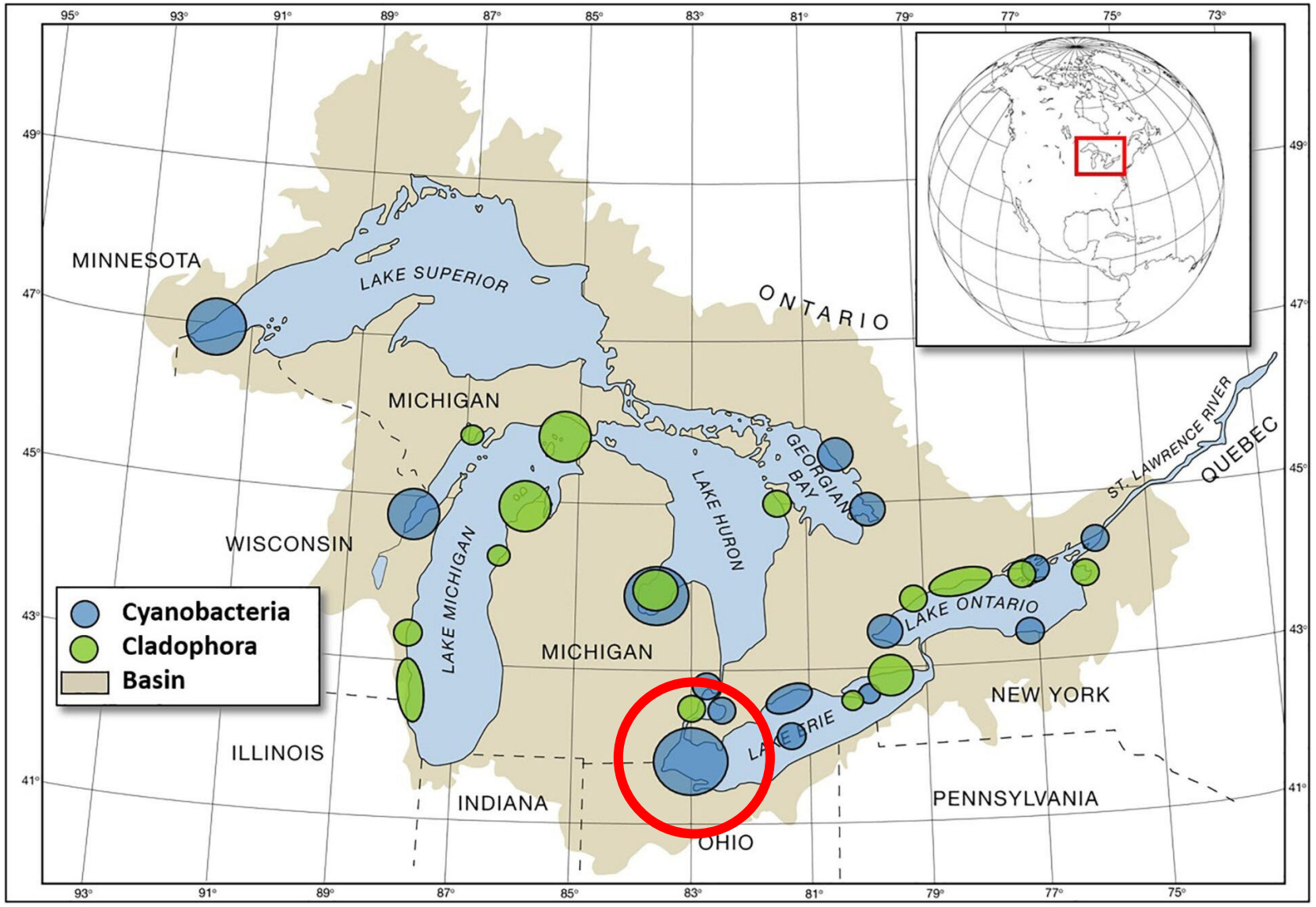
Use and improvements in SWAT for the Great Lakes Region: Lessons and current direction from a multi-institutional effort

Haley Kujawa*, Margaret Kalcic, Jay Martin, Anna Apostel, Jeffrey Kast, Asmita Murumkar, Grey Evenson, Michael Brooker, Noel Aloysius, Chelsie Boles, Todd Redder, Remegio Confesor, Richard Becker, Rebecca Muenich, Awoke Dagnew, Yu-Chen Wang, Donald Scavia

SWAT International Conference 2023

Aarhus, Denmark

Harmful algal blooms prominent issue in Laurentian Great Lakes
~20% of the world's freshwater



NOAA GLERL https://www.glerl.noaa.gov/

A Lake Erie Harmful Algal Bloom (HAB) Primer

Harmful Algal Blooms (HABS) more severe since 1995

Blooms largely caused by Phosphorus (P), DRP doubled since 1995

Maumee River contributes 50% of Phosphorus & drives Lake Erie HABs

Maumee River watershed >75% agriculture

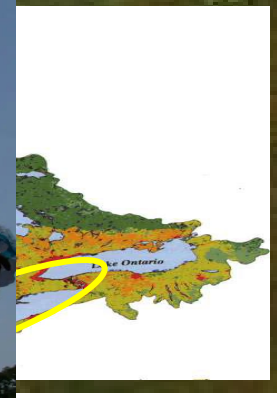
A Lake Erie Harmful Algal Bloom (HAB) Primer

2014 Toledo water crisis

- ***Half a million*** people without potable water for 3-days

The New York Times

Tap Water Ban for Toledo Residents



Harmful Algal

Blooms largely caused b

Maumee River contributes 50%

1995

1995

HABs

Maumee River watershed >75% agriculture

Binational agreement – phosphorus loading targets for Lake Erie

- New targets based on lake modeling are more nuanced
- Reaching targets requires agricultural conservation

OLD TARGET

1970s-2015; Annual	All Lake Erie
TP Load	11,000 MT

NEW TARGETS

2016-present; March-July	Maumee River	Western Lake Erie
DRP Load*	186 MT	40% of 2008
TP Load*	860 MT	40% of 2008
DRP Concentration**	0.05 mg/L	
TP Concentration**	0.23 mg/L	

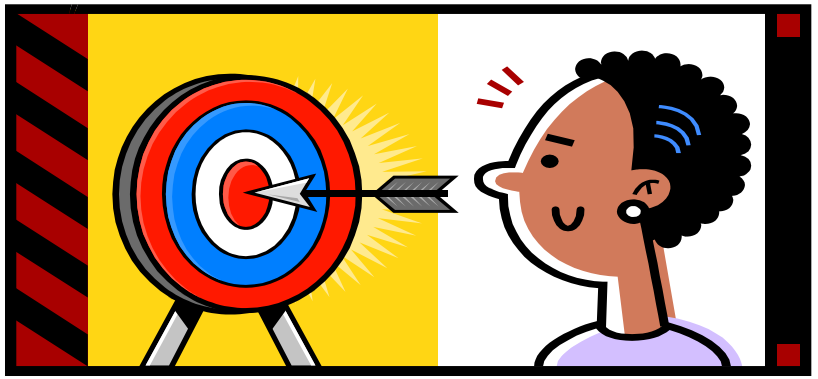
**to be met 9 years out of 10 ** flow weighted mean*

P = Phosphorus
TP = Total Phosphorus
DRP = Dissolved Reactive Phosphorus

Multi-Institutional SWAT modeling efforts

Long-term collaboration: 2015-present

Can these targets be achieved?
What practices & adoption rates?
Can ag. production be maintained?



SWAT models (Soil and Water Assessment Tool)

University of Michigan
Don Scavia
Margaret Kalcic
Rebecca Muenich
Yu-Chen Wang
Awoke Teshager

Heidelberg University
Rem Confesor
Tian Guo

LimnoTech (Water | Environment | Scientists | Engineers)
Joe DePinto
Todd Redder
Chelsie Boles

Ohio State
Jay Martin
Margaret Kalcic
Noel Aloysius
Jeffrey Kast
Anna Apostel
Haley Kujawa

In only one of the two studies:

University of Toledo (1872)
Richard Becker

Blackland Texas A&M AgriLife Research & Extension Center — Leading in Land & Water Solutions – Serving Texas Over 100 Years
USDA ARS United States Department of Agriculture Agricultural Research Service
Haw Yen
Jeff Arnold
Mike White

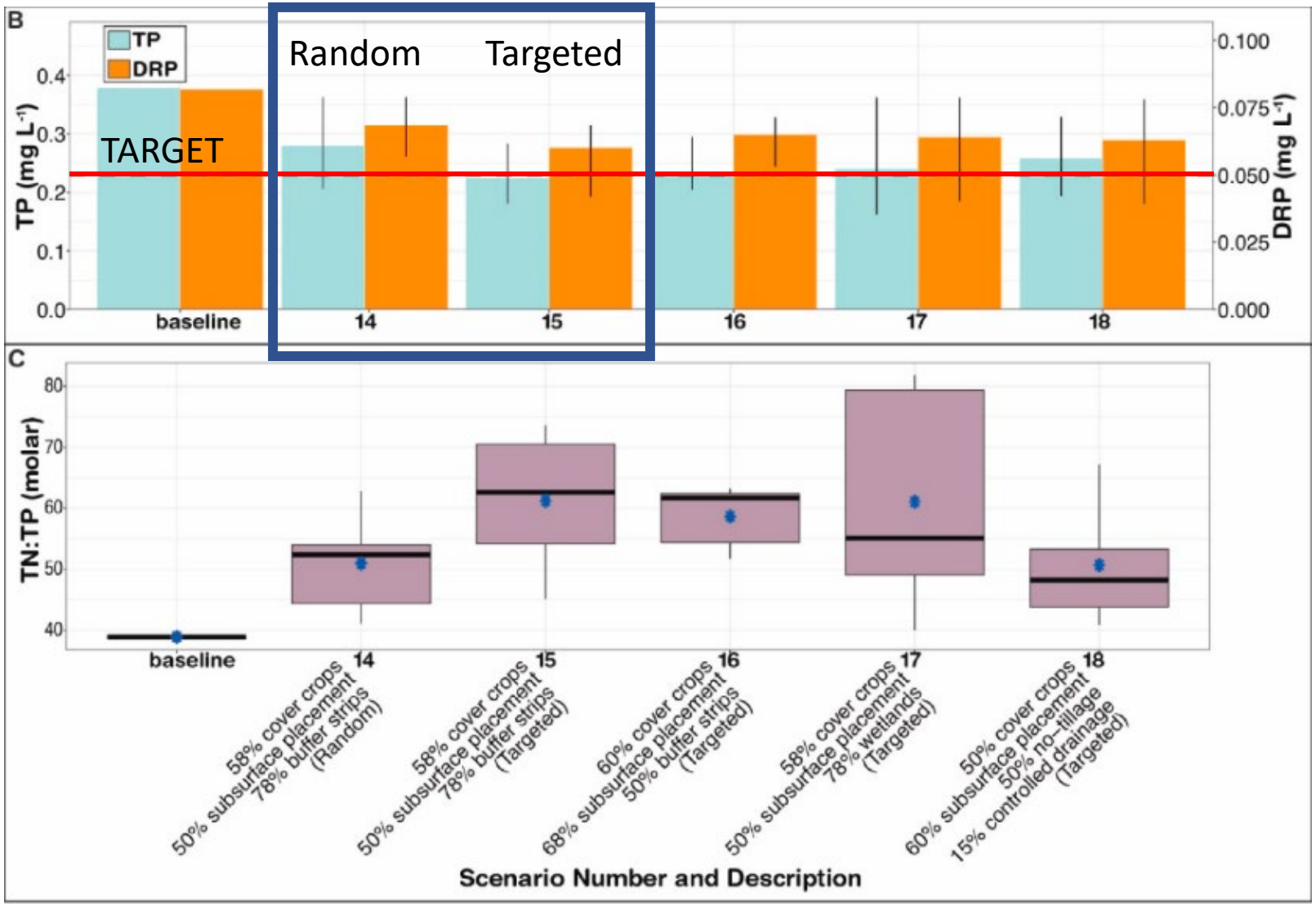
SPARROW model (SPAtially Referenced Regressions On Watershed attributes)

USGS science for a changing world
Dale Robertson

Multi-model: A stakeholder-engaged process

- Stakeholder group featuring ~20 individuals representing ~17 environmental, governmental, and farming groups

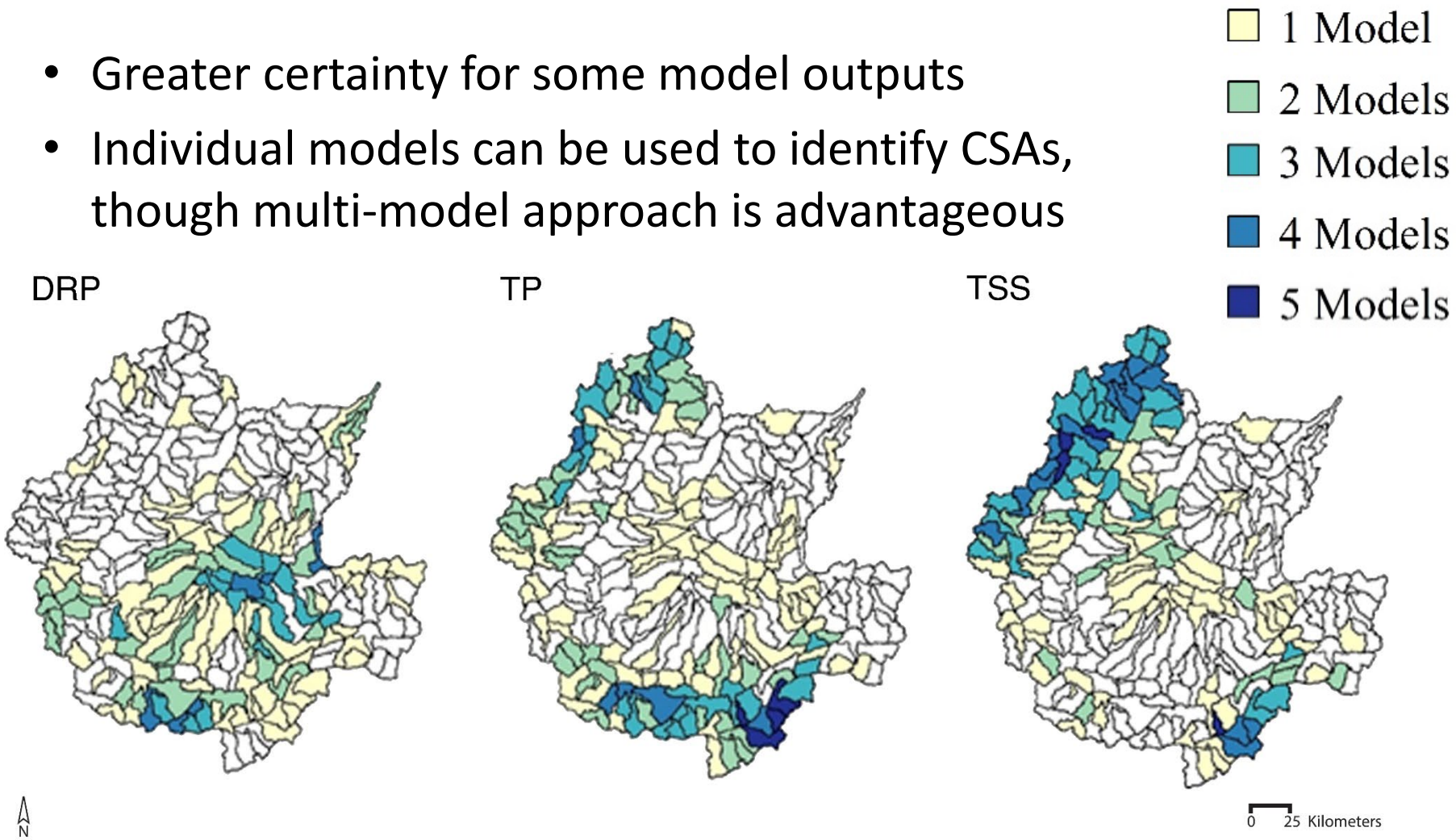
Five SWAT models predict **effectiveness of reaching loading targets**



Martin et al. (2021) "Evaluating management options to reduce Lake Erie algal blooms using an ensemble of watershed models," *Journal of Environmental Management*

Multi-model– **critical source areas**

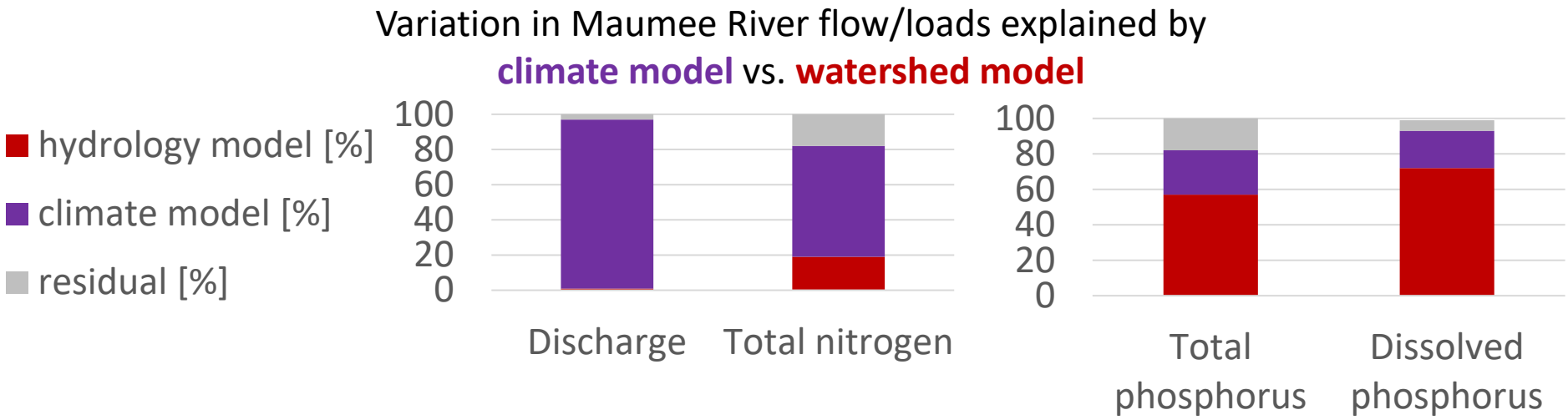
- Greater certainty for some model outputs
- Individual models can be used to identify CSAs, though multi-model approach is advantageous



Evenson et al. (2021) "Uncertainty in critical source area predictions from watershed-scale hydrologic models," *Journal of Environmental Management*

Multi-model– **Climate resilience**

- 6 climate models (RCP 8.5) + 5 SWAT models

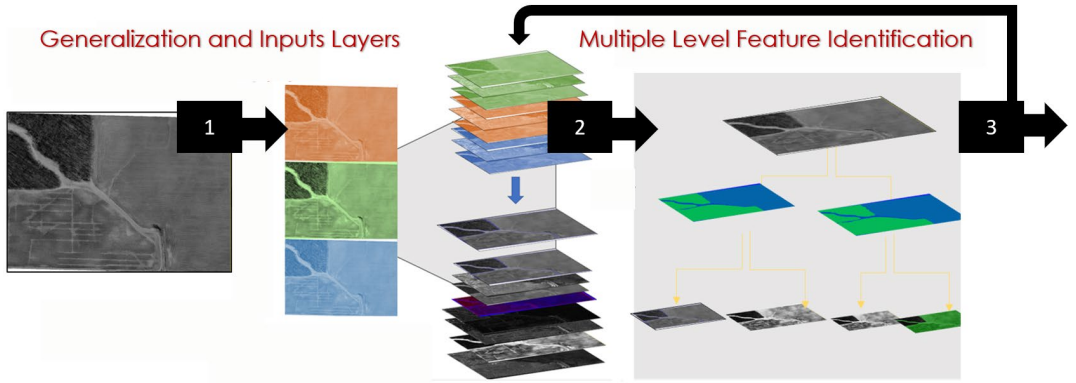


- No clear signal of future change in hydrology, water quality
- Consistency in model ensemble that increased conservation scenario will be effective in reducing nutrients – variation in effectiveness uncertain

1. Kujawa et al. (2020) "The hydrologic model as a source of nutrient loading uncertainty in a future climate" *Science of the Total Environment*
2. Kujawa et al. (2022) "Using a Multi-Institutional Ensemble of Watershed Models to Assess Agricultural Conservation Effectiveness in a Future Climate" *Journal of the American Water Resources Association*

Multi-model key takeaways

- Multi-model ensemble assessed GLWQA nutrient targets
  - Targeting most effective
  - DRP targets difficult to meet
- Significant opportunity to **reduce uncertainty** and **improve trust** in models
  - management assumptions
  - physical process representation



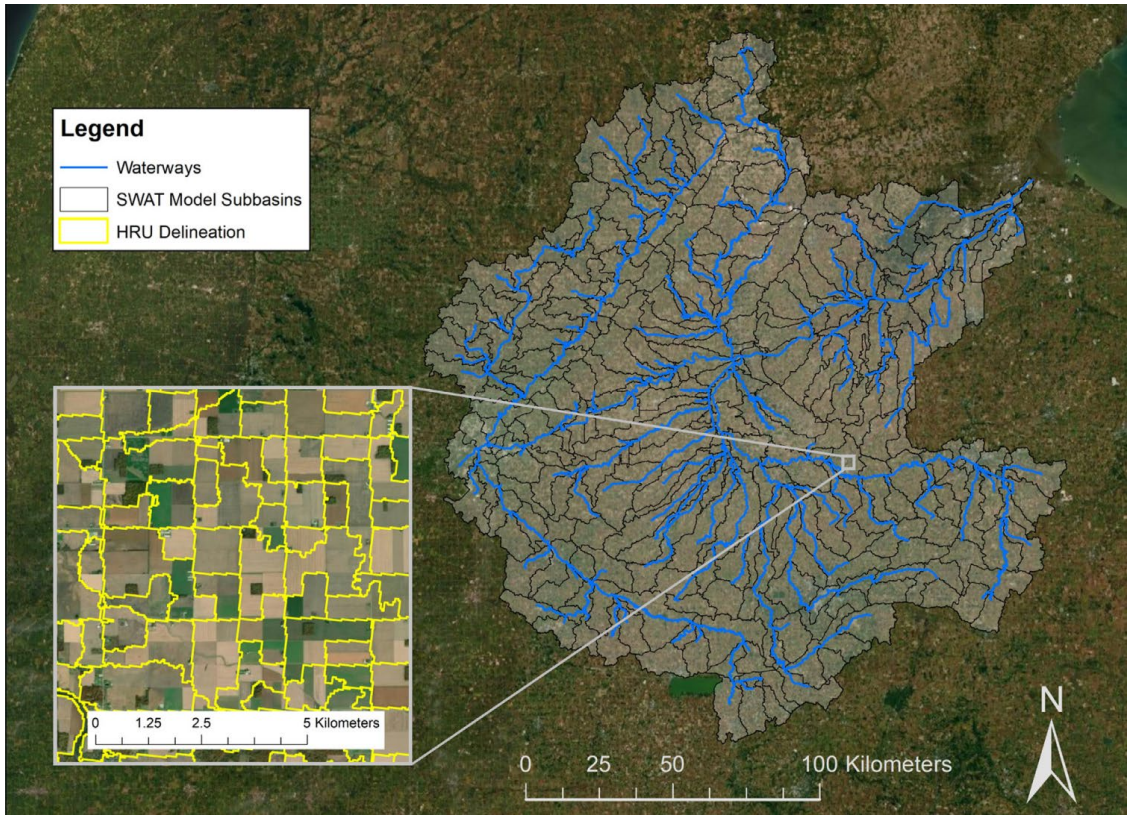
Remote sensing of watershed, University of Toledo

Edge-of-field (EOF) monitoring, USDA

Next generation version of the Maumee SWAT model

Field-scale boundaries

- Maumee watershed draining to western Lake Erie
- Spatial unit: Hydrologic response unit (HRU) approximate fields



Apostel et al. (2021) "Simulating internal watershed processes using multiple SWAT models," *Science of The Total Environment*

Bridging gap between multi-model scenarios and targeting approach

Legacy P fields – historically mismanaged fields with significantly elevated P soil concentrations (STP > 100 ppm Melich-III STP)

1. Disproportionate losses from legacy fields simulated in SWAT

HRU: High soil P, high P fertilizer

- 15% greater P loss

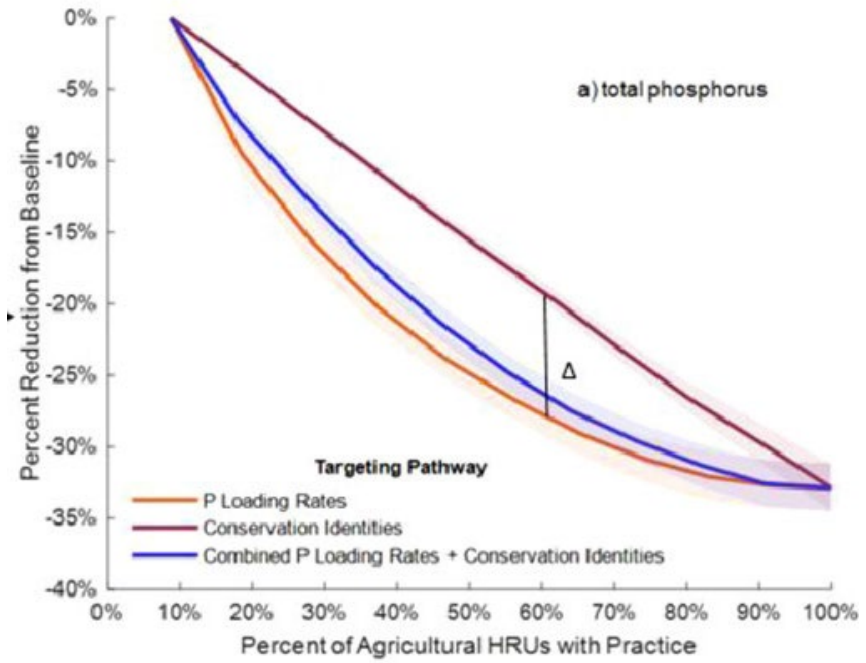
High STP (200% of homogenized STP)

- 20% greater DRP loss
- 35% greater TP loss (channel)

Arrueta et al. (2023). Simulating the Effects of Behavioral and Landscape Heterogeneity on Nonpoint Source Pollution. *Journal of the American Water Resources Association (JAWRA).*

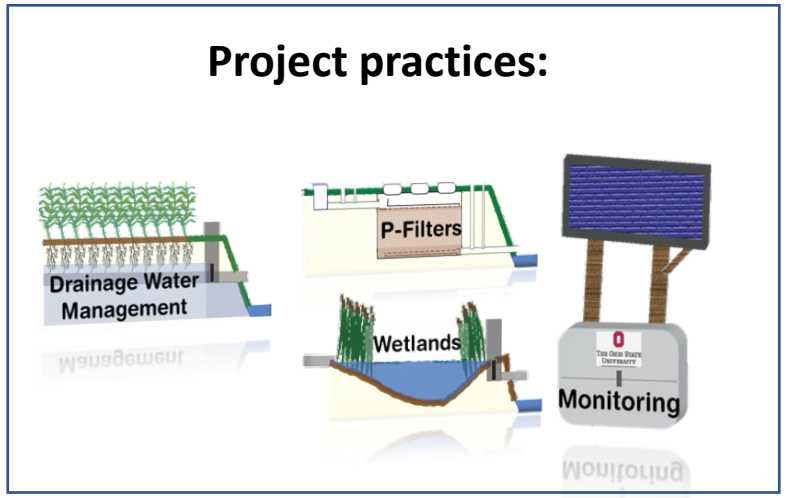
Kast et al. (2021) "Source contribution to phosphorus loads from the Maumee River watershed to Lake Erie" *Journal of Environmental Management*

2. Target fields based on high P loss and conservation identity– equally effective

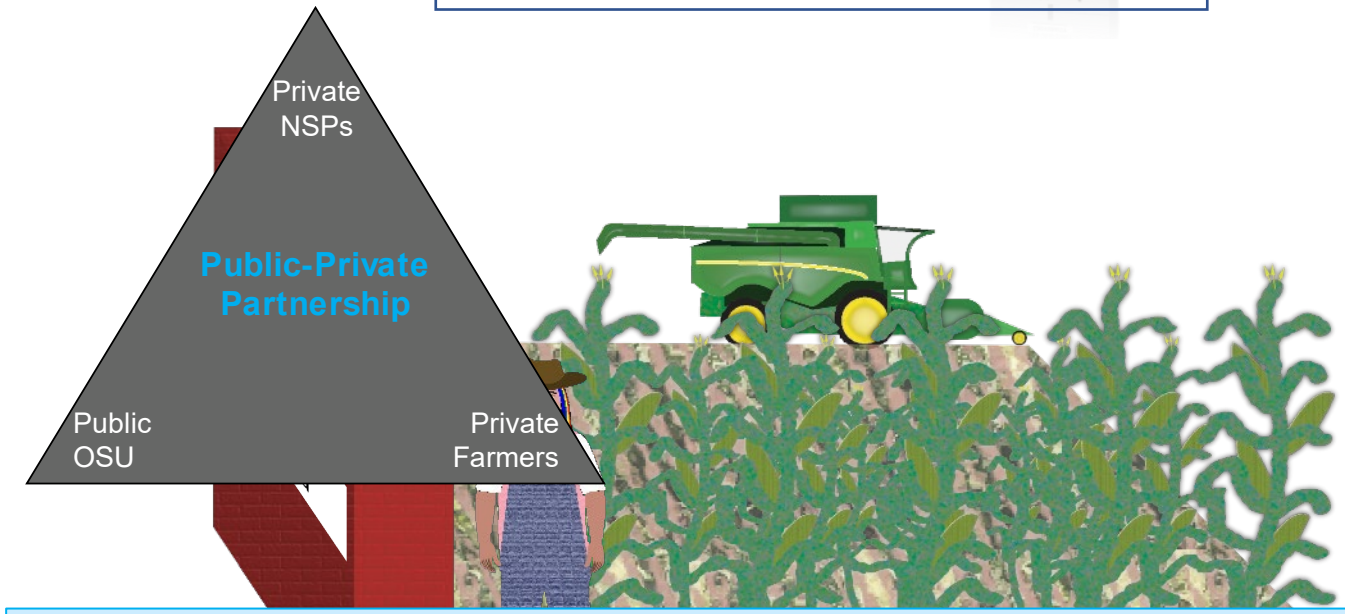


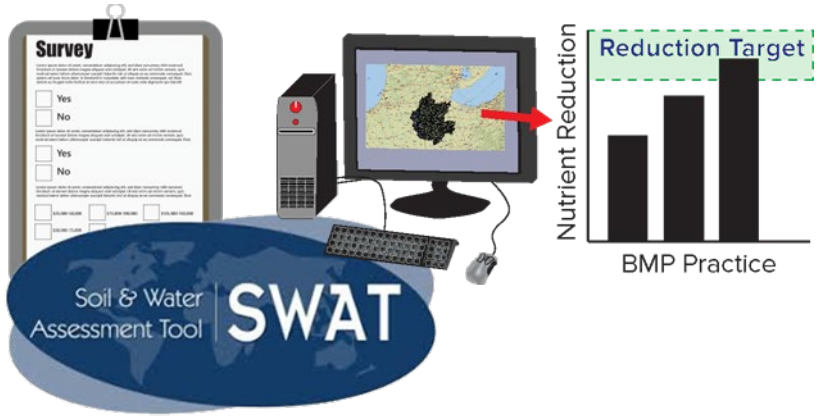
Kast et al. (2020) "Evaluating the efficacy of targeting options for conservation practice adoption on watershed-scale phosphorus reductions" *Water Research*

Monitoring and simulating legacy P fields for better targeting of conservation



- Objective 1:
  - Quantify loads, reductions @ 10 elevated-P fields
- Objective 2:
  - Socio-economics of Partnership
  - Models demonstrate scalability

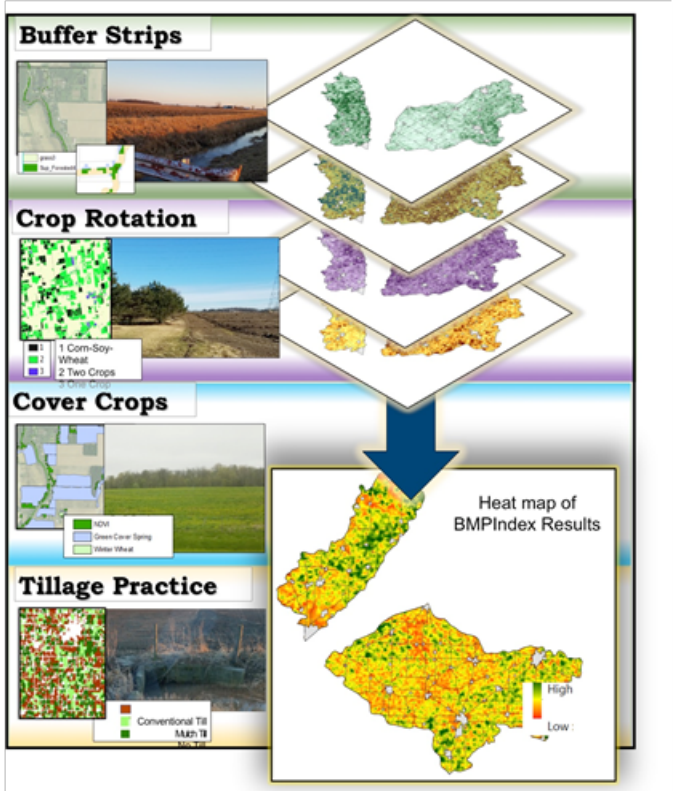




Brooker et al. (2021) "A Public-Private Partnership to Locate Fields for Implementation and Monitoring of Best Management Practices to Treat Legacy Phosphorus" *Frontiers in Sustainable Food Systems*

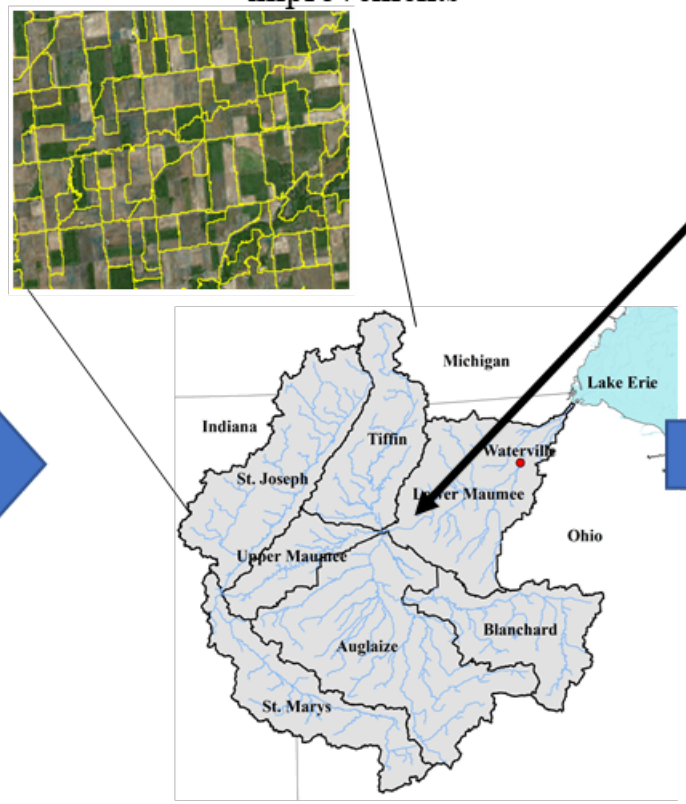
Continued improvements in baseline model and scenario analysis for state of Ohio

Obj.1. Remotely-sensing mapping of conservation practices



Mapped BMP representation

Obj.2. Maumee SWAT model improvements



Improved SWAT model

Obj.3. H2Ohio program water quality benefits evaluation

Current/planned H2Ohio Practices

Reducing P

Wetlands

Septics

Lead contamination

Future H2Ohio Practices & impacts

Ongoing

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SWAT International Conference 2023

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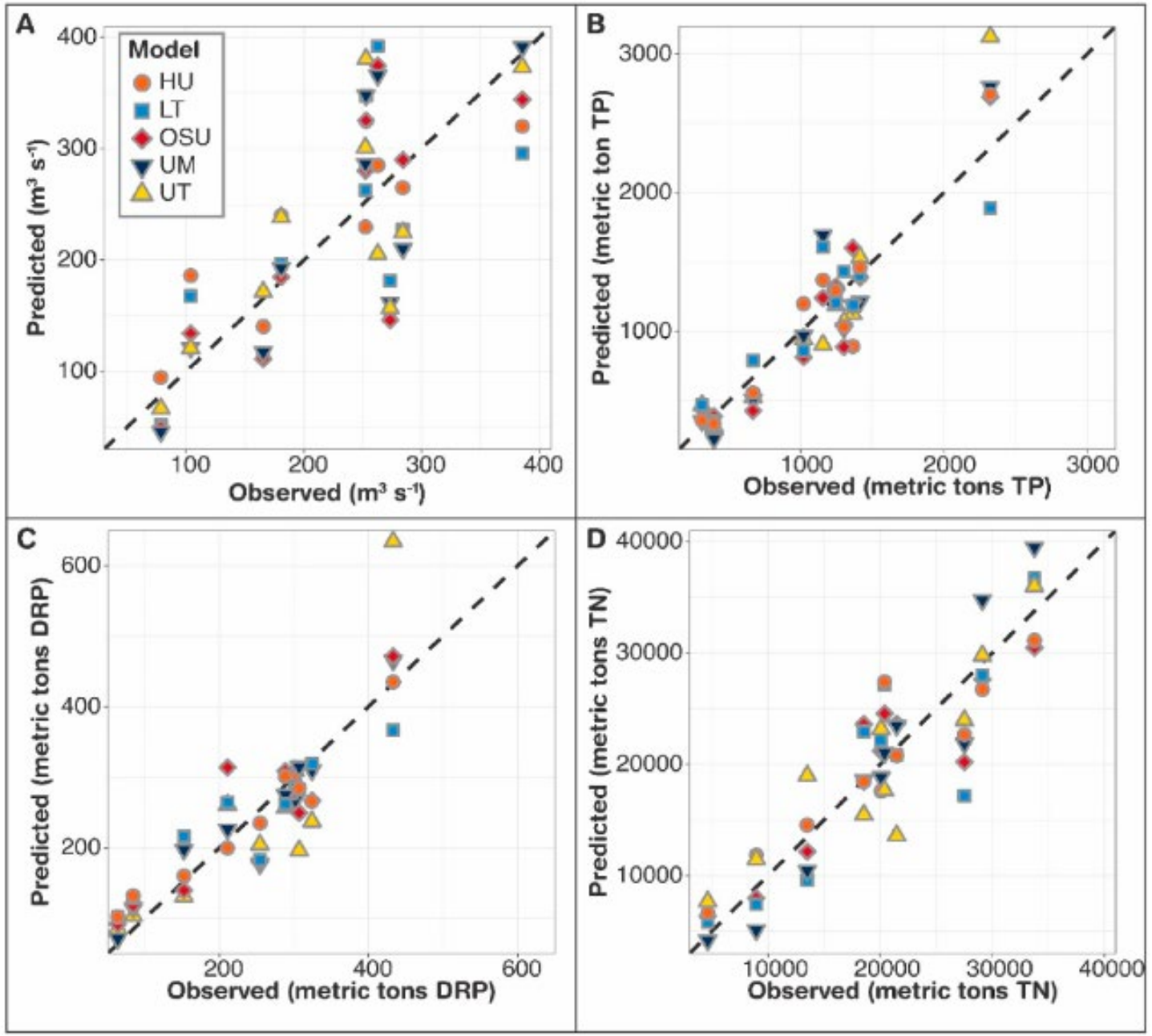
Multi-model calibration

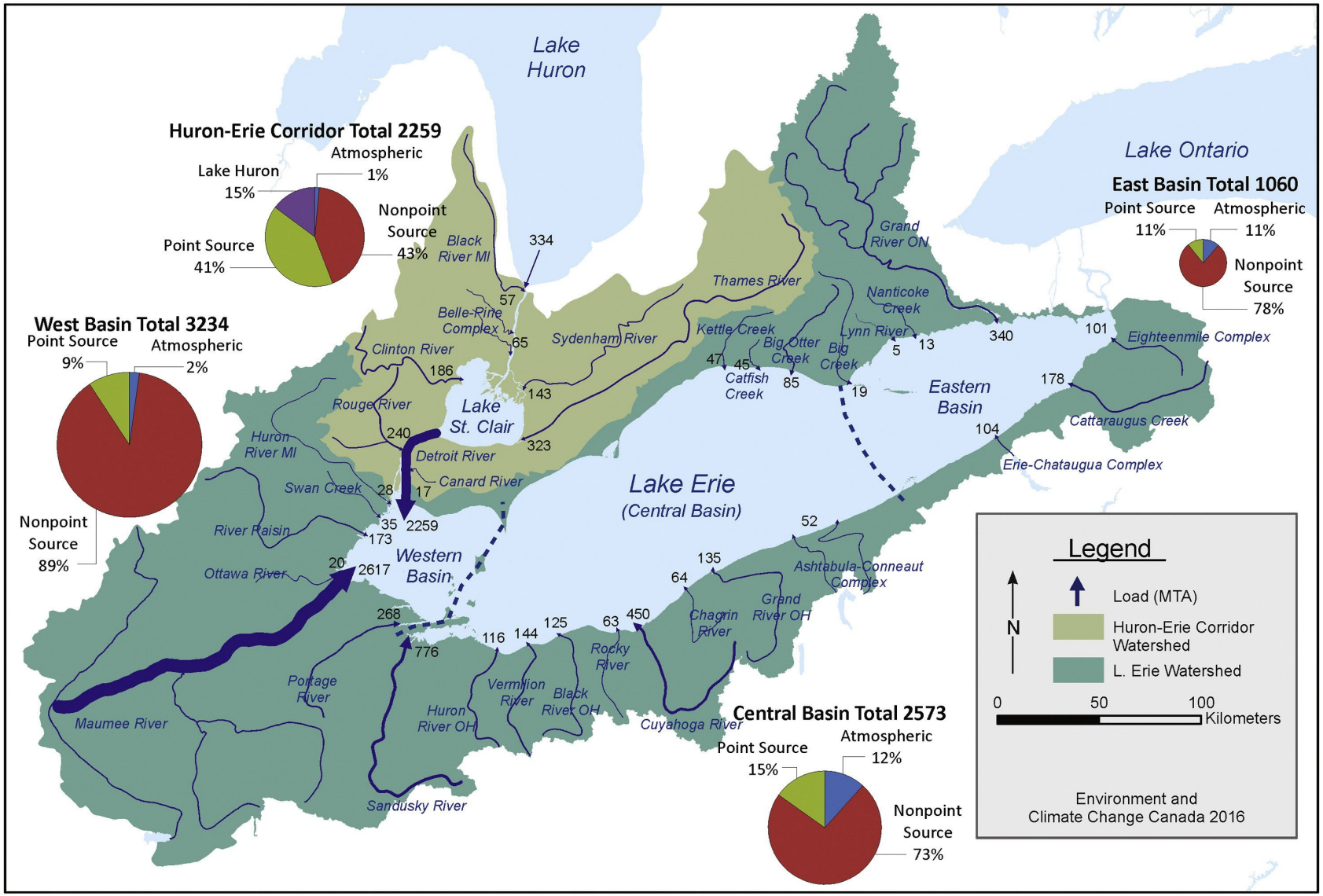
The performance of the five SWAT models were evaluated over the entire 2005–2014 period and were compared to standards for satisfactory performance established by Moriasi et al. (2007)[1] for percent bias (PBIAS) and Nash-Sutcliffe Efficiency (NSE).

		Satisfactory Performance Range[1]	Multi-Model Average	Ohio State University	LimnoTech	University of Michigan	Heidelberg University	University of Toledo
PBIAS (%)	Discharge	+/- 25	2.2	−3	11	1	2	0.1
	TP	+/- 70	−2.7	19	−13	1	−7	−13
	DRP	+/- 70	5	−4	−15	7	7	32
	TN	+/- 70	−11	−11	−24	−4	−3	−12
NSE	Discharge	>0.50	0.89	0.99	0.91	0.94	0.88	0.83
	TP		0.70	0.71	0.77	0.61	0.73	0.66
	DRP		0.67	0.73	0.67	0.69	0.77	0.50
	TN		0.58	0.64	0.59	0.77	0.74	0.17

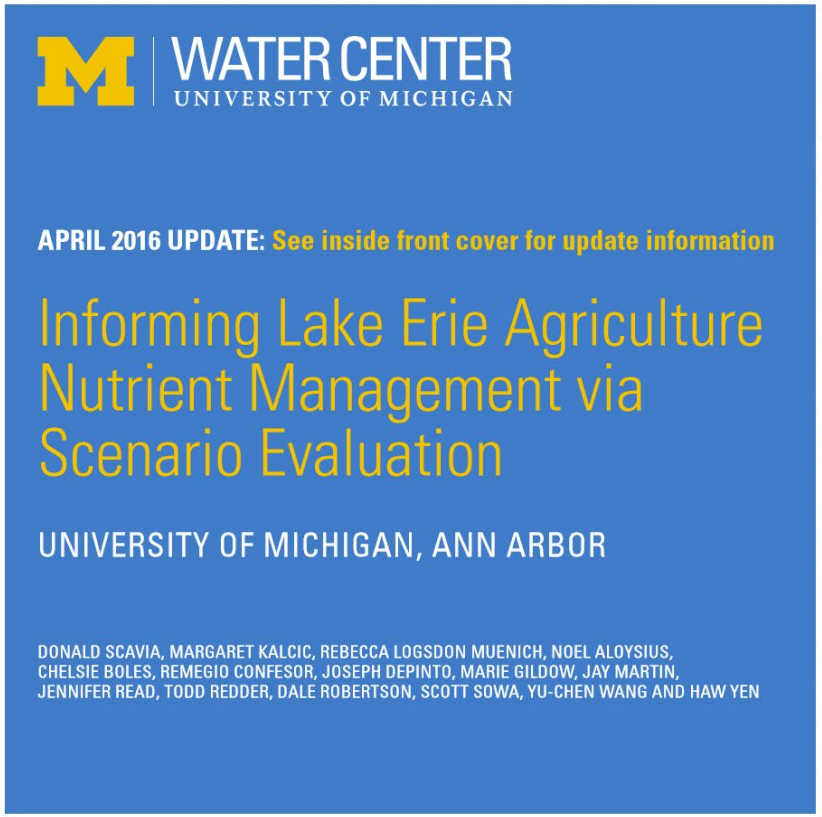
Multi model calibration



Phosphorus delivery to Lake Erie



Maccoux et al., 2016



Building & improving from past to current project

SWAT models (Soil and Water Assessment Tool)

UNIVERSITY OF MICHIGAN

Don Scavia
Margaret Kalcic
Rebecca Muenich
Yu-Chen Wang
Awoke Teshager

HEIDELBERG UNIVERSITY

Rem Confesor
Tian Guo

In only one of the two studies:

THE UNIVERSITY OF TOLEDO 1872

Richard Becker

OHIO STATE

Jay Martin
Margaret Kalcic
Noel Aloysius
Jeffrey Kast
Anna Apostel
Haley Kujawa

BLACKLAND Texas A&M AgriLife Research & Extension Center
LEADING IN LAND & WATER SOLUTIONS · SERVING TEXAS OVER 100 YEARS

USDA ARS
United States Department of Agriculture
Agricultural Research Service

Haw Yen
Jeff Arnold
Mike White

SPARROW model (SPAtially Referenced Regressions On Watershed attributes)

LimnoTech
Water Environment | Scientists Engineers

Joe DePinto
Todd Redder
Chelsie Boles

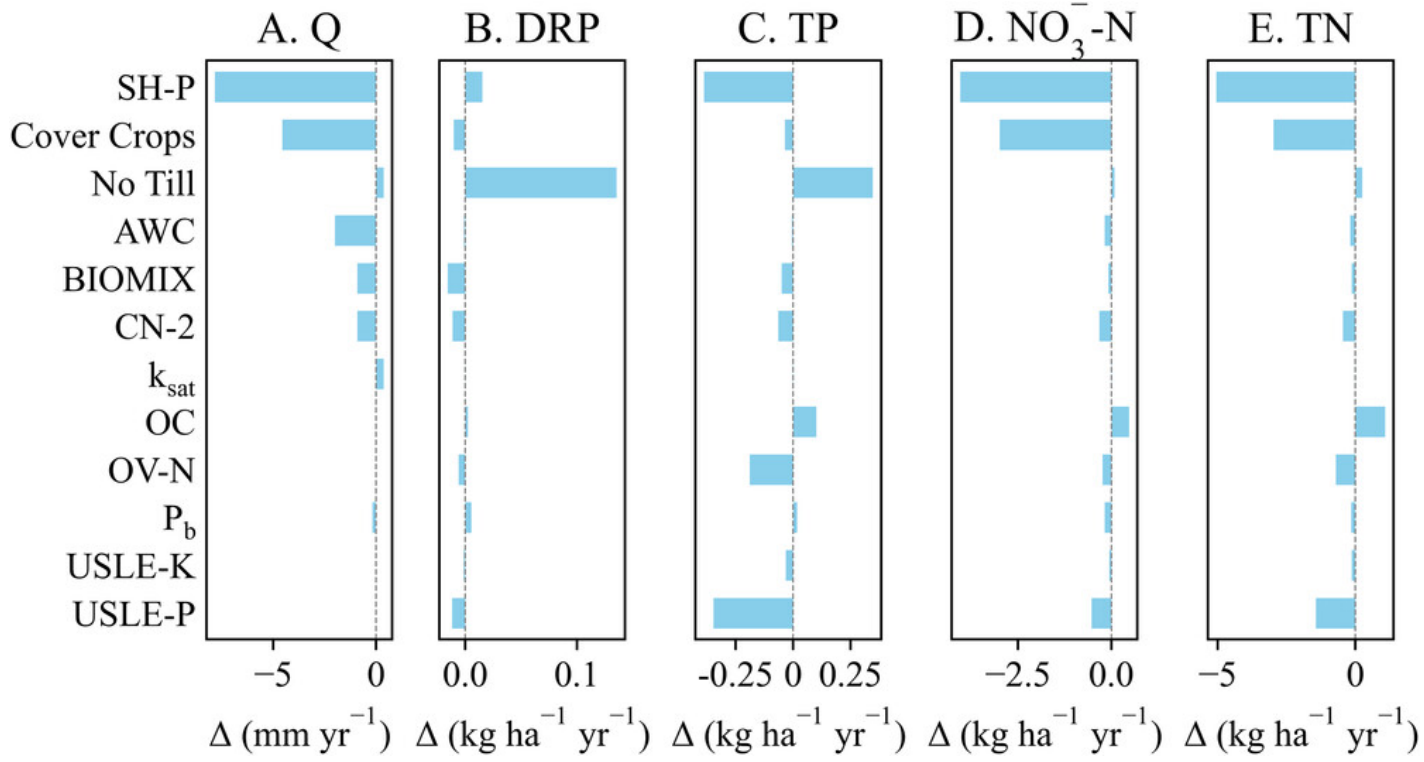
USGS
science for a changing world

Dale Robertson

Scavia et al., 2017. Multiple models guide strategies for agricultural nutrient reductions. Frontiers in Ecology and the Environment.

Projects fueled by stakeholder process: *Soil health & water quality*

- Cover crops, no-till, and a **suite of modified soil descriptive parameters** to depict **soil health practice** on soil properties
- Improving soil health **reduced N and total P loss** but **increased dissolve P loss**
- Need for additional observations on soil health to further verify results and guide future development

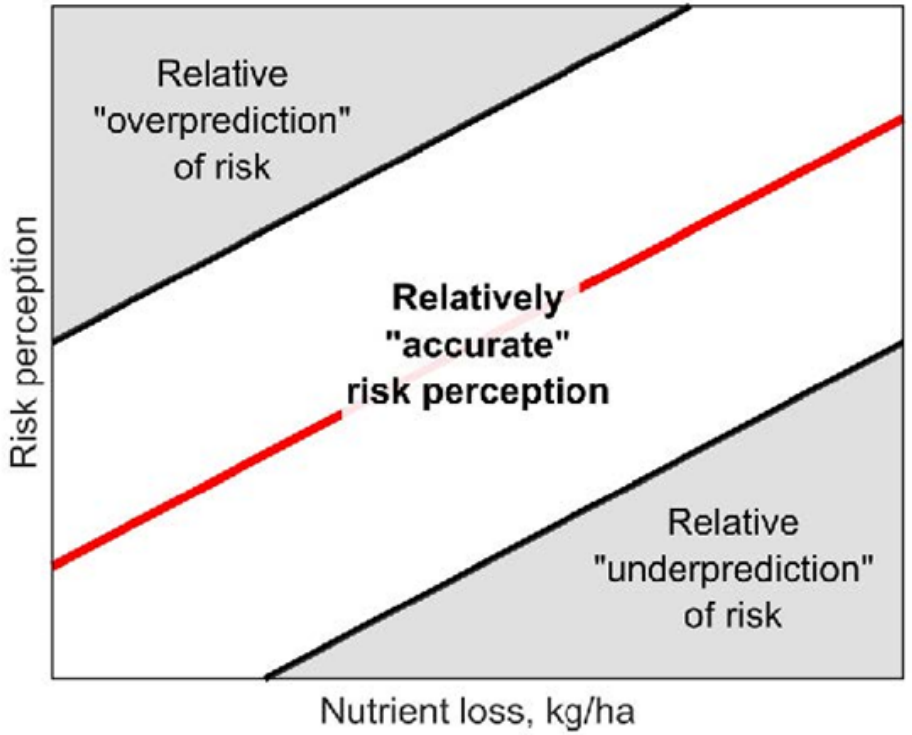


Evenson et al. (2022) "Representing soil health practice effects on soil properties and nutrient loss in a watershed-scale hydrologic model," *Journal of Environmental Quality*

Physical and social factors for targeting conservation

Perceived vs. actual (simulated) nutrient loss

- Use surveys of farmers to identify perceived risk vs. actual risk of nutrient loss as simulated in SWAT



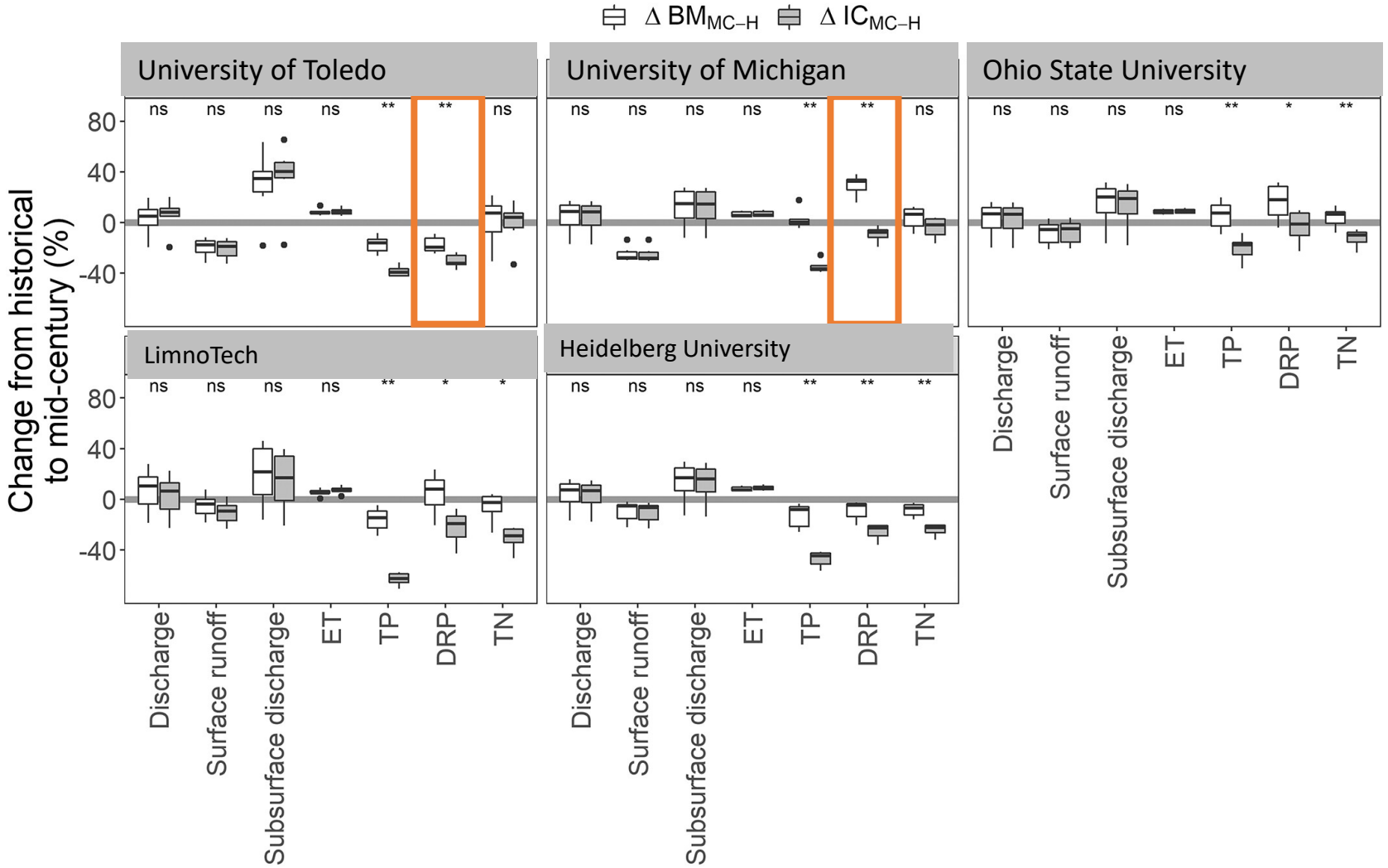
Findings:

- Farmers with higher nutrient loss do not consistently report a higher likelihood of negative consequences from nutrient loss on their farm
- Characteristics of the individual are more important in determining whether farmers are likely to “overpredict” or “underpredict” risk

Published: Schwab et al. (2021) “Assessing the Accuracy of Farmers’ Nutrient Loss Risk Perceptions” *Environmental Management*

Multi-model: Climate and agricultural conservation

- 6 climate models (RCP 8.5)
- 5 SWAT models

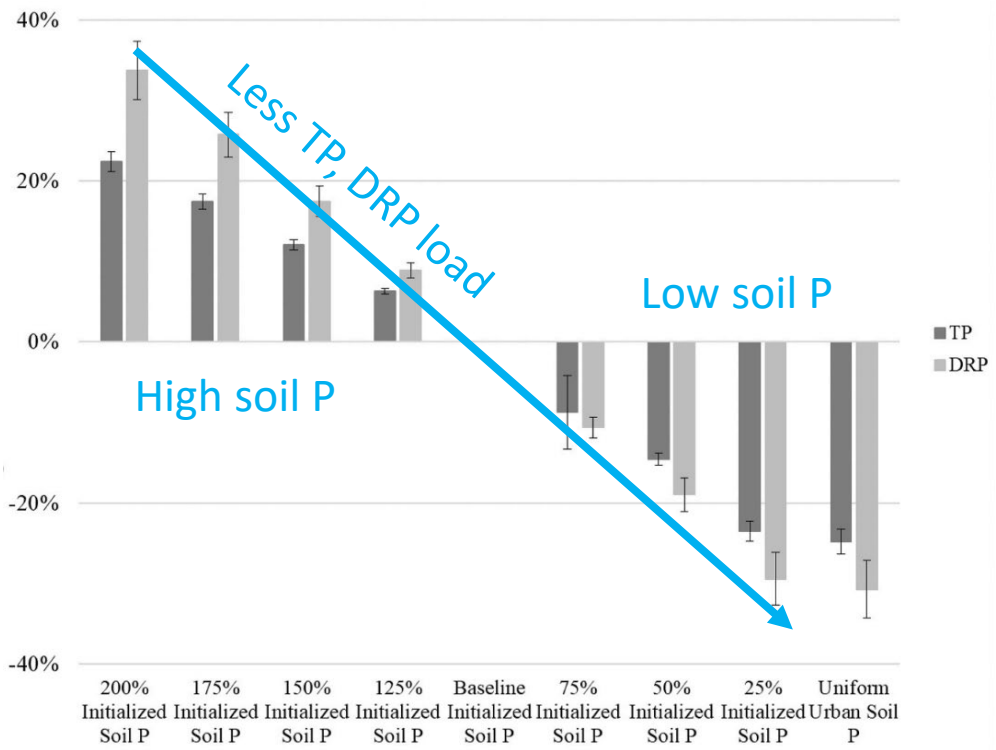


Kujawa et al. (2022) "Using a Multi-Institutional Ensemble of Watershed Models to Assess Agricultural Conservation Effectiveness in a Future Climate" *Journal of the American Water Resource Association*

Projects fueled by stakeholder process: *Nutrient source contributions*

- Improved model for manure application; uniform soil P in cropland
- Sensitivity analysis: soil P source of P load
- Long-term soil P reductions will help!
- Similar delivery ratios for manure as fertilizer

Percent reduction in P loading

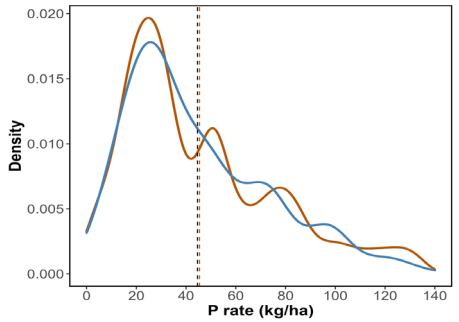


Published: Kast et al. (2021) "Source contribution to phosphorus loads from the Maumee River watershed to Lake Erie" *Journal of Environmental Management*

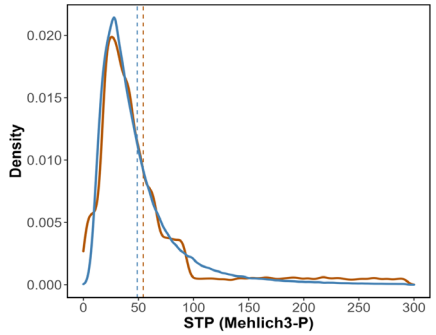
Projects fueled by stakeholder process: *Legacy phosphorus in soils*

- Gauging the level of disproportionality in phosphorus emitters

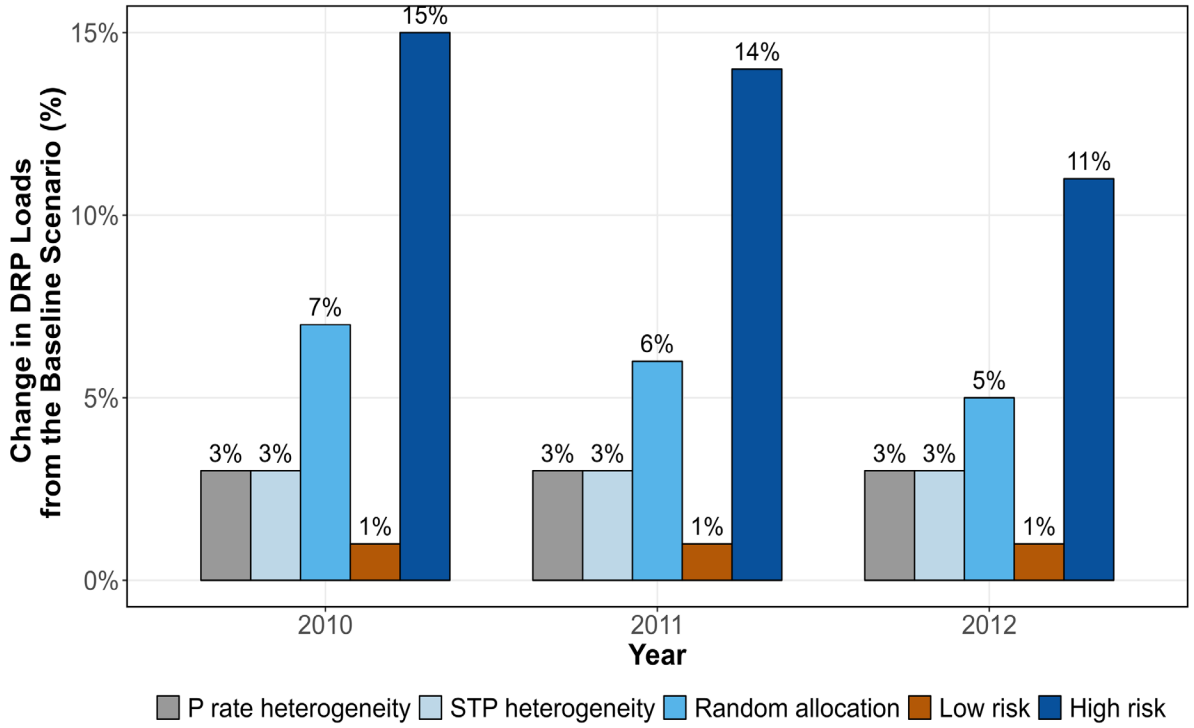
P fertilizer distribution



Soil test P distribution

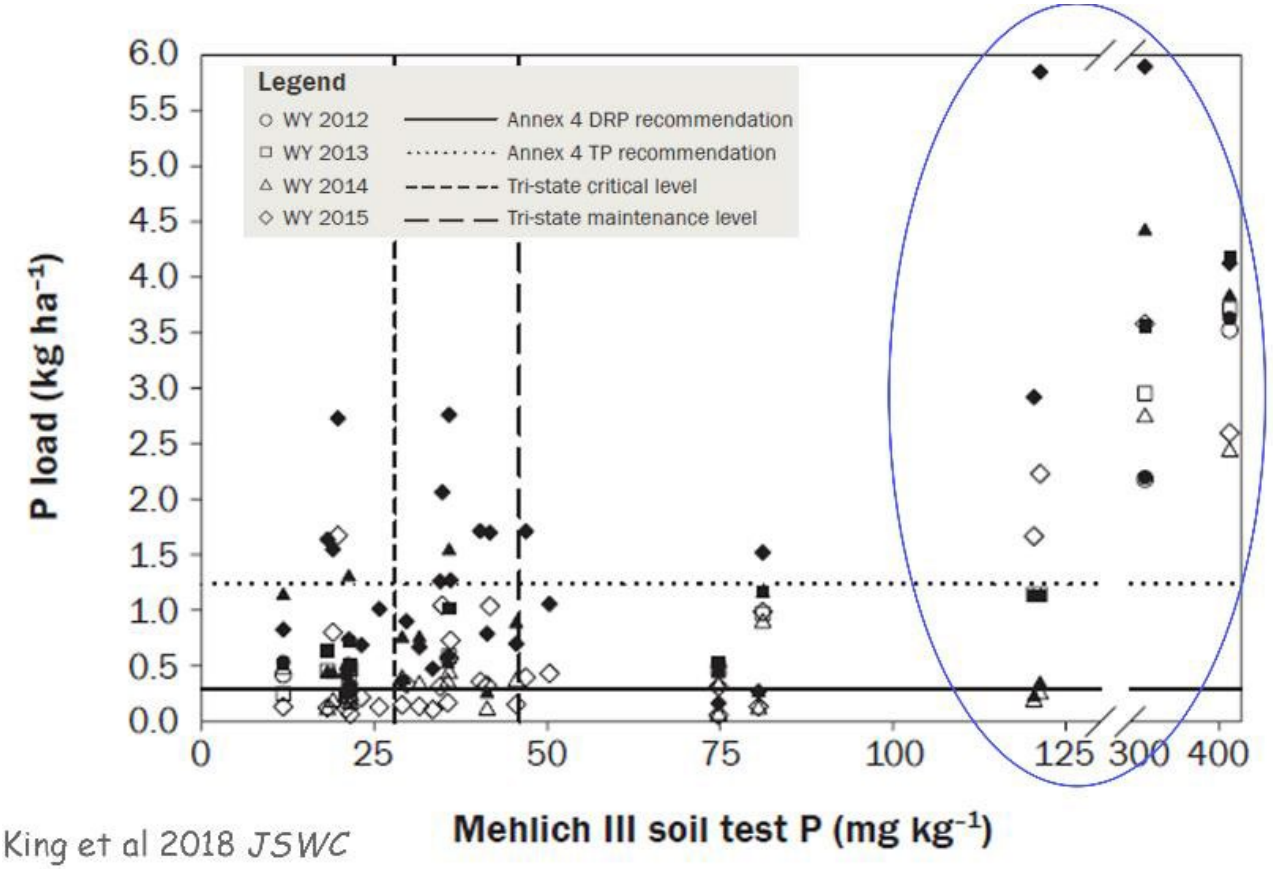


Difference in share of DRP and TP loads produced by 25% highest-emitting fields compared to baseline simulation



Thesis: Lourdes Arrueta Antequera (2020) "Simulating the Effects of Behavioral and Landscape Heterogeneity on Non-point Source Pollution"

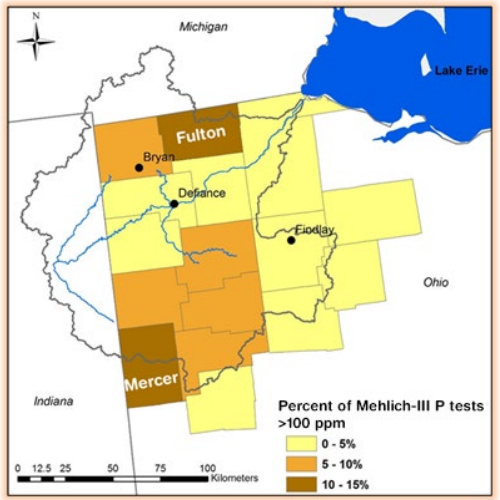
Targeting: Finding fields generating greater loads



King et al 2018 *JSWC*

- Strong relationship between soil P concentration & loading rates
- Must find fields with soil P > agronomic levels

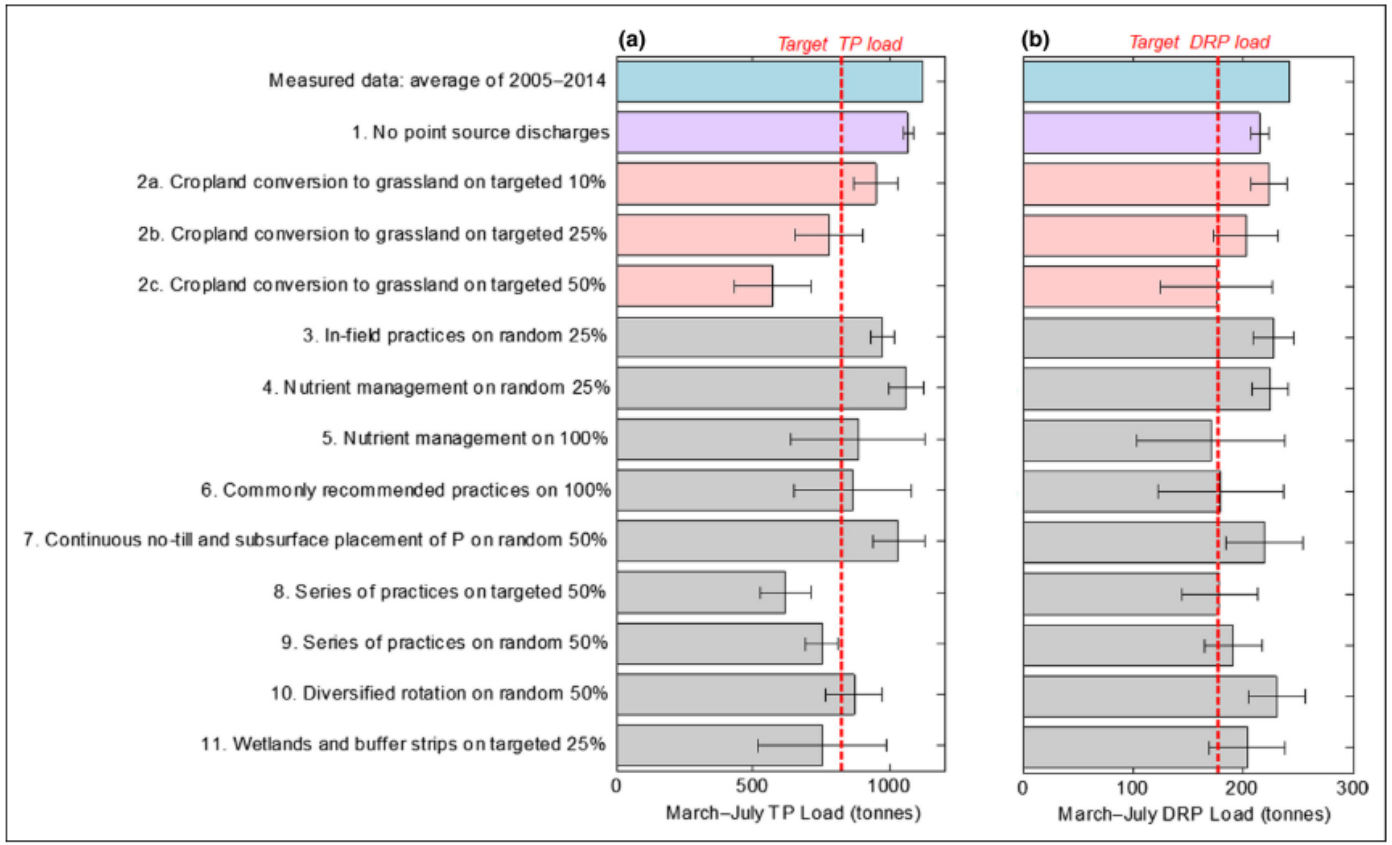
- Aggregate data & Location is proprietary



Libby Dayton personal comm

Five SWAT models predict **effectiveness of reaching loading targets** (1)

- Demonstrates potential of watershed-scale implementation in reaching water quality targets
- This study looked at the targets as an average load, not 9/10 years, and did not include manure sources



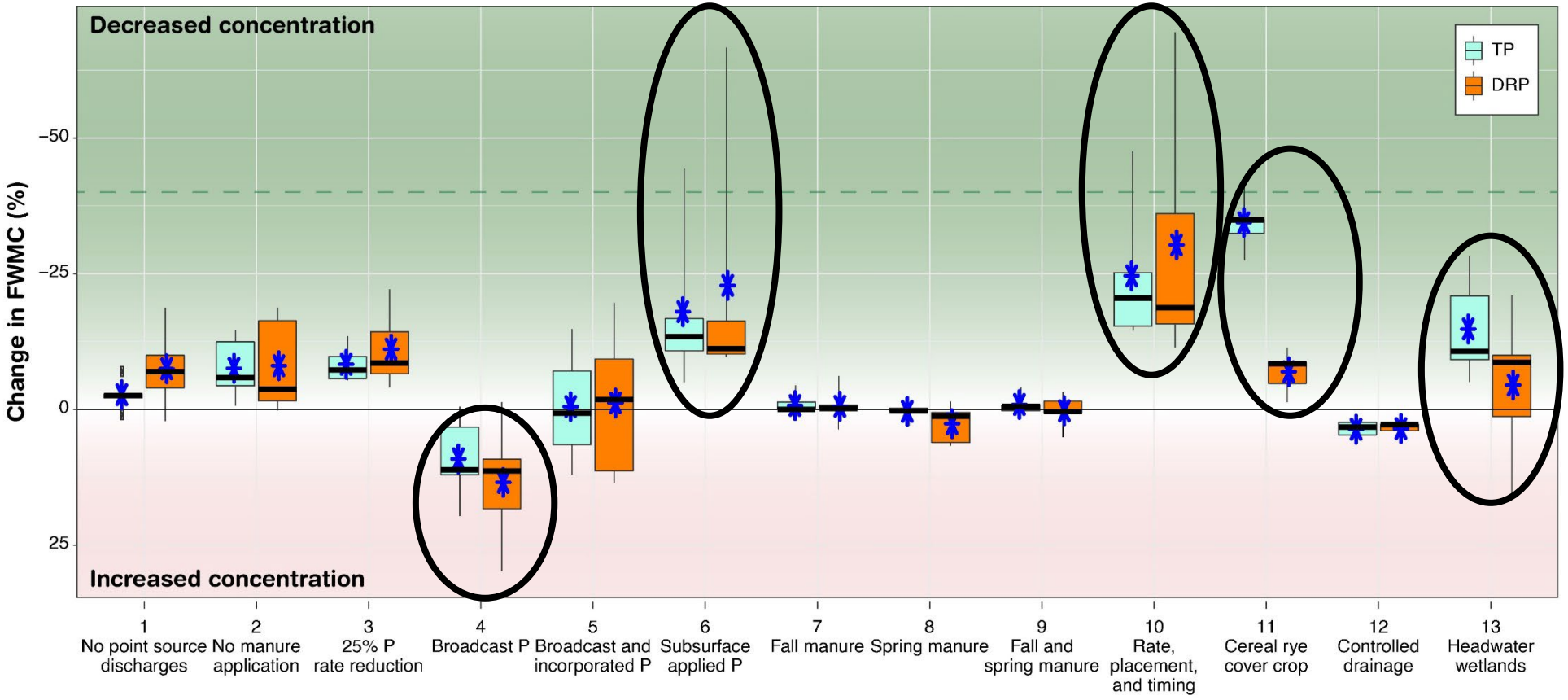
Published: Scavia et al. (2017) "Multiple models guide strategies for agricultural nutrient reductions," *Frontiers in Ecology and the Environment*

Five SWAT models predict **effectiveness of reaching loading targets** (2)

- Effectiveness of individual practices

Second iteration:
+ Improved manure sources

+ Investigate targets more closely to Annex 4



High-resolution watershed modeling

Remote sensing data
- Crop rotations
- Cover crops
- Tillage practices
- Buffer strips

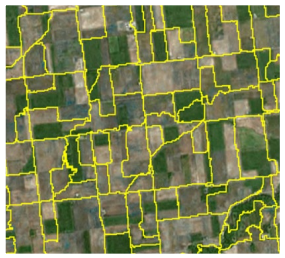
Soil Test Phosphorus

County level STP distributions used to apply a heterogeneous representation of soil P values

Manure
- Locations of permitted and unpermitted facilities
- Kast et al 2020 allocations
- Applied according to STP values and crop needs

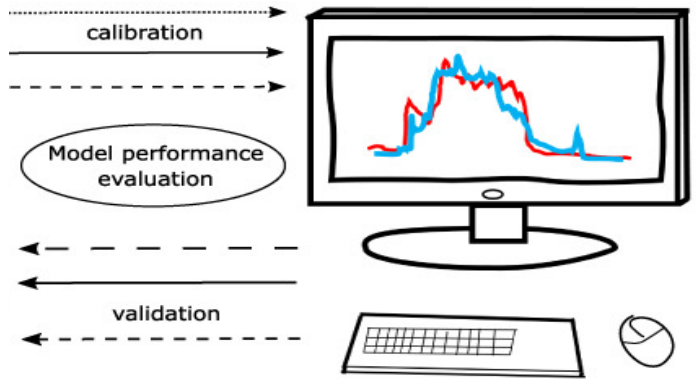
Inorganic Fertilizer
- County level rates of N and P scaled to meet plant needs
- Applied to field where manure does not meet plant needs

Additional linked practices
- Subsurface application
- Tile drainage-spacing
- Wetland locations

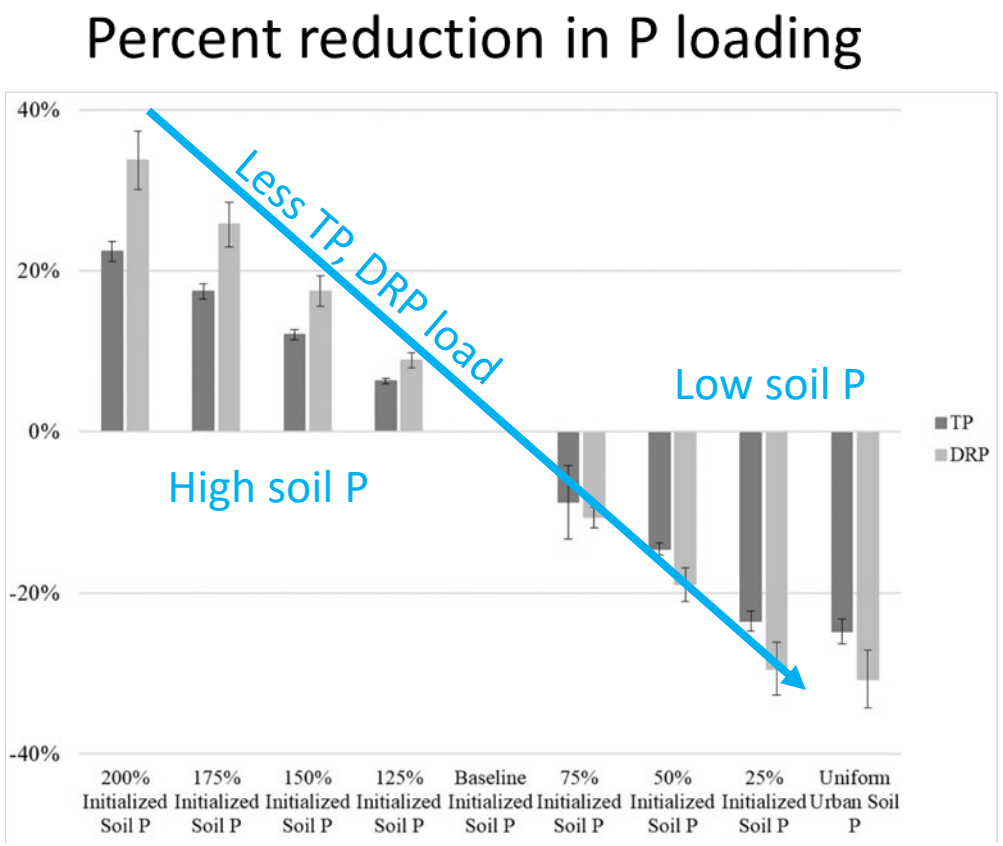


Field-scale SWAT Model

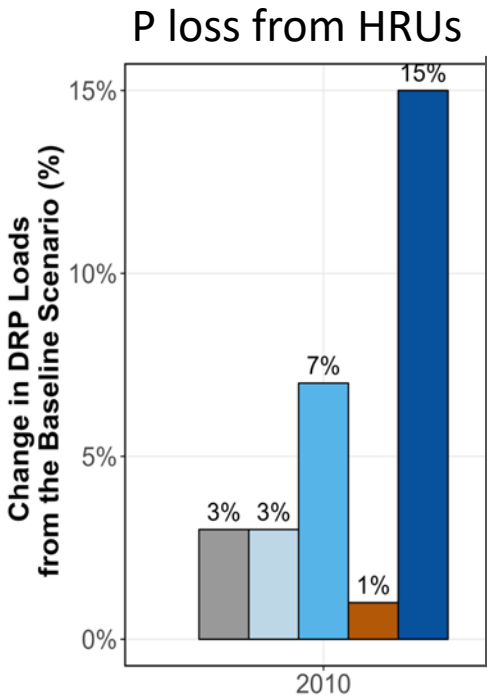
Maumee River Watershed



Addressing heterogeneity in P sources – legacy contributions



Legacy P fields – historically mismanaged fields with significantly elevated P soil concentrations (STP > 100 ppm Melich-III STP)



- Fertilizer rate heterogeneity—random
- STP heterogeneity—random
- Fertilizer + STP heterogeneity – random
- Low risk (High STP, low fertilizer)
- High risk (High STP, high fertilizer)

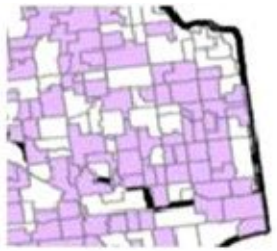
Published: Kast et al. (2021) "Source contribution to phosphorus loads from the Maumee River watershed to Lake Erie" *Journal of Environmental Management*

Published: Arrueta et al. (2023). Simulating the Effects of Behavioral and Landscape Heterogeneity on Nonpoint Source Pollution. *Journal of the American Water Resources Association (JAWRA).*

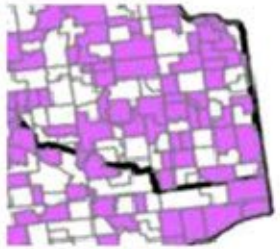
Social factors for targeting conservation–
Targeting based on conservation identity

Maumee River Watershed SWAT Model

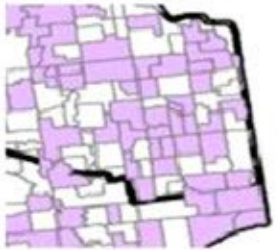
Conservation Practice Adoption (Buffer Strips and Subsurface P Placement)



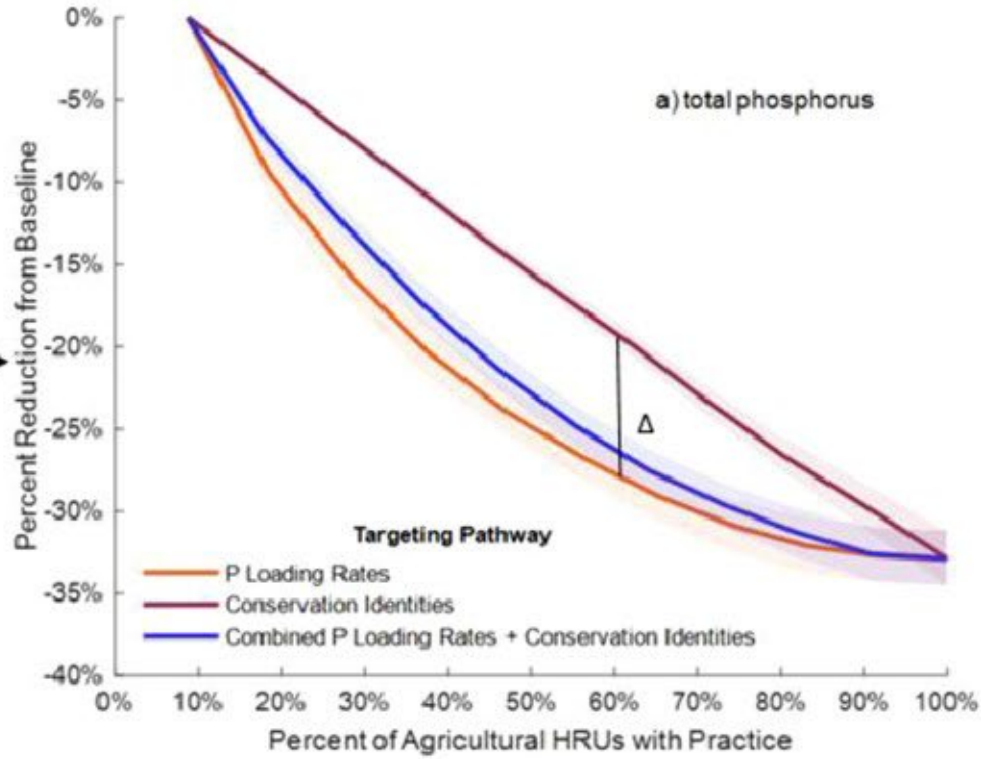
Greatest Phosphorus Loading Rates



Greatest Farmer Conservation Identities



Greatest Combined Phosphorus Loading Rates and Farmer Conservation Identities



Published: Kast et al. (2020) "Evaluating the efficacy of targeting options for conservation practice adoption on watershed-scale phosphorus reductions" *Water Research*