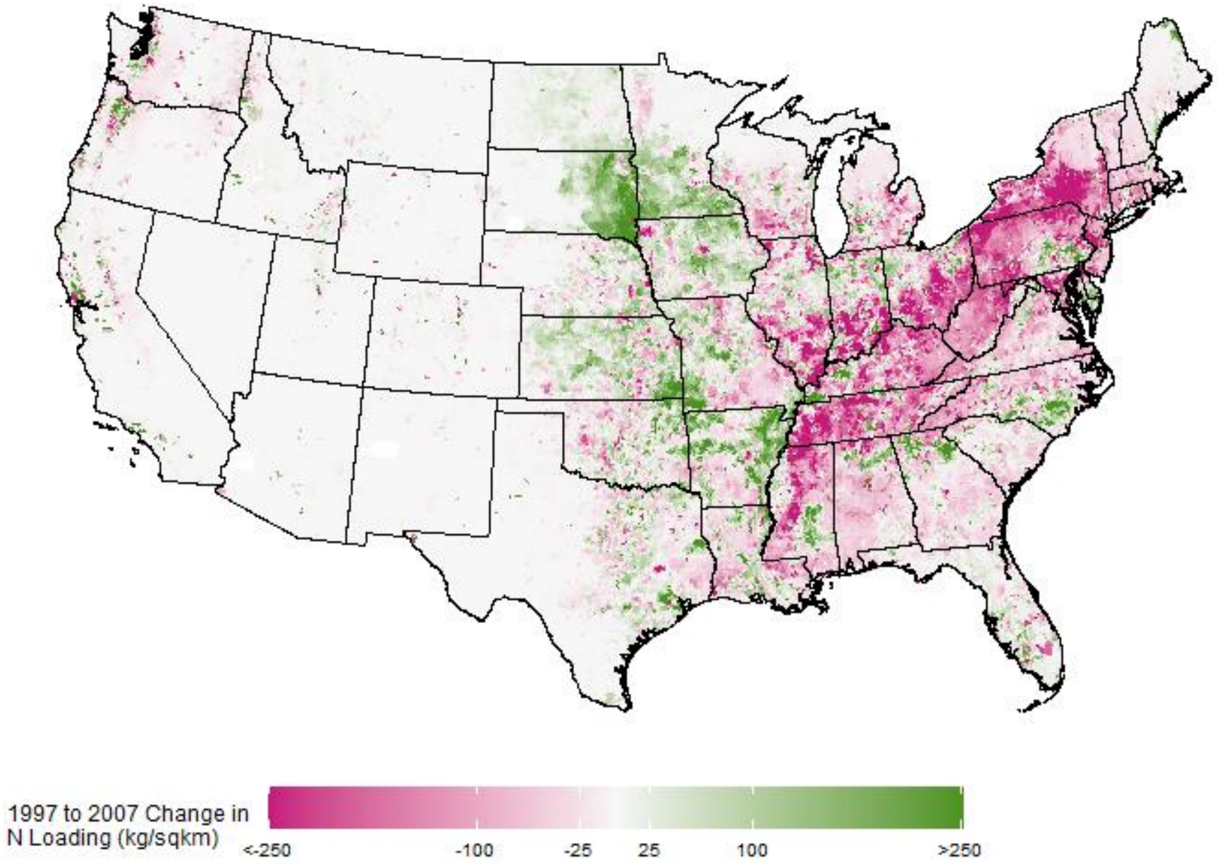
Mean annual discharge drives interannual variation, agricultural surplus drives spatial gradient in nitrogen loads, BUT…

Predictor	Pred Formula Log10[Annual True Condition Load_adjusted] Bagged Mean 2 Contribution	Portion	Rank
Discharge_m	67760.5	0.4776	1
10-year Mean Agricultural N Surplus	27250.3	0.1921	2
Mean Annual Precipitation	26311.5	0.1855	3
Total Atmospheric N Deposition	7887.9	0.0556	4
Total Atmospheric S Deposition	5753.6	0.0406	5
Point Source N Load	3058.8	0.0216	6
Subsurface Tile Drainage Area_adjusted	1785.2	0.0126	7
Mean Annual Temperature	492.8	0.0035	8
Percent Organic Matter Content	487.2	0.0034	9
Percent Sand Content	384.1	0.0027	10
Mean Soil pH	204.2	0.0014	11
Percent Clay Content	202.2	0.0014	12
Soil Erodibility	195.5	0.0014	13
Urban N Fertilizer	95.8	0.0007	14

Portion of variance explained by predictors for monitoring stations across the contiguous US. Note this plot does not highlight the influence of variables in terms of interactions or the sensitivity of nitrogen loading response to shifts in a particular factor; it communicates the loss of predictive performance if a variable is dropped from the model.

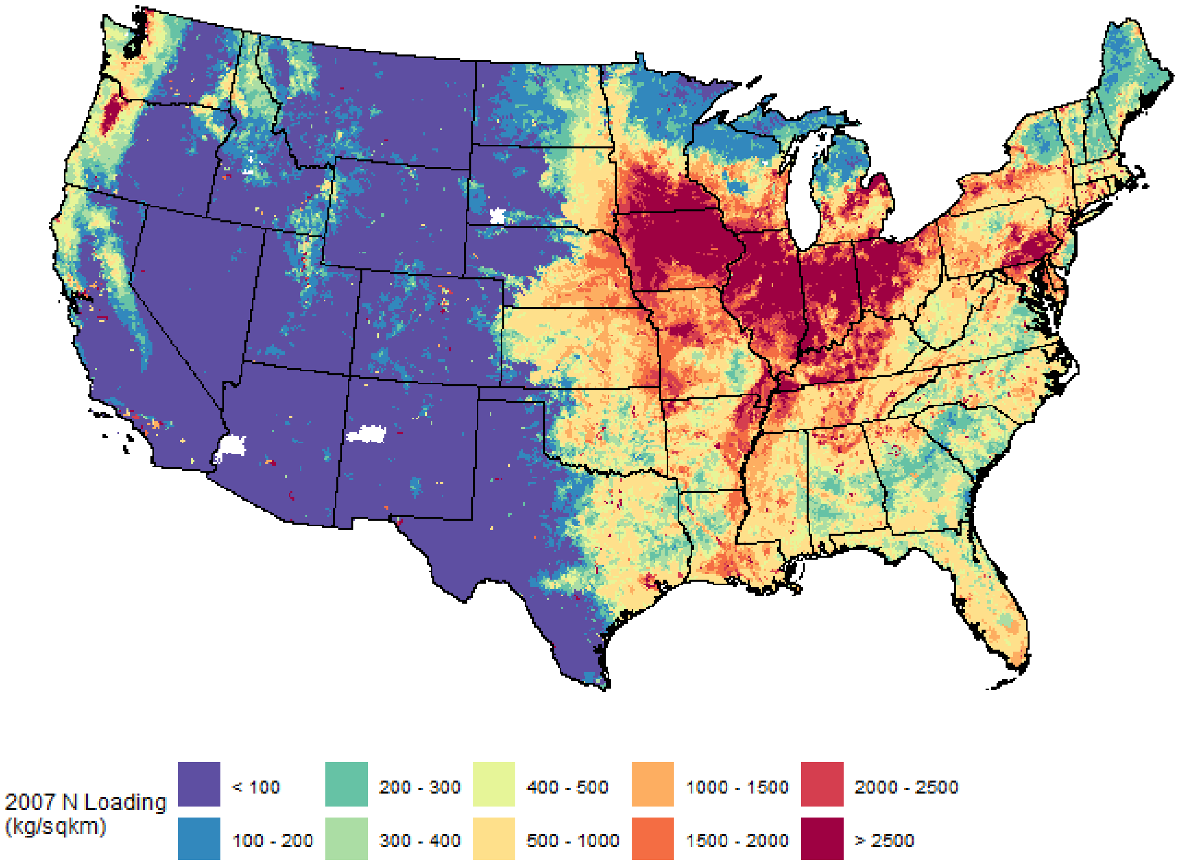
Counterfactual 1: Major urban and agricultural nitrogen pollution hotspots identified by NN and NNI

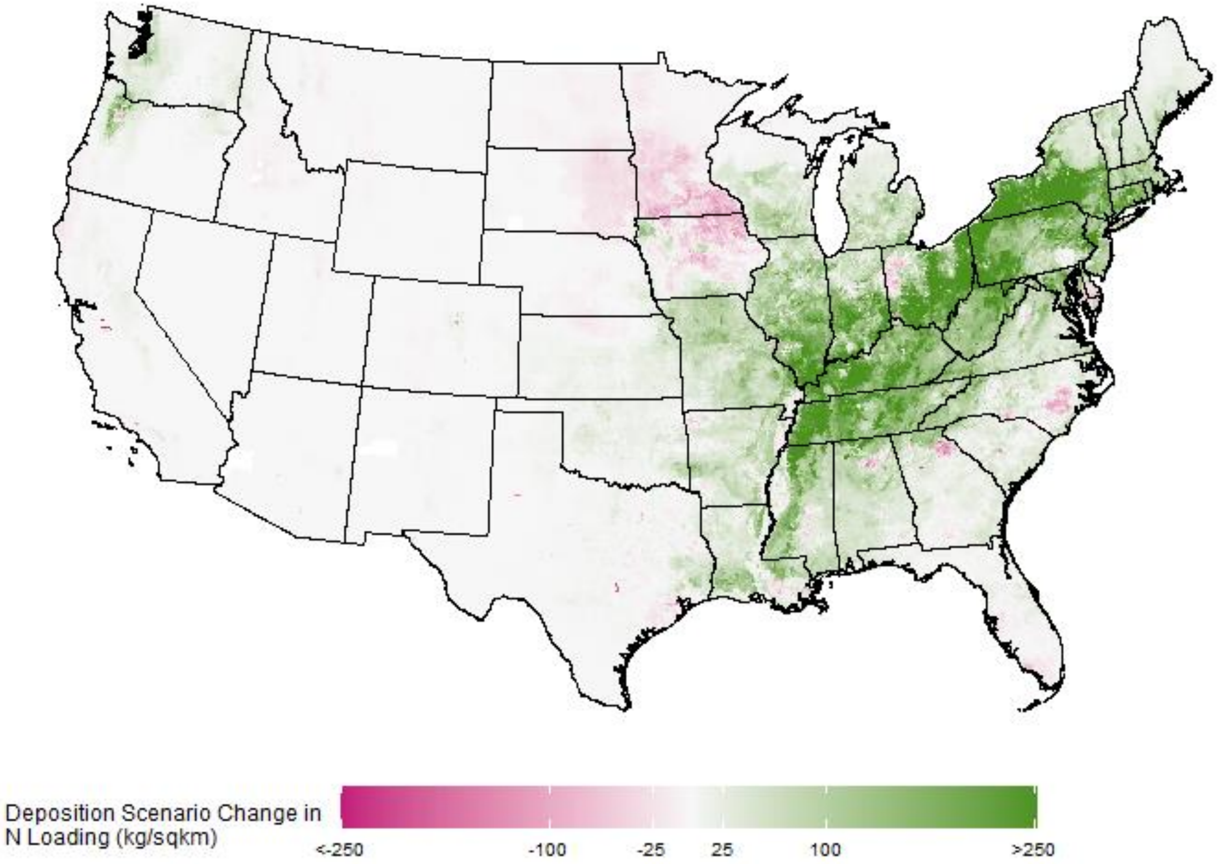




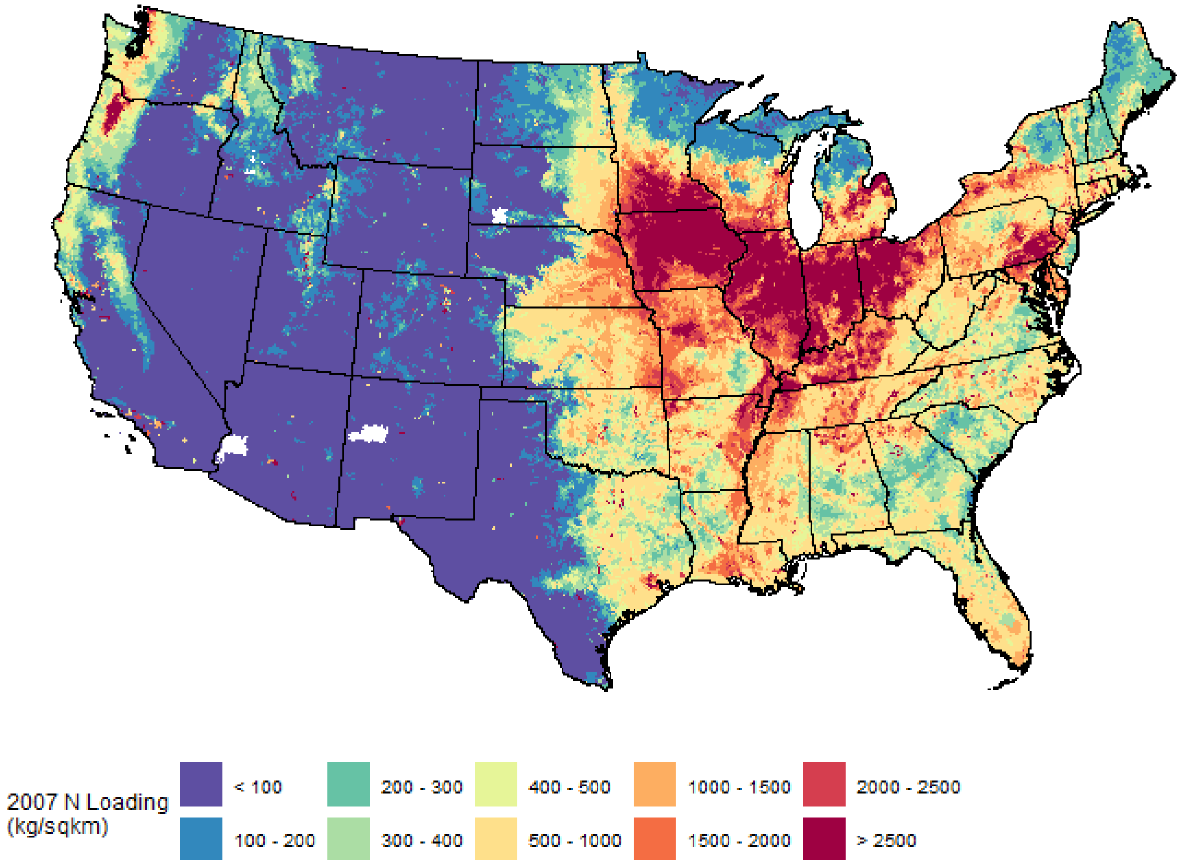
Note that these predictions rely on water yield maps that essentially describe “natural water yields” at HUC12 scale; thus, highly irrigated agricultural areas like the Central Valley of California and Southern Idaho will have low TN loading rates due to low precipitation rates. We plan to generate additional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

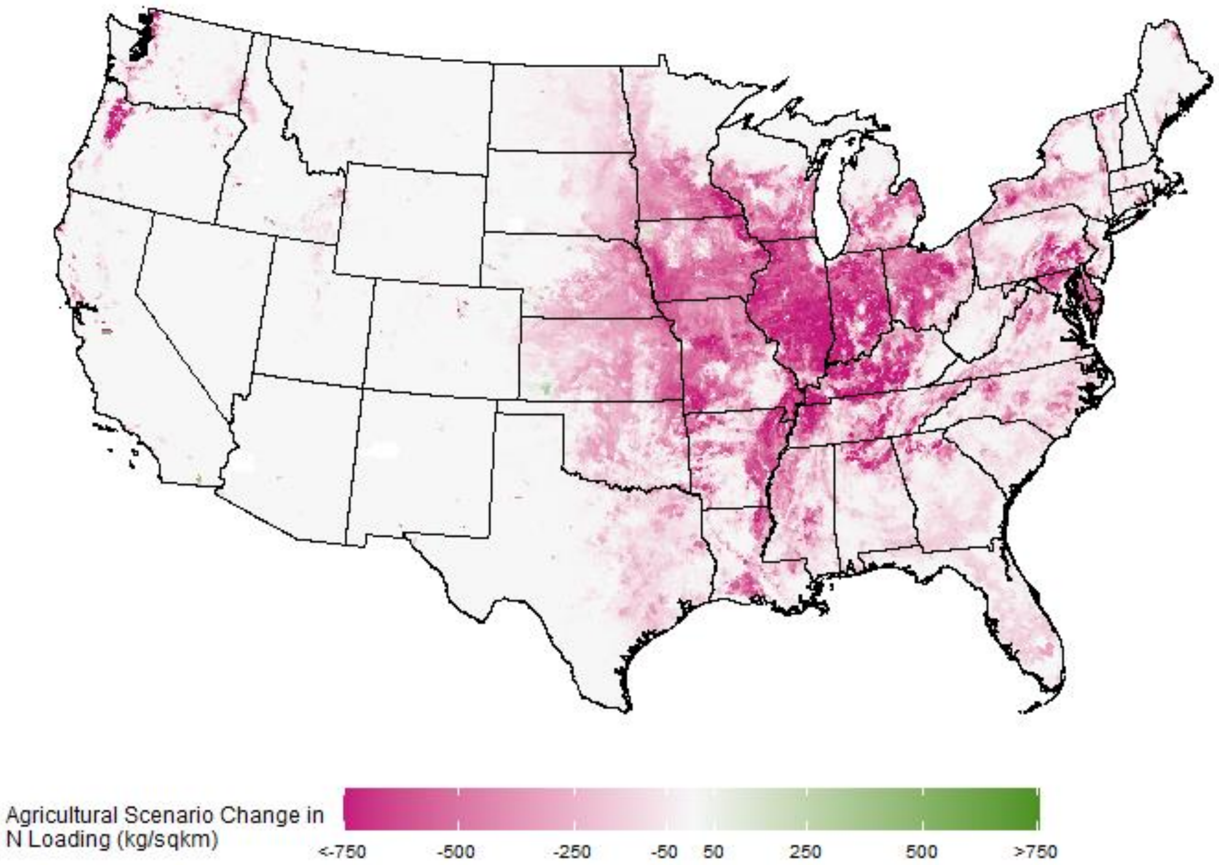
Counterfactual 2: Many parts of the eastern US have benefitted from NO_x emission reductions since 1997



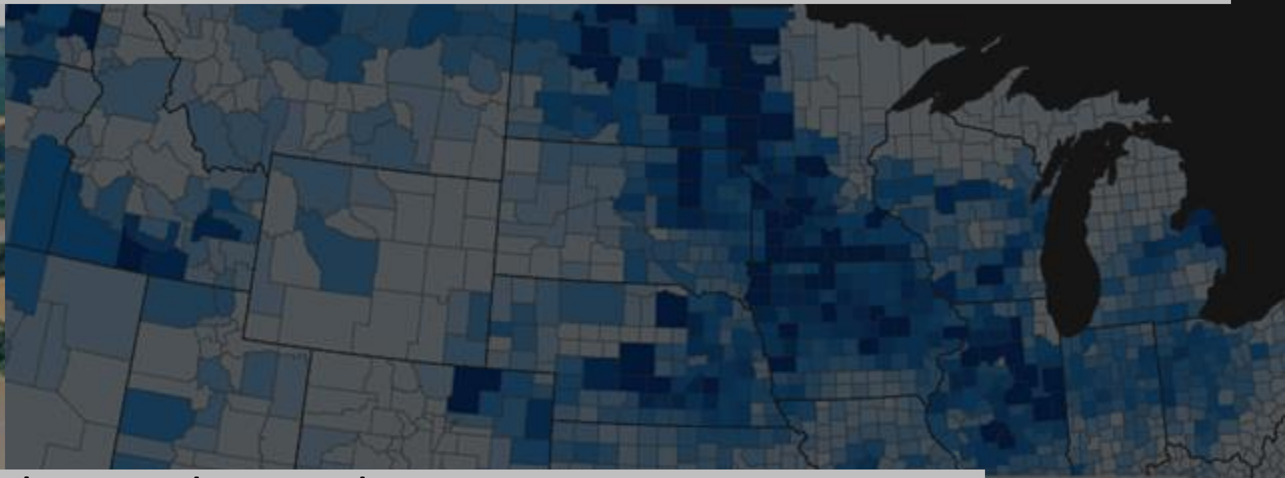


Counterfactual 3: 50% reduction in agricultural surplus results in 19% reduction in N loads to waterways, nationwide





Moving beyond accessing individual databases and publications— *EPA National Nutrient Inventory Explorer* (LATE FY26)



1. Access and download all NNI and water quality prediction data at state, county, HUC2, and HUC12 subbasin scales
2. Generate compelling visuals, including maps, time series, and histograms, to aid in your planning efforts to protect local and downstream water resources
3. Helpful links to other EPA NNI related products and tools including StreamCat^{NNI} and Drinking Water Risk Tool

<u>User test volunteers needed</u>, please reach out if you are interested.

Conclusions

- The NNI portfolio provides **accessible, actionable** research products that:
  - Offer quantitative insight into likely nutrient pollution hotspots
  - Track sector-specific nutrient pollution sources with intuitive metrics
  - Link spatial and temporal trends in sources to water quality endpoints using powerful statistical and deep learning models
  - Provide helpful prioritization schemes
  - Empower states, tribes and others to develop innovative, cost-effective solutions and prioritize resources for specific subbasins and management practices
- The NNI Team is committed to developing research products that help states reach their goals for safe and clean water resources for all.

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ORD's National Nutrient Inventory Website (NNI)

We appreciate your feedback, tips, and guidance to make this research more useful for you and your communities – THANK YOU!