Measuring the impact of nutrient management planning on surface water quality in Wisconsin

Andrew Beguhl (US Air Force Academy) and Marin Skidmore
(University of Illinois)

Nutrient loading is a perennial problem for Wisconsin

Cyanobacteria bloom on Lake Monona, June 29, 2019. Photo courtesy of Finn Ryan of yaharaproject.org.

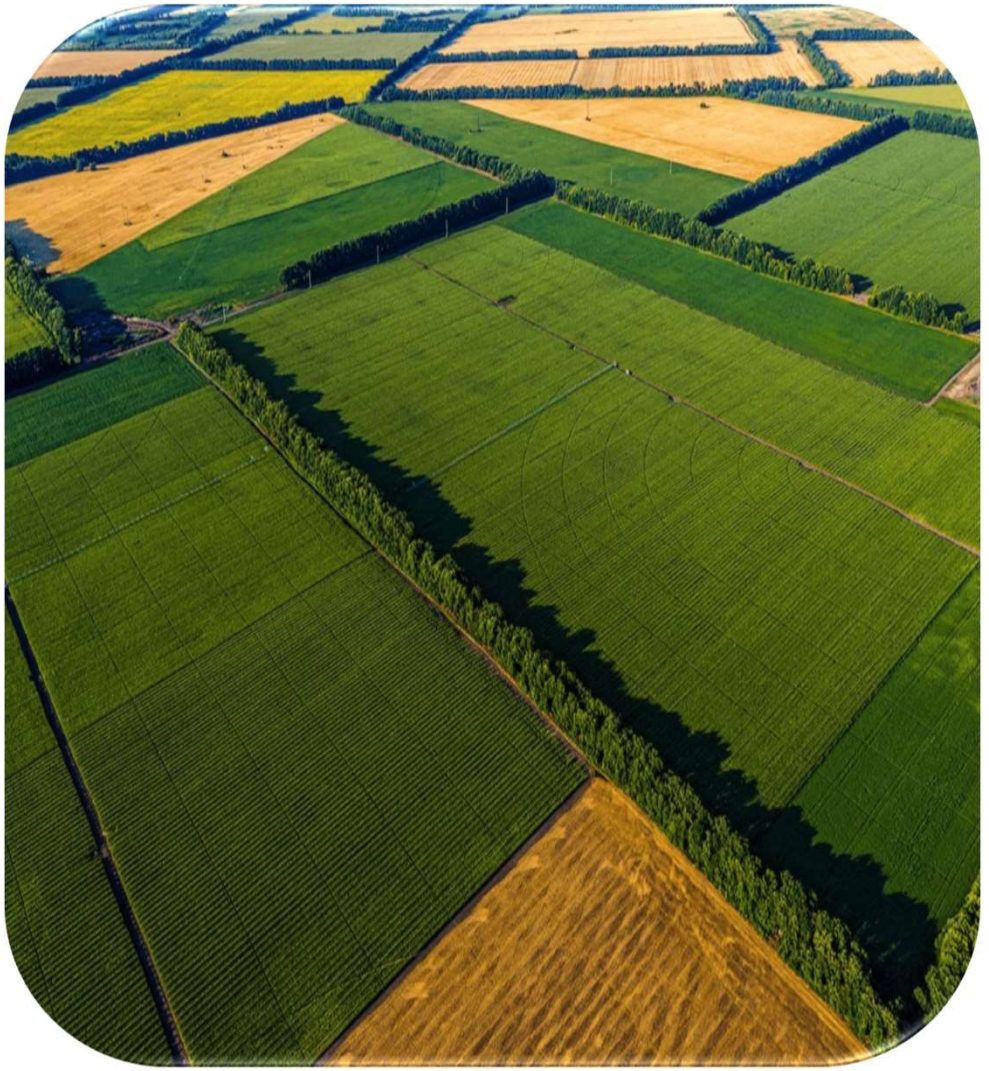
Agriculture and water quality

Agriculture contributes significant nutrients that lead to worsening water quality:

- Paudel and Crago (2020)
- Rossi et. al. (2023)

BMPs may help mitigate this effect:

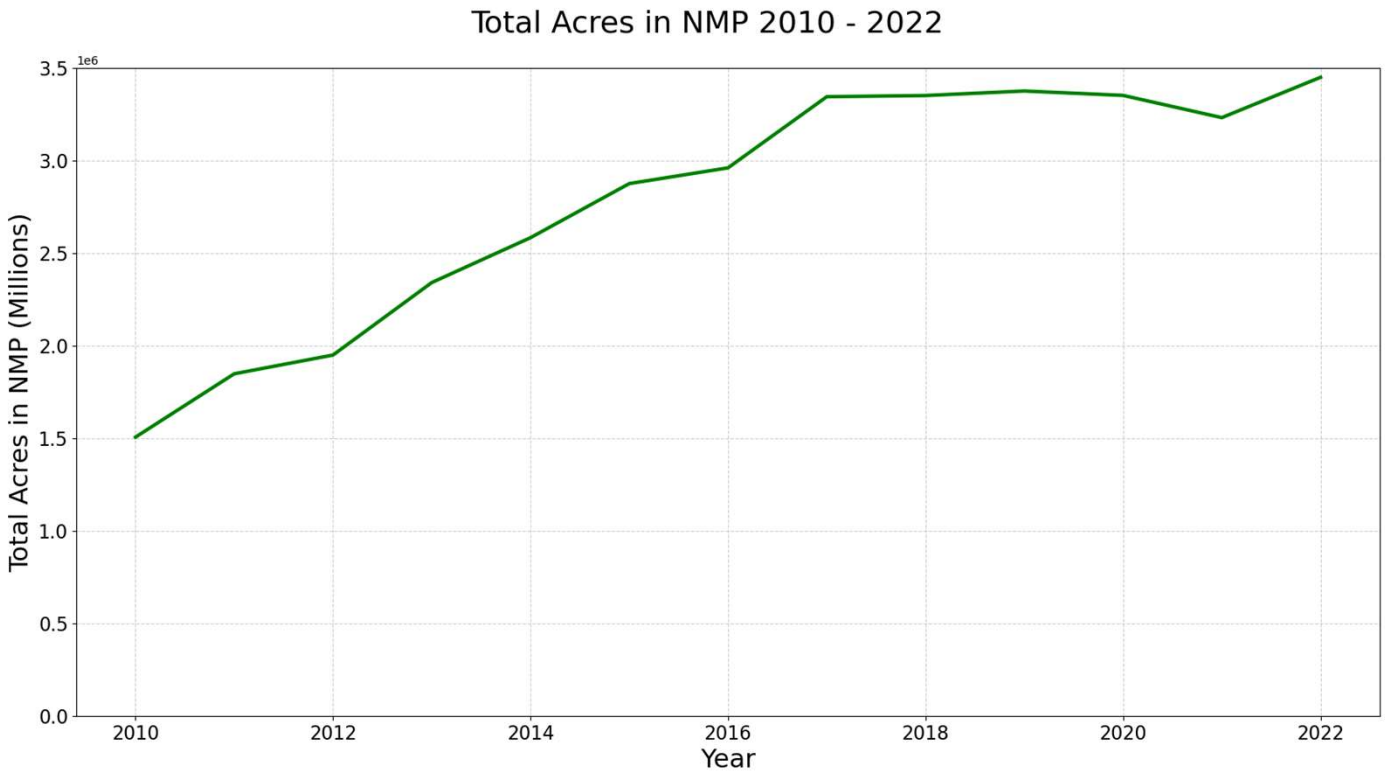
- Cover crops (Hsieh et al., 2023)
- Reduced- or no-till
- Nutrient management plan (NMP) requirements improve nitrogen concentration: Skidmore et. al. (2023)

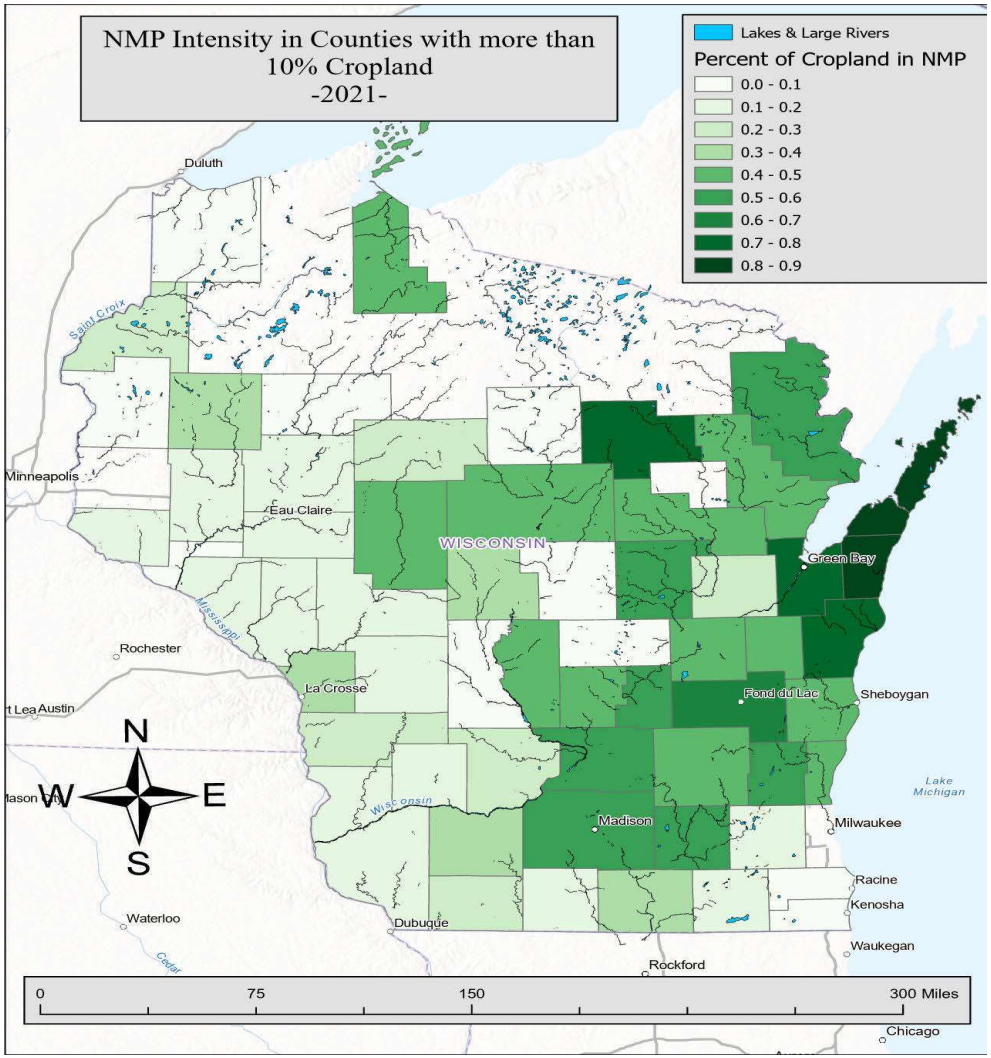


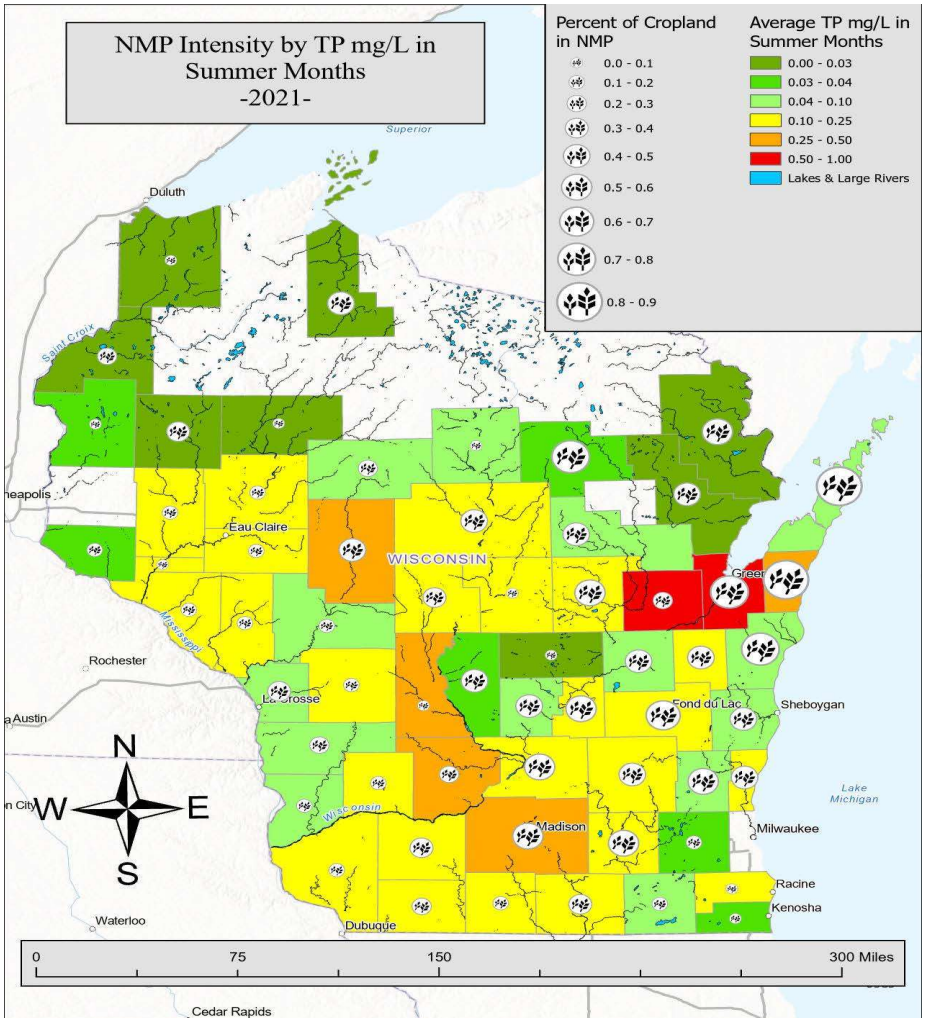
Nutrient Management Planning

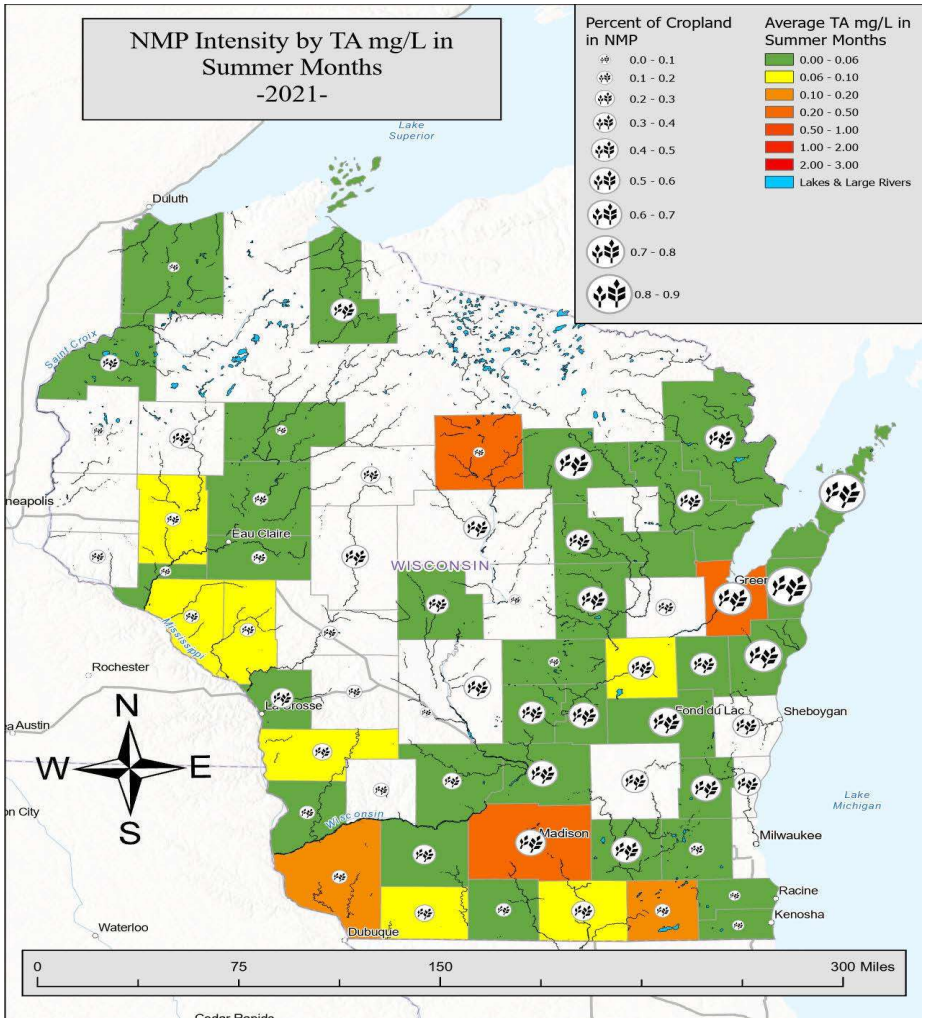
- NMPs plan for a crop's nutrient needs
- 4Rs updated to SMART recommendations
  - Source, Method, Assessment, Rate, and Time
- How much do nutrient management plans improve water quality?
  - Hard to measure: NMP adoption happens where water quality is already bad

NMP adoption grew and then plateaued




NMP Intensity in Counties with more than 10% Cropland -2021-
Lakes & Large Rivers
Percent of Cropland in NMP
0.0 - 0.1
0.1 - 0.2
0.2 - 0.3
0.3 - 0.4
0.4 - 0.5
0.5 - 0.6
0.6 - 0.7
0.7 - 0.8
0.8 - 0.9
Duluth
Saint Croix
Minneapolis
Eau Claire
WISCONSIN
Green Bay
Mississippi
Rochester
La Crosse
Fond du Lac
Sheboygan
Lake Michigan
Madison
Milwaukee
Racine
Kenosha
Waukegan
Waterloo
Dubuque
Rockford
Chicago
N
W
E
S
0
75
150
300 Miles


NMP Intensity by TP mg/L in Summer Months -2021-
Percent of Cropland in NMP
0.0 - 0.1
0.1 - 0.2
0.2 - 0.3
0.3 - 0.4
0.4 - 0.5
0.5 - 0.6
0.6 - 0.7
0.7 - 0.8
0.8 - 0.9
Average TP mg/L in Summer Months
0.00 - 0.03
0.03 - 0.04
0.04 - 0.10
0.10 - 0.25
0.25 - 0.50
0.50 - 1.00
Lakes & Large Rivers
Superior
Duluth
Saint Croix
Eau Claire
WISCONSIN
Mississippi
Rochester
La Crosse
Fond du Lac
Sheboygan
Lake Michigan
Madison
Milwaukee
Racine
Kenosha
Waterloo
Dubuque
Cedar Rapids
N
W
E
S
0
75
150
300 Miles


NMP Intensity by TA mg/L in Summer Months -2021-
Percent of Cropland in NMP
0.0 - 0.1
0.1 - 0.2
0.2 - 0.3
0.3 - 0.4
0.4 - 0.5
0.5 - 0.6
0.6 - 0.7
0.7 - 0.8
0.8 - 0.9
Average TA mg/L in Summer Months
0.00 - 0.06
0.06 - 0.10
0.10 - 0.20
0.20 - 0.50
0.50 - 1.00
1.00 - 2.00
2.00 - 3.00
Lakes & Large Rivers
Lake Superior
Duluth
Saint Croix
Eau Claire
WISCONSIN
Mississippi
Rochester
La Crosse
Fond du Lac
Sheboygan
Lake Michigan
Madison
Milwaukee
Racine
Kenosha
Waterloo
Dubuque
N
W
E
S
0
75
150
300 Miles

The Farmland Preservation Program and NMP adoption

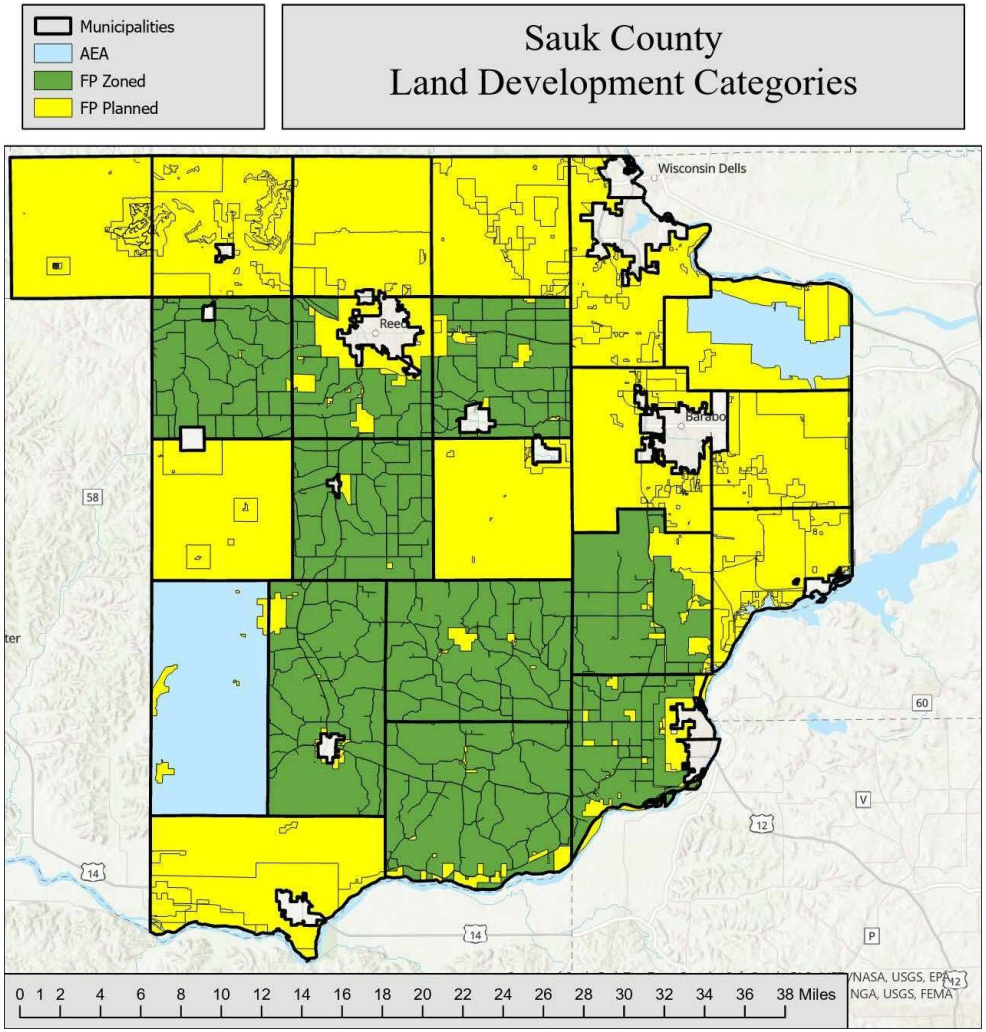
- Farmland Preservation Program (FPP) exists statewide to preserve land in agriculture
- Offers tax credit to participants and requires NMP adoption
  - Intuition: FPP program gives financial incentive to some (not all!) farmers for NMPs. This allows us to compare water quality in areas with higher NMP adoption due to the tax credit (not due to previous water quality problems or farmer preferences)
- Sauk County Land Conservation Department provided us with:
  - GIS map of FPP participation
  - GIS map of all NMP coverage
  - We would love to include other counties that have both of these datasets

Data

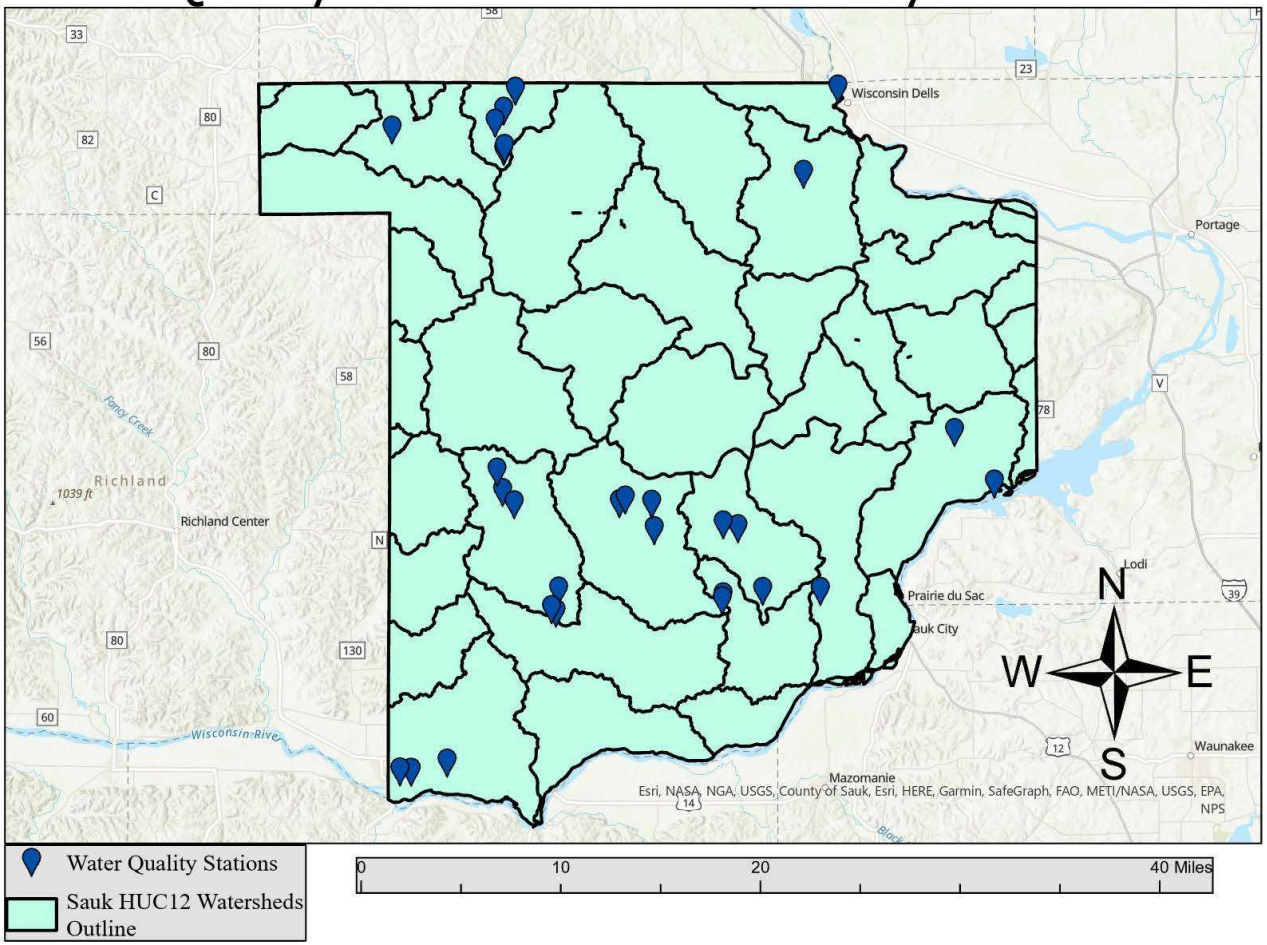
- **Outcome:** Filtered ammonia and total phosphorus concentrations from the Water Quality Portal
- **Treatment:** Nutrient management plans data from Sauk County
- **Land Use:**
  - CAFO locations from Wisconsin DNR
  - Crop production from USDA's Cropland Data Layer
  - Precipitation and temperature from PRISM
  - Farmland Preservation Zoning Districts and Agriculture Enterprise Areas from DATCP
  - Sub-watershed data from Wisconsin's DNR
- **Time Period:** 2021 – August 2023

Land Development Categories for the Farmland Preservation Program

1) FP Zoned Districts: binding, chosen by municipality to prevent land development
2) AEAs: binding, developed by at least 5 farmers with at least 1,000 acres each
3) Farms in either an FP zoned area or AEA may enroll in FPP and receive tax credits
    1) $5 per acre – AEA
    2) $7.50 per acre – FP zoning district
    3) $10 per acre – AEA and FP zoning district



Water Quality Stations in Sauk County - 2021 -2023

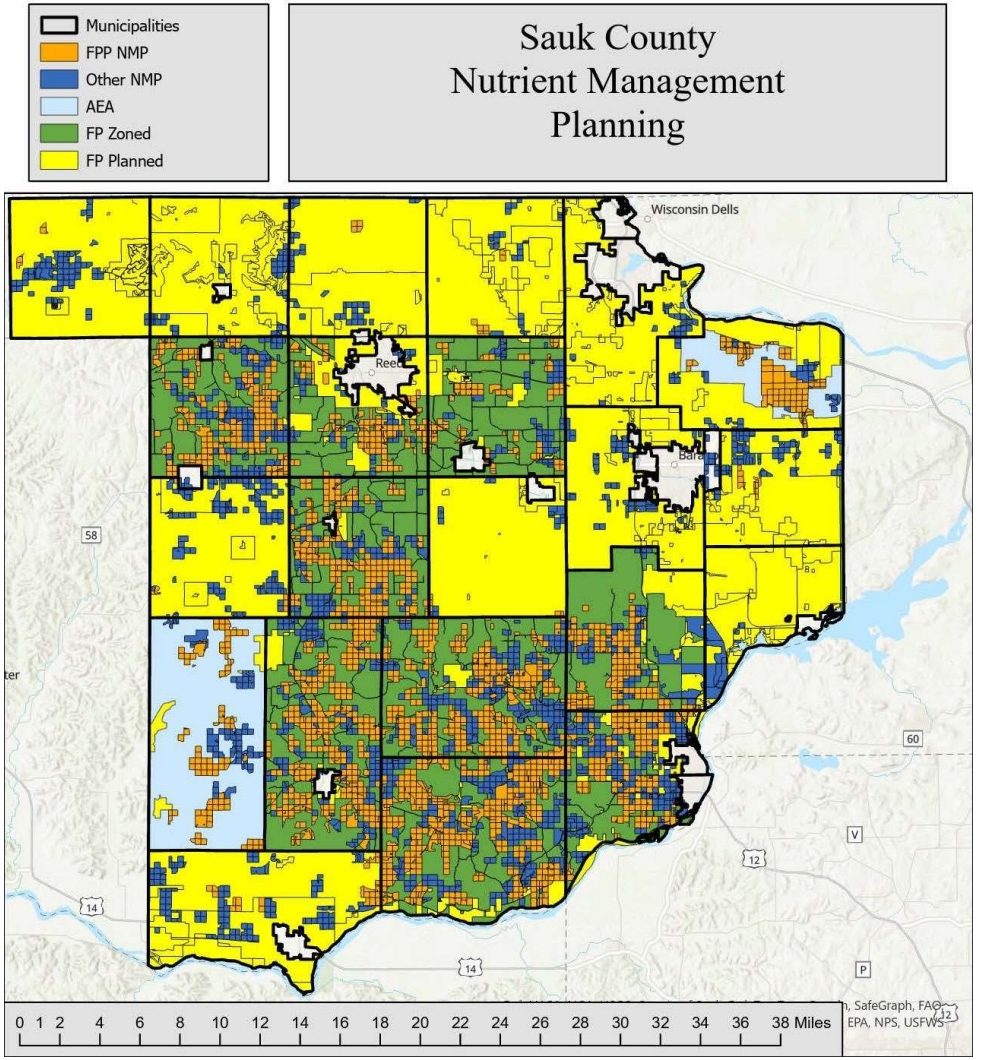


Two-stage regression analysis

- Linear regression ($Y = a + bX$)
- Stage 1: is NMP adoption higher in sub-watersheds when more of the cropped area is eligible for FPP tax credits?
- Stage 2: is water quality better in sub-watersheds where NMP adoption is higher **due to FPP eligibility?**
- We include control variables like weather, soil type, and seasonal variation in water quality

Results: step 1

- More FPP eligibility increases NMP adoption
  - As we increase FP zoned districts in a sub-watershed (HUC12) by 10 percentage points, we see NMP increase by 4.97 percentage points.
  - As we increase AEA's in a sub-watershed (HUC12) by 10 percentage points, we see NMP increase by 3.31 percentage points.



Second stage results: effect of NMP on ammonia

	Ammonia Regression Results		
	Minimum Controls	Maximum Controls	Maximum Controls & Fixed Effects
Percent of HUC12 in NMP	-0.0543	-0.698**	-0.640**
	(0.0354)	(0.228)	(0.233)
Quarter Fixed Effects	No	No	Yes
Sample Size	114	114	114

Note - Standard errors in parentheses, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Second stage results: effect of NMP on phosphorus

	Phosphorus Regression Results		
	Minimum Controls	Maximum Controls	Maximum Controls & Fixed Effects
Percent of HUC12 in NMP	-0.260***	-0.0329	-0.0193
	(0.0404)	(0.0525)	(0.0446)
Quarter Fixed Effects	No	No	Yes
Sample Size	466	466	466

Note - Standard errors in parentheses, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Conclusions

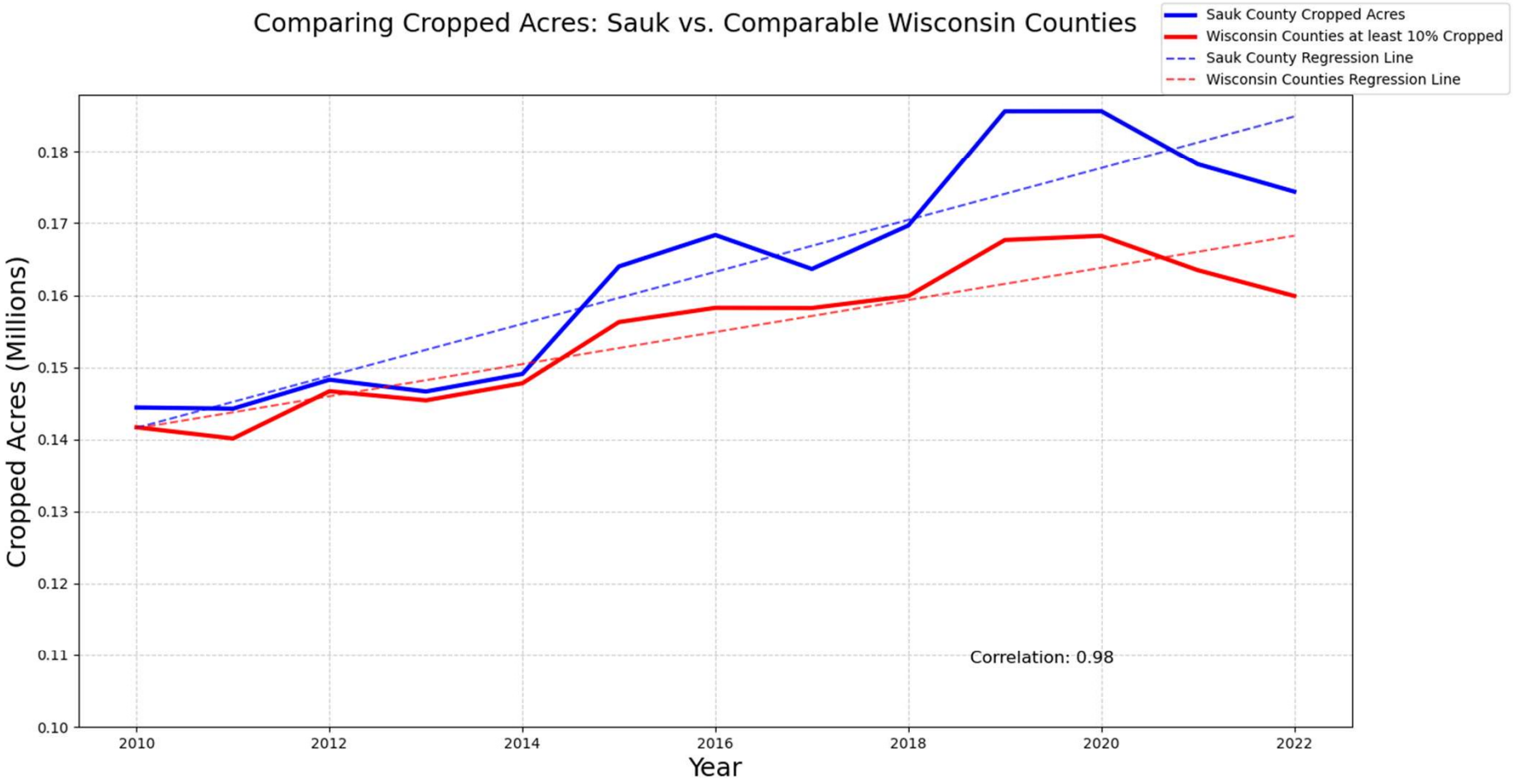
- Statewide water quality is worse in areas with more NMP adoption, but this isn't the whole story.
- NMP adoptions is significantly higher in areas with Farmland Preservation Program eligibility.
- 10-percentage point increase cropped area with an NMP in a sub-watershed leads to a 6.4% reduction in ammonia concentrations.

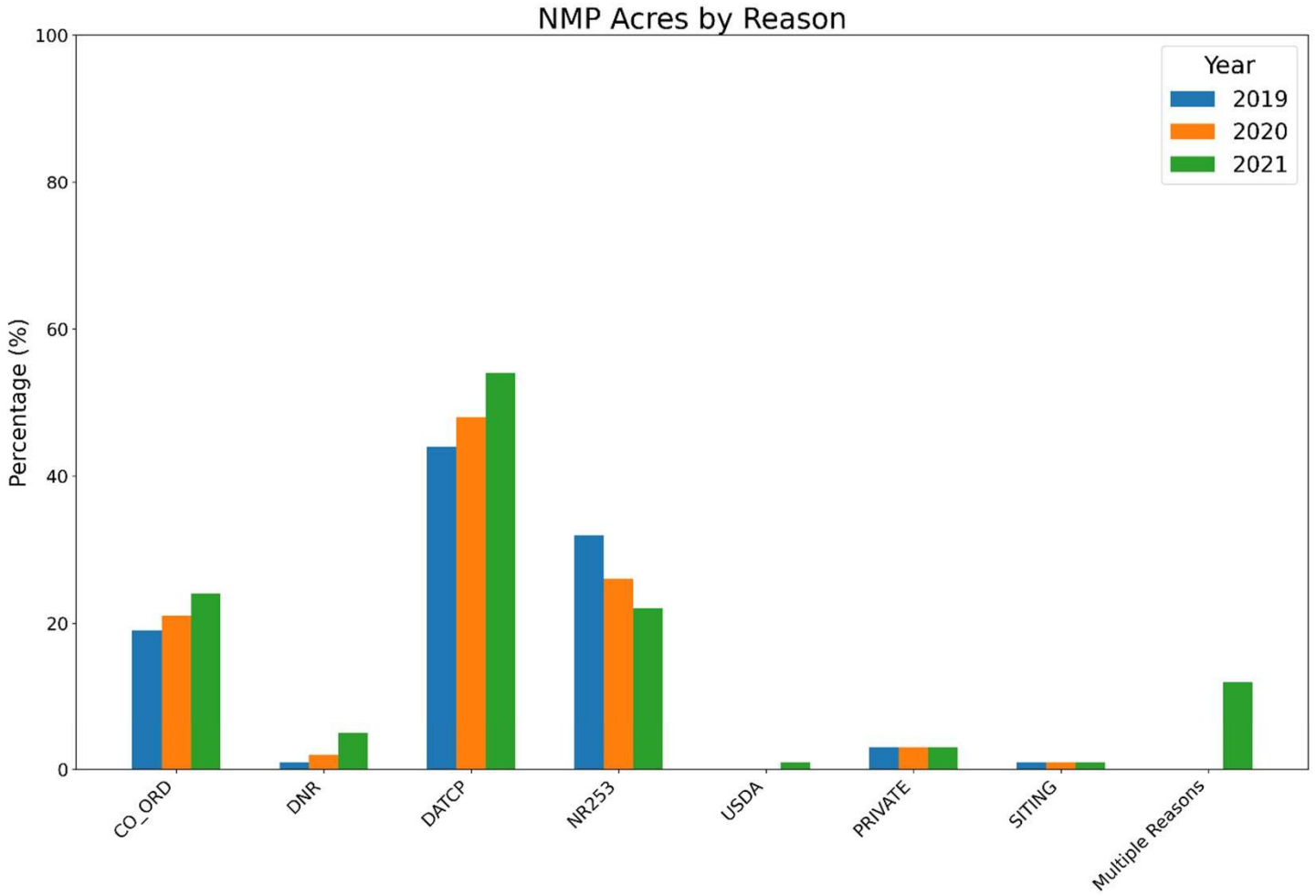
Thank you!

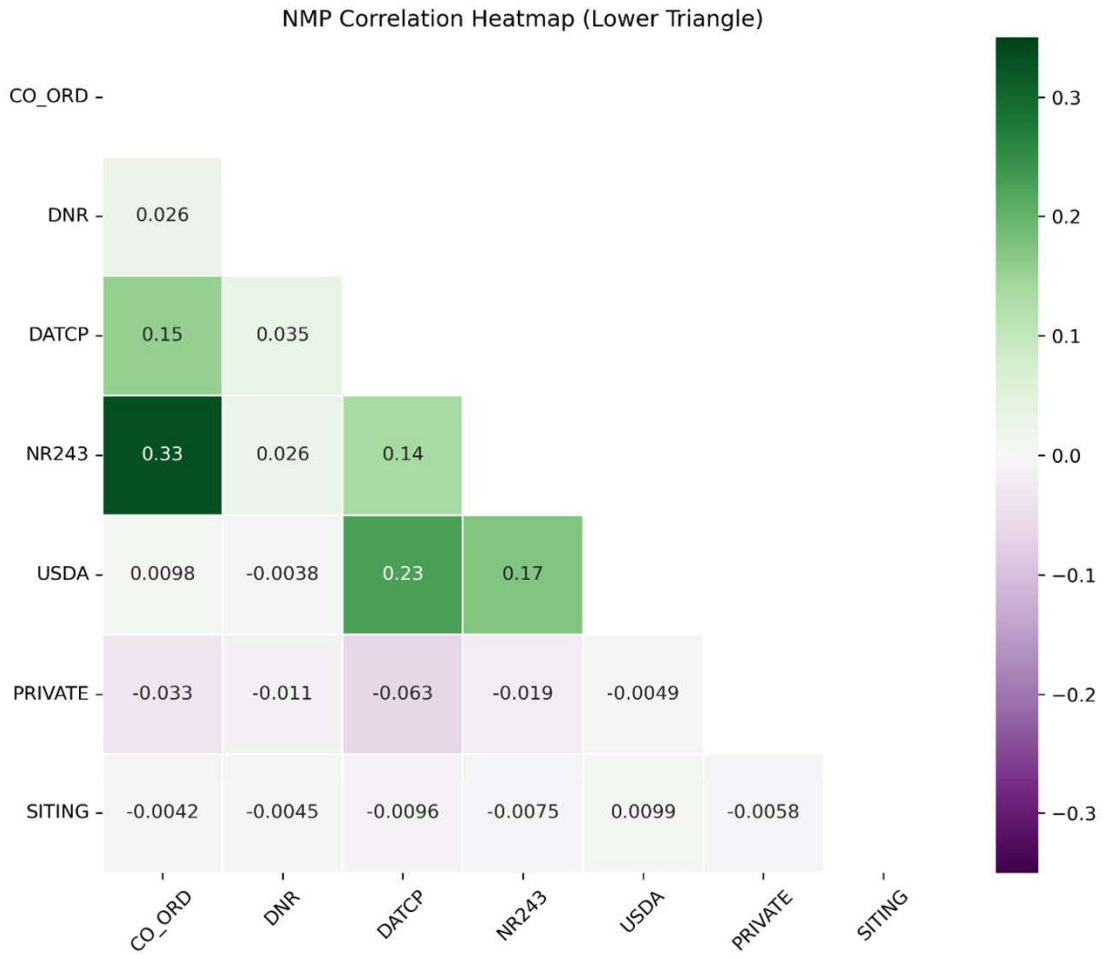
- andrew.beguhl@afacademy.af.edu
- marins@illinois.edu

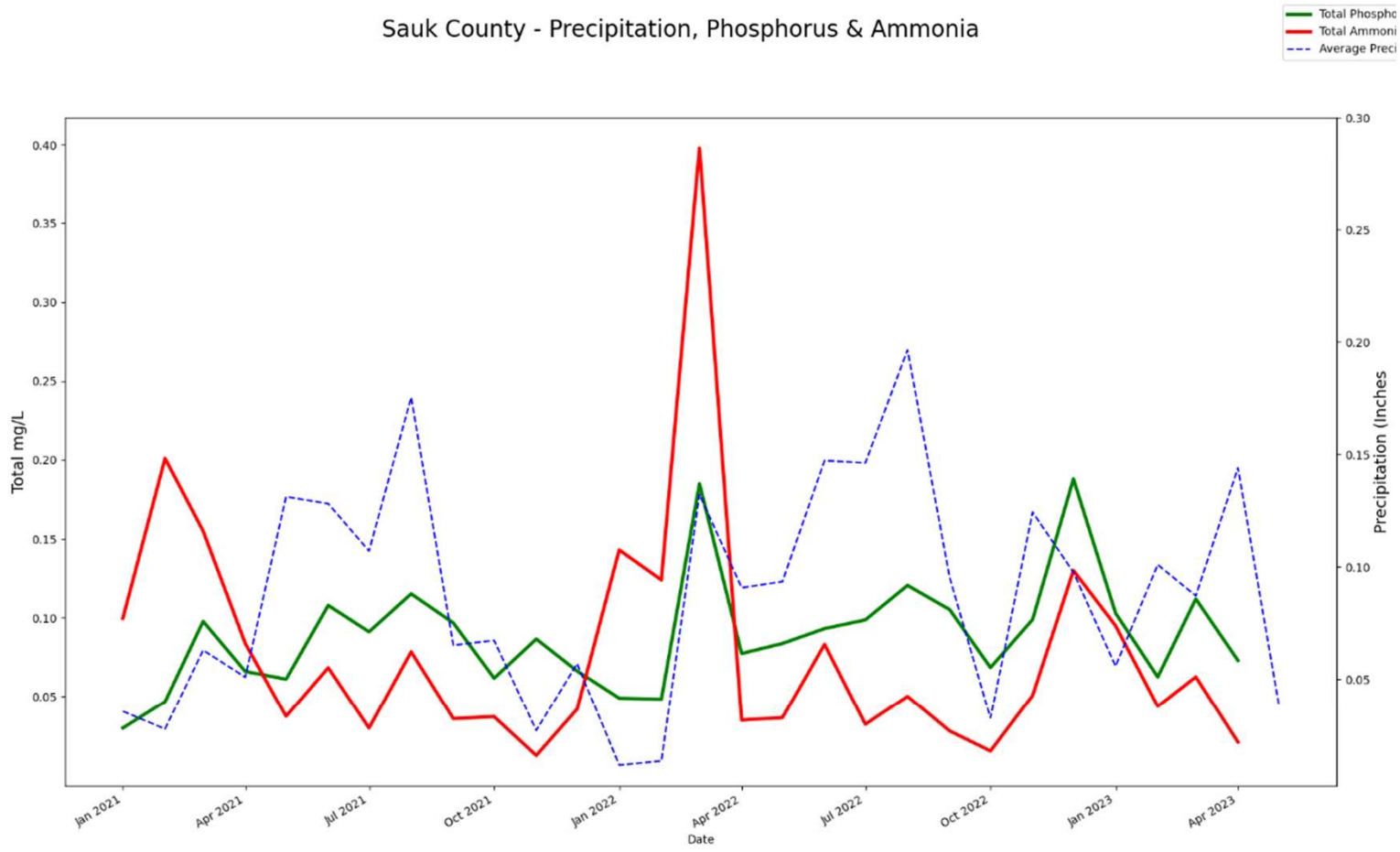
Table 2 - Summary Statistics

Variable	N	Mean	Std. Dev.	Min	Max
Phosphorus Sample	466	.2010489	.3201347	0	2.64
Ammonia Sample	114	.05344	.0704692	0	.58
Percent in NMP	581	.1720757	.1640185	.0066802	.5821059
Percent FP Zoned	581	.1932297	.3531183	0	.9569068
Percent in AEA	581	.02193297	.04815696	0	.1724051
Percent of HUC12 Cropped	581	.2201173	.1369381	0	.4441842
Precipitation in Inches	581	.2538898	.5427691	0	3.02
Average Temperature	581	57.05766	16.01567	3.2	81.1
CAFO Density	581	.1135972	.3282729	0	2
Sampled at Lake	140				
Sampled at River or Stream	441				


Comparing Cropped Acres: Sauk vs. Comparable Wisconsin Counties
Sauk County Cropped Acres
Wisconsin Counties at least 10% Cropped
Sauk County Regression Line
Wisconsin Counties Regression Line
Cropped Acres (Millions)
0.18
0.17
0.16
0.15
0.14
0.13
0.12
0.11
0.10
2010
2012
2014
2016
2018
2020
2022
Year
Correlation: 0.98


NMP Acres by Reason
Year
2019
2020
2021
Percentage (%)
100
80
60
40
20
0
CO_ORD
DNR
DATCP
NR253
USDA
PRIVATE
SITING
Multiple Reasons


NMP Correlation Heatmap (Lower Triangle)
CO_ORD
DNR
DATCP
NR243
USDA
PRIVATE
SITING
0.026
0.15
0.035
0.33
0.026
0.14
0.0098
-0.0038
0.23
0.17
-0.033
-0.011
-0.063
-0.019
-0.0049
-0.0042
-0.0045
-0.0096
-0.0075
0.0099
-0.0058
0.3
0.2
0.1
0.0
−0.1
−0.2
−0.3


Sauk County - Precipitation, Phosphorus & Ammonia
Total Phospho
Total Ammoni
Average Preci
Total mg/L
Precipitation (Inches
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.30
0.25
0.20
0.15
0.10
0.05
Jan 2021
Apr 2021
Jul 2021
Oct 2021
Jan 2022
Apr 2022
Jul 2022
Oct 2022
Jan 2023
Apr 2023
Date

NMP and water quality correlation

Table 1 – NMP Crop Ratio to Water Quality in Summer Months 2021

	Phosphorus	Ammonia
NMP Crop Ratio	1.000***	0.387***
	(0.0386)	(0.0807)
Sample Size	3951	682

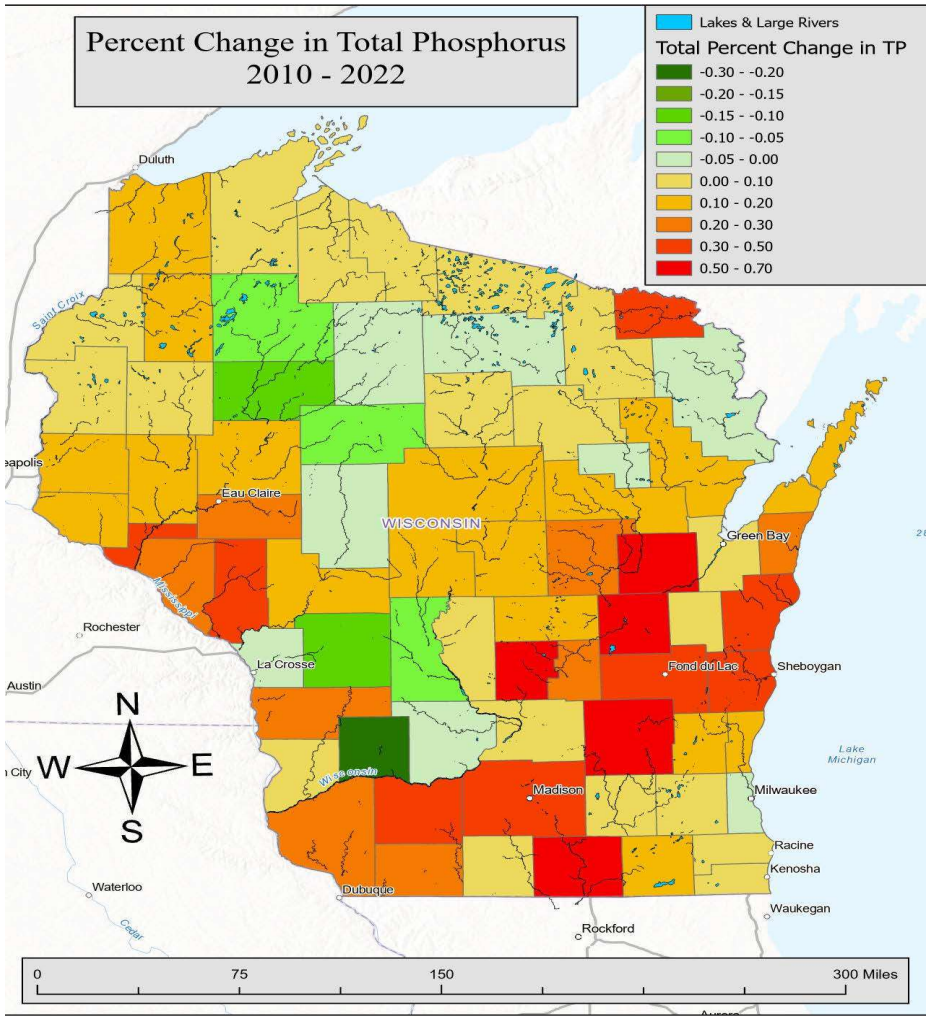
Note - Standard errors in parentheses, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

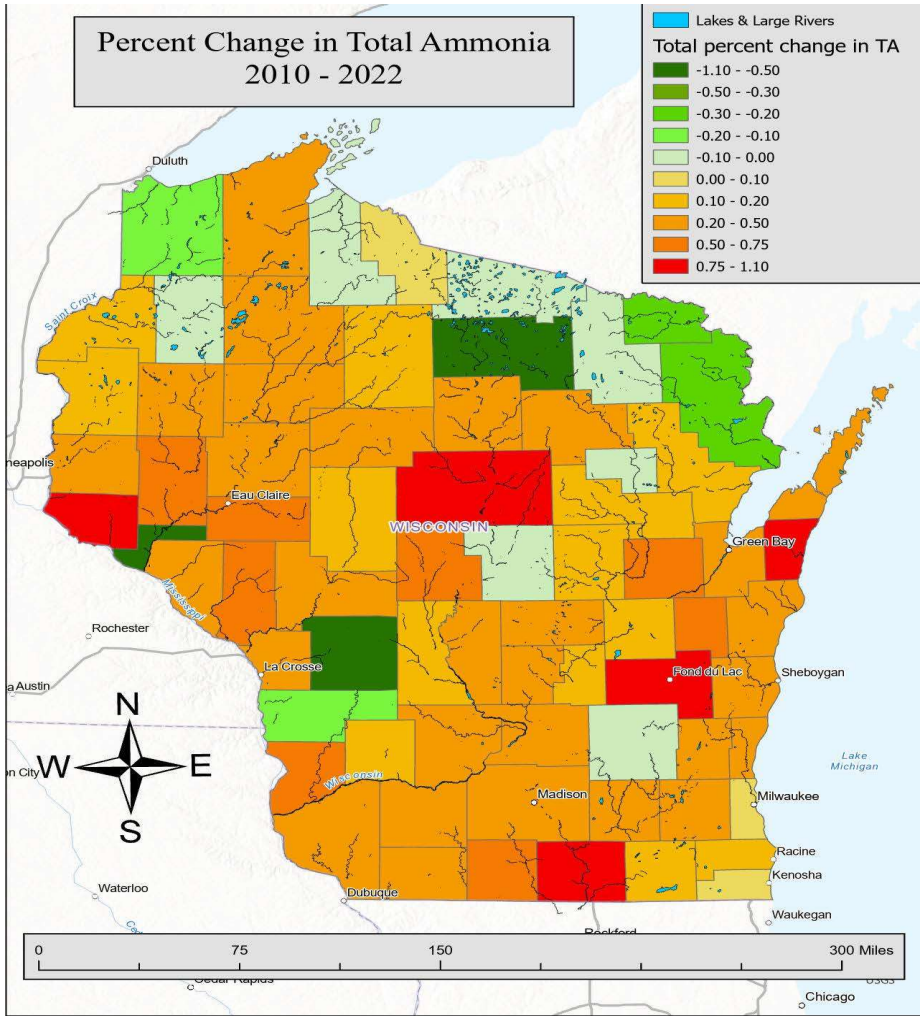
Relevance assumption

Table 4 – First-stage Results

Percent of HUC12 in NMP	
Percent of HUC12 in FP Zoning	0.497***
	(0.0400)
Percent of HUC12 in an AEA	0.331***
	(0.287)
Sample Size	11

- I run the following tests:
  - Kleibergen-Paap rk LM statistic for under identification
  - Cragg-Donald Wald F statistic for weak identification
  - Sargan statistic for over identification
- In all cases I reject the null hypothesis


Percent Change in Total Phosphorus
2010 - 2022
Lakes & Large Rivers
Total Percent Change in TP
-0.30 - -0.20
-0.20 - -0.15
-0.15 - -0.10
-0.10 - -0.05
-0.05 - 0.00
0.00 - 0.10
0.10 - 0.20
0.20 - 0.30
0.30 - 0.50
0.50 - 0.70
Duluth
Saint Croix
Eau Claire
WISCONSIN
Green Bay
Rochester
La Crosse
Fond du Lac
Sheboygan
Austin
Lake Michigan
Madison
Milwaukee
Racine
Kenosha
Waterloo
Dubuque
Waukegan
Rockford
N
W
E
S
0
75
150
300 Miles


Percent Change in Total Ammonia
2010 - 2022
Lakes & Large Rivers
Total percent change in TA
-1.10 - -0.50
-0.50 - -0.30
-0.30 - -0.20
-0.20 - -0.10
-0.10 - 0.00
0.00 - 0.10
0.10 - 0.20
0.20 - 0.50
0.50 - 0.75
0.75 - 1.10
Duluth
Saint Croix
Eau Claire
WISCONSIN
Green Bay
Rochester
La Crosse
Fond du Lac
Sheboygan
Lake Michigan
Madison
Milwaukee
Racine
Kenosha
Waterloo
Dubuque
Waukegan
N
W
E
S
0
75
150
300 Miles
Chicago

Evidence that BMPs improve water quality

- Nutrient type e.g., liquid urea, slow-release fertilizers – Wang et. al. (2020)
- Split applications of nutrients reduces nitrogen loss – Motasim et. al. (2022)
- Conservation tillage reduces phosphorus loss – Daryanto et. al. (2017)
- Riparian buffers reduce erodibility and absorb nutrients – Correll (2005)
- Grassed buffer strips absorb nitrates and phosphates – Cole et. al. (2020)
- Cover Crops reduce nitrogen leaching and soil erodibility – Blanco-Canqui (2018)