Evaluating field- and watershed -scale water quality benefits of agricultural conservation practices in the Maumee River watershed using a high-resolution SWAT model

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Session B2: Agricultural and Climate Change Scenarios for a Sustainable Future

1.University of Wisconsin-Madison
2.Ohio State University
3. University of Toledo
4. USDA ARS

Outline for today's talk

- **Background on Lake Erie Algal Blooms and mitigation efforts**
- **Maumee River watershed (MRW) SWAT model development**
- **Best Management Practice (BMP) scenario development, validation, and preliminary results**

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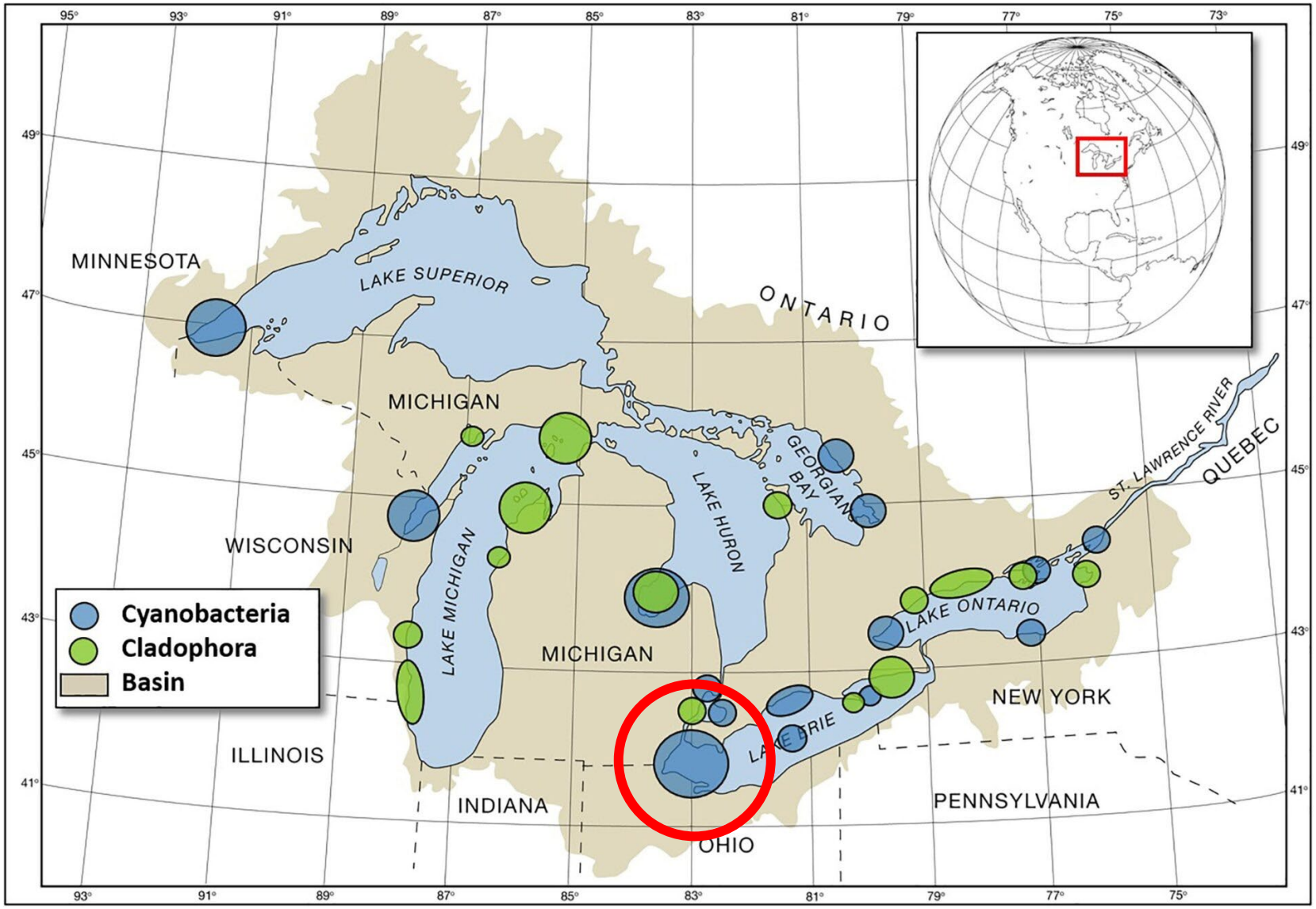
- **USDA-ARS**
  - Kevin King
- **Maumee Watershed Modeling Stakeholder Advisory group**

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)

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

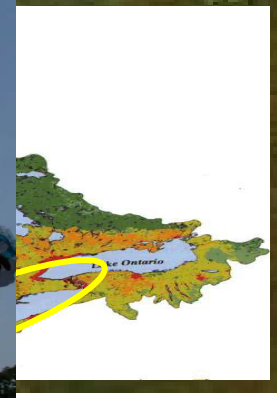
A Lake Erie Harmful Algal Bloom (HAB)

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 B 1995

Blooms largely caused b 1995

Maumee River contributes 50% 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

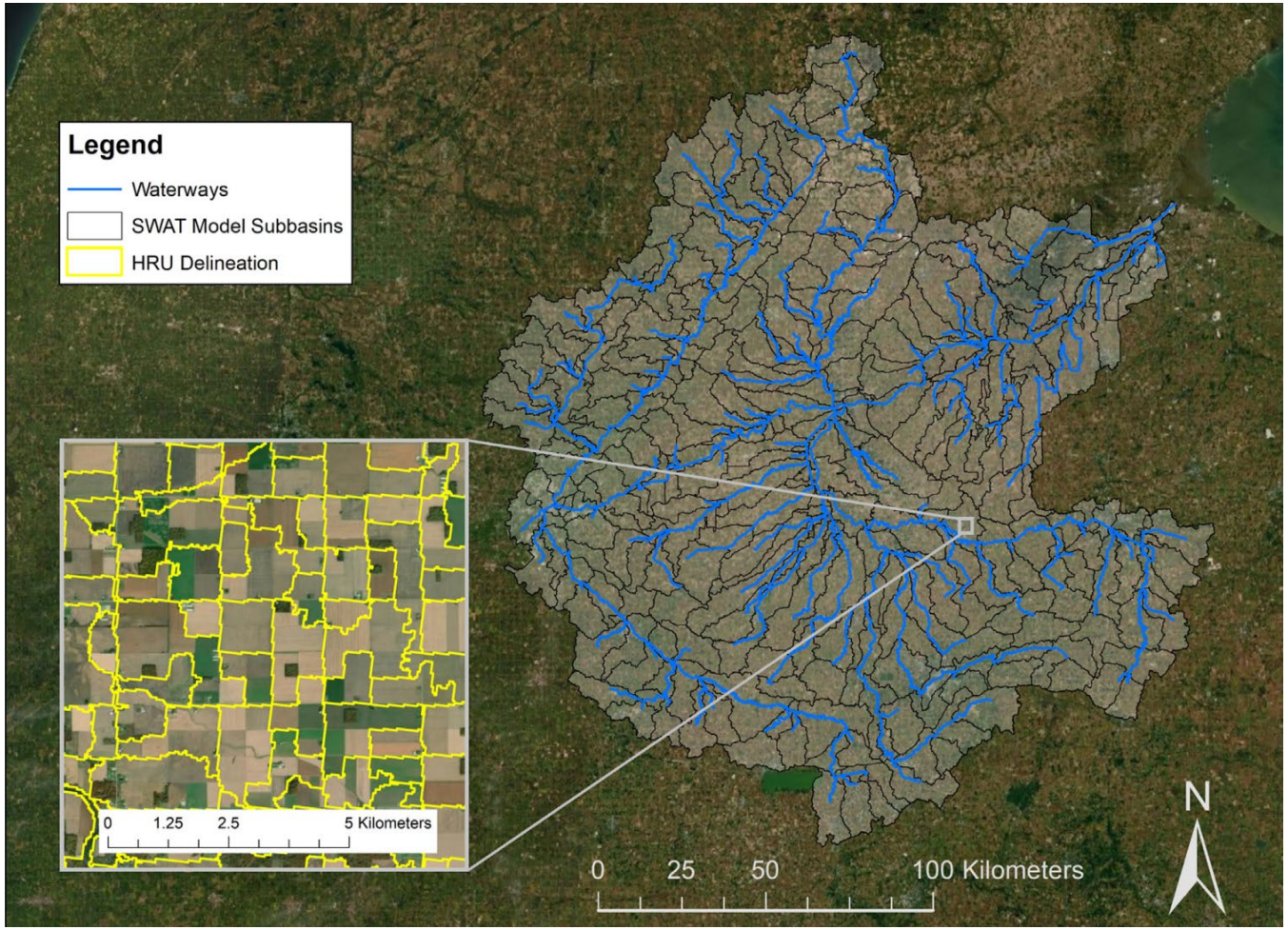
2016-present; March-July	Maumee River	Western Lake Erie
DRP Load*	186 MT	40% of 2008
TP Load*	860 MT	40% of 2008
DRP Concentration**	0.05 mg/L	
TP Concentration**	0.23 mg/L	

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

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

Maumee River Watershed SWAT model

- 4th SWAT 2012 model iteration of the Maumee watershed in the research group
- Near-field level resolution:
  - Smallest land unit (HRU) averages ~70 acres in size
  - Improved spatial representation of management practices
  - Spatially continuous field units



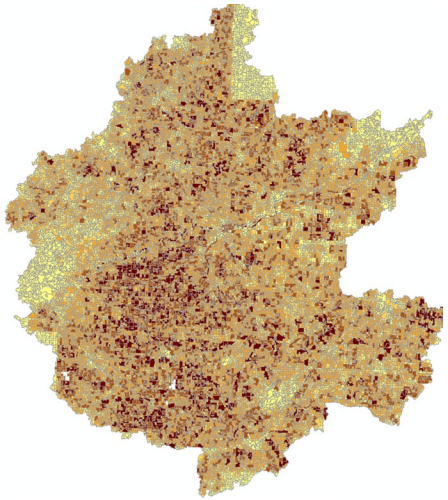
Apostel et al. (2021)

Identification of agricultural practices using remote sensing and *in situ* field data

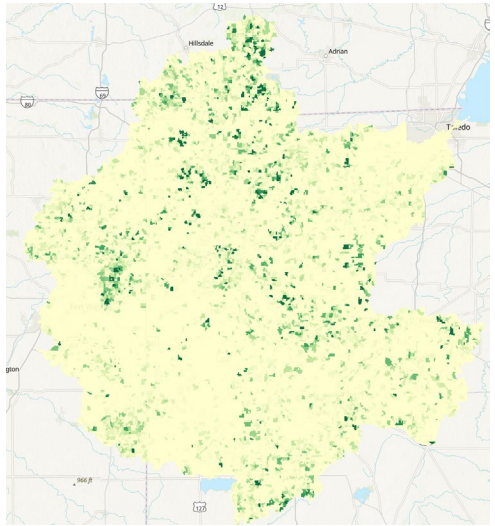
Input Data & Type	Tillage	Cover Crops	Buffer Strips	Crop Rotation
Raster	LANDSAT Satellite Images: 30 meter	LANDSAT Satellite Images: 30 meter	Aerial Imagery - National Aerial Image Program 2016/2017	National Agriculture Statistics Survey Cropland Data Layer (CDL)
Classified Raster	National Agriculture Statistics Survey Cropland Data Layer (CDL)	National Agriculture Statistics Survey Cropland Data Layer (CDL)	Aerial Imagery - Ortho Images (OGRIP)	LANDSAT Satellite Images: 30 meter
Training & Validation	UT Field Data Observations	UT Field Data Observations	UT Field Data Observations	UT Field Data Observations

THE UNIVERSITY OF TOLEDO

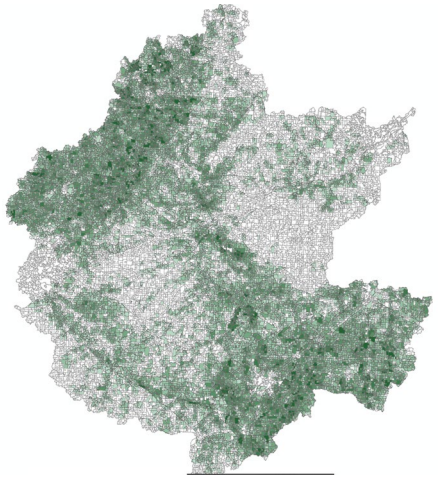
Layer Examples



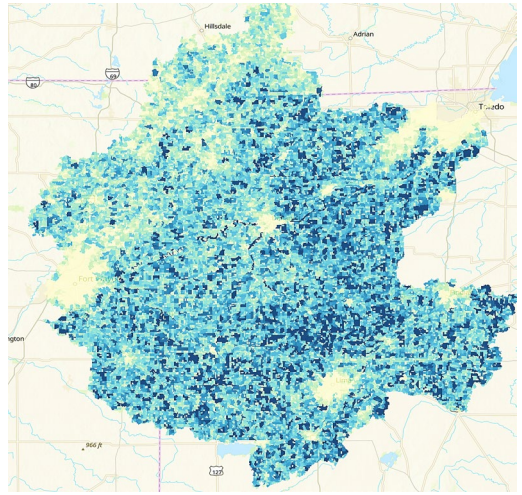
Conventional Till



Cover Crops



Filter Strips



Traditional Crop Rotation C-S-W

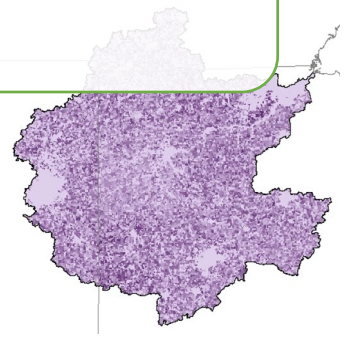
Improvements in fertilizer application and management

Crop Rotations

- Based on remote sensing data
- Corn, Soybean, Winter Wheat, alfalfa rotations

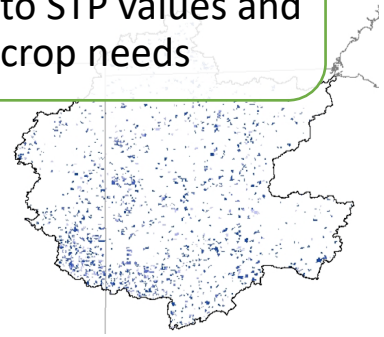
Soil Test Phosphorus

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



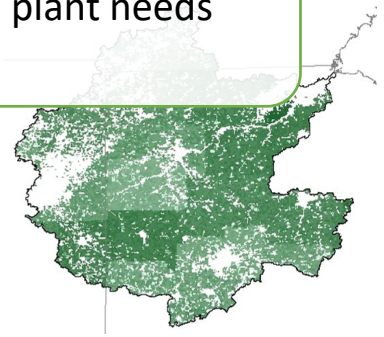
Manure

- Locations of permitted and unpermitted facilities (EWG, 2022)
- Kast et al 2020 allocations
- Applied according to STP values and crop needs



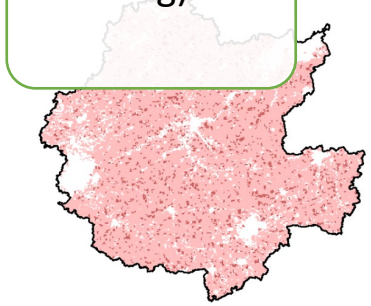
Inorganic Fertilizer

- 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

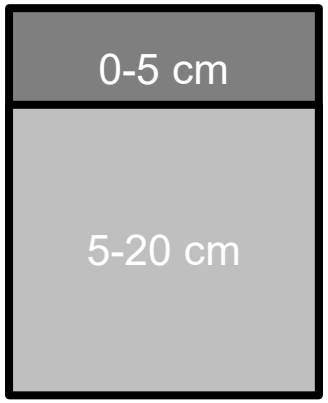
- Subsurface application
- Tillage practices (remote sensing)
- Cover crops (remote sensing)

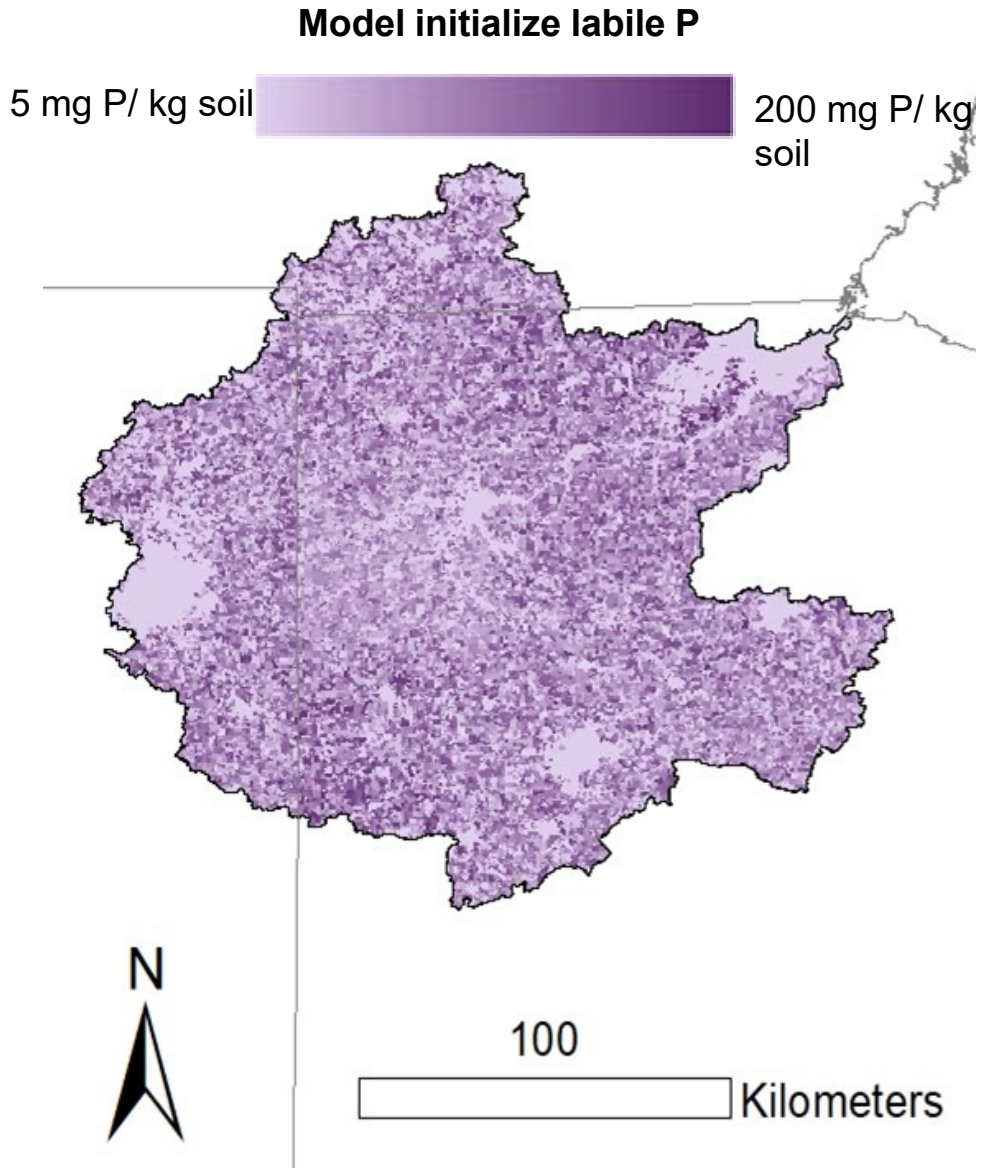


Soil Test Phosphorus

- STP values are represented through the SOL_SOLP parameter → Soil labile P (mg/kg)
- Soil labile P values were applied based on a county-by-county distribution of STP data in the region (Dayton et al., 2020)
- Soil stratification was implemented based on Baker et al (2017) stratification results from the Sandusky River Basin to model impacts of tillage reduction and increased stratification

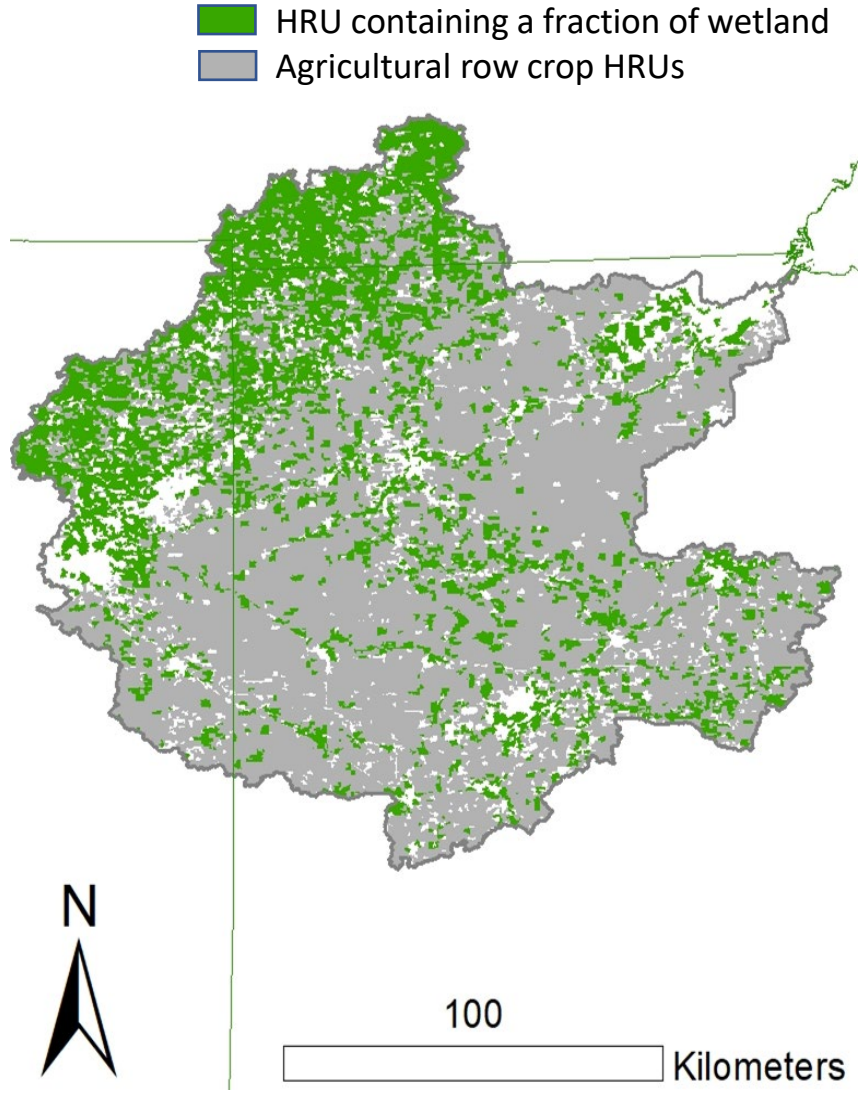
	Agricultural HRUs	
	Labile P	Mehlich-3
0-5 cm (0-1.9 in)	31.02	62.49
5-20 cm (1.9-7.8 in)	18.38	32.01
Soil Column Average	*21.54*	*39.63*





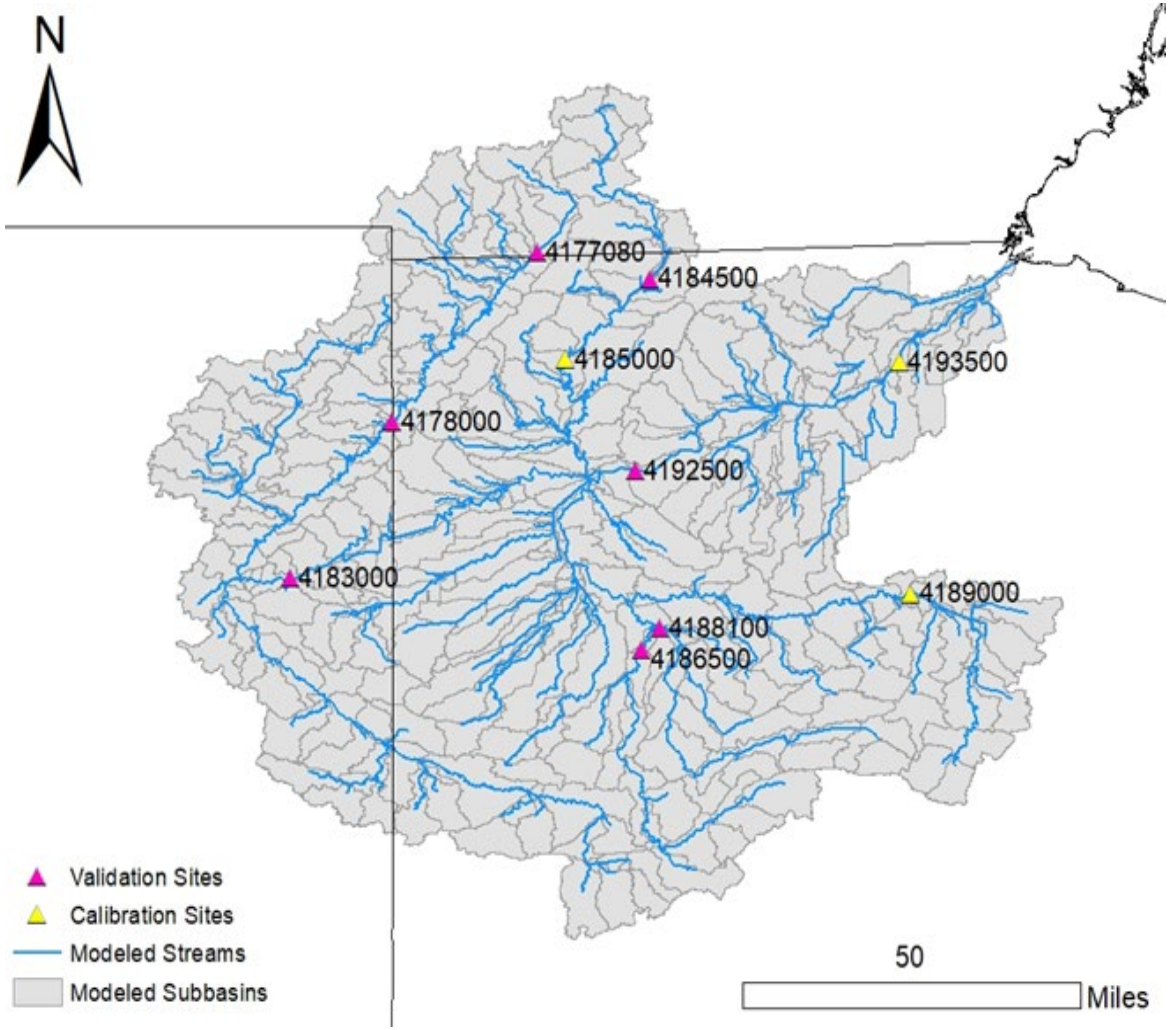
Wetlands

- Non-floodplain wetlands represented through modified pothole representation (Evenson et al., 2023):
  - SWAT 2012 rev 659
  - Modified pothole representation to mirror wetland impacts on all nutrient forms, not only nitrate and DRP
  - Added the capability of tile effluent to routed through an HRU wetland
- Wetland placement using National Wetland Inventory Data
- Wetland parameterization
  - N and P removal efficiencies based on regional literature review of wetland effectiveness



Calibration and Validation

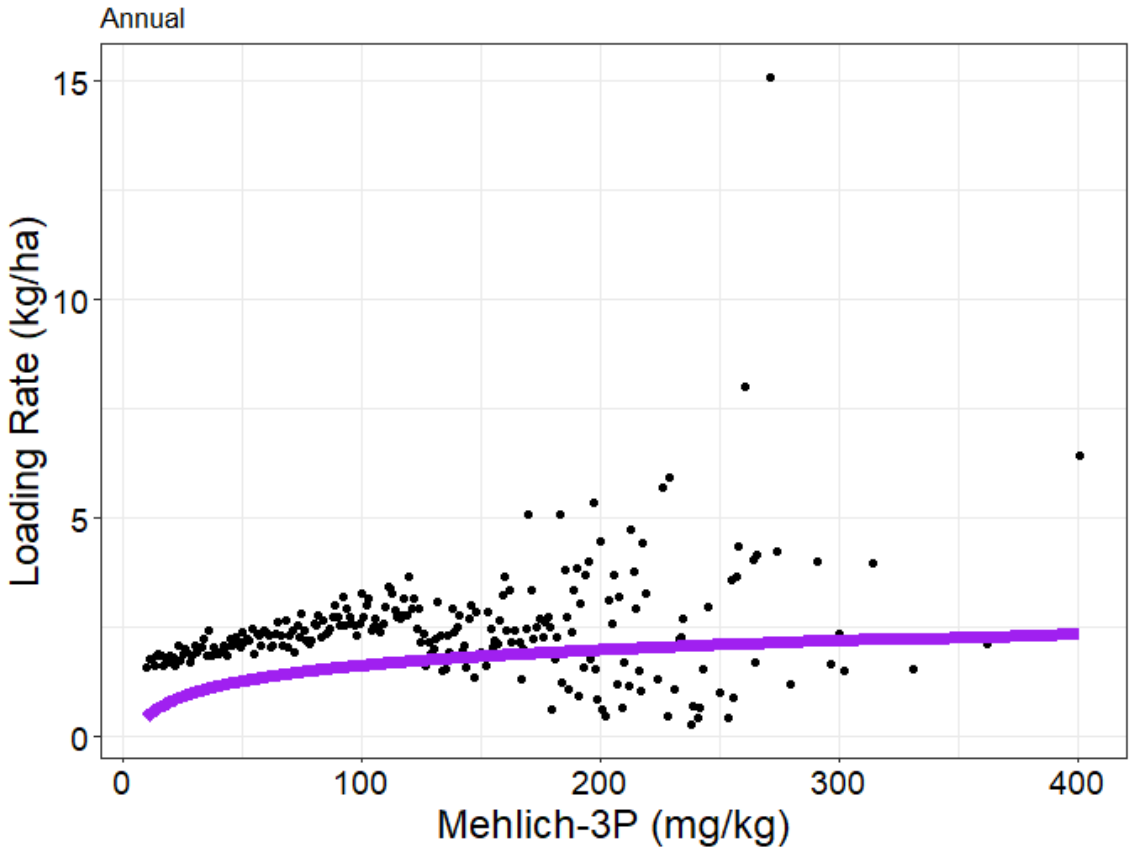
- Instream calibration and validation sites:
  - Yellow calibration sites were used for calibration (2007-2021) and back validation (2002-2006).
  - Pink validation sites were only used for validation (2007-2021).
- Field-level validation:
  - USDA-ARS Soil Drainage Research Unit (Williams et al., 2016)
  - OSU edge-of-field monitoring networks (Brooker et al., 2021)



Calibration/Validation Results

- *Watershed outlet*: Very good performance
- *Other calibration gages:* Good performance for discharge, mixed nutrient performance
- *Validation stream gages*: Good performance for Discharge and DRP, mixed TP performance
- *Edge-of-field*: Reasonable predictions (significant correlation relationship, tendency to over-predict)

Field level loading results per soil test values



Scenario Development

- Stakeholder led scenario development
- Scenarios developed with guidance from Ohio agency personnel to evaluate individual practices and mitigation program implementation
- Reviewed by the Maumee Watershed Modeling Stakeholder Advisory group

Sensitivity Scenarios: Implementation

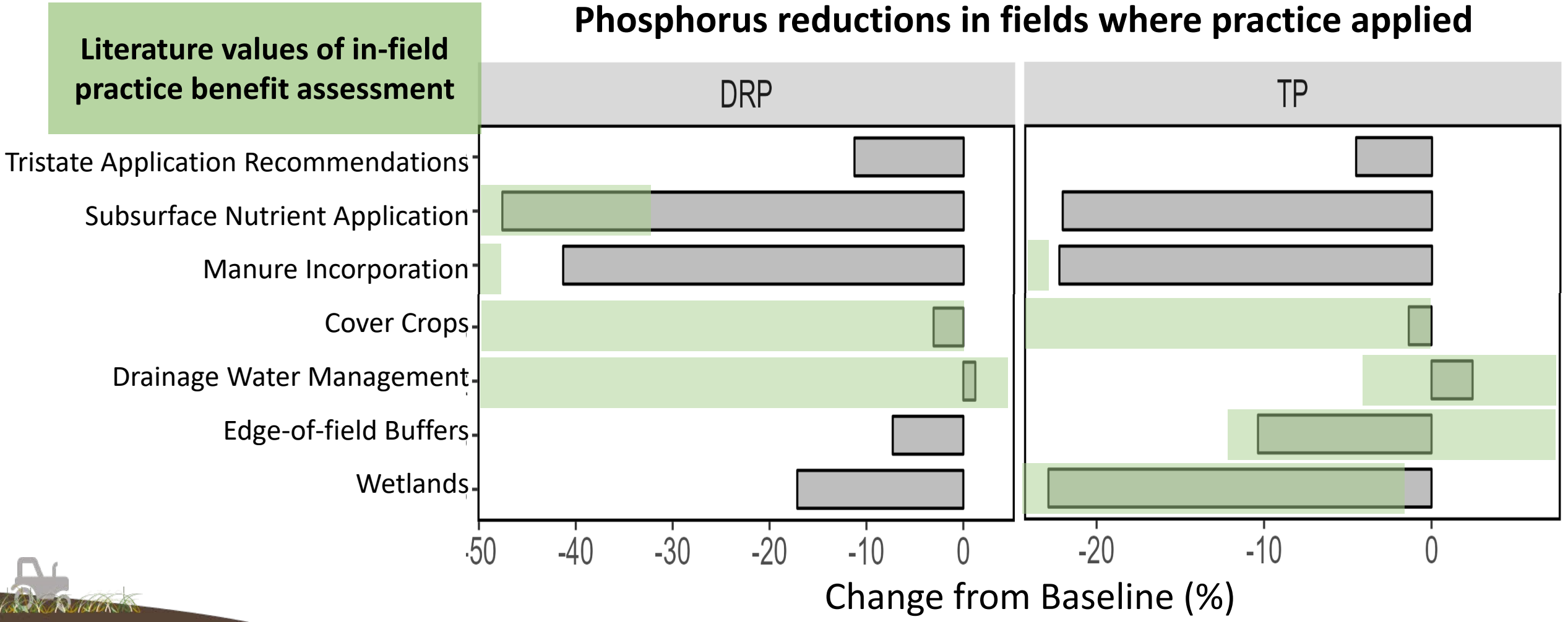
Management Practice	Implementation	% of all row crop acres in model	
		Baseline	Scenario
*Tri-state Recommended Application Rates**	N and P rates modified to follow application guidance based on soiling testing	50%	100%
Subsurface Nutrient Application	Broadcast fields targeted and modified to receive subsurface inorganic nutrient application	10%	23%
Manure Incorporation	Liquid manure immediately incorporated after application	12%	18%
Cover Crops	Winter rye planted over winter following a corn or soybean harvest	10%	30%
*Drainage Water Management***	Depth to tile drain modified throughout year following management guidance	1%	9%
*Edge-of-field Buffers***	EOF buffers added at varying efficiencies	35%	49%
*Wetlands***	Wetlands implemented on tile drained fields with the guidance of 1.5% of field being removed from production and 25% of tile effluent would be routed through wetland	20%	30%

**Resulted in 5% reduction in P fertilizer across watershed, 10% on changed fields*

***Percentage of acres impacted by practice*

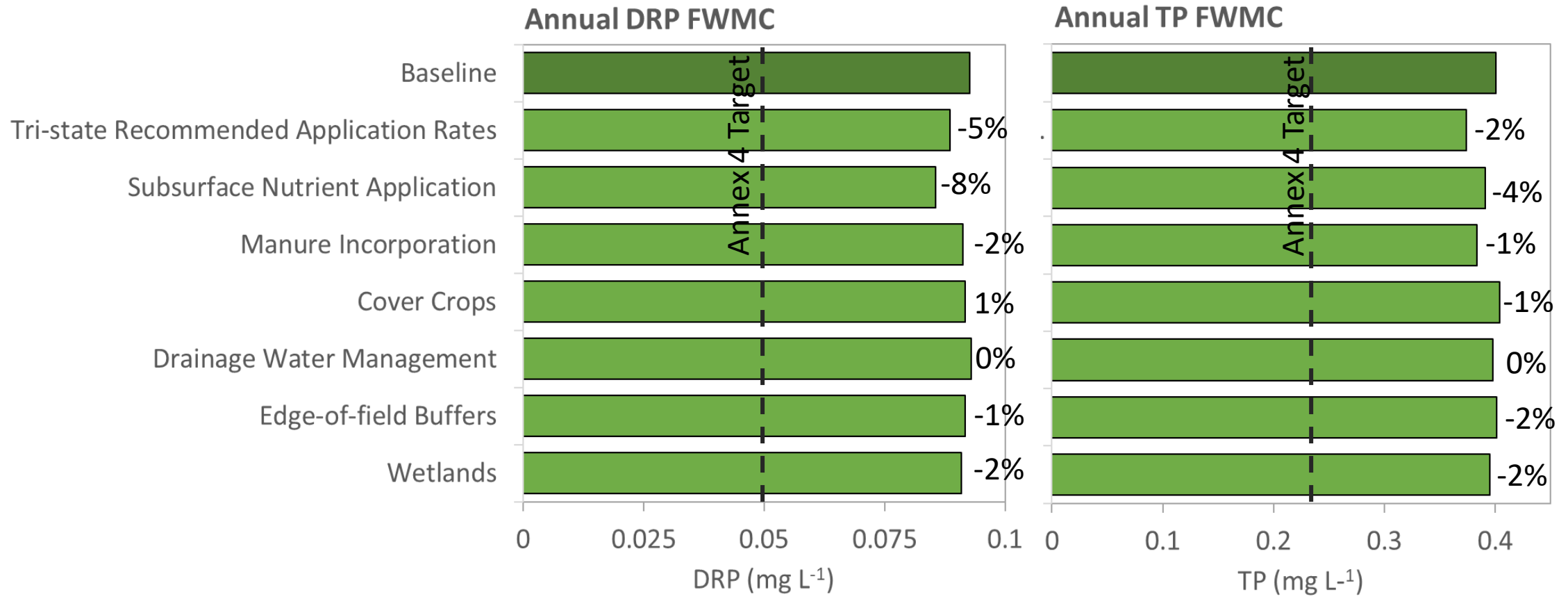
Sensitivity Scenarios: Field-level Results

Literature values of in-field practice benefit assessment



Sensitivity Scenarios: Watershed Results

Outlet Flow Weighted Mean Concentration. Numbers to the right of the bars are the percent change from baseline rounded to the nearest whole number.



% of all row crop acres	
Base.	Scen.
50%	100%
10%	23%
12%	18%
10%	30%
1%	9%
35%	49%
20%	30%

Bundled Scenarios: Implementation

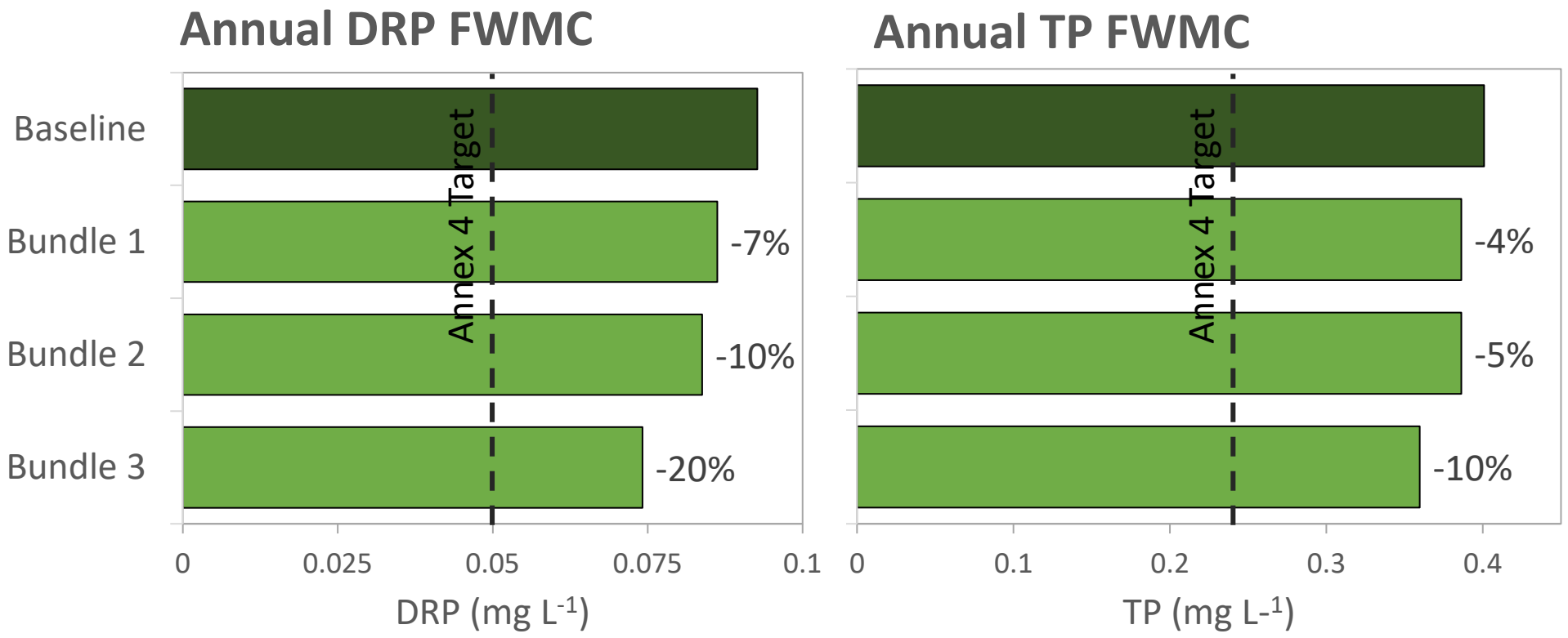
Bundled practice scenarios

Management Practice	Baseline	Bundle 1	Bundle 2	Bundle 3
Tri-state Recommended Application Rates	50%	87%	100%	100%
Subsurface Nutrient Application	10%	16%	19%	36%
*Manure Incorporation**	12%	14%	15%	20%
Cover Crops	10%	17%	19%	39%
*Drainage Water Management***	1%	2%	3%	4%

% acres impacted above baseline	-	53%	73%	116%***

**Manure percentages calculated as a percent of manure fields*
***Drainage water management implemented as a number of structures*
****Values over 100% possible because of stacked practices*

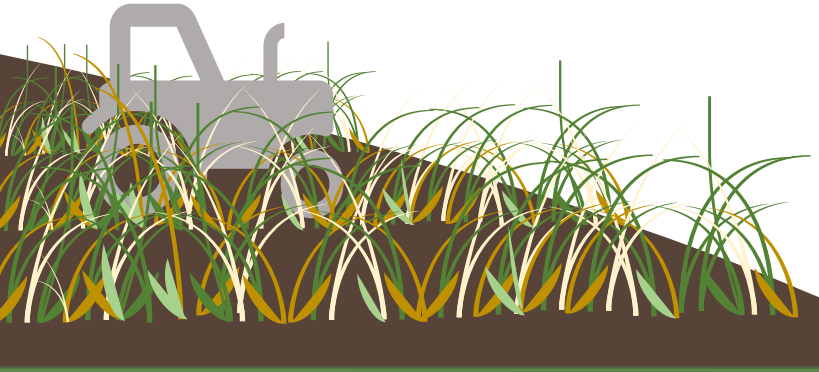
Bundle Scenarios: Watershed Results



% acres impacted above baseline
-
53%
73%
116%

Key Messages

- Models like SWAT are a critical tool in the evaluation and adaptive guidance of programs targeting land management improvements
- When guiding policy, effectively validating at the implementation scale is needed
- Guided stakeholder modeling helps assess true policy concerns while uncovering innovation needs within the model



Thank you for listening!

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Acknowledgements

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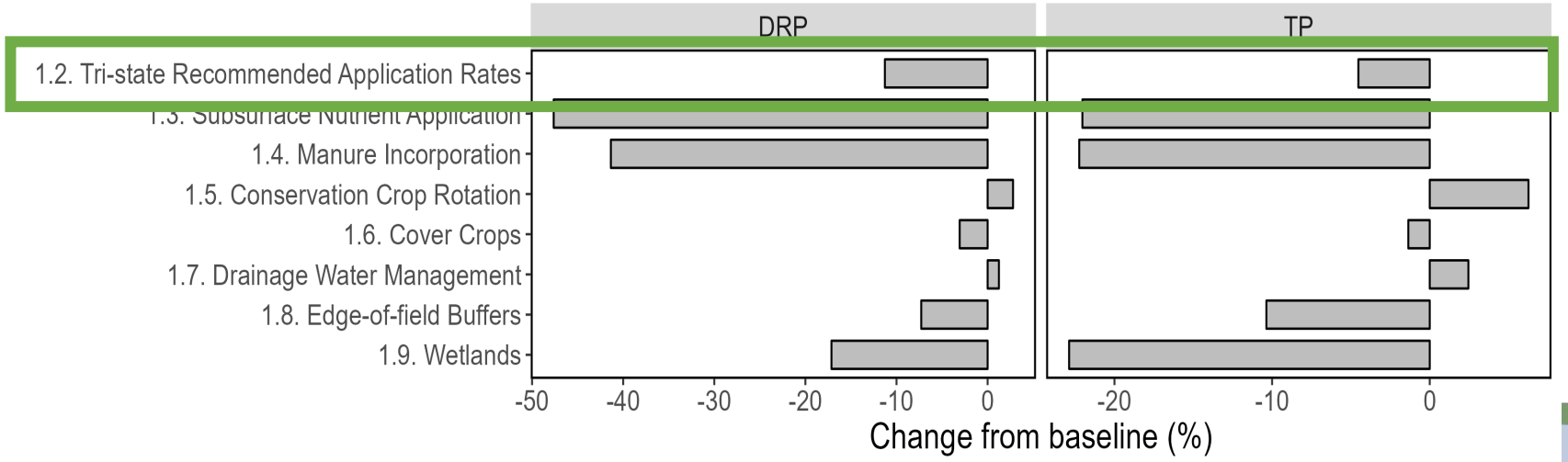
National Center for Water Quality Research
Heidelberg University

Scenario Results: Management Sensitivities

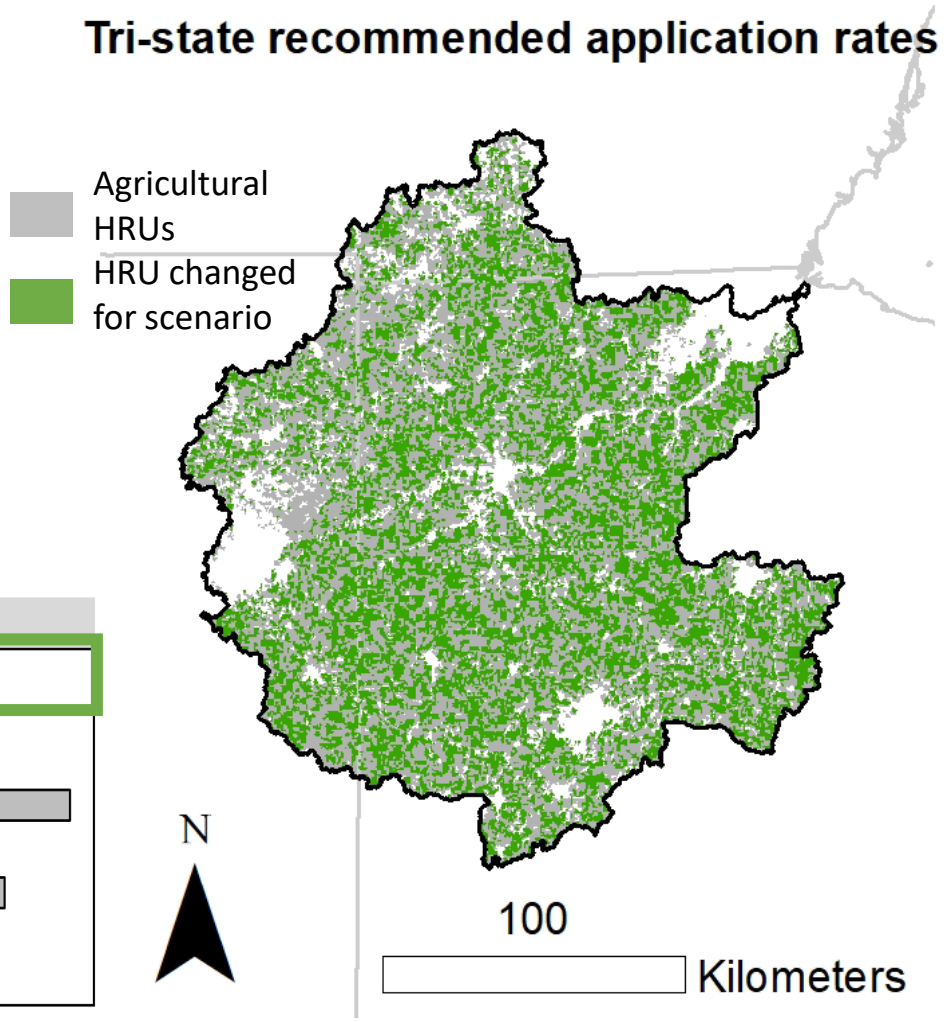
SCENARIO IMPLEMENTATION:

- Application rates of N and P fertilizer were modified to followed tri-state recommendations based on the fields soil test phosphorus value.
- *Baseline: 50%, Scenario Implementation rate: 100%*
  - *Resulted in 10% reduction in P fertilizer across watershed*
- *Maumee watershed DRP reduction: 5%, TP reduction: 2%*

Phosphorus reductions in fields where practice applied



Tri-state recommended application rates



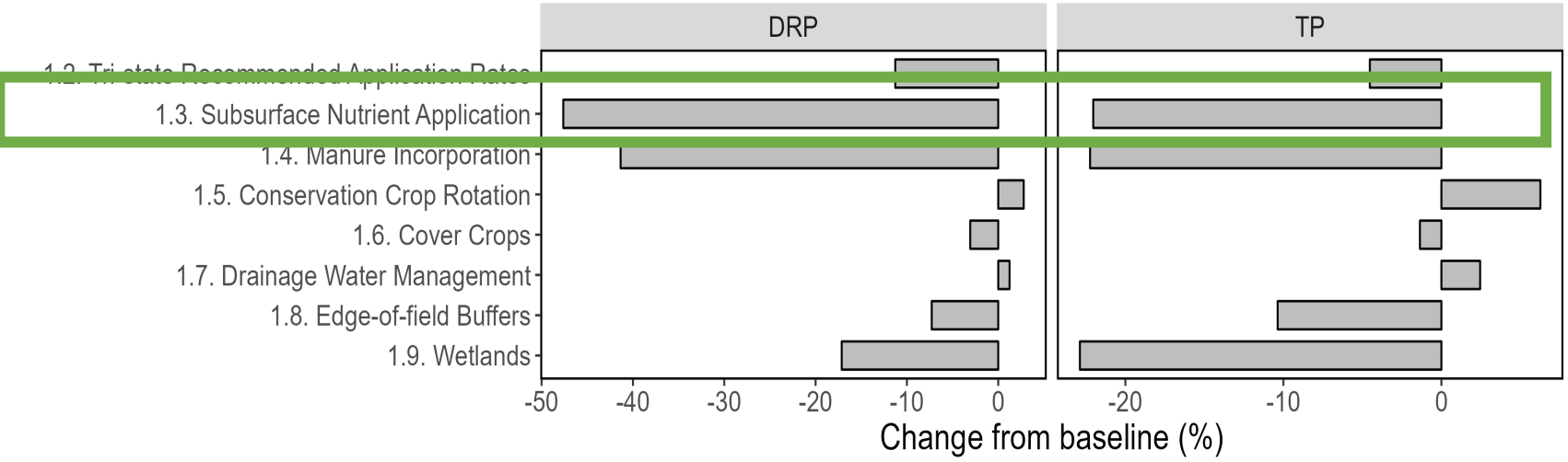
Scenario Results: Management Sensitivities

SCENARIO IMPLEMENTATION:

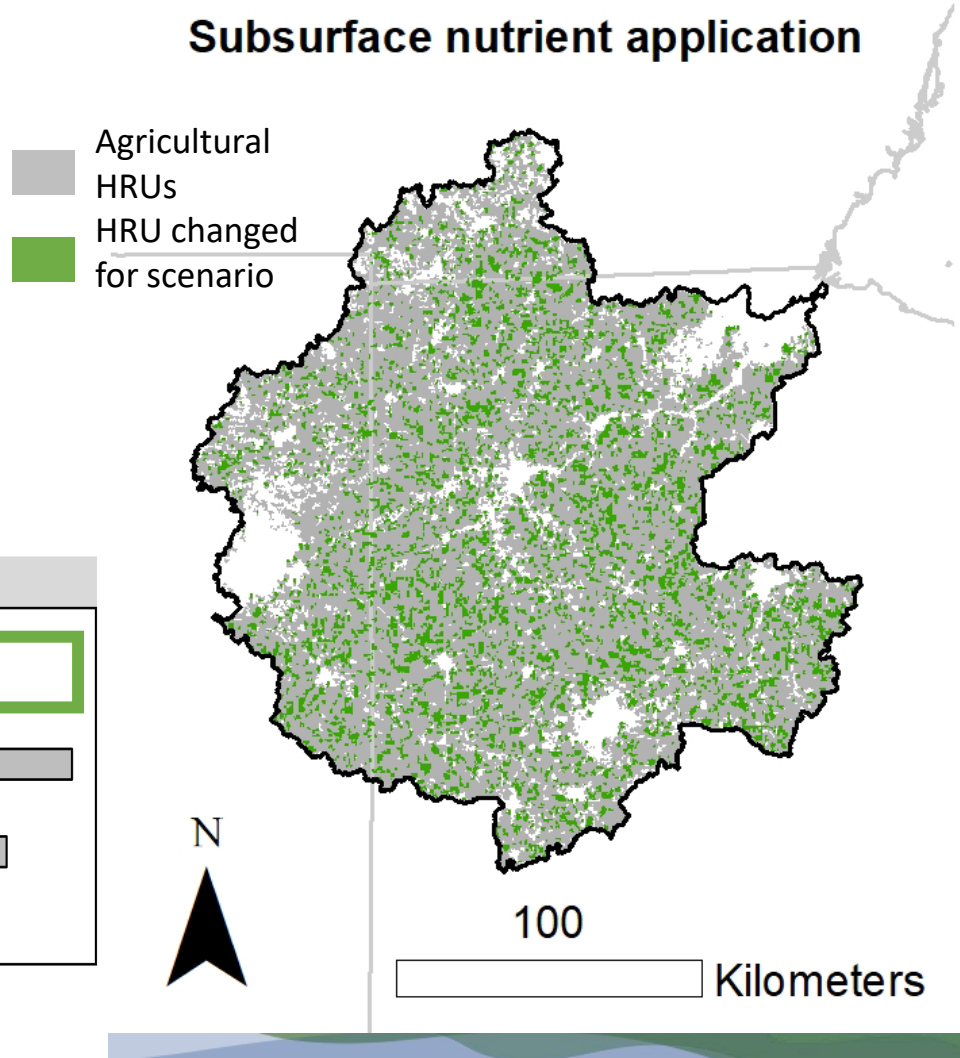
- Application of N and P was changed to subsurface application (default is broadcast or broadcast with tillage incorporation)

- *Baseline: 10%, Scenario Implementation rate*: 23%
- Maumee watershed DRP reduction: 8%, TP reduction: 2%

Phosphorus reductions in fields where practice applied



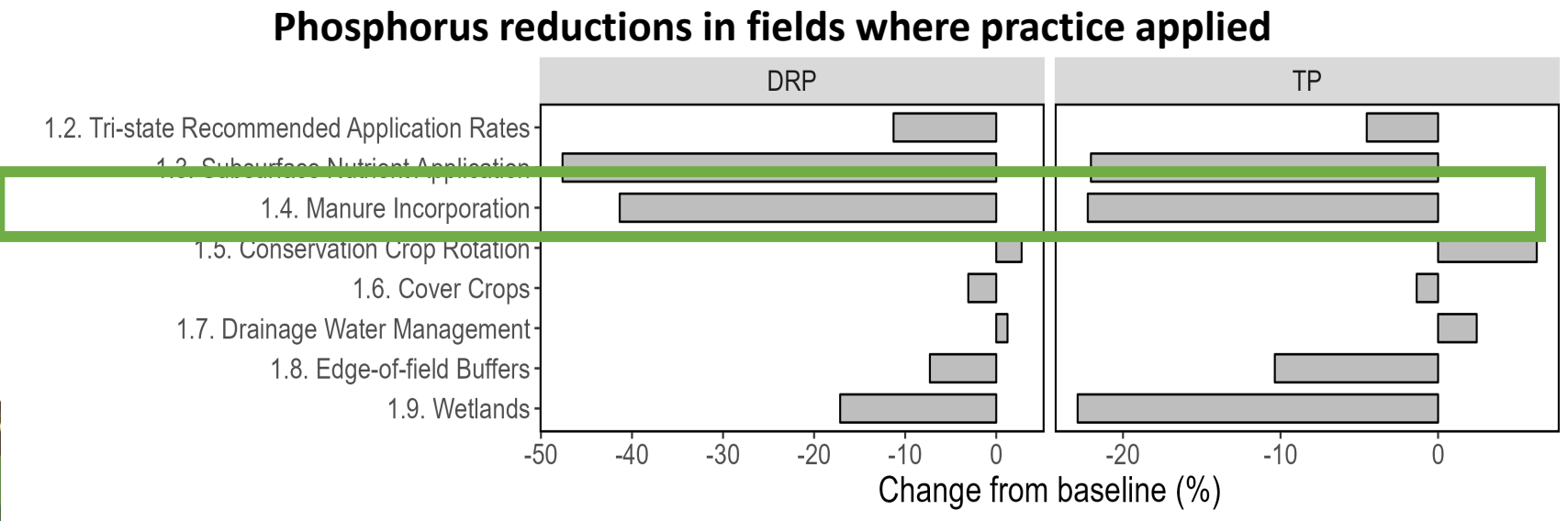
Subsurface nutrient application

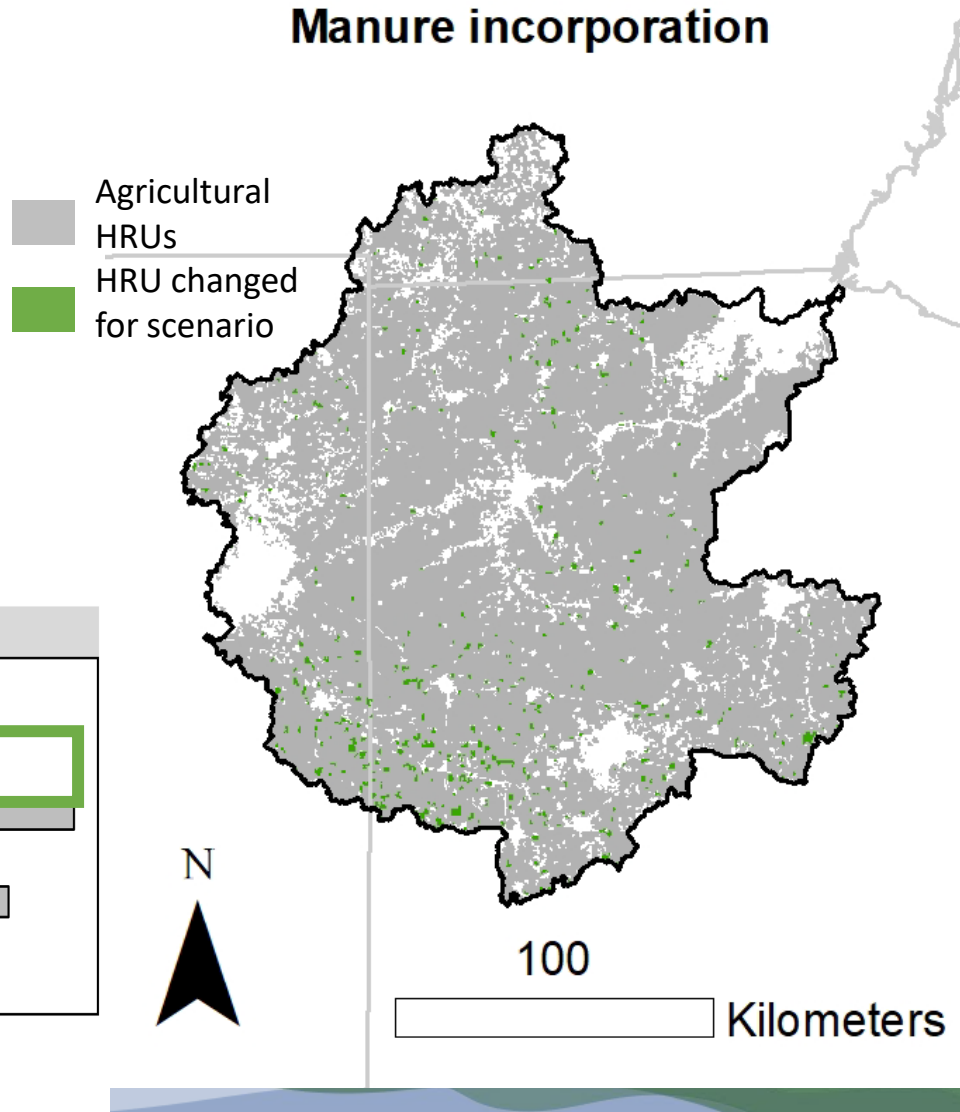


Scenario Results: Management Sensitivities

SCENARIO IMPLEMENTATION:

- Liquid manure was immediately incorporate when applied to a field.
- *Baseline: 60%, Scenario Implementation rate*: 70% (on manure only fields)
- Maumee watershed DRP reduction: 2%, TP reduction: 1%



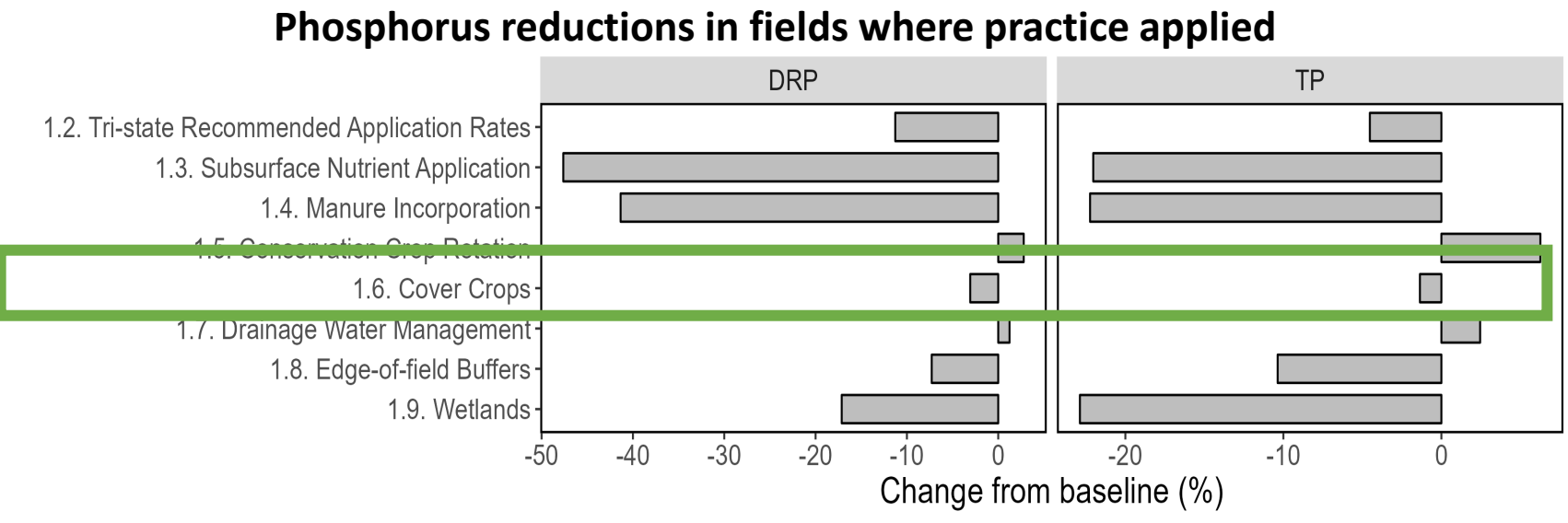


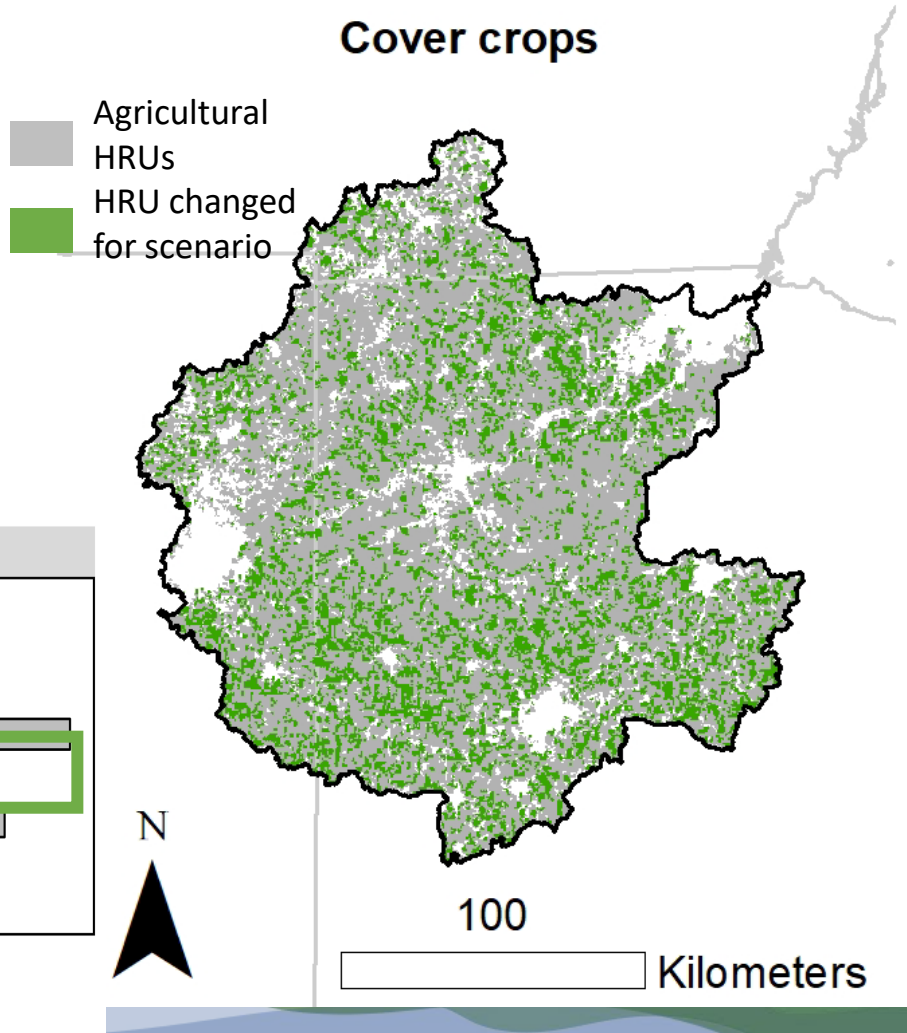
Scenario Results: Management Sensitivities

SCENARIO IMPLEMENTATION:

- Winter rye was planted over winter after a corn or soybean harvest. If alfalfa or winter wheat was already in the rotation, no cover crop was added that year.

- *Baseline: 10%, Scenario Implementation rate*: 30%
- Maumee watershed DRP reduction: 1%, TP reduction: 1%





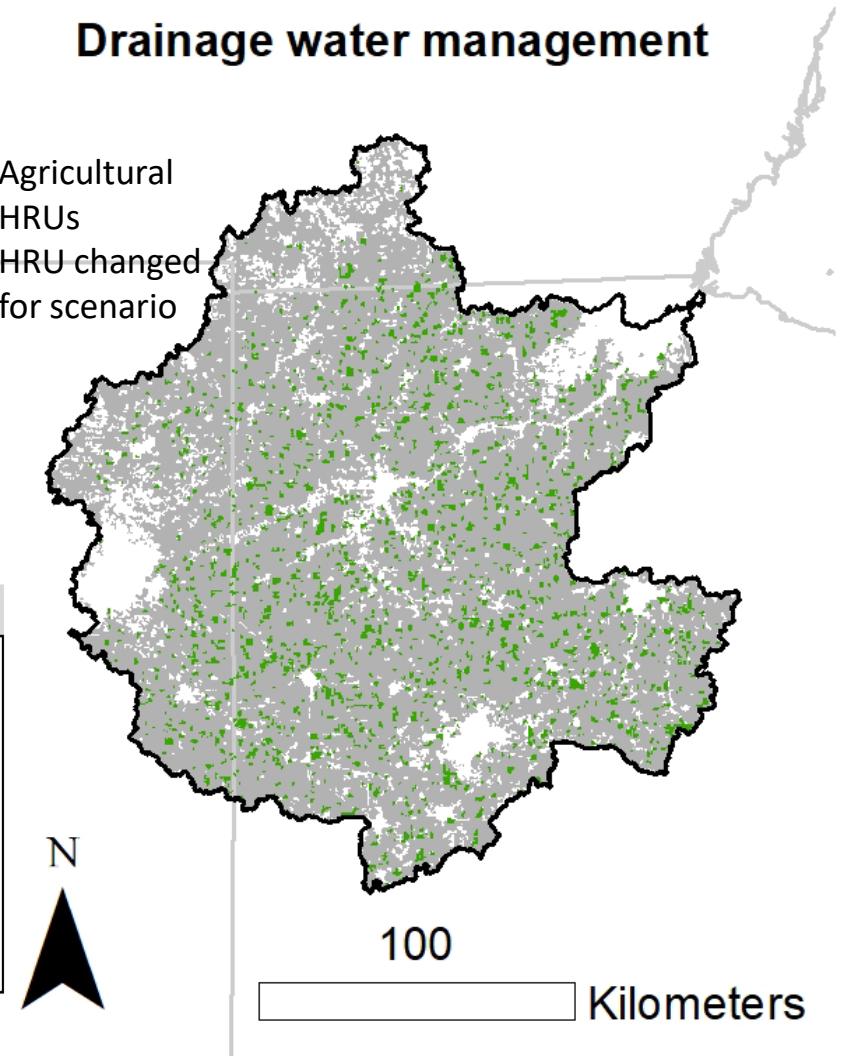
Scenario Results: Management Sensitivities

SCENARIO IMPLEMENTATION:

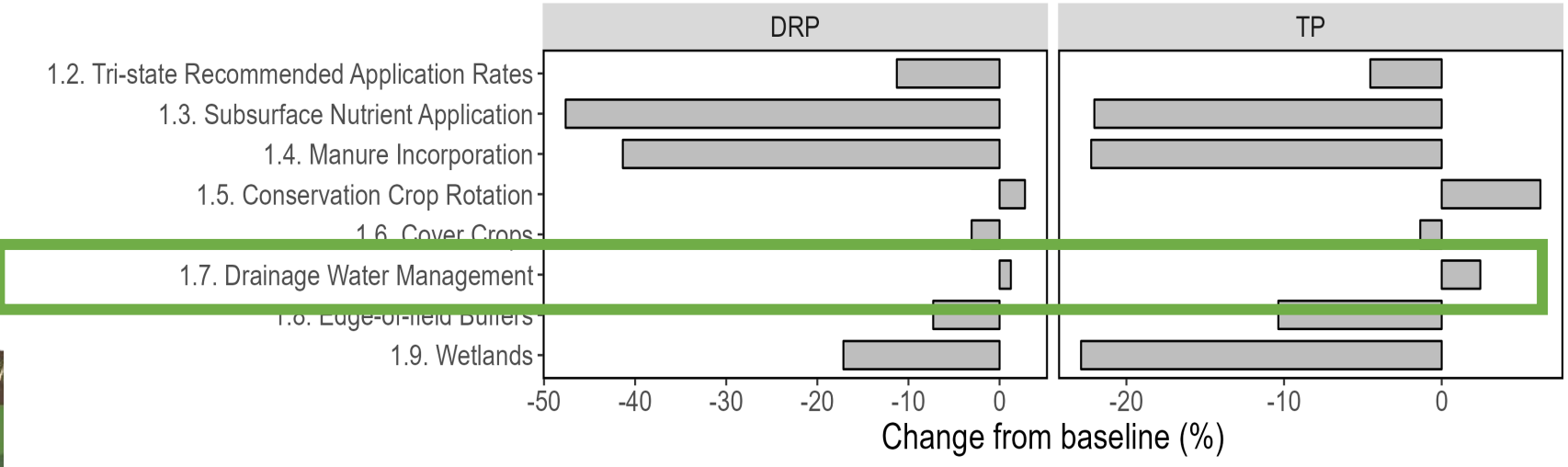
- Drainage water management was applied to tile drained fields.

- *Baseline: 215 structures, Scenario Implementation*: *1909 structures*
- *Maumee watershed DRP increase: <1%, TP increase: <1%*

Drainage water management



Phosphorus reductions in fields where practice applied

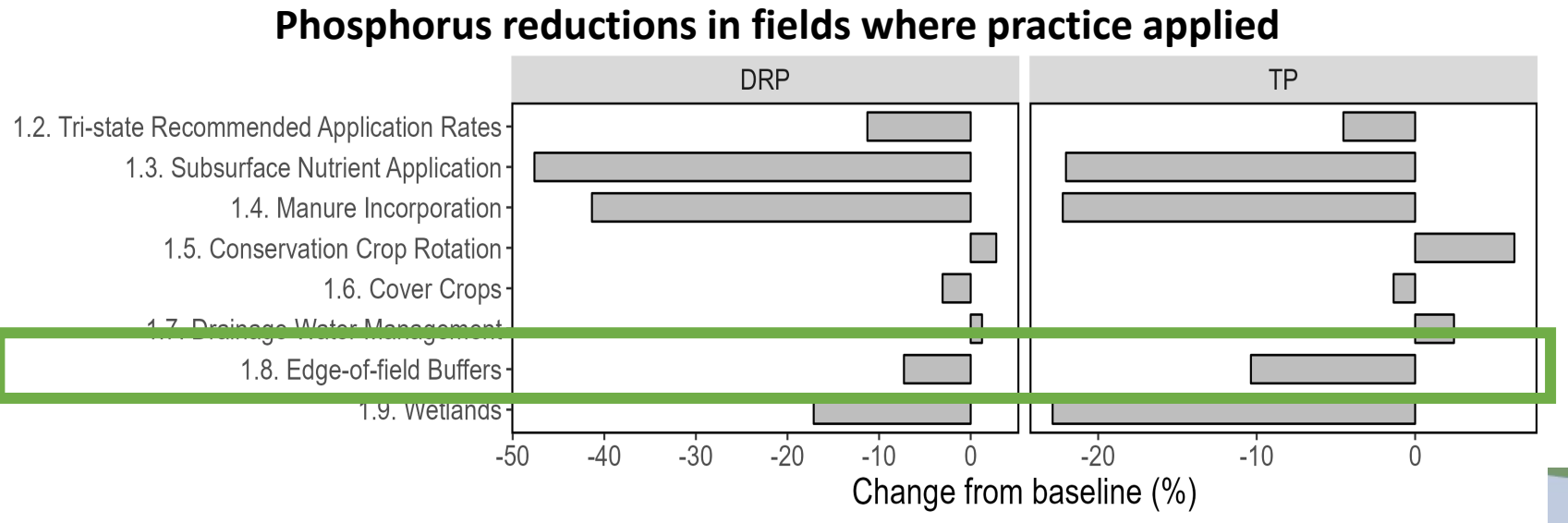


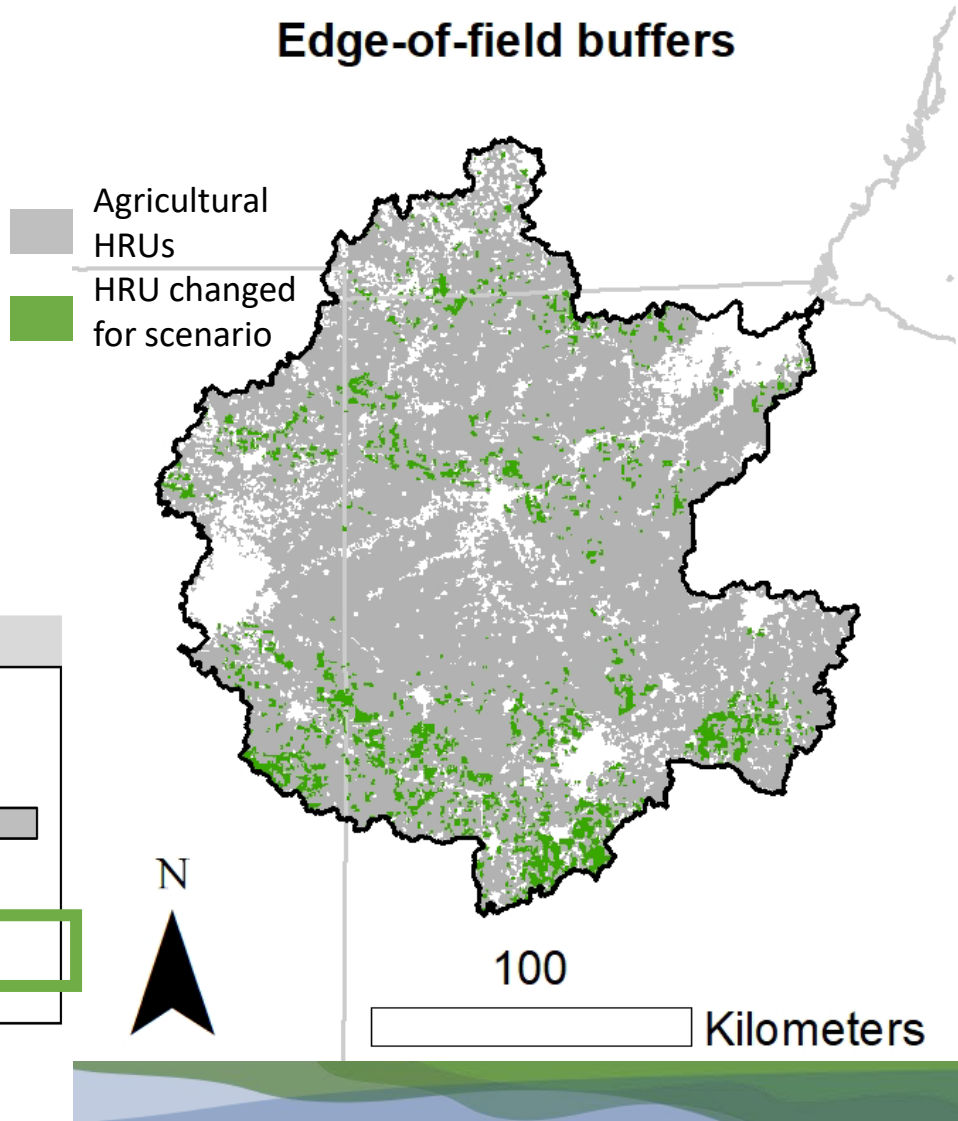
Scenario Results: Management Sensitivities

SCENARIO IMPLEMENTATION:

- Edge-of-field buffers of varying effectiveness were implemented across the watershed.

- *Baseline: 35%, Scenario Implementation rate*: 49%
- Maumee watershed DRP reduction: 1%; TP reduction:1%





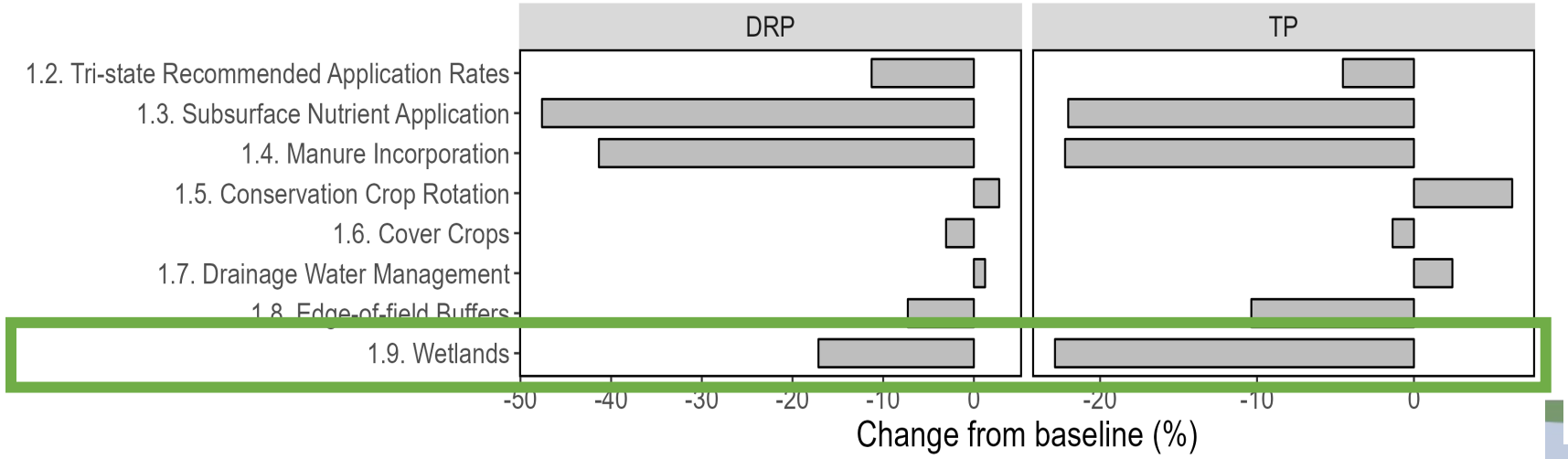
Scenario Results: Management Sensitivities

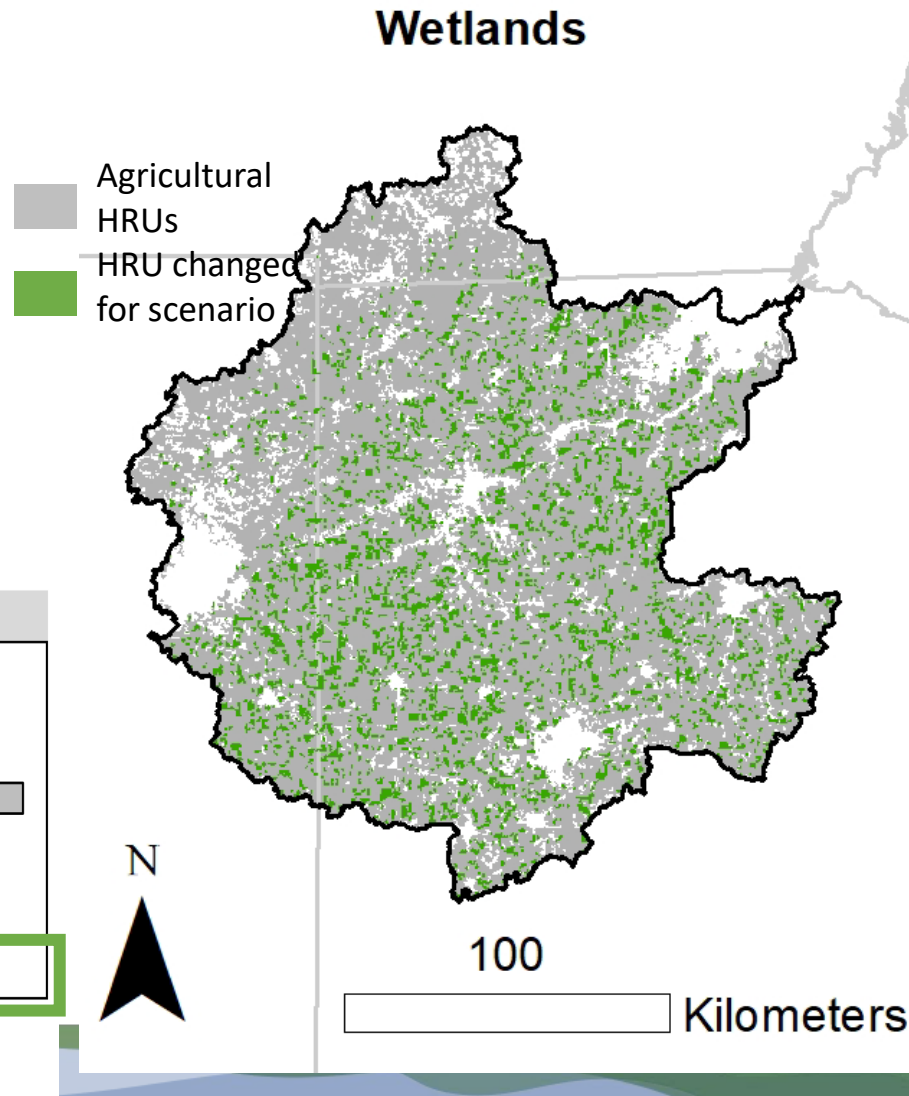
SCENARIO IMPLEMENTATION:

- Wetlands were implemented on tile drained fields with the specifications the 1.5% of the field would be taken out of production and 25% of the tile effluent would be routed through the wetland.

- *Baseline: 20%, Scenario Implementation rate*: 30%
- Maumee watershed DRP reduction: 2%; TP reduction: 2%

Phosphorus reductions in fields where practice applied





Conservation practice	DRP change	TP change	TN change	Surface runoff change	Subsurface discharge change
Cover crops (rye) (1–8)	Variable (-63% to No significant difference)	Variable (-68% to No significant difference)	Decrease (30% to 60%)	Variable (-46% to No significant difference)	No significant difference
Crop rotation (CSW) (9)	Increase	Increase	Decrease		
Drainage water management (10–13)	Variable (-56% to 65%)	Variable (-5% to 13%)	Decrease (9% to 45%)	Increase (50% to 407%)	Decrease (8% to 85%)
Edge-of-Field Buffers (17–21)		Decrease (12% to 100%)			
Subsurface fertilizer application (19–22)	Decrease (31% to 95%)				
Manure incorporation (20,23–28)	Decrease (63% to 98%)	Decrease (59% to 93%)			
Wetlands (18,29–34)		Decrease (2% to 100%)	Decrease (22% to 60%)		

Reference for BMP lit review

1.Dougherty BW, Pederson CH, Mallarino AP, Andersen DS, Soupir ML, Kanwar RS, et al. Midwestern cropping system effects on drainage water quality and crop yields. J Environ Qual. 2020 Jan;49(1):38–49.
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Daily outlet and upstream calibration results

Variable	Calibration Targets	SWAT Subbasin	USGS Site	R2	NSE	PBIAS	Simulated average (Observed average)	Simulated standard deviation (Observed standard deviation)
Discharge	R^2 >0.6	59	4193500 (Waterville)	0.71	0.7	10.1	171.76(191.03)	247.73(294.00)
	NSE > 0.5	91	4185000 (Tiffin)	0.67	0.66	7.3	10.67(11.50)	16.39(17.49)
	PBIAS <±15	208	4189000 (Blanchard)	0.61	0.56	26.2	7.69(10.42)	13.93(23.70)
Total Phosphorus	R^2 >0.4*	59	4193500 (Waterville)	0.61	0.57	-10.3	7275.27(6595.56)	14994.19(15342.89)
	NSE > 0.35*	91	4185000 (Tiffin)	0.59	-6.35	-250.5	865.55(246.97)	2041.65(634.16)
	PBIAS <±30	208	4189000 (Blanchard)	0.33	0.11	-43.6	582.30(405.53)	1406.14(1375.71)
Dissolved Reactive Phosphorus	R^2 >0.4*	59	4193500 (Waterville)	0.69	0.62	-17.1	1791.51(1529.40)	3164.53(2951.90)
	NSE > 0.35*	91	4185000 (Tiffin)	0.65	0.39	-30.3	85.87(65.91)	181.99(140.40)
	PBIAS <±30	208	4189000 (Blanchard)	0.39	0.32	46.7	68.72(128.89)	151.63(347.75)
Total Nitrogen	R^2 >0.3*	59	4193500 (Waterville)	0.52	0.45	29.4	73005.52(103353.34)	162713.52(175922.70)
	NSE > 0.35*	91	4185000 (Tiffin)	0.52	0.24	17.2	4027.31(4863.66)	10181.87(8157.55)
	PBIAS <±30	208	4189000 (Blanchard)	0.44	0.38	27.6	3858.01(5331.09)	10358.75(11903.39)
Sediment	R^2 >0.4*	59	4193500 (Waterville)	0.52	0.40	44.6	1345.93(2430.89)	3005.66(7079.28)
	NSE > 0.45*	91	4185000 (Tiffin)	0.51	0.03	88.4	8.18(70.41)	17.59(230.25)
	PBIAS <±20	208	4189000 (Blanchard)	0.29	0	93.8	6.90(110.94)	17.07(546.42)

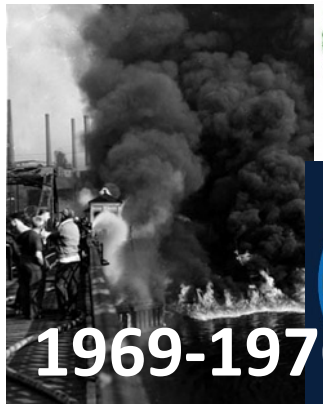
Daily upstream validation at calibration sites (2002-2006)

Variable	Targets	SWAT Subbasin	USGS Site	R^2	NSE	PBIAS
Discharge	R^2 >0.6 NSE > 0.5 PBIAS <±15	59	4193500 (Waterville)	0.66	0.65	19.37
		91	4185000 (Tiffin)	0.54	0.49	30.54
		208	4189000 (Blanchard)	0.28	0.26	28.21
Total Phosphorus	R^2 >0.4* NSE > 0.35* PBIAS <±30	59	4193500 (Waterville)	0.54	0.53	-18.41
		91	4185000 (Tiffin)	-	-	-
		208	4189000 (Blanchard)	-	-	-
Dissolved Reactive Phosphorus	R^2 >0.4* NSE > 0.35* PBIAS <±30	59	4193500 (Waterville)	0.57	0.56	-13.20
		91	4185000 (Tiffin)	-	-	-
		208	4189000 (Blanchard)	-	-	-
Total Nitrogen	R^2 >0.3* NSE > 0.35* PBIAS <±30	59	4193500 (Waterville)	0.53	0.47	-43.84
		91	4185000 (Tiffin)	-	-	-
		208	4189000 (Blanchard)	-	-	-
Sediment	R^2 >0.4* NSE > 0.45* PBIAS <±20	59	4193500 (Waterville)	0.47	0.29	-67.88
		91	4185000 (Tiffin)	-	-	-
		208	4189000 (Blanchard)	-	-	-

Daily upstream validation results – non-calibration gages (2007-2021)

Variable	Targets	Tributary	SWAT Subbasin	USGS Site	R^2	NSE	PBIAS	Simulated Mean (Observed Mean)	Simulated Standard Deviation (Observed Standard Deviation)
Discharge	R^2 >0.6 NSE > 0.5 PBIAS <±15	St Joseph	16	4177080	0.63	0.59	-5.03	2.57(2.44)	3.06(3.10)
		Tiffin	30	4184500	0.75	0.74	7.79	6.00(6.51)	6.92(9.03)
		St Joseph	122	4178000	0.59	0.54	35.32	13.48(20.84)	17.92(24.67)
		Maumee	141	4192500	0.75	0.75	11.24	148.39(167.19)	205.93(242.64)
		Maumee	257	4183000	0.72	0.70	14.82	51.35(60.28)	65.72(71.05)
		Auglaize/Blanchard	260	4188100	0.70	0.70	3.97	11.95(12.44)	19.37(25.27)
		Auglaize/Blanchard	286	4186500	0.67	0.67	-2.57	11.27(10.99)	20.14(24.47)
Total Phosphorus	R^2 >0.4* NSE > 0.35* PBIAS <±30	St Joseph	16	4177080	0.38	-0.88	-158.45	143.36(55.47)	316.83(192.37)
		Tiffin	30	4184500	0.46	-0.60	-166.23	449.44(168.82)	947.86(595.22)
		St Joseph	122	4178000	0.56	-1.26	-71.20	822.08(480.18)	1882.55(867.32)
		Maumee	141	4192500	0.59	0.53	-9.63	6913.53(6306.11)	13592.41(13565.97)
		Maumee	257	4183000	0.56	0.13	-29.50	2687.71(2075.44)	4865.80(3509.59)
		Auglaize/Blanchard	260	4188100	0.30	0.16	-18.87	546.01(459.35)	1144.99(1258.47)
		Auglaize/Blanchard	286	4186500	0.33	-0.03	-66.57	746.57(448.20)	1703.51(1489.23)
Dissolved Reactive Phosphorus	R^2 >0.4* NSE > 0.35* PBIAS <±30	St Joseph	16	4177080	0.19	0.18	23.27	8.61(11.21)	17.52(51.14)
		Tiffin	30	4184500	0.65	0.62	9.88	25.04(27.79)	50.41(76.21)
		St Joseph	122	4178000	0.67	0.52	53.04	68.42(145.68)	134.23(273.02)
		Maumee	141	4192500	0.73	0.70	20.11	1369.66(1714.36)	2370.07(3249.25)
		Maumee	257	4183000	0.67	0.51	45.91	408.27(754.84)	653.15(1178.07)
		Auglaize/Blanchard	260	4188100	0.51	0.42	41.52	79.08(135.22)	148.34(204.37)
		Auglaize/Blanchard	286	4186500	0.51	0.45	28.39	88.09(123.02)	180.00(367.70)

A brief history of pollution and mitigation efforts in Lake Erie

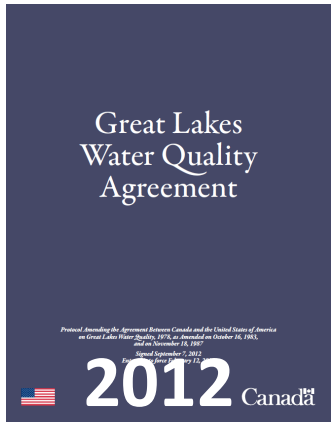


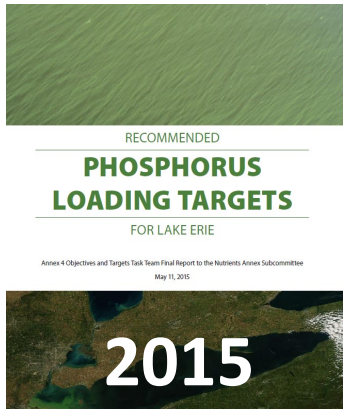
1969-1970

NEPA
NATIONAL ENVIRONMENTAL POLICY ACT

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

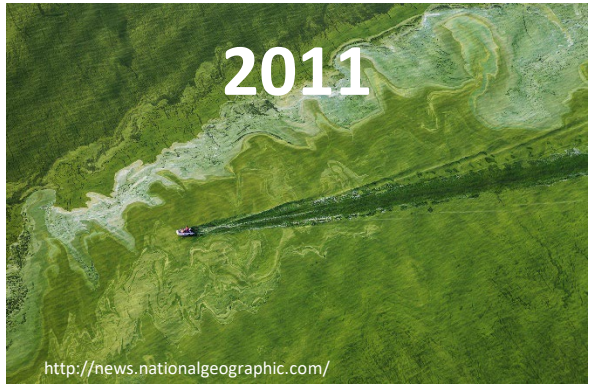
1986





1972-1978

GREAT LAKES WATER QUALITY AGREEMENT
UNITED STATES AND CANADA



The New York Times

Tap Water Ban for Toledo Residents