Office of Research and Development

Safe and Sustainable Water Resources Research Program

Mississippi River Basin and Gulf Hypoxia Research Overview

HTF Coordinating Committee

August 11, 2022

United States Environmental Protection Agency

EPA ORD Mississippi River Basin Modeling Efforts: Current Work + Next Steps

Data & Synthesis-Based Approaches

Nutrient Inventories: Links to MRB Water Quality (Lead: Robert Sabo)

Synthesis of BMP Effectiveness in the UMRB (Lead: Yongping Yuan)

Simulation Approaches

Modeling the UMRB: wetlands, nutrients, and more
(Leads: Heather Golden, Grey Evenson, Jay Christensen, Charles Lane)

Multi-media modeling of the MRB & Northern GOM Hypoxia
(Leads: Brandon Jarvis, Yongshan Wan, Yongping Yuan)

United States Environmental Protection Agency

Nutrient Inventories: Links to MRB Water Quality

Robert Sabo

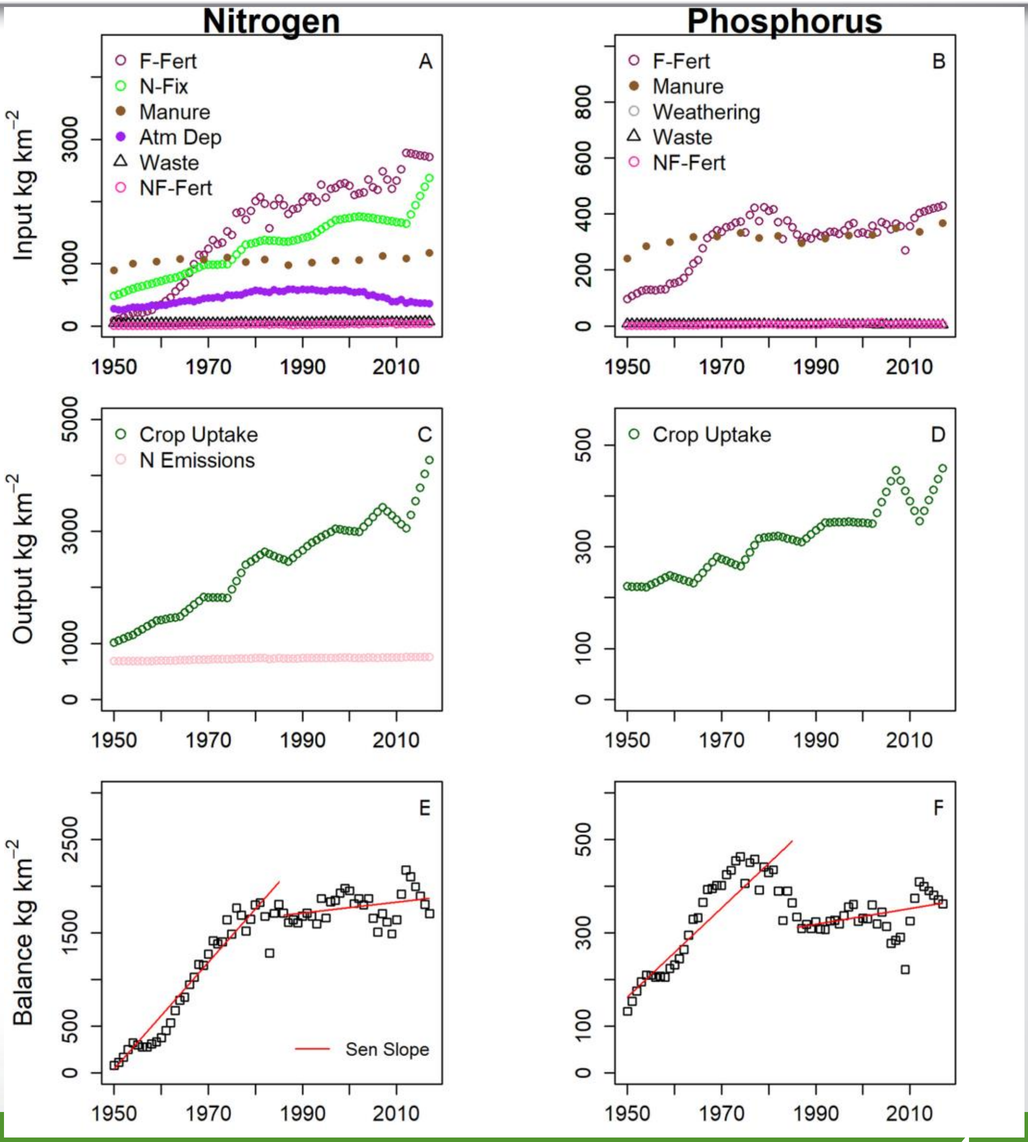
Long-Term Mississippi River Trends Expose Shifts in the River Load Response to Watershed Nutrient Balances

Issue: Unclear how point and non-point pollution sources have evolved in MR basin and how shifts in pollution sources relate to observed nitrogen and phosphorus loading trends

Approach: Developed highly empirical nutrient inventories to track shifts in urban and agricultural point and non-point sources of pollution. After calculating balances, we related shifts in excess nutrients to observed nutrient loading trends.

Observations from Inventory:

1. After ~1980, excess nitrogen and phosphorus left on farm fields largely stabilized and declined, respectively.
2. Improvements in nutrient management coincided with ~80% increase in crop removal—good news.



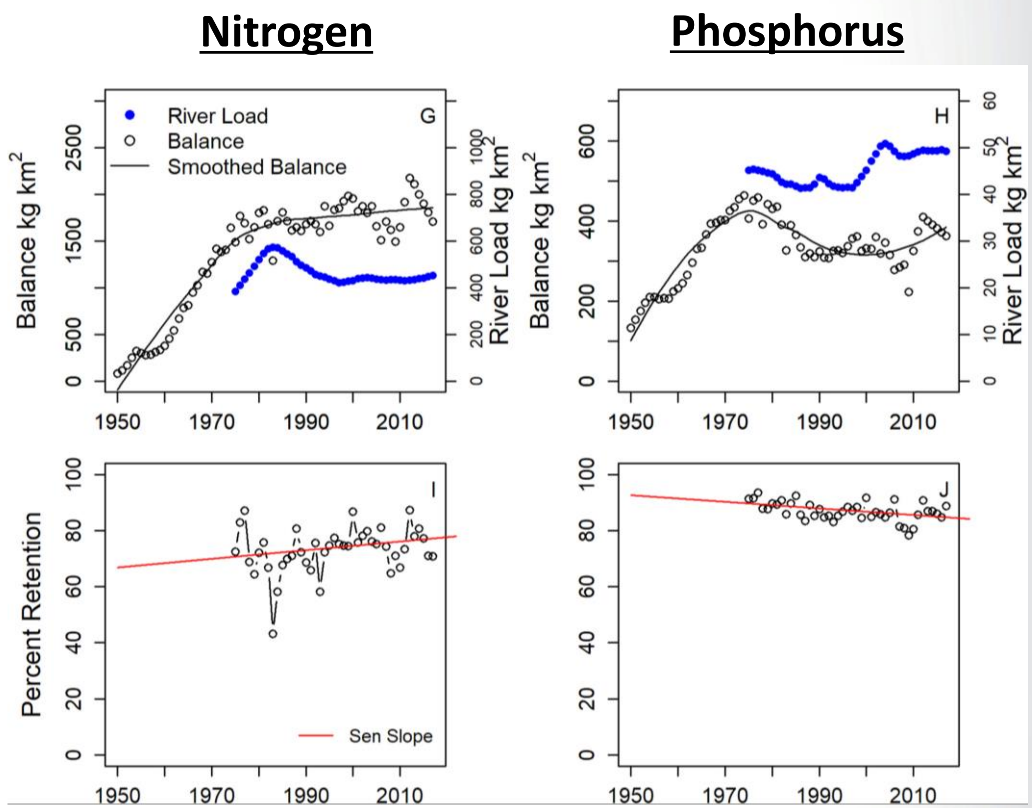
Long-Term Mississippi River Trends Expose Shifts in the River Load Response to Watershed Nutrient Balances

1. After 1980, WRTDS flow-normalized nitrogen loads declined (blue dots) despite nitrogen balances remaining generally stable (open circles).

2. Retention of nitrogen surplus has increased

3. After ~2000, WRTDS flow-normalized phosphorus loads increased despite declines in phosphorus balances

4. Retention of phosphorus has declined in the MS basin



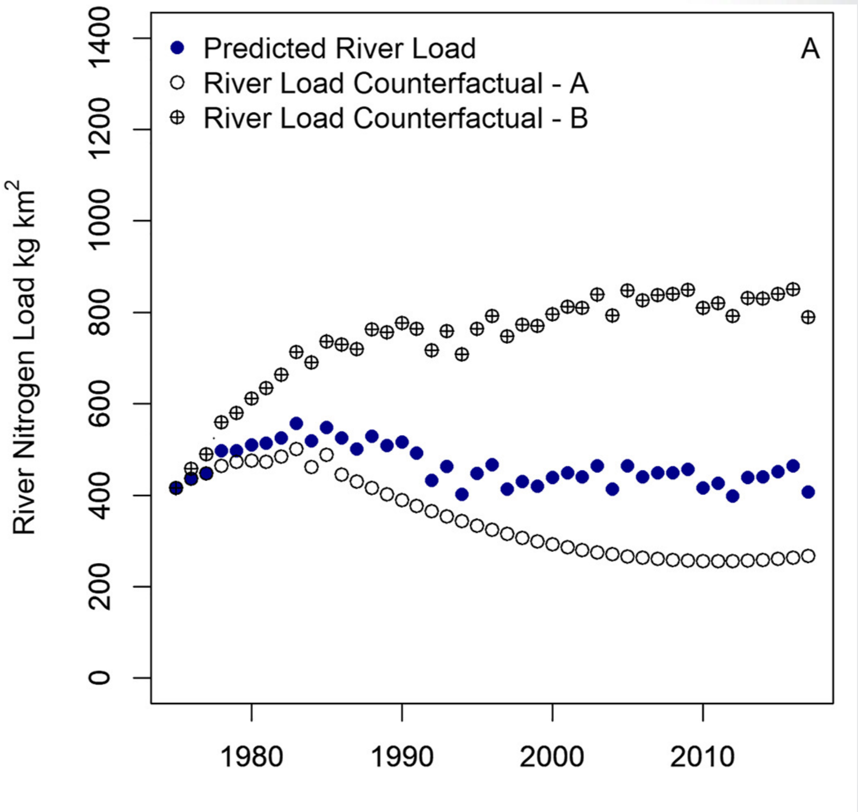
Latent processes that enhanced nitrogen retention offset further increases in nitrogen loads

1. Efficient regression models statistically captured the net effect of lagged nutrient balances and latent processes that altered N retention (blue circles)

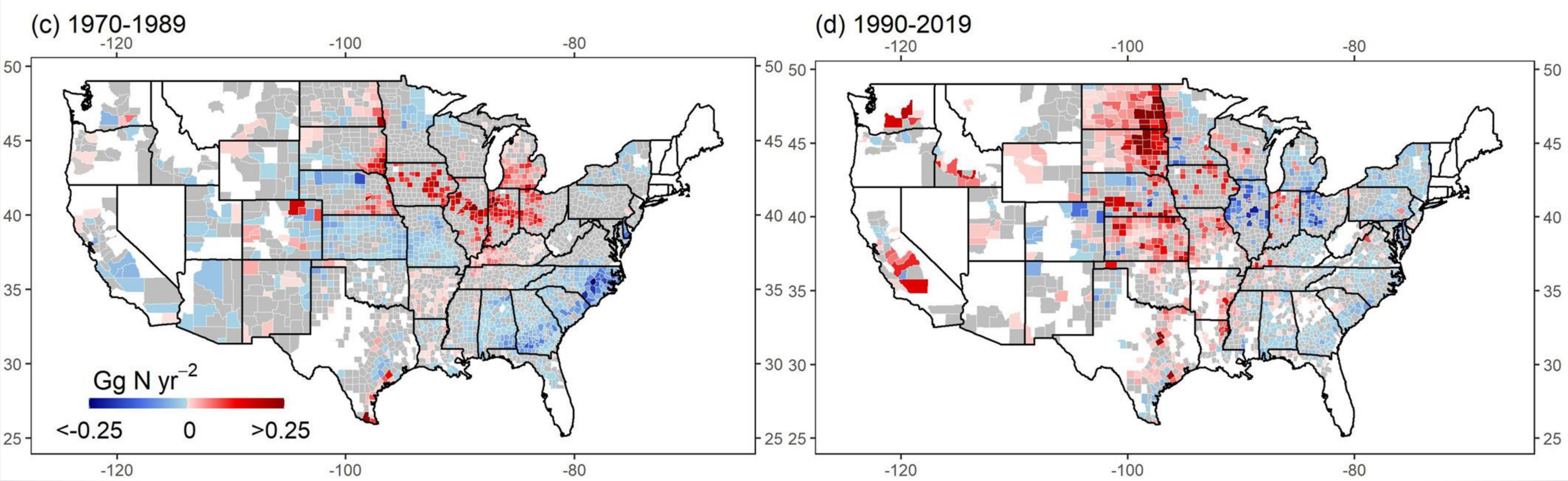
2. Ran a counter-factual where 1) latent processes did not have a positive effect on nitrogen retention (checkered circles) and 2) nutrient balances were returned to lower 1975 levels (open circles)

3. If farmers lowered nitrogen balances, combined with the processes that enhanced retention, would have cut N loads to Gulf of Mexico by ~**<u>half compared to observed values.</u>**

4. Decrease the surplus, save the Gulf?

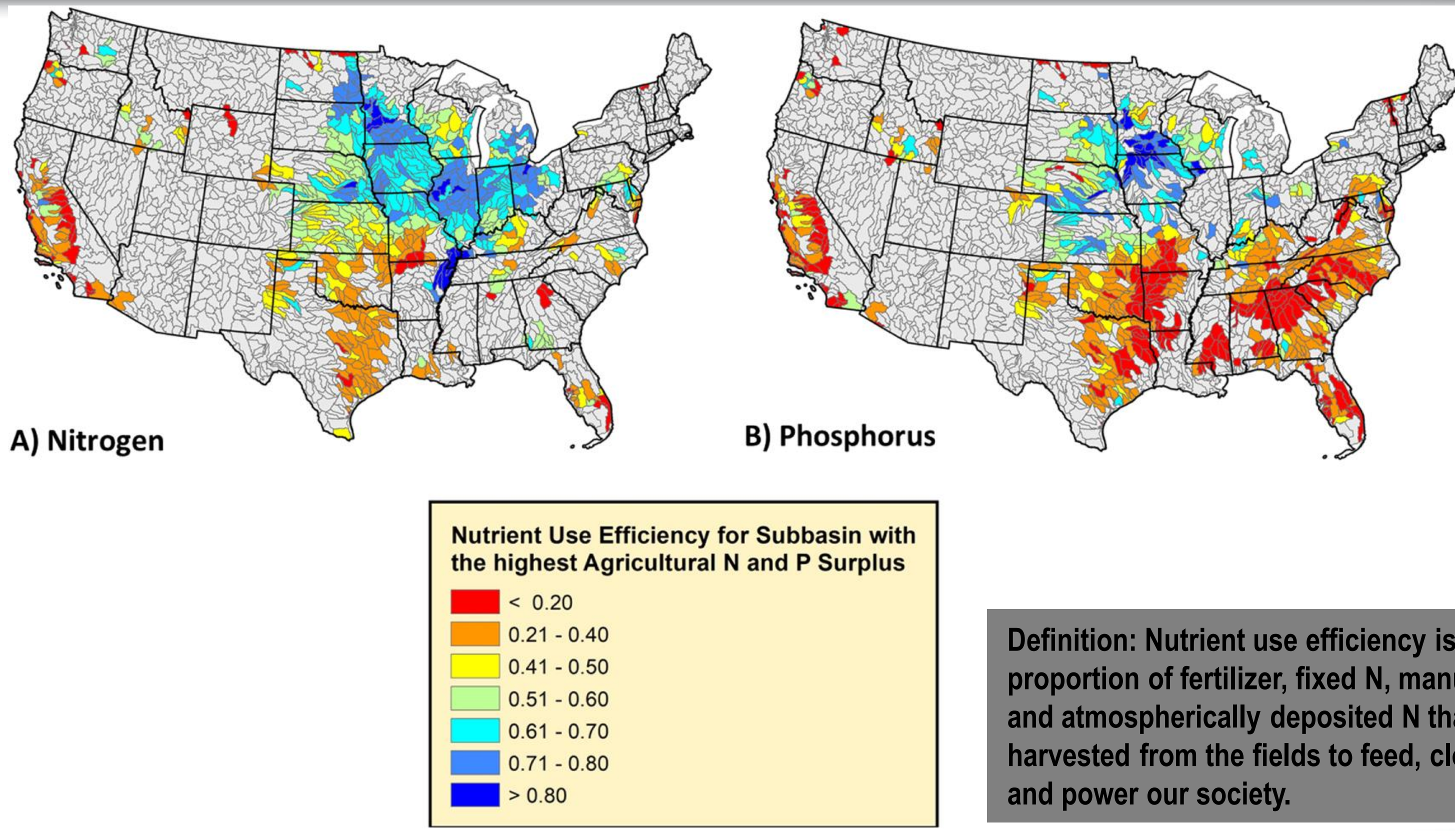


Why has agricultural surplus not declined in the MS basin?



- Since 1990, Ohio and Illinois farmers have decreased the amount of nitrogen left on fields
- Other parts of the basin had large increases in surplus (e.g., North and South Dakota) or remained stable/slightly increased (Iowa)
- Net effect of shifts in agricultural non-point pollution sources resulted in a generally stable or slightly increased surplus trajectories in MS basin

Nitrogen and phosphorus inventories can be leveraged to identify pollution hotspots and offer actionable metrics for stakeholders to improve



Definition: Nutrient use efficiency is the proportion of fertilizer, fixed N, manure, and atmospherically deposited N that is harvested from the fields to feed, clothe, and power our society.

1. Nutrient use efficiency targets of 80-90% are ideal to maintain crop yields, most subbasins are below this target
2. Recent USDA CEAP report and our inventory finds farmers are applying manure on top of fertilizer in many areas
3. Some area of the country have NUE exceeding 80%, may have to incorporate other BMPs besides ensure better NUE

Key take aways from the nutrient inventories for MS River Basin

- Agricultural non-point sources of pollution have largely stabilized for nitrogen and slightly declined for phosphorus
- Latent process altered the retention of nitrogen and phosphorus surplus
  - Nitrogen retention increased, leading to decreased export to the Gulf of Mexico
  - Phosphorus retention decreased, leading to increased export to the Gulf of Mexico
  - We can discuss speculations and further research initiatives later on, your guidance is key to craft products that meet your information needs
- Decreased nitrogen balances, using 4R principles, can lead to decreased nitrogen loads within 5-15 years.
- Certain states have decreased the magnitude of agricultural non-point nitrogen pollution sources but have been offset by recent increases in other states
- Nitrogen and phosphorus inventories can be leveraged to identify pollution hotspots for prioritization efforts and guide the watershed implementation plans.

Synthesis of BMP Effectiveness in the UMRB

Yongping Yuan

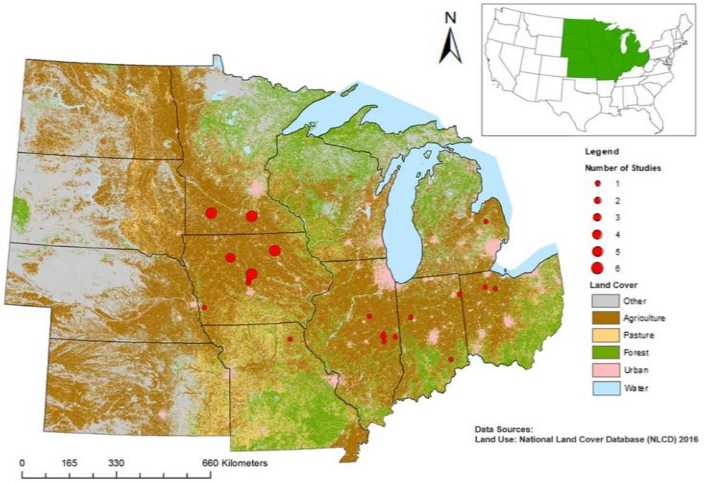
Effectiveness of Nutrient Management on Nitrate-Nitrogen Loss from Subsurface Drainage

Issue: Excess nutrient fluxes from agricultural fields have been linked to occurrences of lake eutrophication, leading to harmful algae blooms (HABs), and hypoxia in the ocean worldwide such as the Gulf of Mexico.

Approach: Synthesizing available information on nitrogen (N) fertilizer rate, source, application method and timing, along with related drainage water quality and crop yield data.

Impact: Information gained from this research will help: 1) improve nutrient management plans; and 2) inform the selection of ACPs for water quality improvement. Ultimately, it helps the federal government agencies (e.g. USDA-NRCS and EPA-OW) and state government agencies to prioritize their funding for ACPs selection and implementation to achieve water quality goals.

Partners/Clients: Office of Water, Regions 5 and 7



Fertilizer information	Categories	Descriptions
Fertilizer rate groups	Low	< 134 kg N ha^{-1}
	Moderate	134 – 167 kg N ha^{-1}
	High	167 – 200 kg N ha^{-1}
	Very high	> 200 kg N ha^{-1}
Fertilizer sources	Inorganic	Urea, UAN[†], and other synthetic fertilizers
	Organic	Liquid manure & manure
	Other	No specific sources or no fertilizer applied
Application methods[*]	Injected	
	Incorporated	
	Surface applied	Including broadcast applied.
	Banded	

Response of Crop Yields and NO_3-N Losses to Fertilizer Application Rates

The response of [NO_3-N] (Fig. 1b) to fertilizer rate is different from that of crop yield (Fig. 1a).

a. At low-rate, yields increase as fertilizer rate increases.

b. The change in concentration is smaller for low-rate groups (i.e., low to medium); but is higher for higher rate groups.

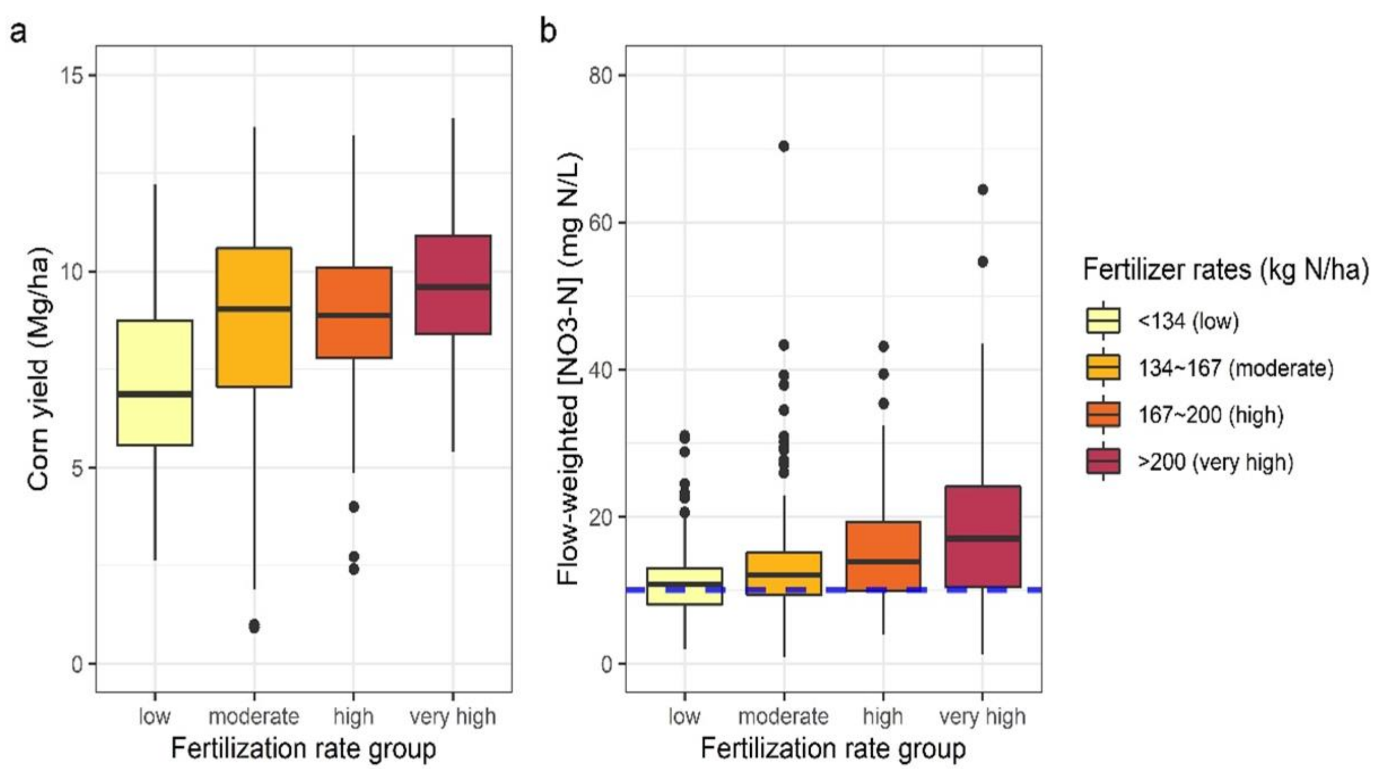


Figure 1. Corn yield (a) and [NO_3-N] (b) for different categories of fertilizer rates.

Impacts of Fertilizer Sources on Crop Yields and NO_3-N Losses

a. Organic fertilizer consistently produced higher corn yields compared to inorganic fertilizer.

b. Organic fertilizer al so produced higher [NO3-N] for all rate groups except the very high group

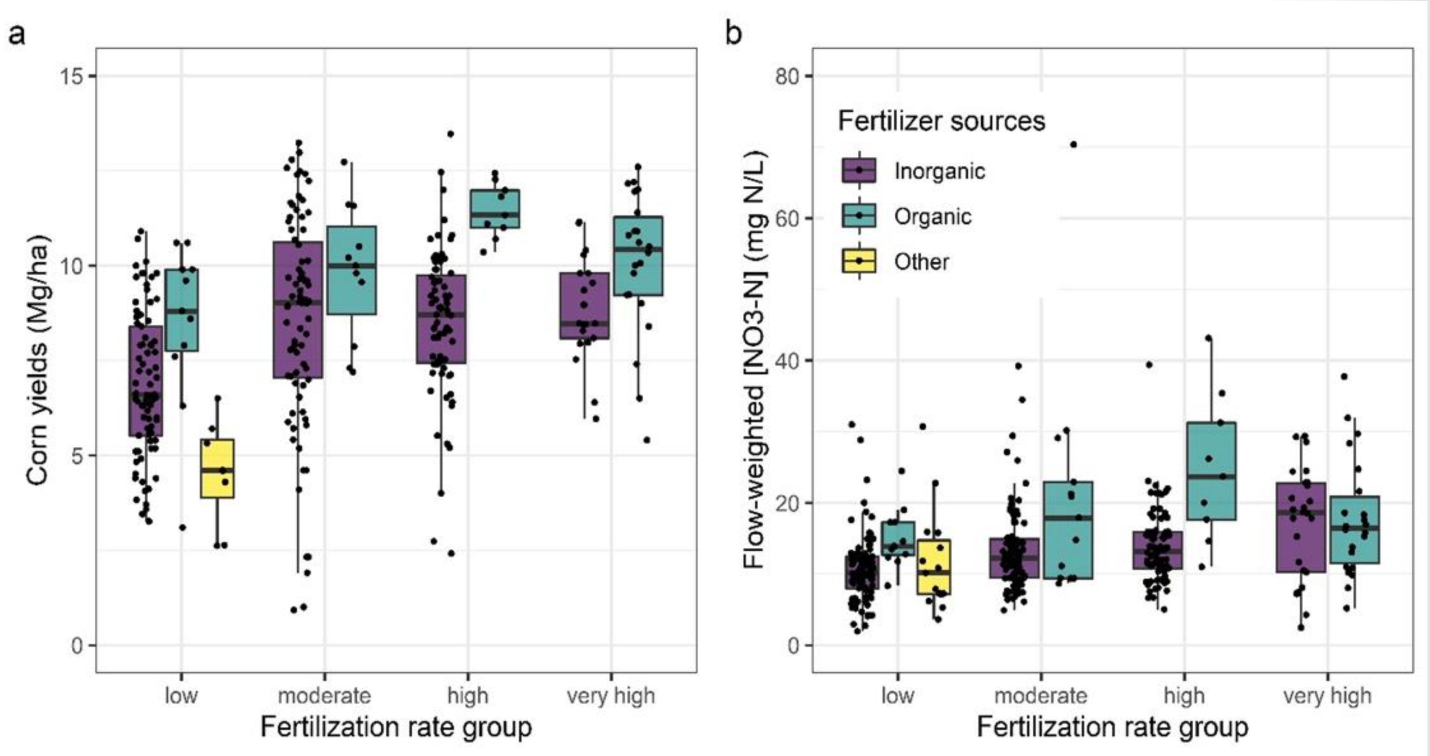


Figure 2. Comparison of crop yield (a) and [NO_3-N] (b) for different fertilizer sources at different fertilizer rate groups. Only site-years with single applications were included in this study.

Effectiveness of Nutrient Management on Nitrate-Nitrogen Loss from Subsurface Drainage

Take home message(s): Fertilizer rate was found to be the most important factor controlling flow-weighted nitrate-N concentrations; and with higher fertilization rates, corn yields, NO_3-N loads, and flow-weighted [NO_3-N] increased. However, the change in corn yield is higher for low-rate groups; while change in concentration is smaller for low-rate groups, but higher for higher rate groups. Furthermore, we did not find significant differences in nitrate-N export among fertilizer application methods or timing.

Future Research Directions (FY 23-26): SSWR 405.3: Nutrient Reduction Approaches

For more information:

- Contact info for PI: Yongping Yuan
- Liu, W., Y. Yuan, AND L. Koropeckyj-Cox. 2021. Effectiveness of Nutrient Management on Water Quality Improvement: A Synthesis on Nitrate-Nitrogen Loss from Subsurface Drainage. Transactions of the ASABE. 64(2): 675-689.
- Koropeckyj-Cox, L., R. D. Christianson, Y. Yuan. 2021. Effectiveness of Conservation Crop Rotation for Water Pollutant Reduction from Agricultural Areas. Transactions of the ASABE 64(2): 691-704.

Modeling the UMRB: wetlands, nutrients, and more

Heather Golden, Grey Evenson,

Jay Christensen, Charles Lane

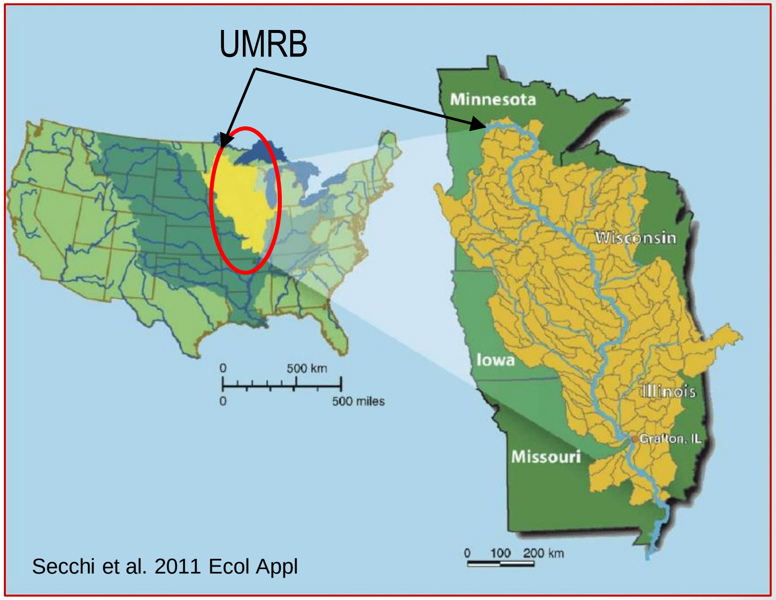
Wetland restoration and dynamic N responses across the UMRB

Issue: Excess nitrogen in the UMRB is transported to streams via runoff and groundwater connections during storm events and baseflow, respectively. *Wetland restoration may help mitigate this surplus nitrogen*.

Approach: We simulated wetland restoration scenarios across the UMRB + characteristics of wetlands and wetland drainage areas and assessed changes in nitrate at 279 subbasins and the UMRB outlet.

Impact: Restoring ~8,000 km^2 of wetlands will reduce mean annual nitrate loads to the UMRB outlet by 12%. However, these results are dependent on numerous factors (more on these nuances next...)

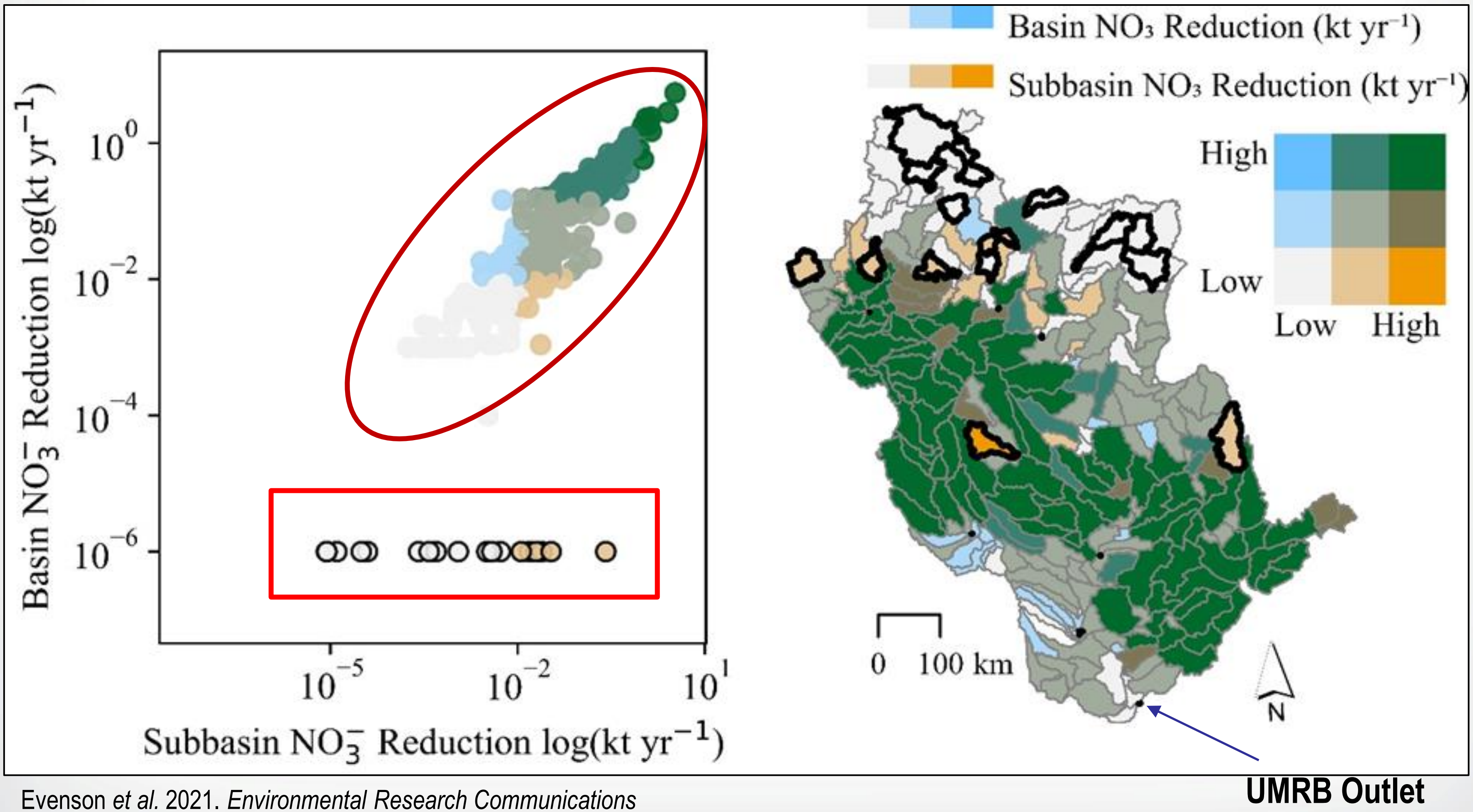
Partners/Clients: EPA Regions 7 and 5, Upper Mississippi River Basin Association, EPA Office of Water



Secchi et al. 2011 Ecol Appl

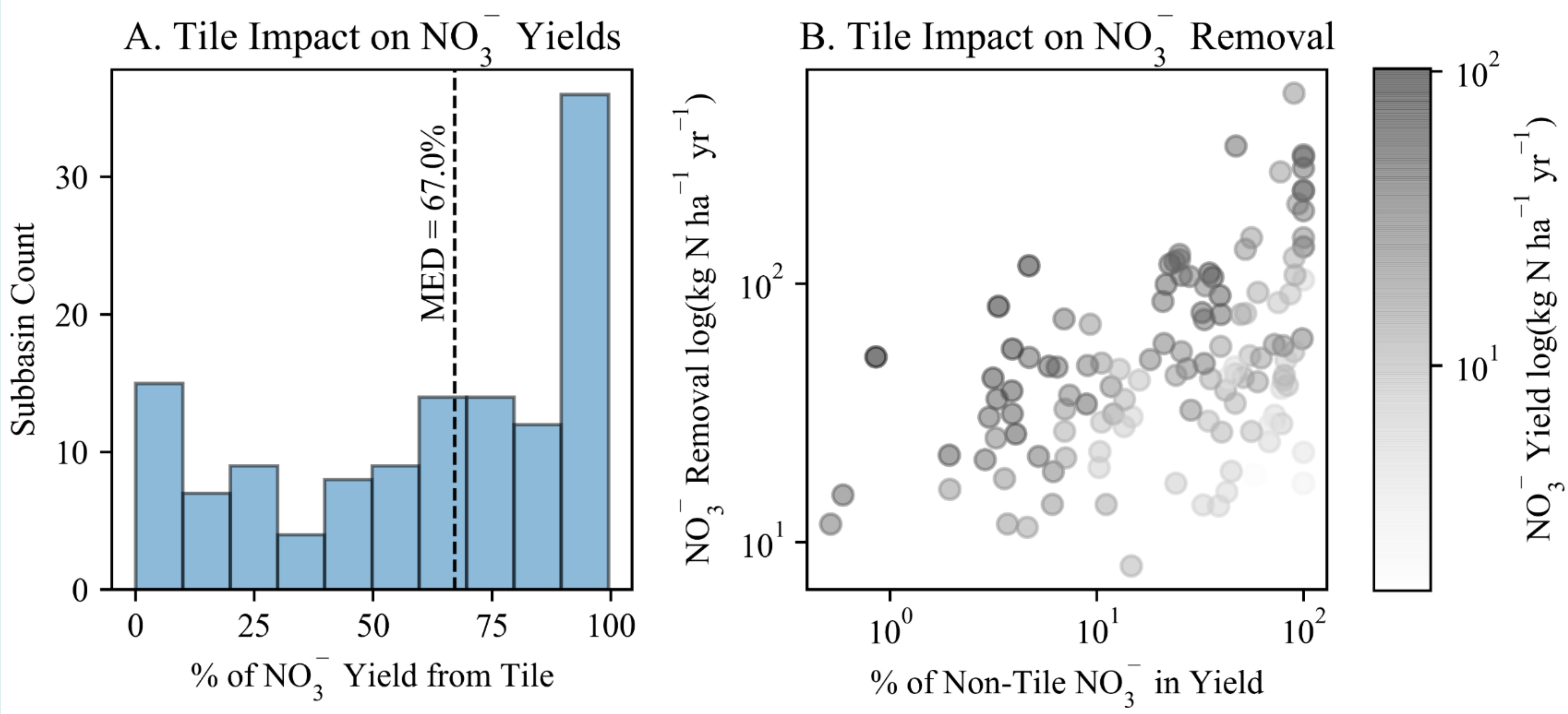

Golden et al. 2019 ES&T

Nitrate load reductions at subbasin-scales from wetland restoration often, but not always, resulted in load reductions at the UMRB outlet



Evenson *et al.* 2021. *Environmental Research Communications*

Nitrate yields are mostly from tiles in tile-drained subbasins = less wetland N removal



Evenson *et al.* 2021. *Environmental Research Communications*

Characteristics (factors) did not have equal influence on nitrate reductions from wetlands

Factor	Partial Correlation Coefficient
Catchment-to-wetland area ratio	0.6
Areal extent	-0.52
Location (via dummy variable)	0.23
Maximum storage (depth)	-0.15
Fraction of tile effluent intercepted	-0.09
Seepage rate	-0.06
Nitrogen removal efficiency	-0.03

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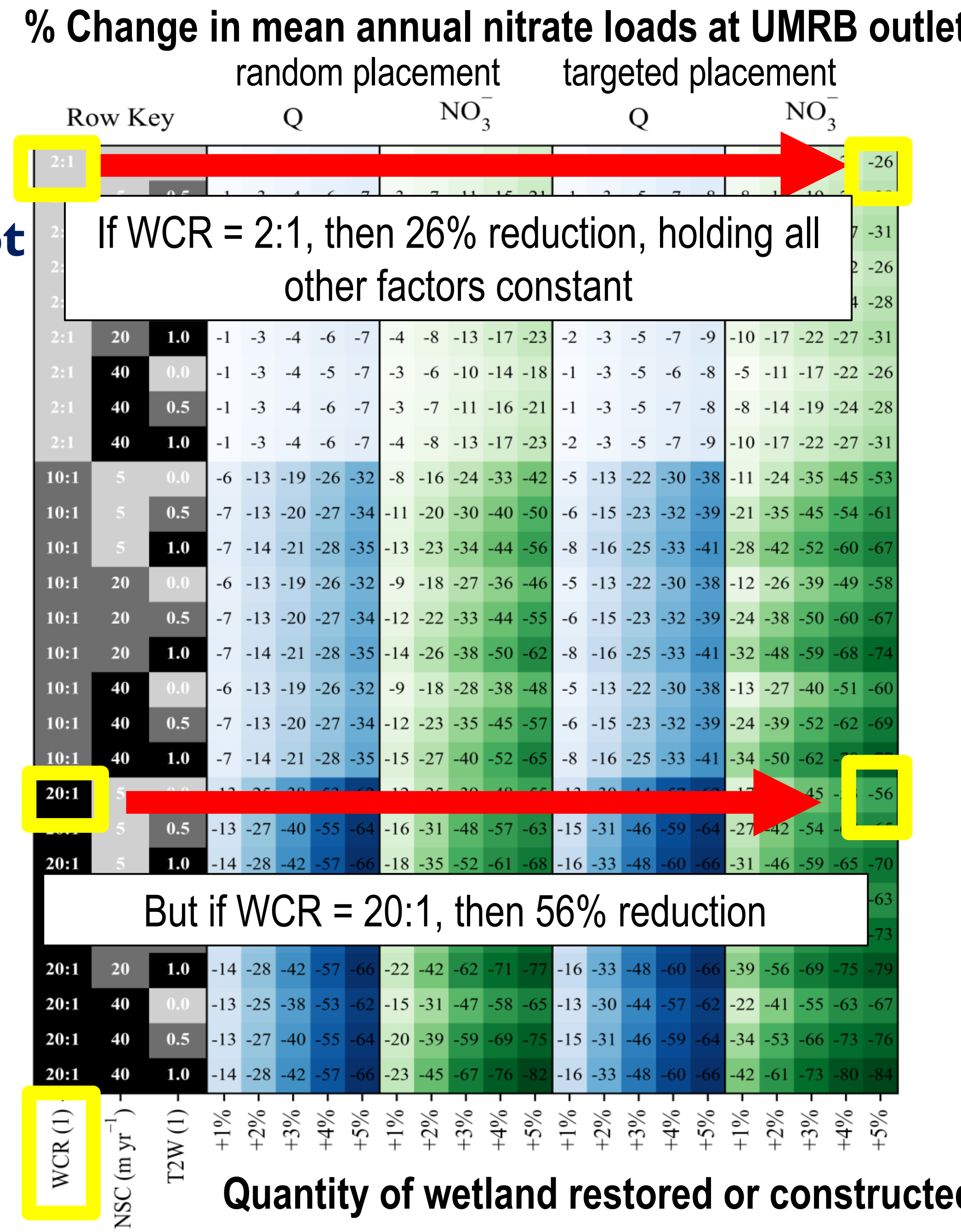


Wetland restoration and dynamic N responses across the UMRB

Take home message(s): Wetland mitigate surplus nitrogen across the UMRB, yet <u>their effectiveness is dependent several factors</u>: distance to the river basin outlet, wetland catchment-to-area ratios, fraction of tile drainage intercepted by wetlands, and relative abundance of existing wetlands across a subbasin – among others.

Future Research Directions (FY 23-26):

- Potential processes causing lags between BMPs (e.g., wetlands) and changes in water UMRB water quality

- How groundwater and soil N legacy storage + N legacy/climate change interactions mediate wetland restoration effects on N across the UMRB

For more information:

- Contact: golden.heather@epa.gov; evenson.grey@epa.gov; christensen.jay@epa.gov; lane.charles@epa.gov

- Manuscripts: Golden *et al*. 2019 ES&T; Evenson *et al.* 2021 ERC; Evenson *et al* (in prep)

United States Environmental Protection Agency

Multi-media modeling of the MRB & Northern GOM Hypoxia

Brandon Jarvis, Yongshan Wan,

Yongping Yuan

Multimedia modeling of northern Gulf of Mexico hypoxia

Issue: What will Gulf hypoxia look like in a changing climate? How will nutrient reduction effectiveness be impacted?

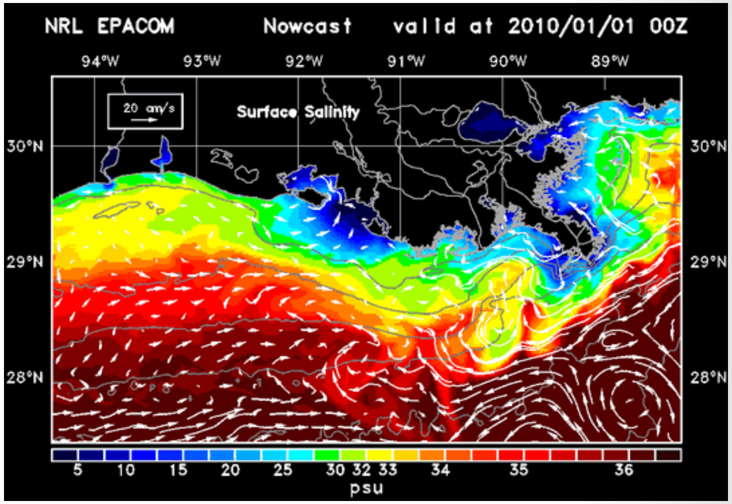
Approach: Integration of air, watershed, hydrodynamic, and ecosystem models

- Air: Community Multiscale Air Quality model [CMAQ]
- Watershed: Soil & Water Assessment Tool [SWAT]
- Hydrodynamic: Hybrid Coordinate Ocean Model [HYCOM]
- Ecosystem: Coastal Generalized Ecosystem Model [CGEM]

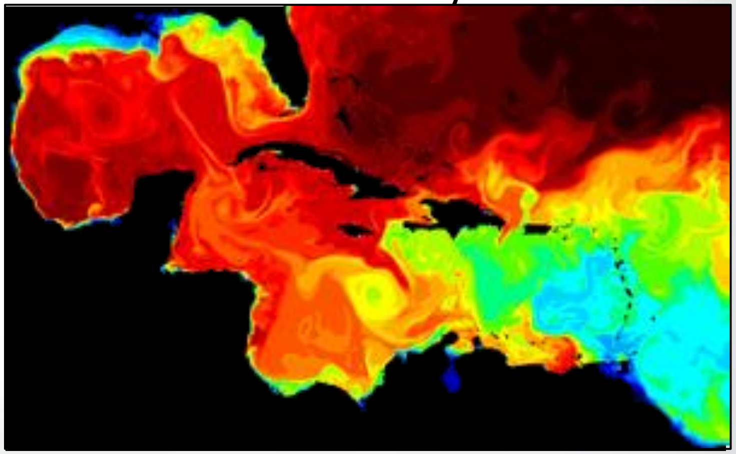
Impact: Application of a more comprehensive modeling tool to predict climate change effects on hypoxia and inform proactive nutrient management policies

Partners/Clients: EPA Office of Water, Regions 4 and 6, Hypoxia Task Force

Louisiana Shelf

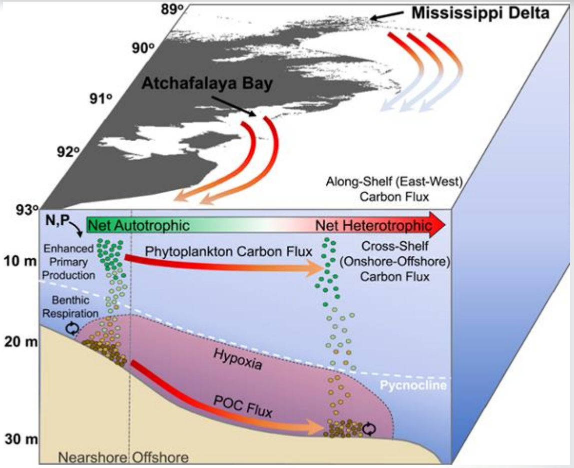


Basin-scale Boundary Conditions



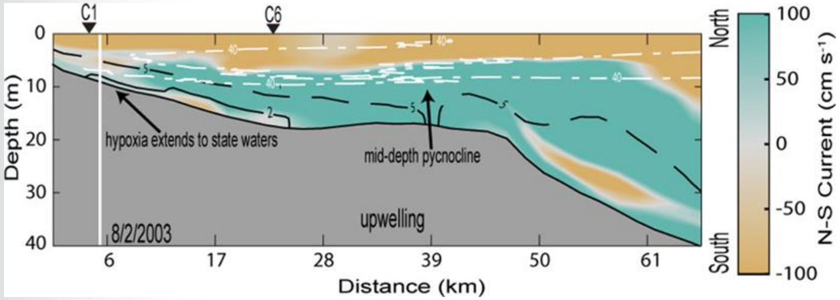
Multimedia modeling of northern Gulf of Mexico hypoxia

Past Research:



Spatiotemporal Carbon Dynamics

Shifting emphasis from east-west transport to importance of nearshore production

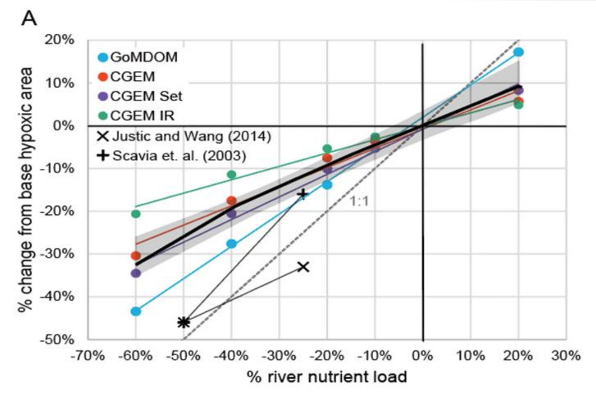


Contiguous Hypoxia

Linked nearshore-offshore hypoxia dynamics for regulatory management between state and federal waters

Model Load Reduction Response

Different model formulations affect estimates of hypoxia response to reduced nutrient loads

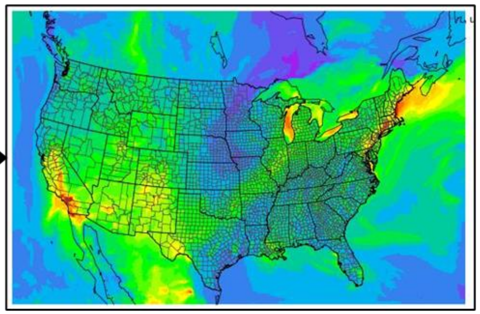


Multimedia modeling of northern Gulf of Mexico hypoxia

Gulf Hypoxia Multi-Media Modeling Framework

Climate Change Scenarios →

WRF-CMAQ

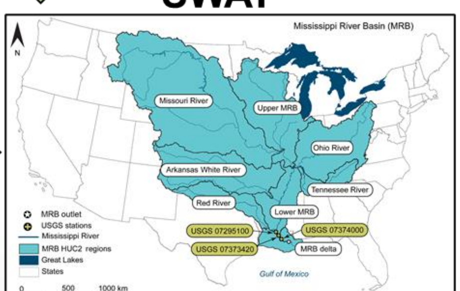


Atmospheric N & P Deposition

Atmospheric N & P Deposition

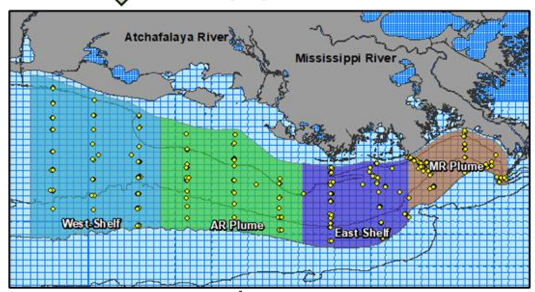
Climate Change Scenarios →

SWAT



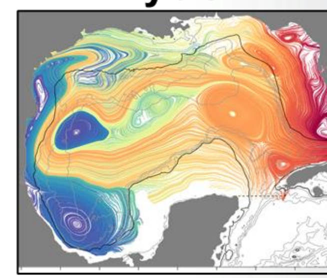
Discharge & River Nutrient Loading

CGEM



Hydrodynamics

HyCOM



Climate Change Scenarios

Outputs
- Hypoxia Hindcasts
- Climate Change Scenarios
- Legacy Nutrients
- Load Reduction Analysis

Coastal Generalized Ecosystem Model (CGEM)
Hybrid Coordinate Ocean Model (HyCOM)

Soil & Water Assessment Tool (SWAT)
Weather Research and Forecasting (WRF)
Community Multiscale Air Quality Modeling System (CMAQ)

Multimedia modeling of northern Gulf of Mexico hypoxia

Take home message(s): Simulation models are essential tools to inform nutrient management decisions. Models must comprehensively address the multitude of climate change factors to predict future effects on hypoxia.

Future Research Directions (FY 23-26): Development of an integrated modeling approach utilizing national and regional scale models. Emphasis on predicted effects of nutrient reductions and legacy nutrients in the context of climate change.

For more information:

- Brandon Jarvis (Jarvis.Brandon@epa.gov)

  - Jarvis, B.M., Pauer, J. J., Melendez, W., Wan, Y., Lehrter, J.C., Lowe, L.L., and Simmons, C.W. (2022) Inter-model comparison of Gulf of Mexico hypoxia and its response to reduced nutrient loads: Effects of Phytoplankton and Organic Matter Parameterization. Environmental Modelling & Software. 151. https://doi.org/10.1016/j.envsoft.2022.105365
  - Jarvis, B.M., Greene, R.M, Wan, Y., Lehrter, J.C., Lowe, L.L., Ko, D.S. (2021) Contiguous Low Oxygen Waters Between the Continental Shelf Hypoxia Zone and Nearshore Coastal Waters of Louisiana, USA: Interpreting 30 Years of Profiling Data and Three-Dimensional Ecosystem Modeling. 2021. Environ. Sci. Technol. 55 (8), 4709-4719. https://doi.org/10.1021/acs.est.0c05973
  - Jarvis B., Lehrter, J., Lowe, L., Hagy, J., Wan, Y., Murrell, M., Ko, D., Penta, B., Gould, R. (2020). Modeling Spatiotemporal Patterns of Ecosystem Metabolism and Organic Carbon Dynamics Affecting Hypoxia on the Louisiana Continental Shelf. JGR-Oceans. https://doi.org/10.1029/2019JC015630