Improving Nutrient Management in the Chesapeake Bay Watershed through System and Transdisciplinary Approaches

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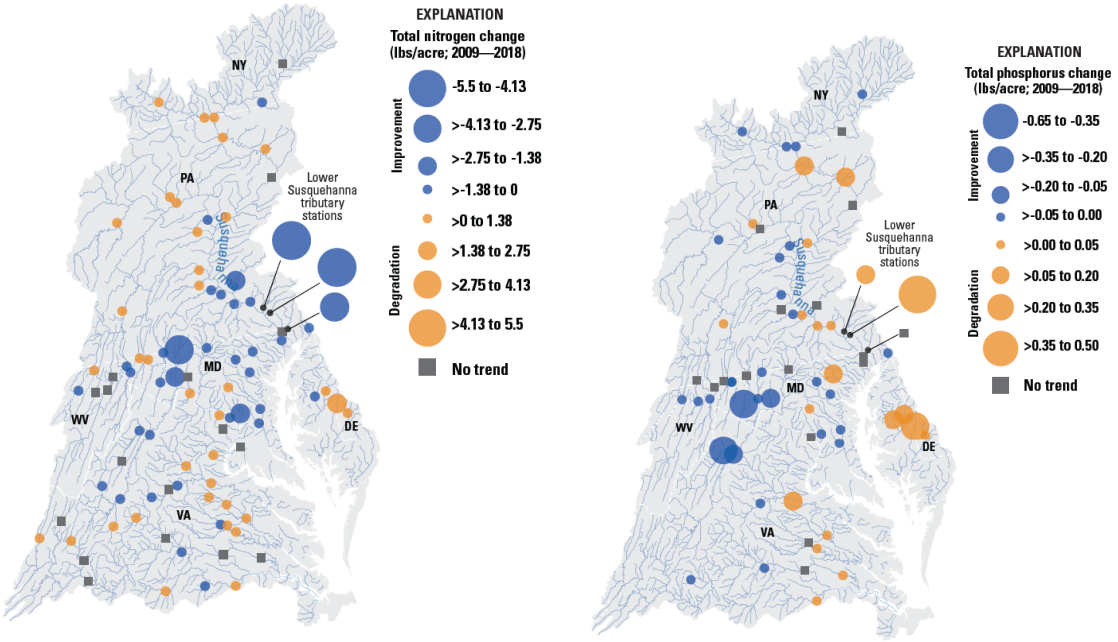
Two nutrient management gaps in the Chesapeake Bay watershed

1. Limited progress in **nitrogen (N) and phosphorus (P)** management

Trends in total nutrient (N and P) at nontidal monitoring stations (2009-2018)



Total N (left)

- **Reduction: 41%** of stations.
- **Increase: 40%** of stations.
- **No trend: 19%** of stations.

Total P (right)

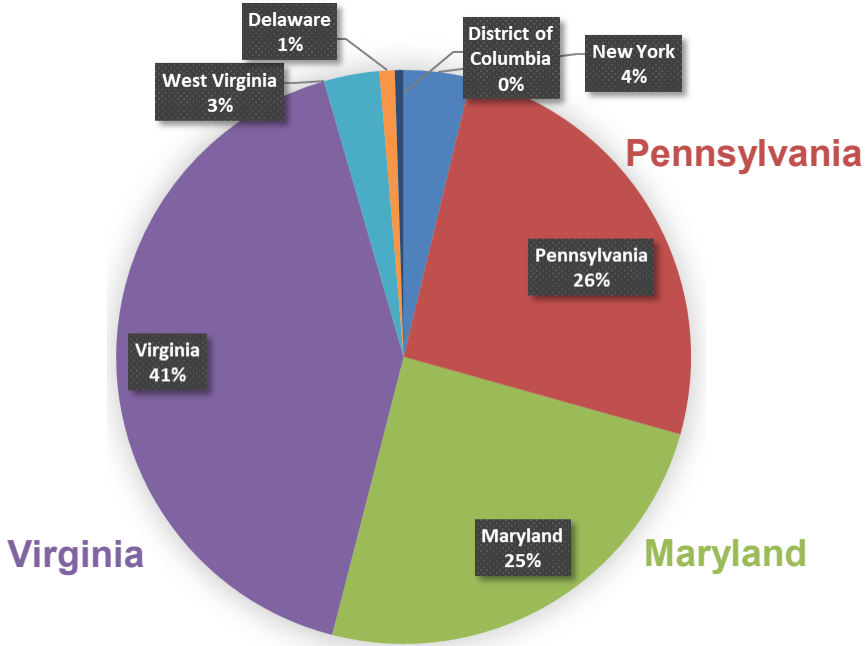
- **Reduction: 44%** of stations.
- **Increase: 32%** of stations.
- **No trend: 24%** of stations.

USGS 2021 Nutrient Trends and Drivers in the Chesapeake Bay Watershed

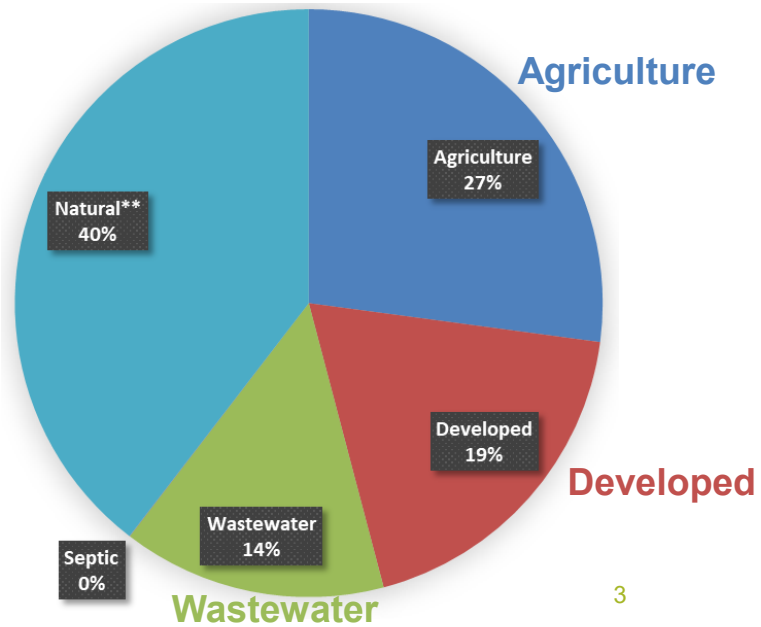
Two nutrient management gaps in the Chesapeake Bay watershed

1. Limited progress in N and P management
2. Management performance **varying by region and source**

2023 Simulated P Load to the Bay by jurisdiction



2023 Simulated P Load to the Bay by source



*Loads simulated using CAST19 version of Watershed Model and wastewater discharge data reported by Bay jurisdictions.
**The Natural sector contains the following load sources: CSS Forest, Harvested Forest, True Forest, CSS Mixed Open, Mixed Open, Shoreline, Stream Bed and Bank, Headwater or Isolated

How can the two management gaps be addressed?

What we did…

1. System approach
(*Zou et al., 2024, Environ. Res. Lett.*)

2. Transdisciplinary approach

Research questions

1. What are the historical and spatial patterns of N and P use on and beyond croplands?

2. How can nutrient management be connected and improved across systems?

3. How can nutrient management be enhanced through stakeholder engagement?

System approach: the *CAFE* framework

- Quantified nutrient budget by county and year from 1985 to 2019 across 4 systems.
- Data sources: Chesapeake Assessment Scenario Tool (CAST), and literature

CAFE Framework System Scales

Zou et al., 2024; Zhang et al., 2020; Li et al., 2022.

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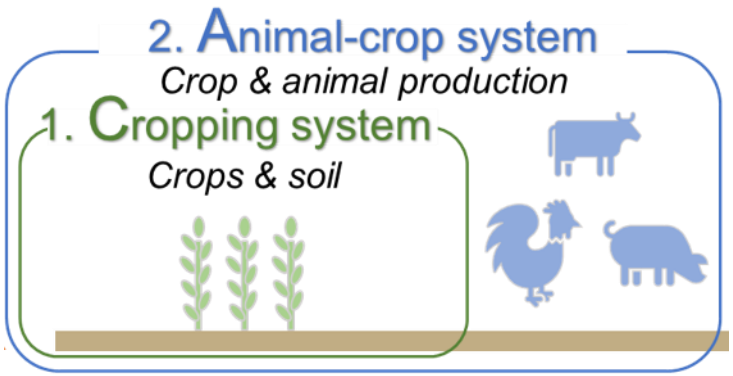

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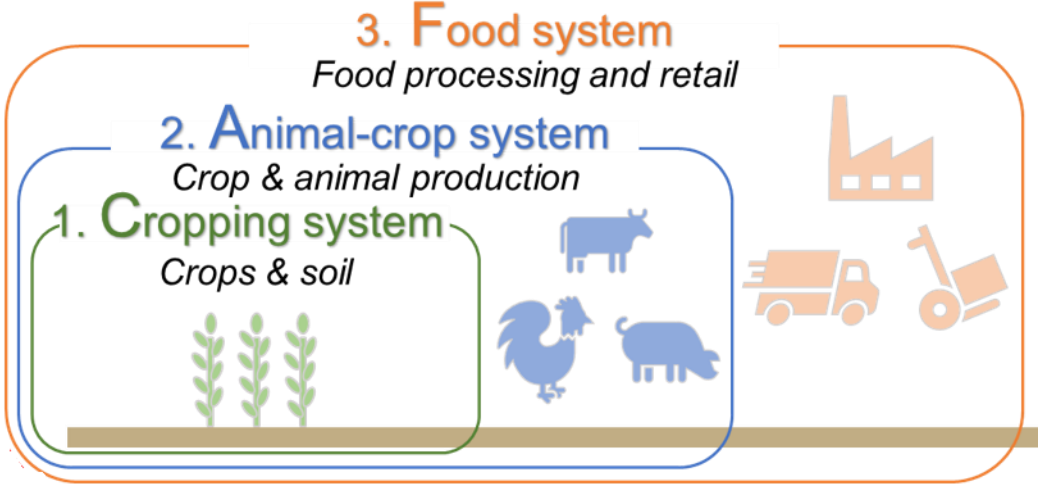

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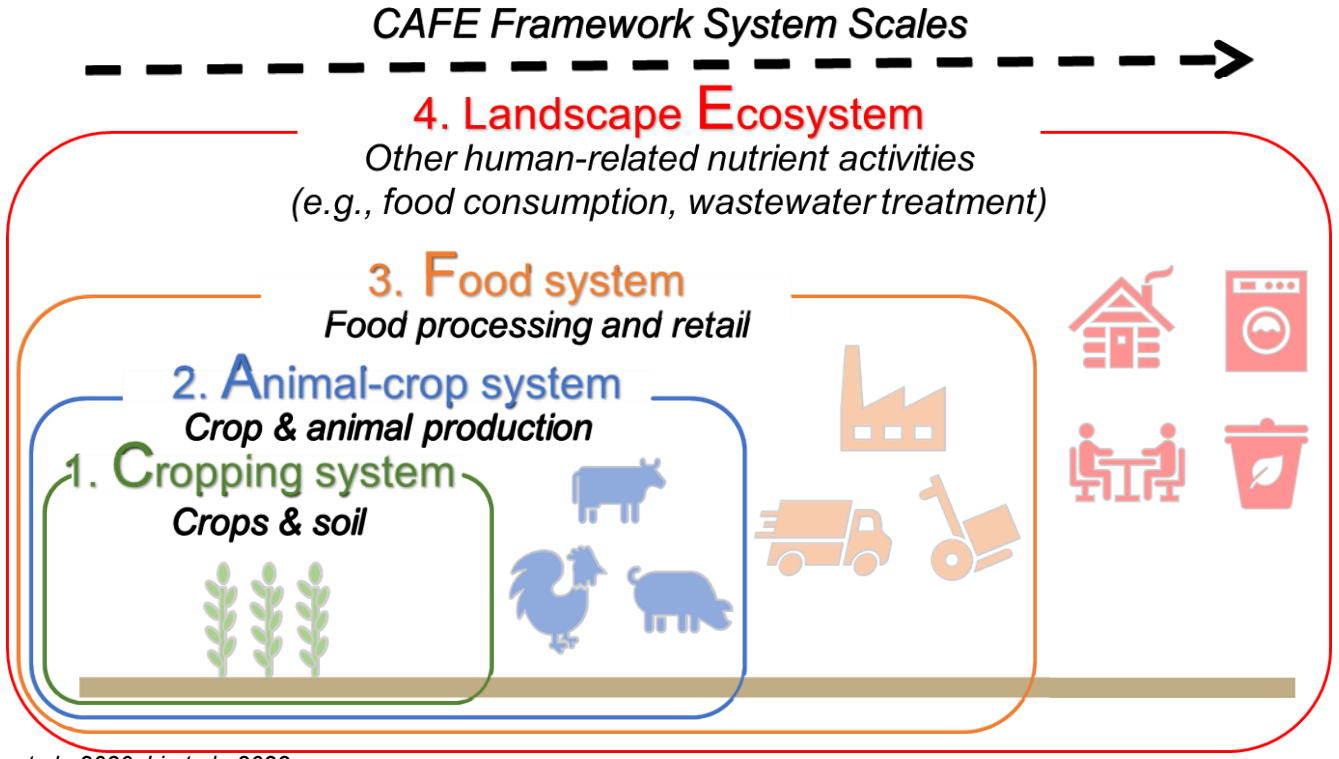

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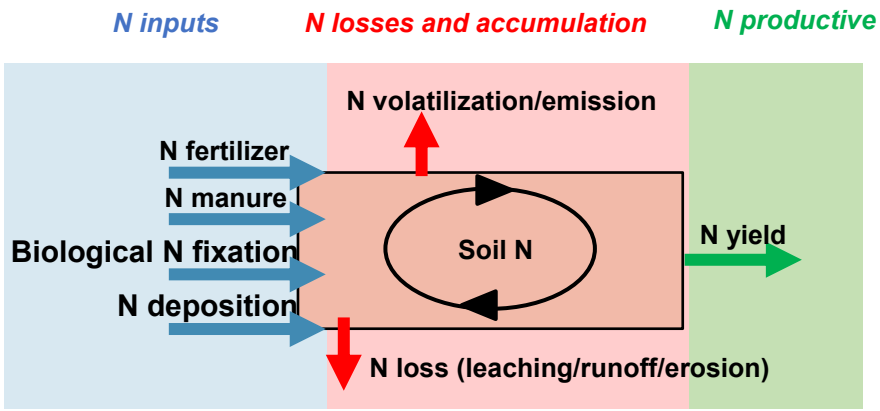
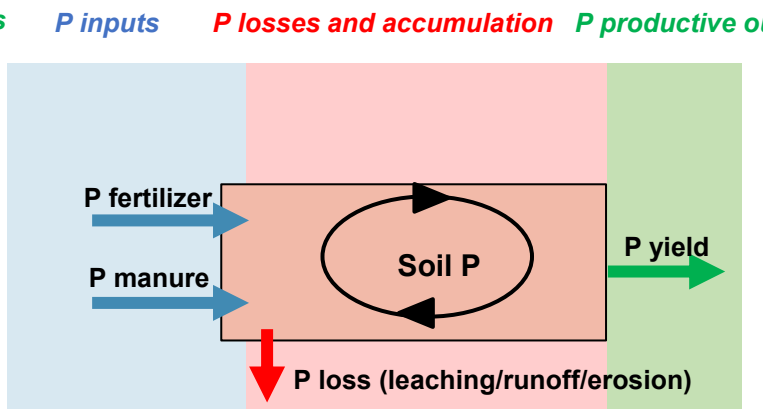
Nutrient management indicators





$$\textbf{\textit{N use efficiency (NUE)}} = \frac{system\ N\ productive\ outputs}{system\ N\ inputs} \times 100\%$$

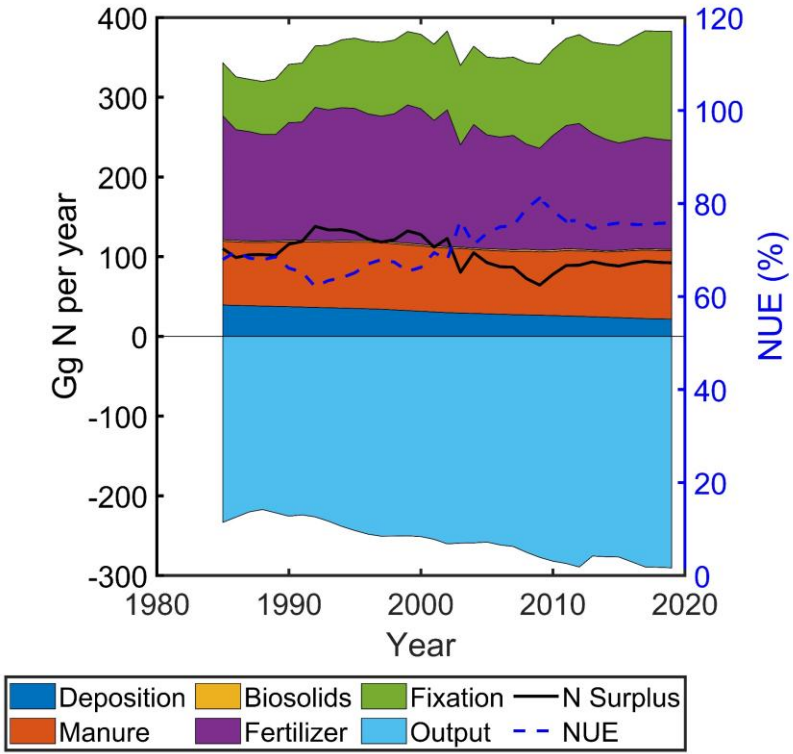
$$\textbf{\textit{N surplus}} = system\ N\ inputs - system\ N\ productive\ outputs$$

$$\textbf{\textit{P use efficiency (PUE)}} = \frac{system\ P\ productive\ outputs}{system\ P\ inputs} \times 100\%$$

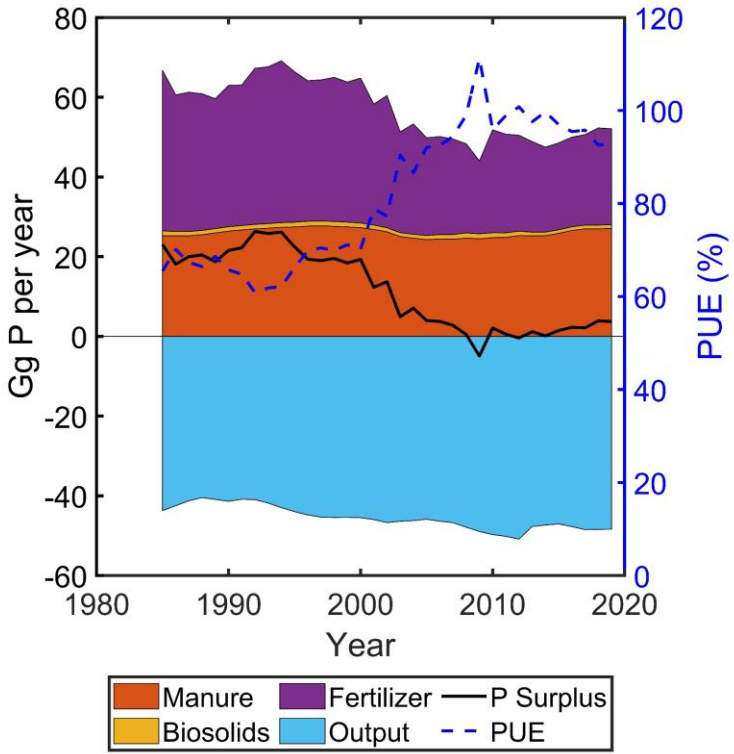
$$\textbf{\textit{P surplus}} = system\ P\ inputs - system\ P\ productive\ outputs$$

Cropland nutrient use: 1. Improved nutrient management

Cropping system N budget (1985-2019)



Cropping system P budget (1985-2019)



Zou et al., 2024, *Environ. Res. Lett.*

Cropland nutrient use: 2. More from fertilizer, increased P manure use

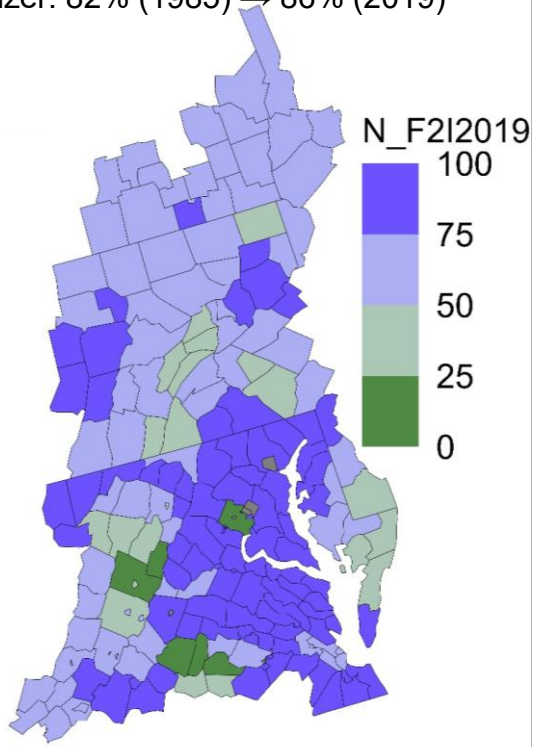
Mineral fertilizer dependency

the percentage of total cropland inputs coming from mineral fertilizer

$$= \frac{mineral\ fertilizer\ input}{mineral\ fertilizer\ input + manure\ input} * 100\%$$

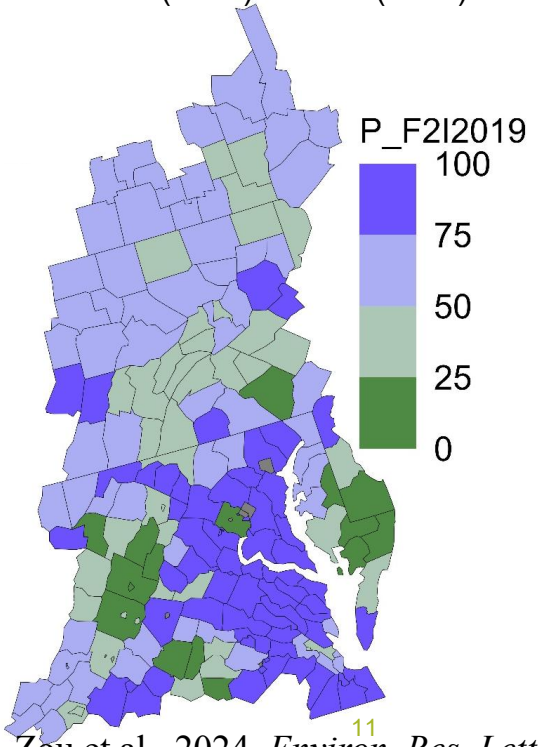
2019 N fertilizer dependency

- Watershed: 62% (1985) → 62% (2019)
- % of counties dependent more on N fertilizer: 82% (1985) → 86% (2019)



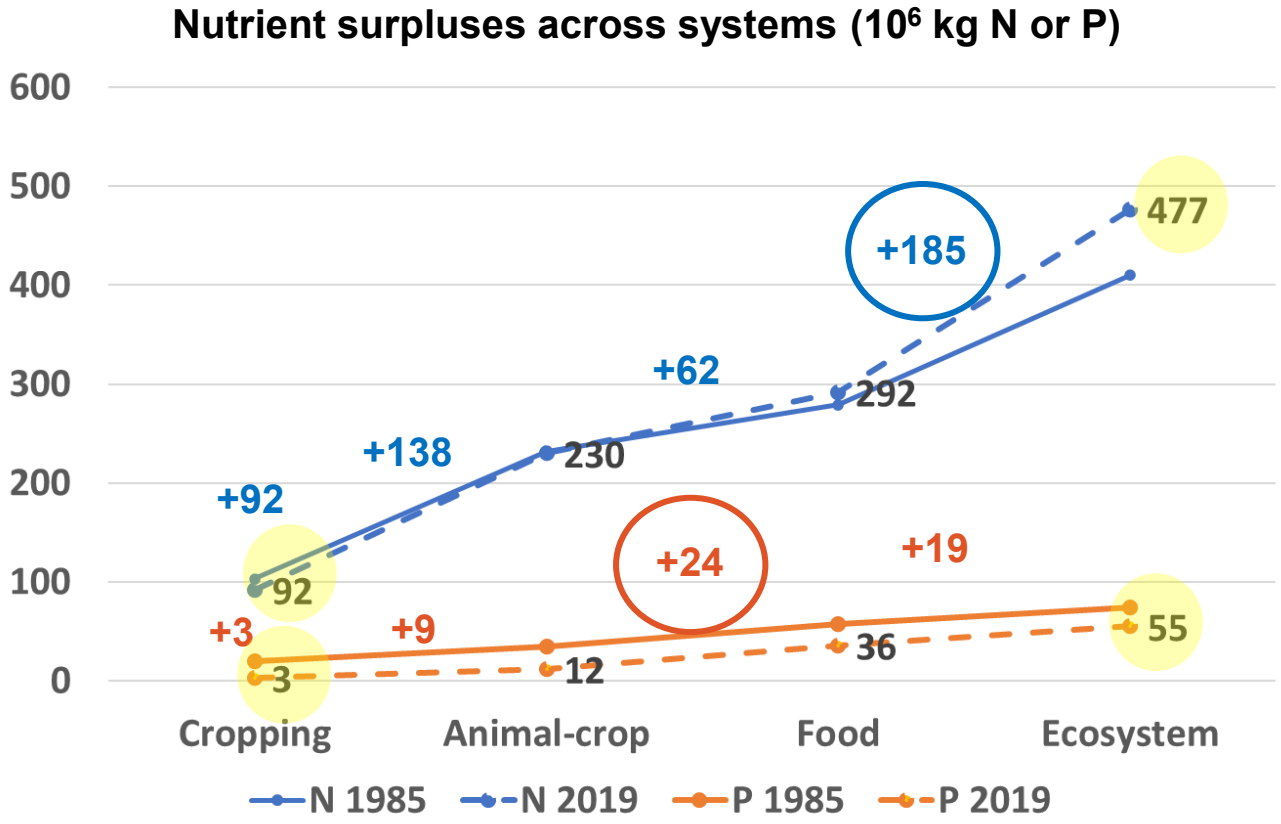
2019 P fertilizer dependency

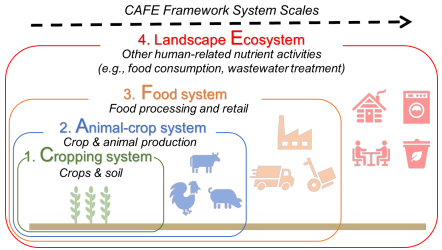
- Watershed: 58% (1985) → 46% (2019)
- % of counties dependent more on P fertilizer: 76% (1985) → 68% (2019)



Zou et al., 2024, *Environ. Res. Lett.*

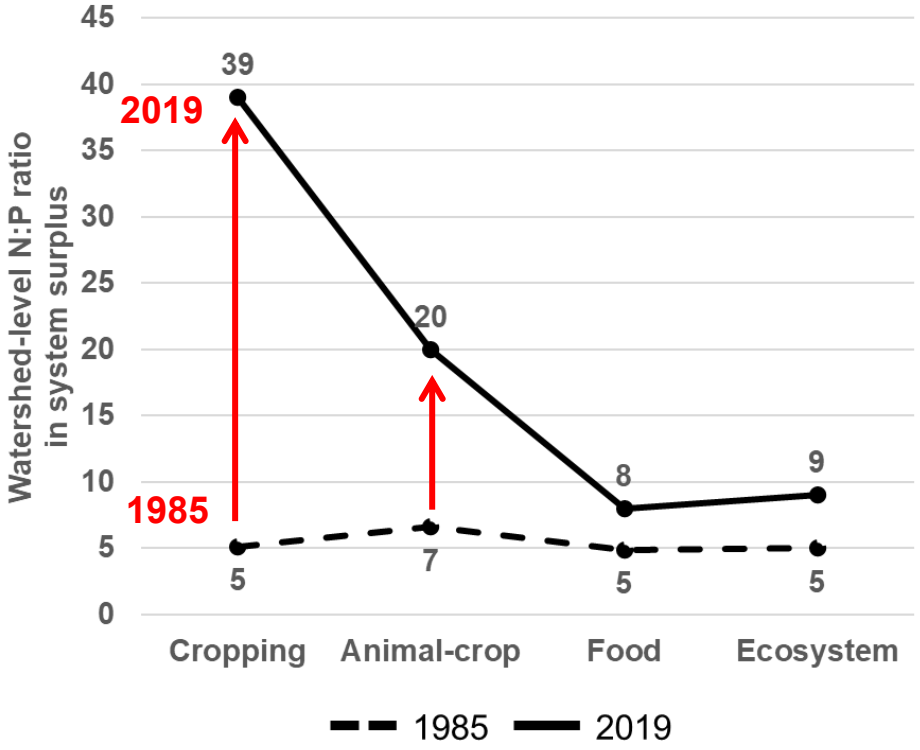
Beyond-cropland nutrient use: 1. Larger potential nutrient loss (surplus)





Beyond-cropland nutrient use: 2. Increased N:P ratios in surpluses

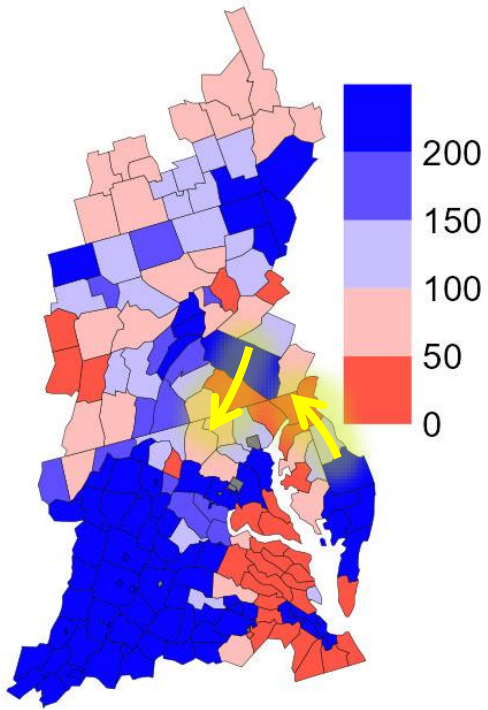
$$\text{N:P ratio in surplus} = \frac{\textit{system N surplus}}{\textit{system P surplus}}$$



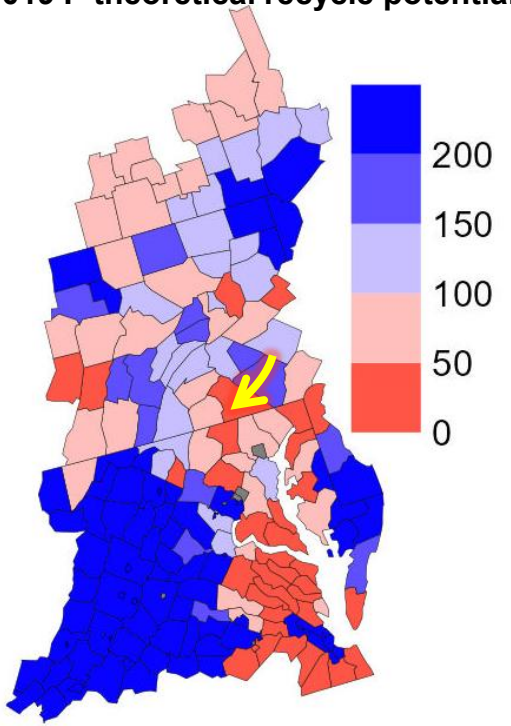
Connecting and improving nutrient management across systems and spatial scales

$$\text{Nutrient theoretical recycle potential} = \frac{\textit{unrecycled N or P}}{\textit{Mineral N or P fertilizer input}} \times 100\%$$

2019 N theoretical recycle potential



2019 P theoretical recycle potential



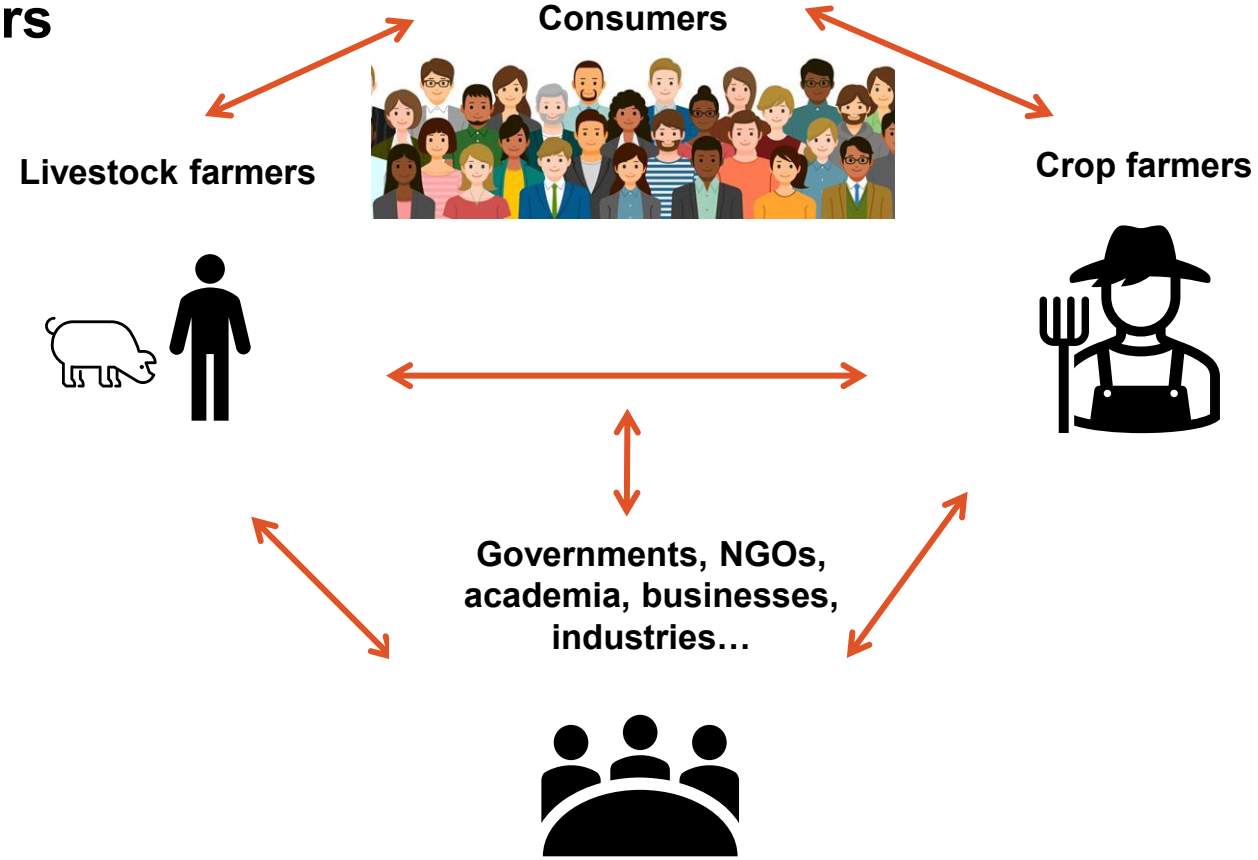
Counties with N potential > 100%:
62% (1985)
66% (2019)

Counties with P potential > 100%:
55% (1985)
62% (2019)

Socioeconomic and technical barriers exist!

Zou et al., 2024, *Environ. Res. Lett.*

Transdisciplinary approach: Engage and collaborate with different stakeholders

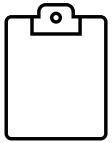


Transdisciplinary approach: Meetings, surveys, interviews

Meetings

share research findings and gather feedback

Surveys

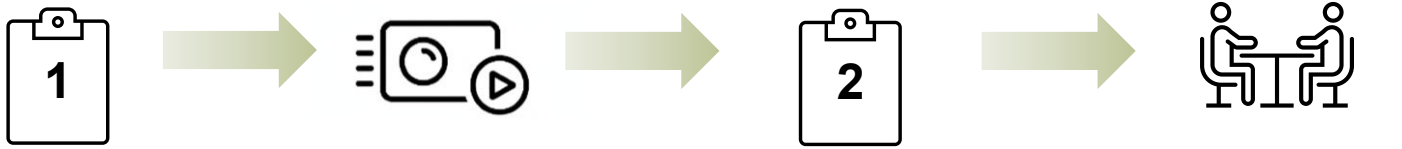


Interviews

understand stakeholders' perspectives on N pollution and management

Transdisciplinary approach: Meetings, surveys, interviews

Survey → **Video** → **Survey** → **Interviews**



87 responses

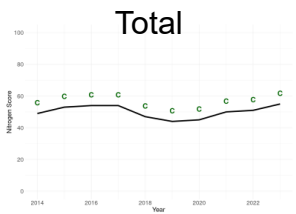
N management across CAFE

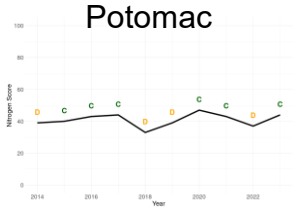
32 responses

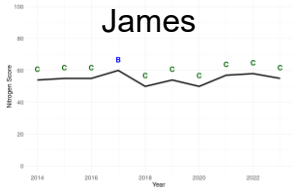
11 responses

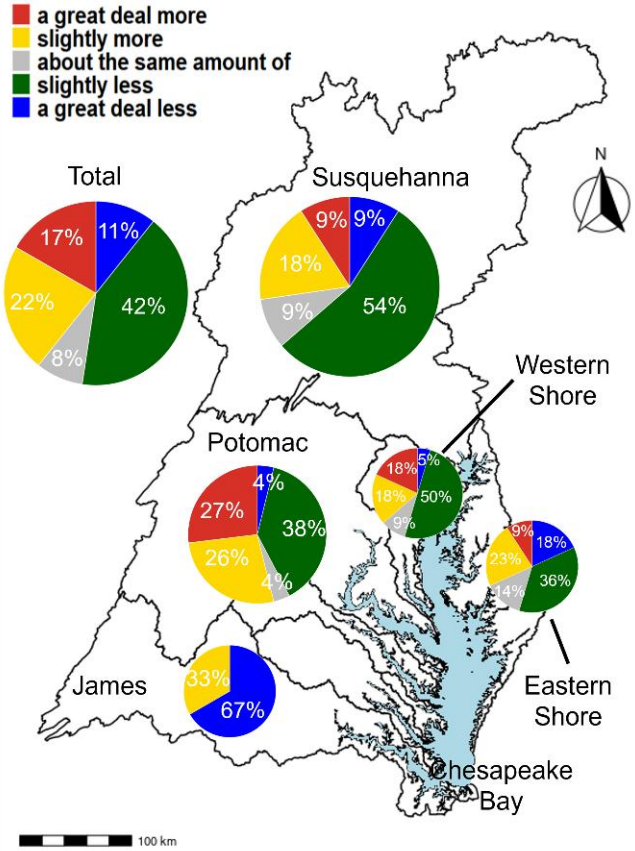
To understand stakeholders' perspectives on N pollution and management

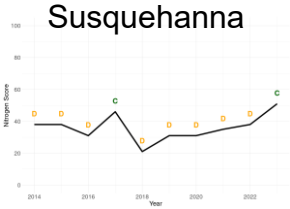
Survey and interview findings – Perceived changes in water quality

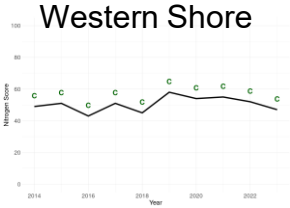


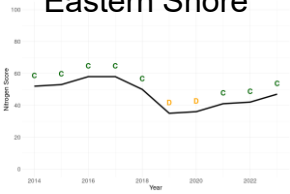






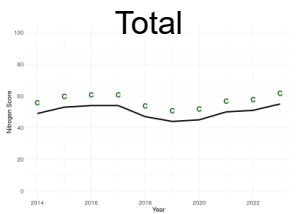


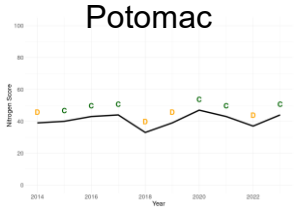


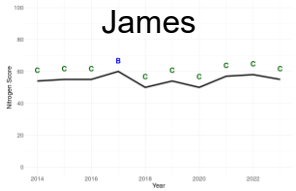


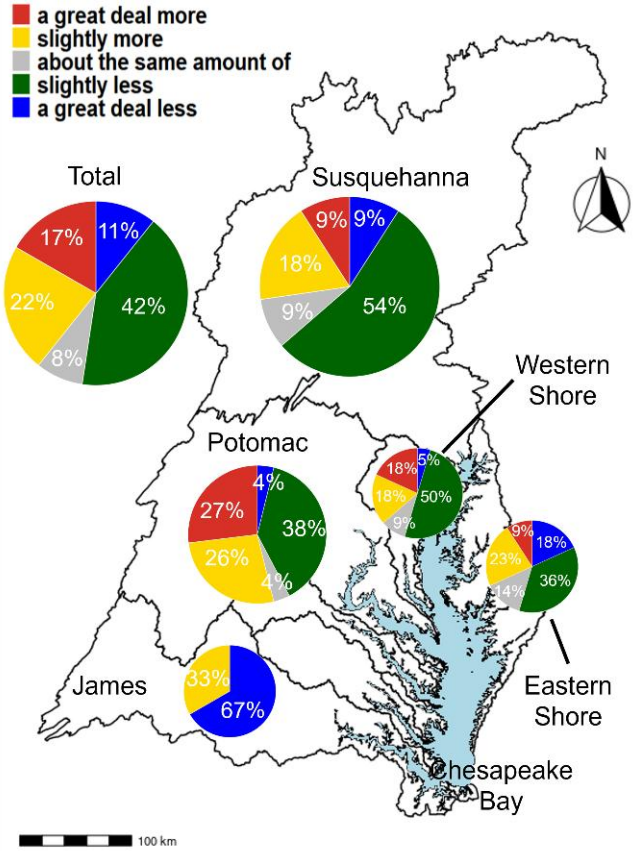
Perception changes:
53% N pollution decreased
39% N pollution increased

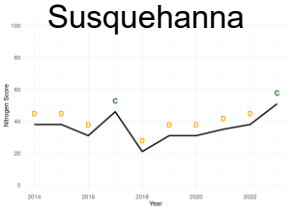
Survey and interview findings – Perceived changes in water quality

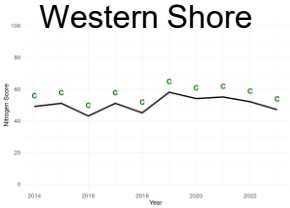


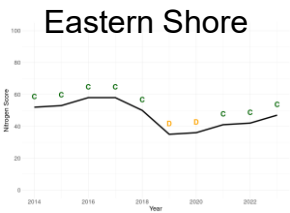












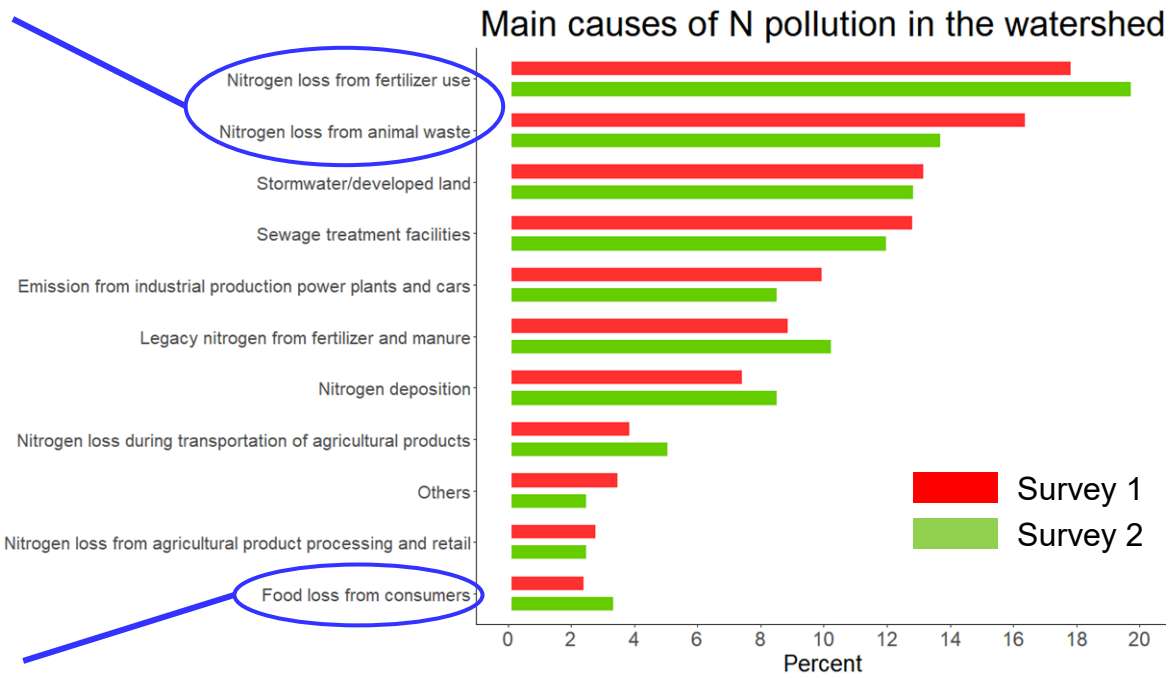
Perception changes:
53% N pollution decreased
39% N pollution increased

Report cards show small improvement

→ Improvements to water quality over the last 10 years not enough to change stakeholder perception of N pollution

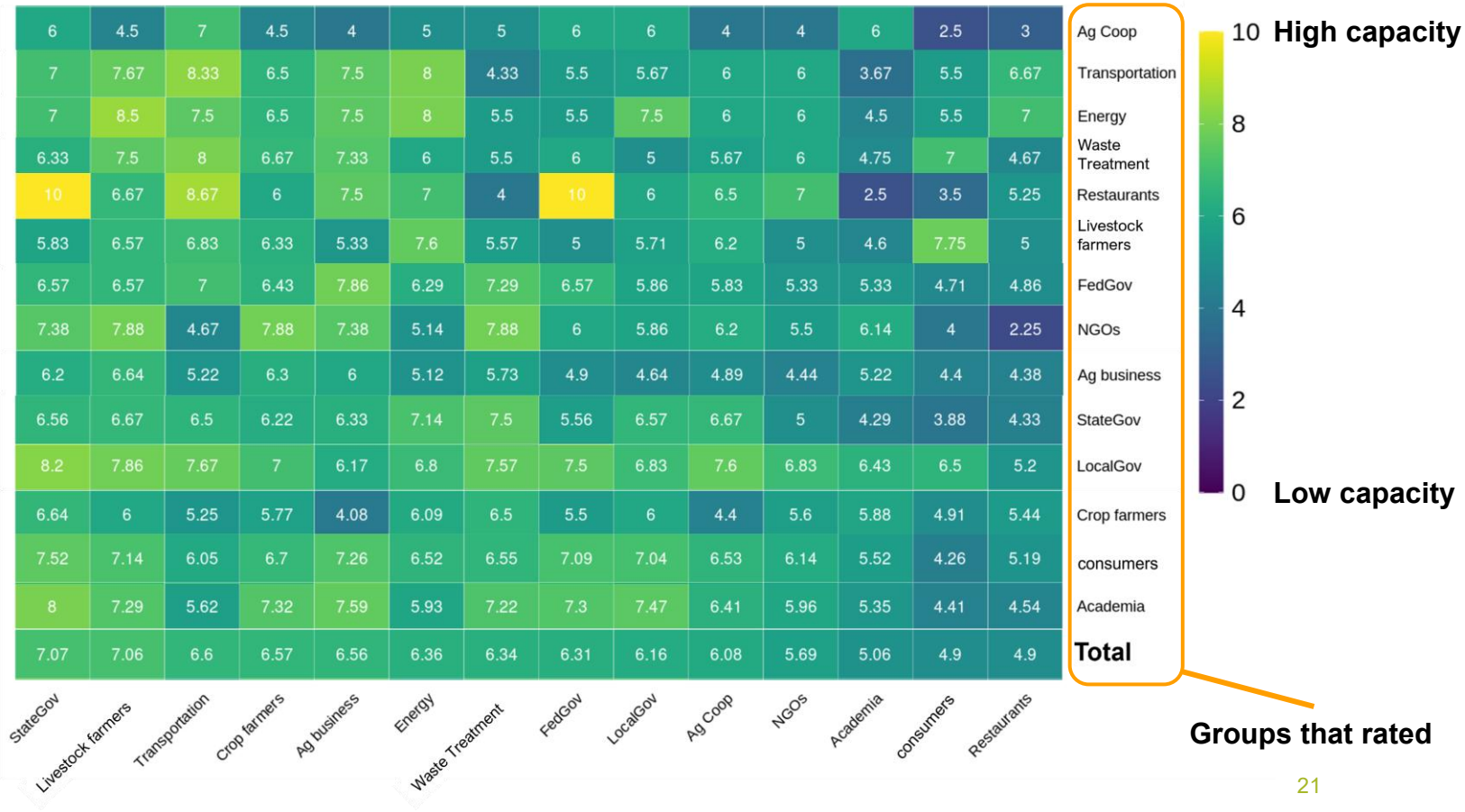
Survey and interview findings – Main causes of N pollution

N loss from agriculture (fertilizer and manure)



N loss from consumers

Survey and interview findings – Perceived capacity of stakeholders



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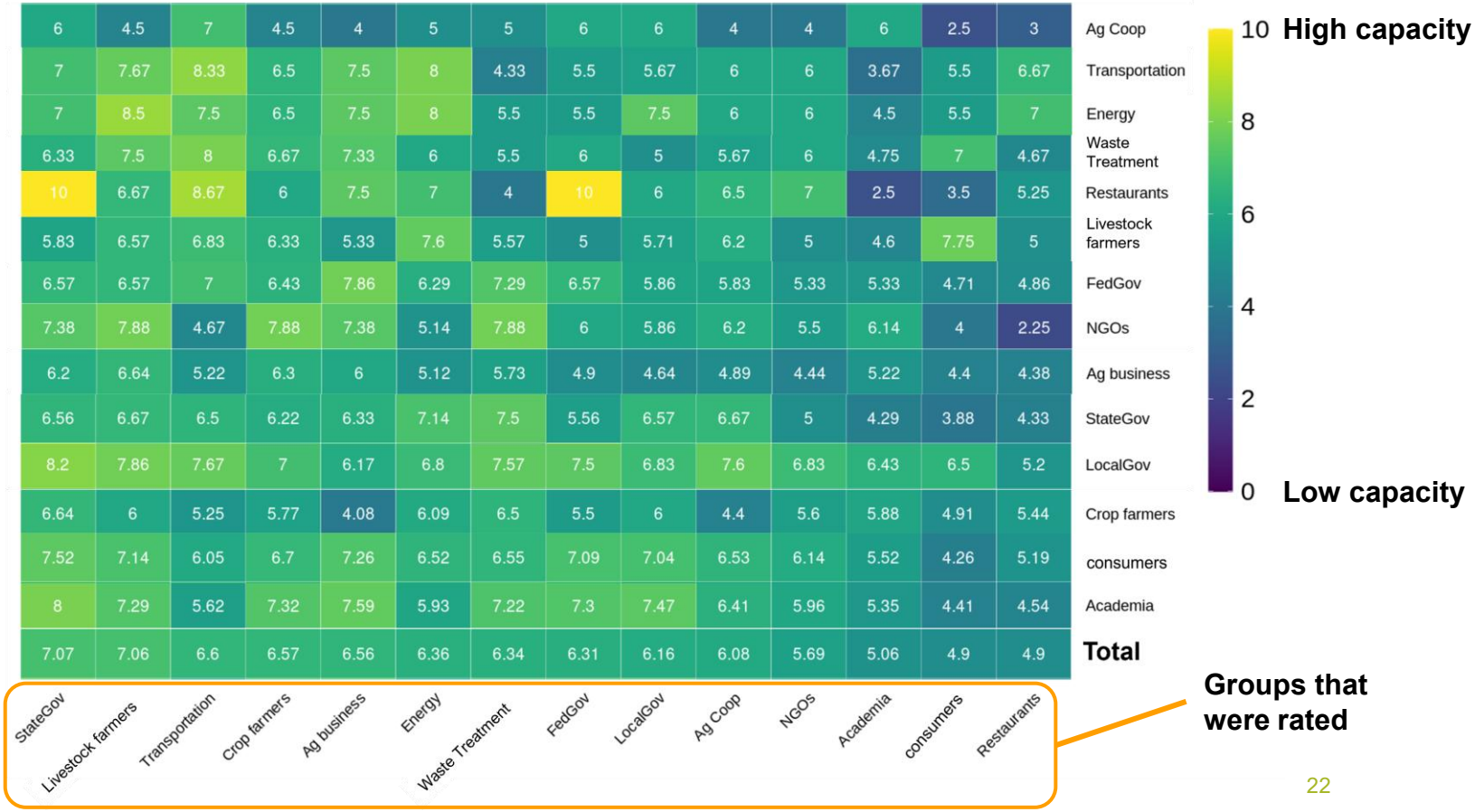

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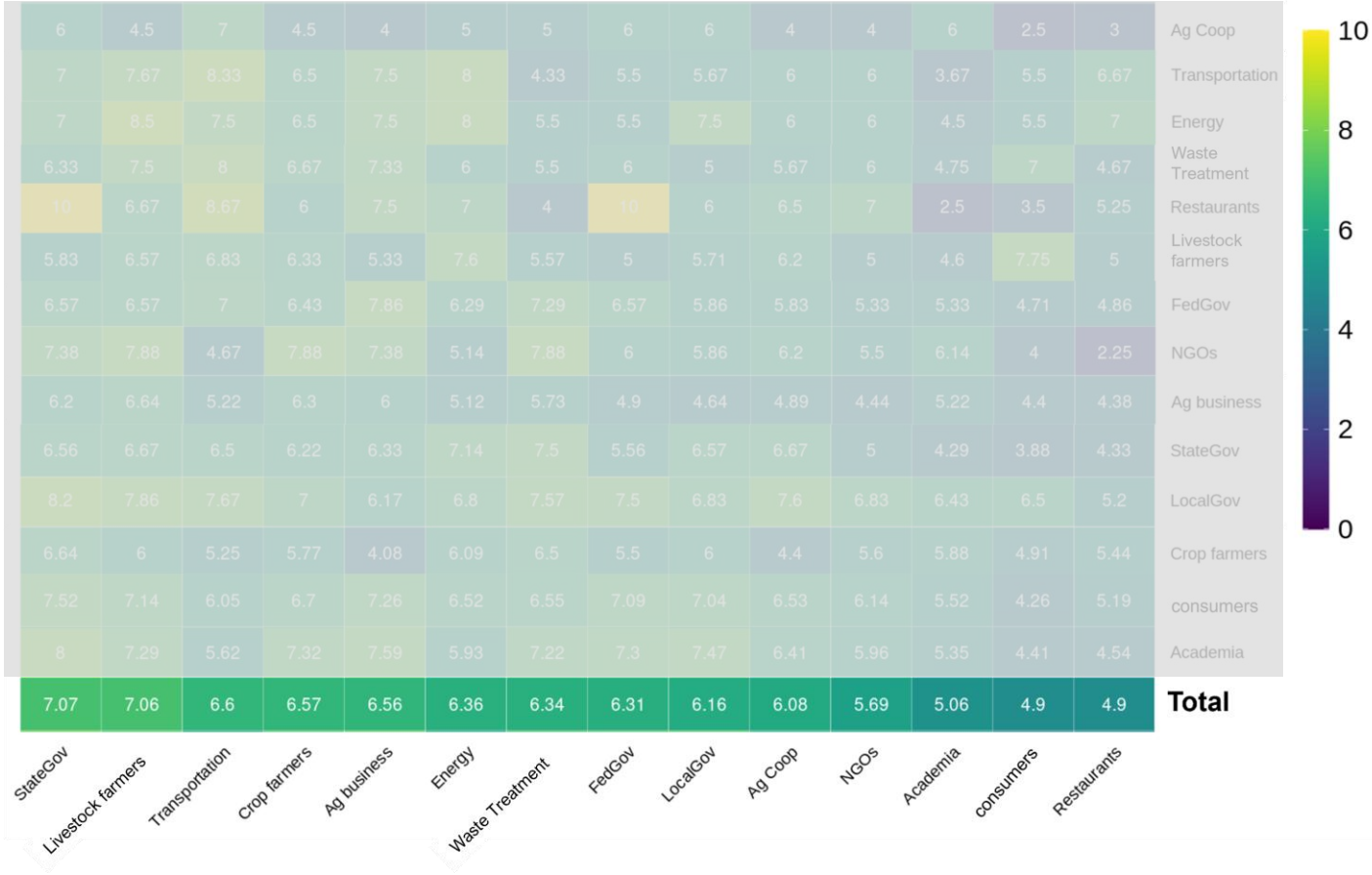
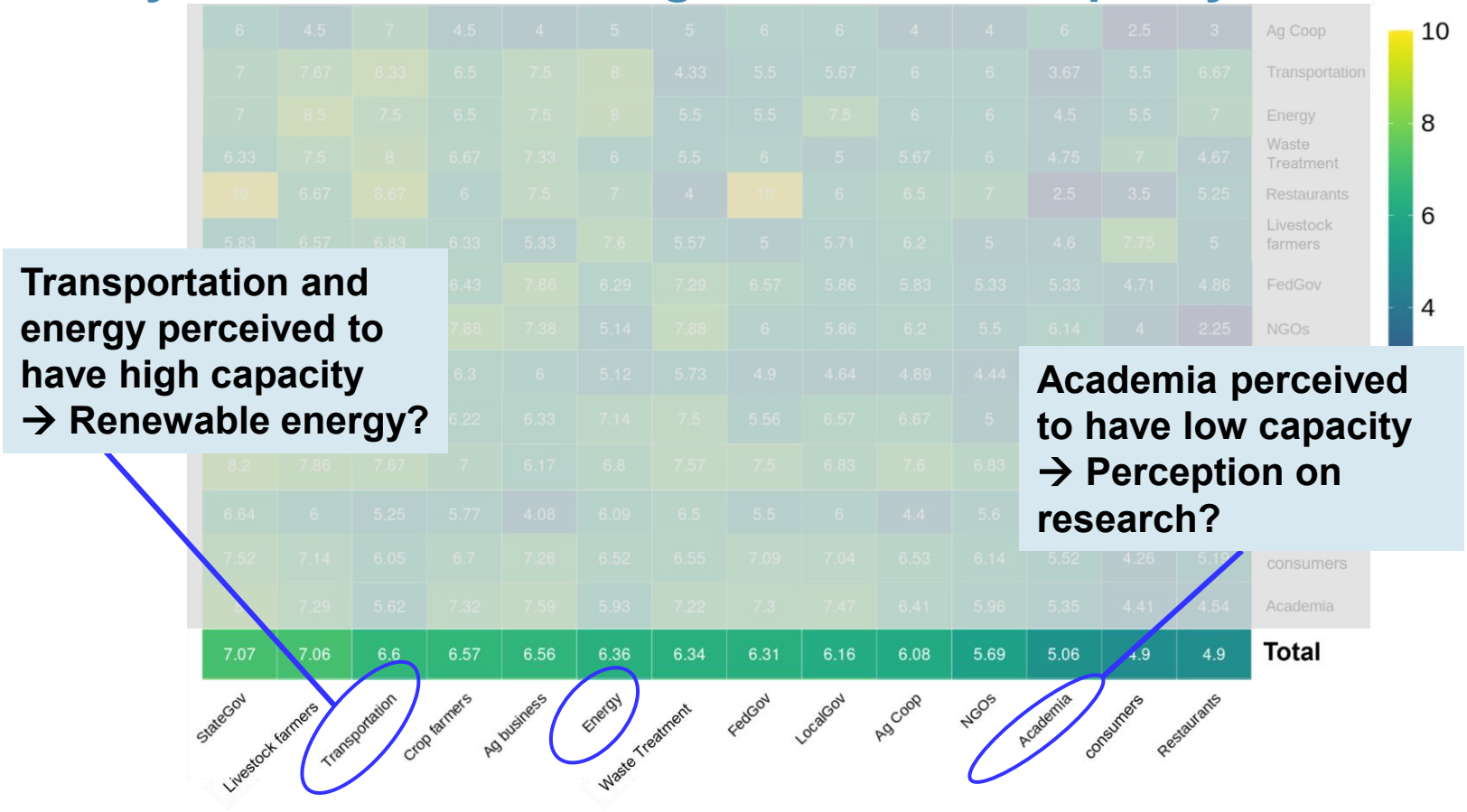


Survey and interview findings – Perceived capacity of stakeholders

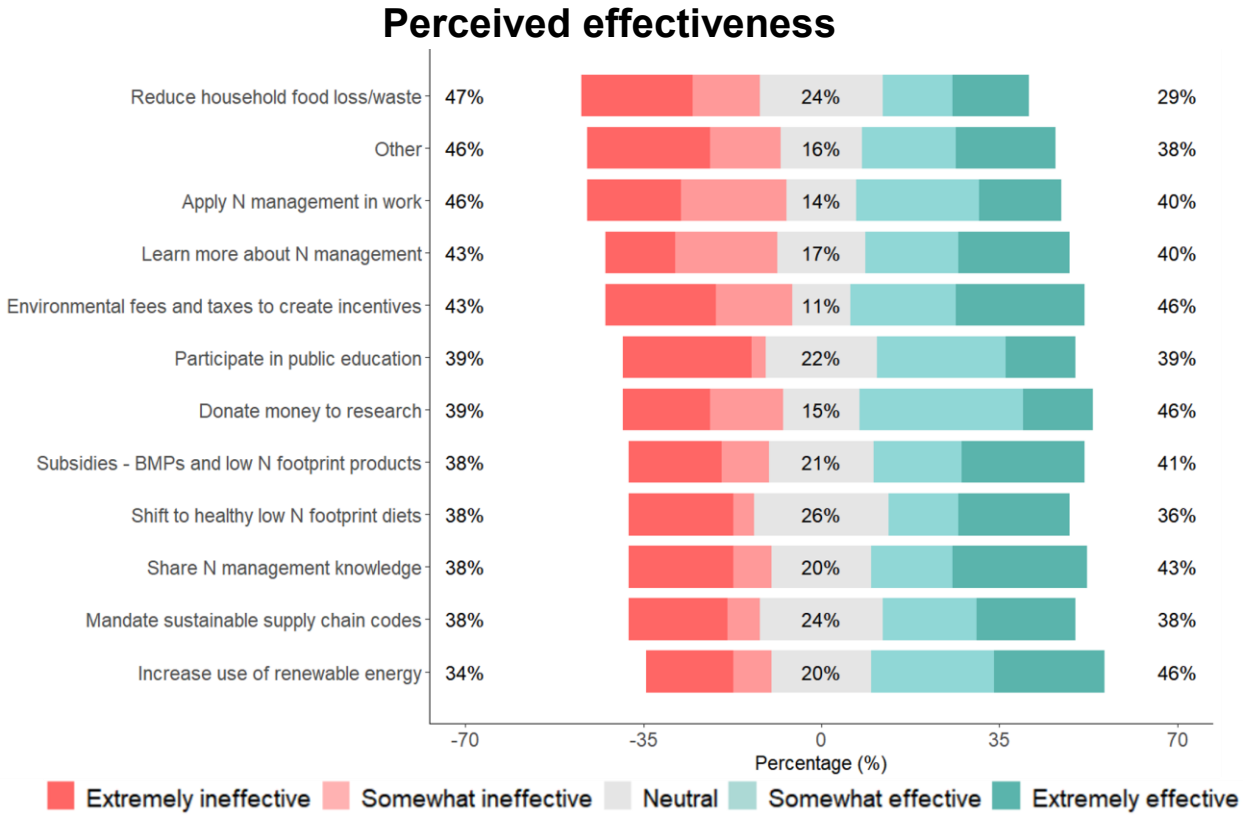
State government and agricultural producers perceived to have highest capacity to reduce N pollution

Individual consumers and restaurants perceived to have lowest capacity to reduce N pollution

Survey and interview findings – Perceived capacity of stakeholders



Survey and interview findings - Adopting beneficial N practices



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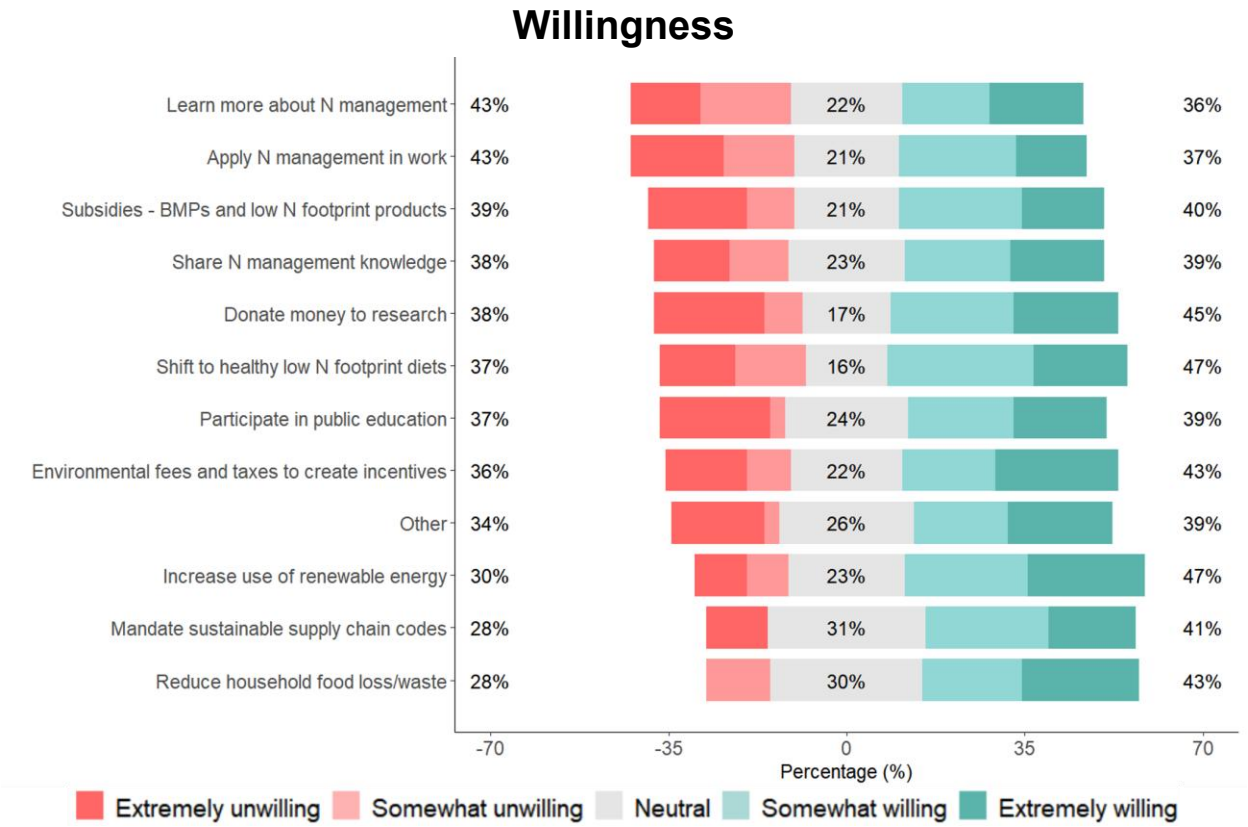
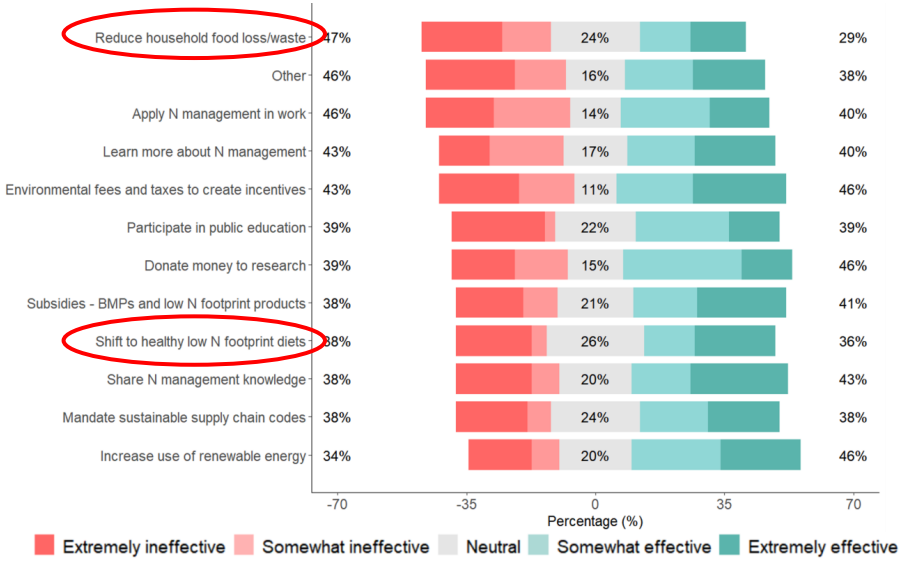


Survey and interview findings - Adopting beneficial N practices

Perceived effectiveness



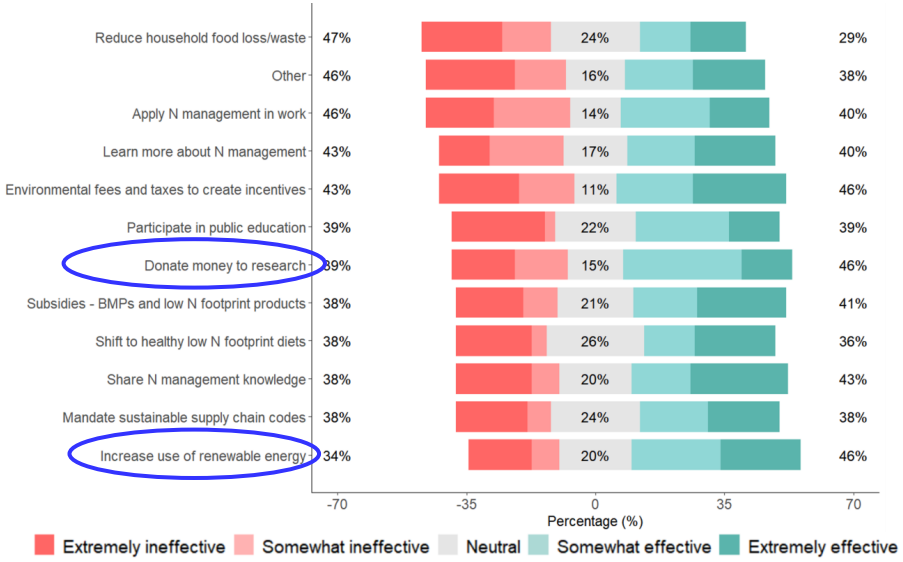
Willingness

Individual practices – Low perceived effectiveness but high willingness

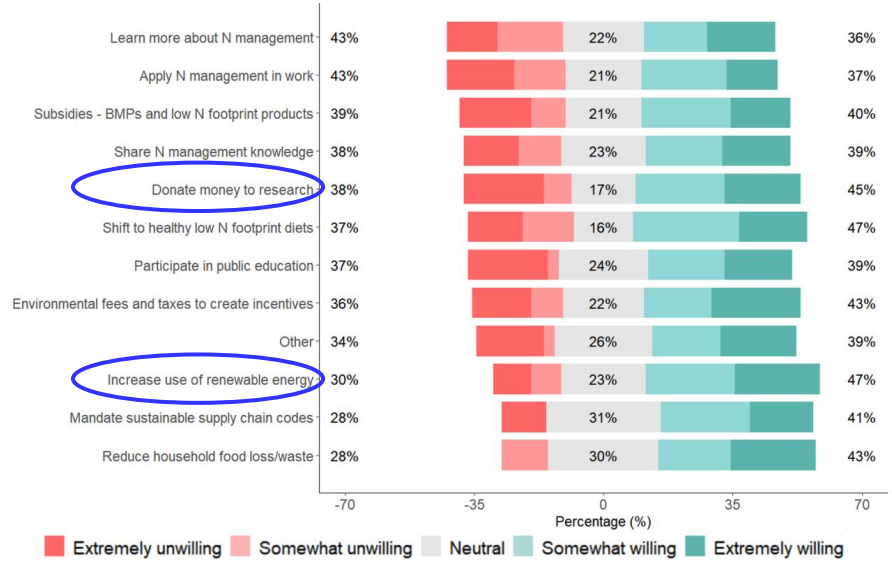
→ Opportunities for improving N management beyond agricultural production

Survey and interview findings - Adopting beneficial N practices

Perceived effectiveness



Willingness



Renewable energy and donating money to research – high perceived effectiveness and willingness

→ Opportunities to discuss energy transition and funding for research

What did we learn?

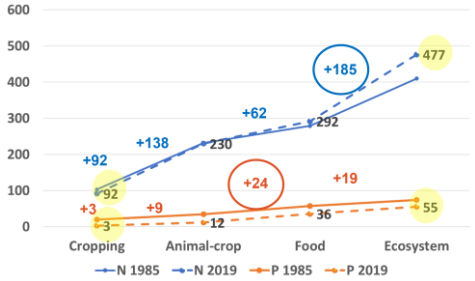
Nutrient management over the last 35 years

- **Improvement in cropland** but **greater nutrient loss beyond cropland** than in cropland

Cropland

	1985	2019
NUE	68%	**76%**
PUE	68%	**95%**

But



What did we learn?

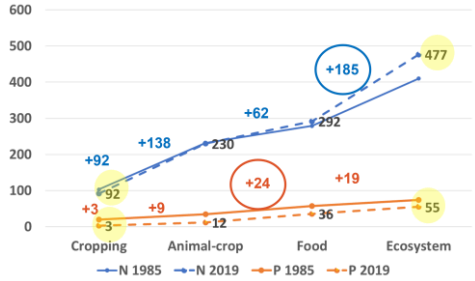
Nutrient management over the last 35 years

- Improvement in cropland but greater potential nutrient loss beyond cropland than in cropland

Cropland

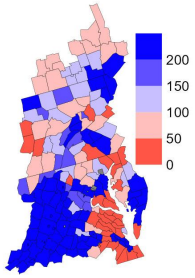
	1985	2019
NUE	68%	**76%**
PUE	68%	**95%**

But

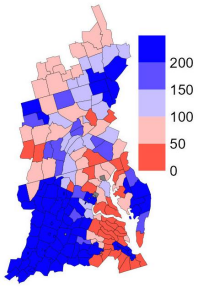


To better connect and improve nutrient management across systems

- Further **increase the recycling of waste** across systems and spatial boundaries
- Better understand and address potential **socioeconomic and technical barriers**



66% of counties with N recycling potential over 100%

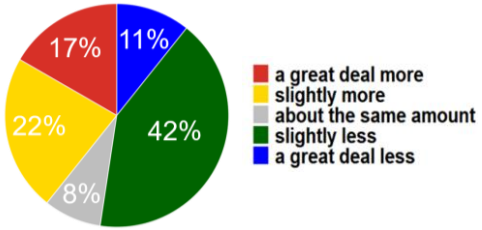


62% of counties with P recycling potential over 100%

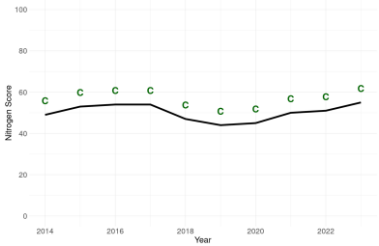
What did we learn?

Gap between water quality improvements and perceived changes in water quality

- **Better communication** of efforts and improvements towards water quality to the public required



Perceived vs Actual



Opportunities for improving nutrient management beyond croplands

- **High willingness** to participate in **individual N management practices**
- Need to **provide stakeholders with better N management practices** they can adopt and **help them understand their capacity to make a change**
- Need to address different stakeholders' concerns and challenges regarding nutrient management

What did we learn?

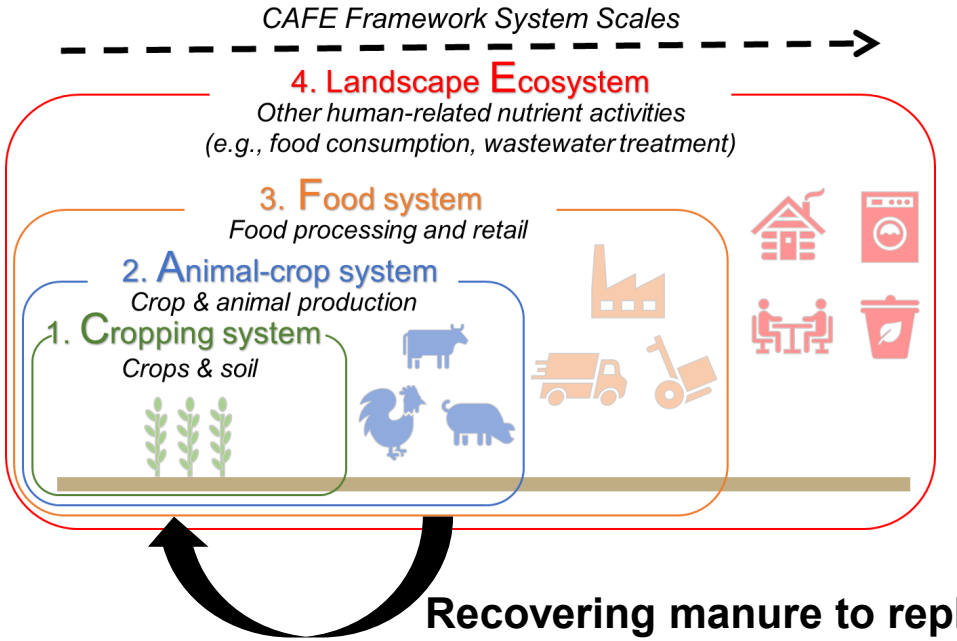
The need for using system and transdisciplinary approaches

- *CAFE* framework: identify management gaps and opportunities across systems and spatial scales
- Transdisciplinary research: improve stakeholder engagement and science communication

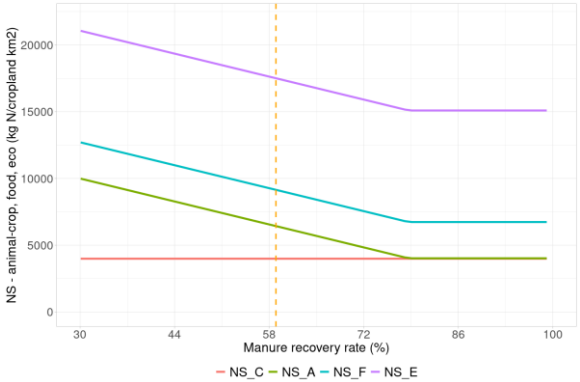
→ Explore how we can better translate science into actionable insights for management and policymaking

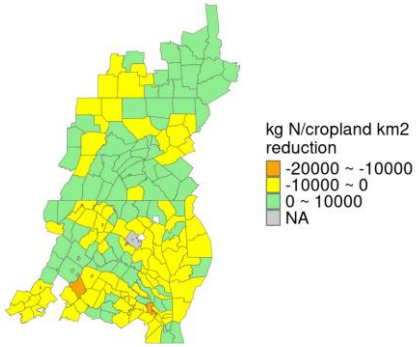
Future research

How can we better connect and improve nutrient management across systems?



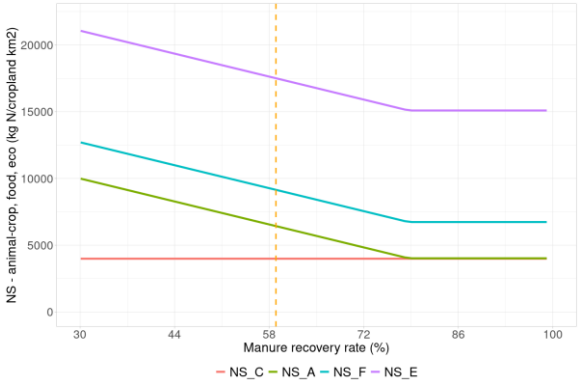
Recovering manure to replace synthetic fertilizer input

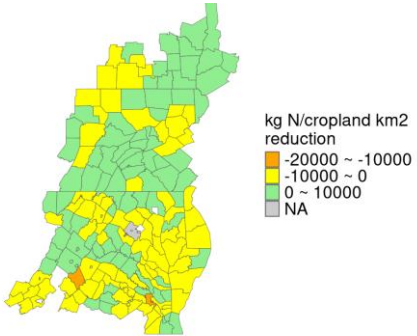


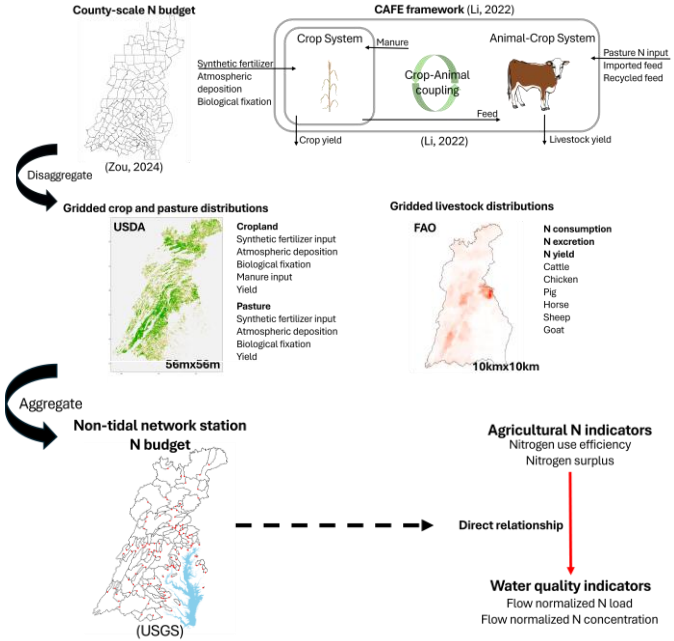


Future research

How would improvements in nutrient management affect water quality?







Thank you!
Questions?

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Li, T., X. Zhang, Y. Zhong, E. A. Davidson, Z. Dou, W. Zhang, P. S. Pavinato, L. A. Martinelli, D. R. Kanter, J. Liu, and F. Zhang. 2022. A Hierarchical Framework for Unpacking the Nitrogen Challenge. Earth's Future 10:e2022EF002870.https://doi.org/10.1029/2022EF002870

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Disparities in nitrogen and phosphorus management across time and space: a case study of the Chesapeake Bay using the *CAFE* framework

Tan Zou[1,*], Eric A Davidson[1,4], Robert D Sabo[2], Graham K MacDonald[3] and Xin Zhang[1,4,*]

Zou et al., 2024, Environ. Res. Lett.

A Hierarchical Framework for Unpacking the Nitrogen Challenge

Tingyu Li[1,2], Xin Zhang[3], Yuxiu Zhong[2], Eric A. Davidson[3], Zhengxia Dou[4], Weifeng Zhang[1,2], Paulo S. Pavinato[5], Luiz A. Martinelli[6], David R. Kanter[7], Jianguo Liu[8], and Fusuo Zhang[1]

Li et al., 2019, Earth's Future