Watershed Modeling for the Upper Fox-Wolf Basins TMDL

Summer 2016 Update

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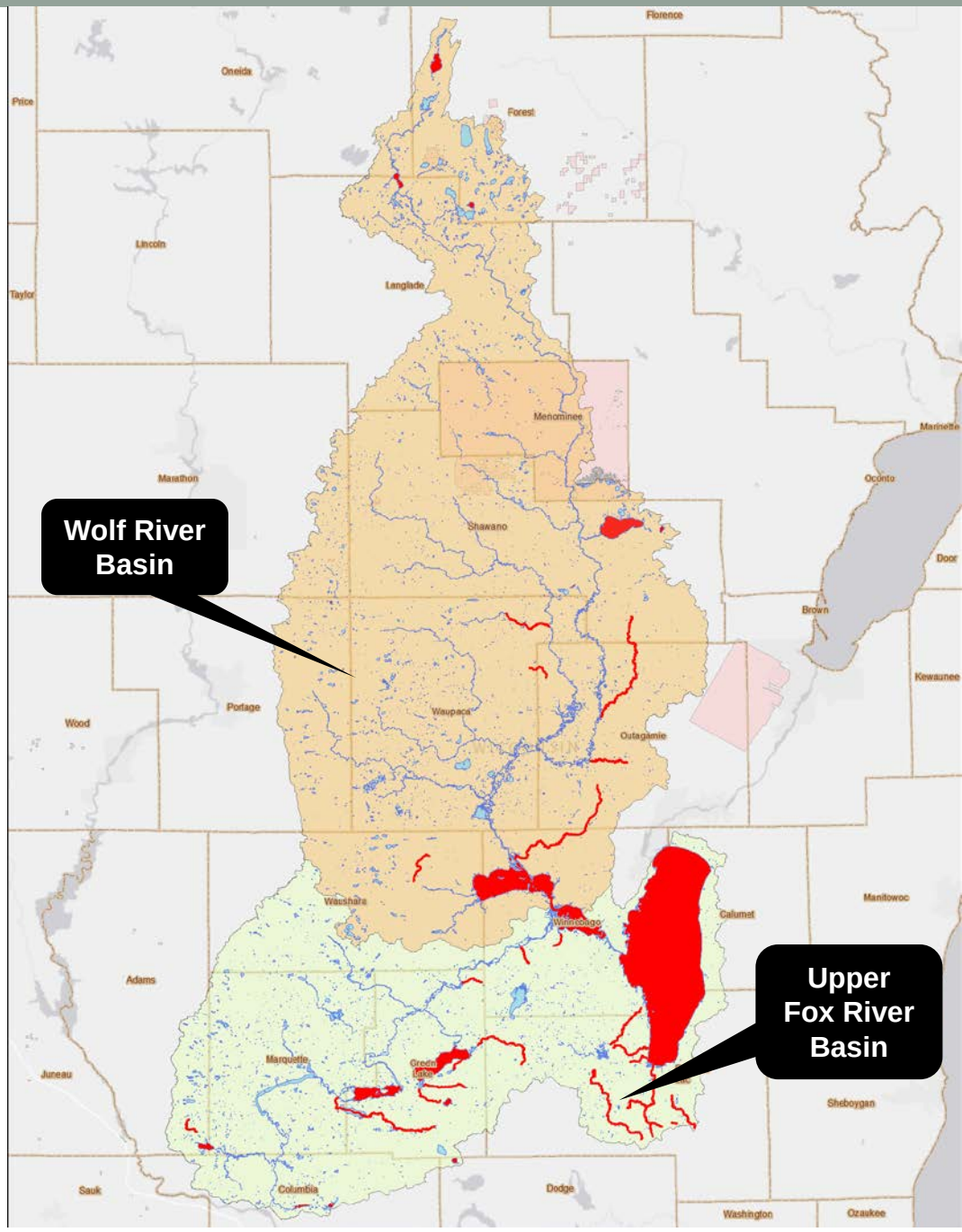
The Cadmus Group
UFWB TMDL Stakeholder Meeting
June 15, 2016

Agenda

1. SWAT Model Background & Setup
2. Review of SWAT Calibration & Validation Results
3. Summary of SWAT Phosphorus & Sediment Predictions

Upper Fox-Wolf Basins (UFWB)

- 5,900 square miles
  - Wolf River Basin = 3,700 square miles
  - Upper Fox River Basin = 2,200 square miles
- 18 Counties
- 5 Tribes
- 40% Farmland, 5% Urban
- 86 Point Sources
- 41 river/stream segments impaired due to phosphorus and/or sediment
- 24 lakes impaired due to phosphorus



Watershed Modeling Purpose & Objectives

1. Estimate average water flows, phosphorus loads, and sediment loads throughout the UFWB stream network.

2. Evaluate relative magnitude of phosphorus and sediment loading from nonpoint sources.

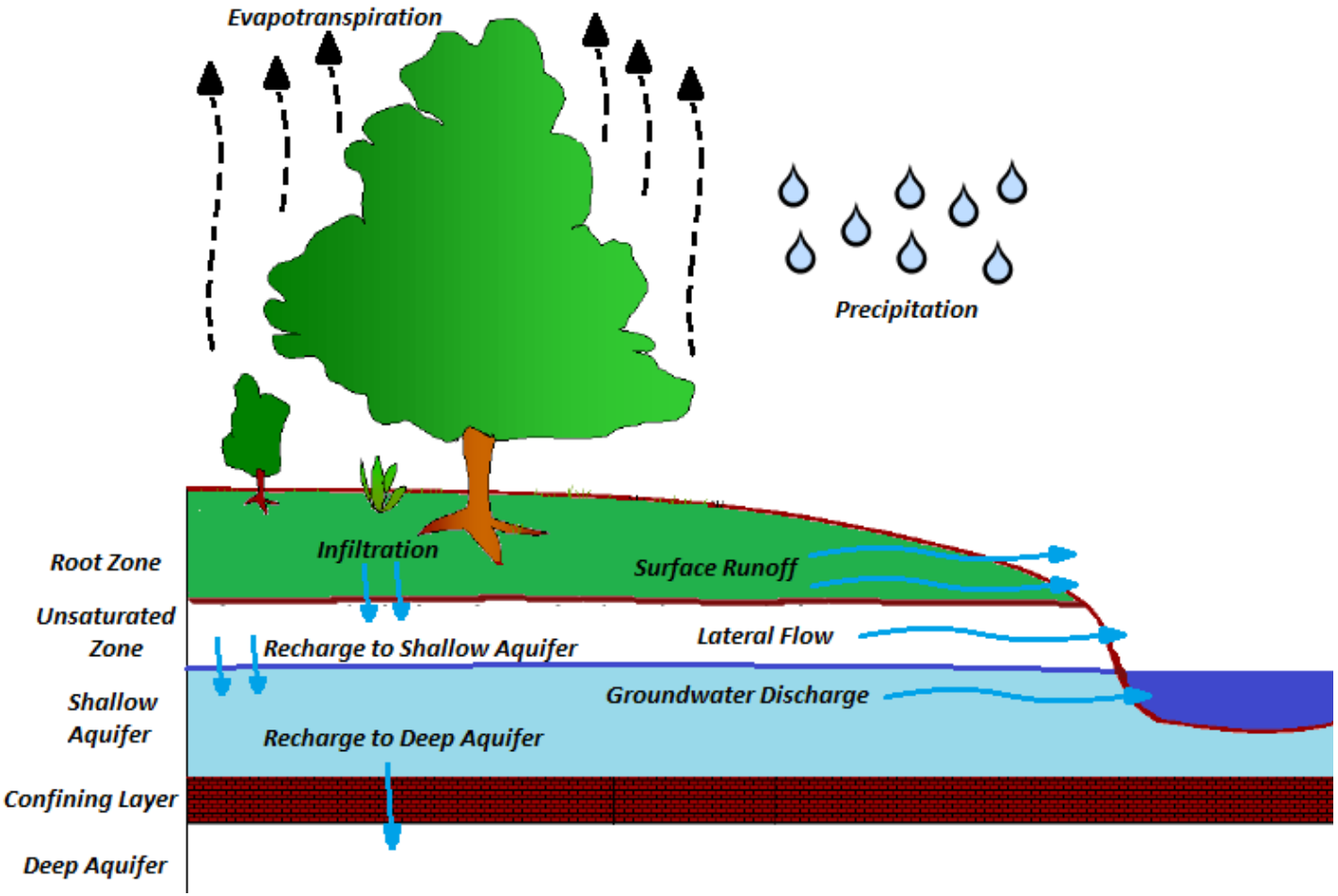
3. Output used for lake modeling and for TMDL allocation analysis.

SOIL & WATER ASSESSMENT TOOL

Soil and Water Assessment Tool (SWAT)

Process-Based

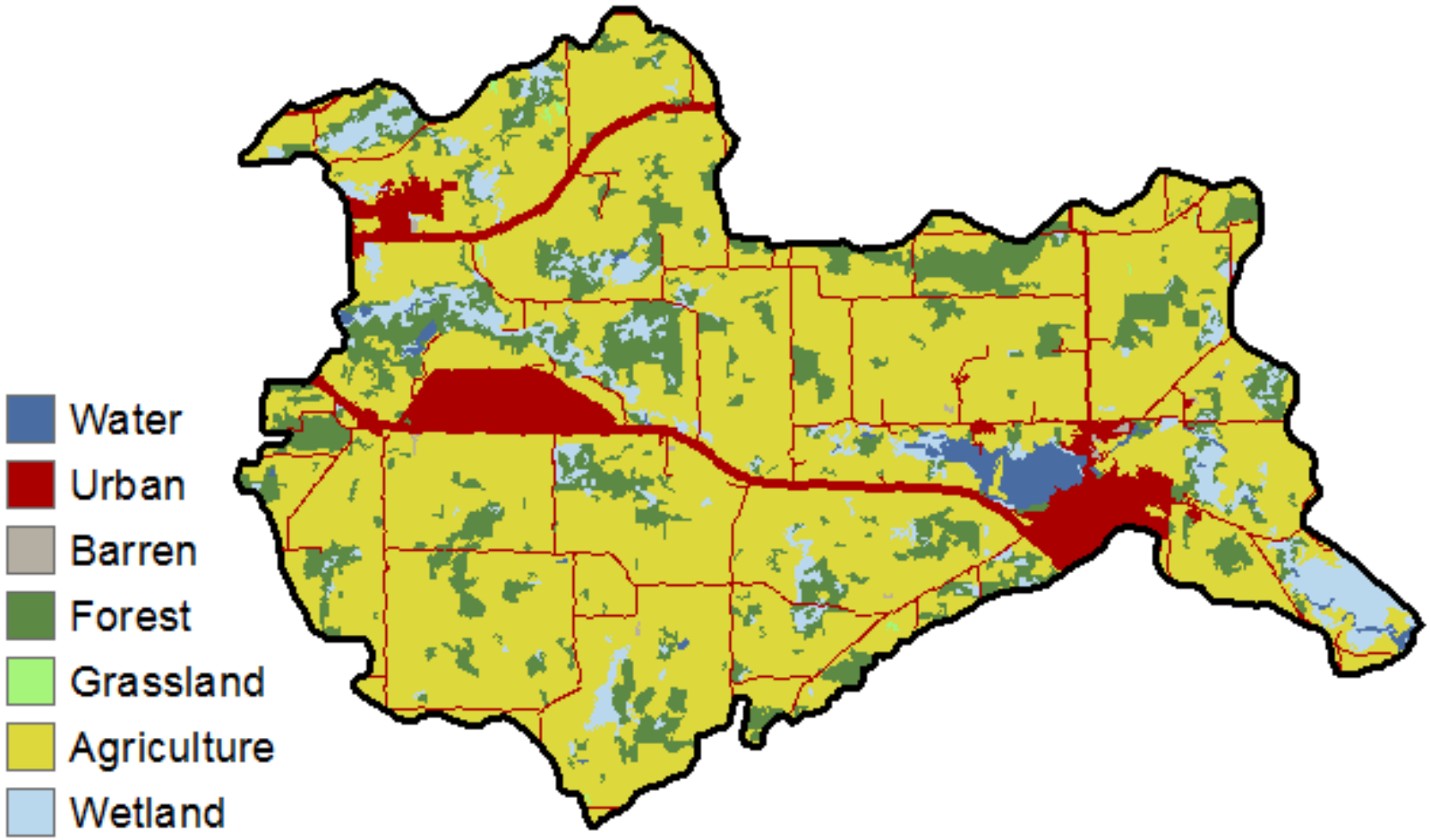
- Simulates hydrologic and water quality ***processes***: surface runoff, evapotranspiration, erosion, groundwater discharge, etc.



Soil and Water Assessment Tool (SWAT)

Spatially-distributed

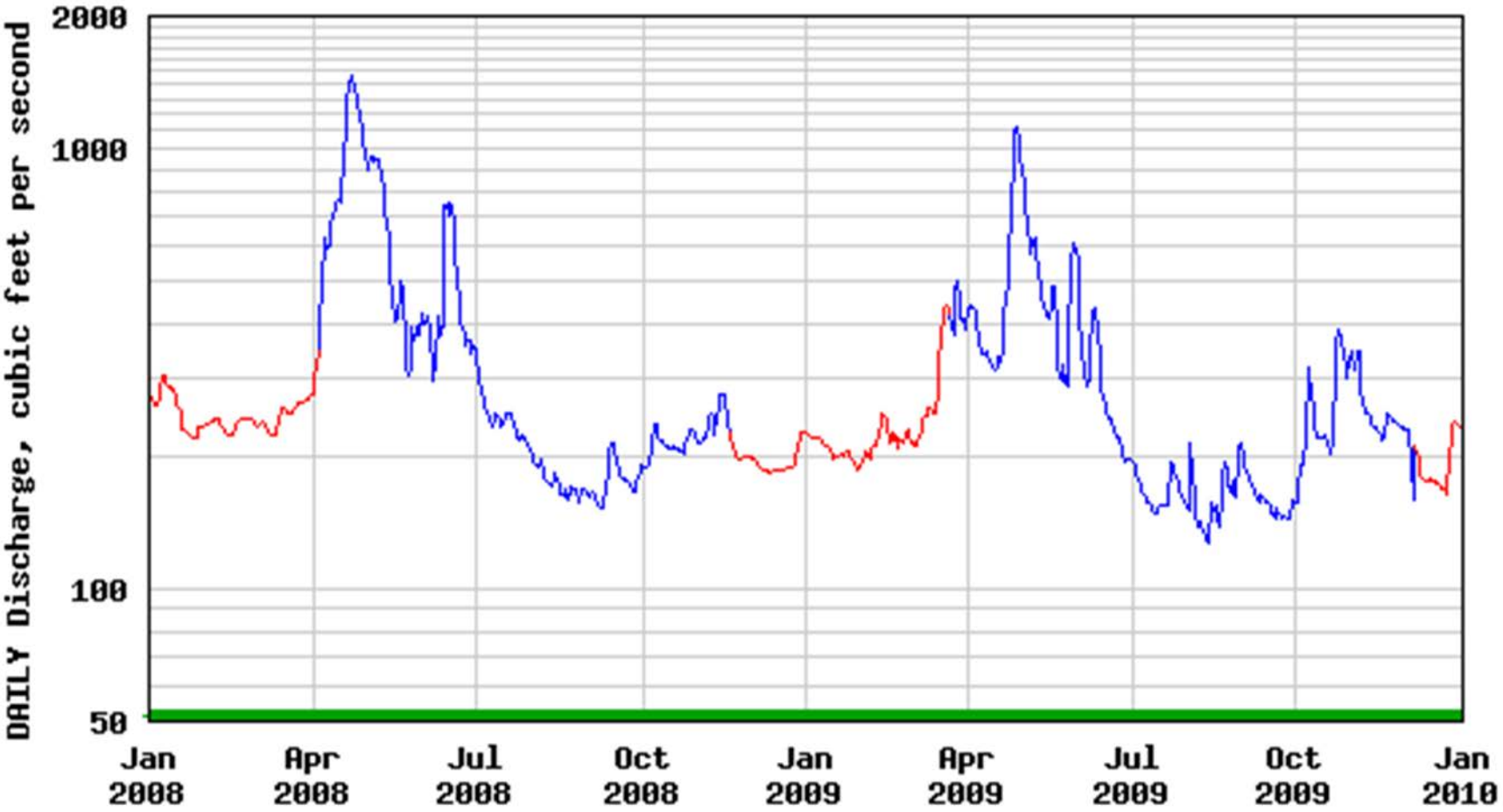
- Parameters affecting runoff and water quality can vary throughout the modeled watershed.



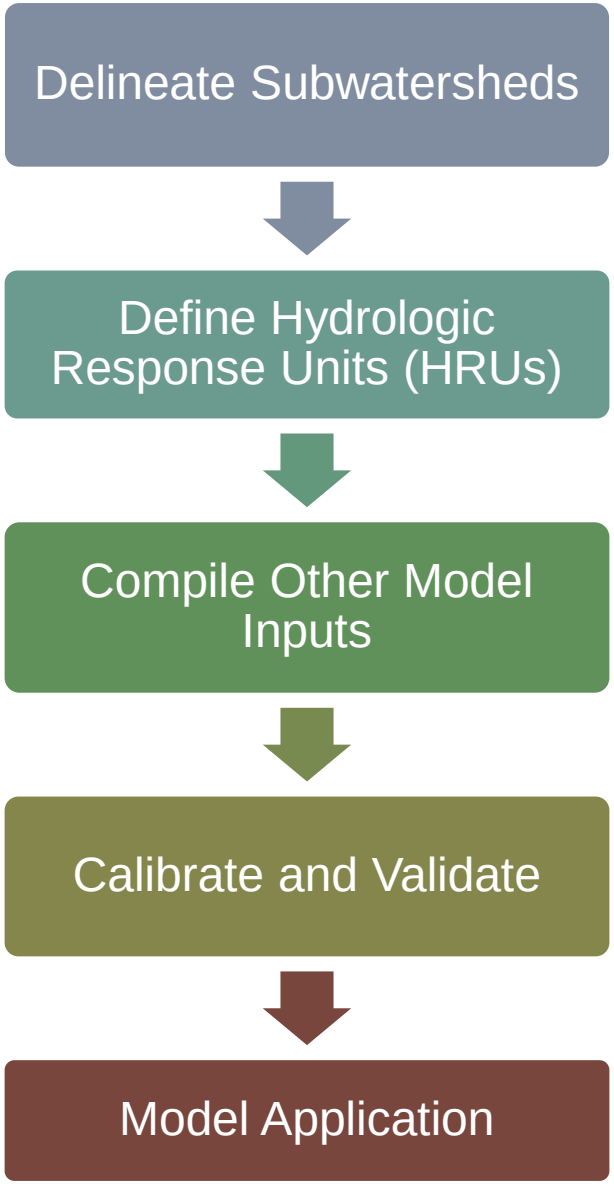
Soil and Water Assessment Tool (SWAT)

Continuous

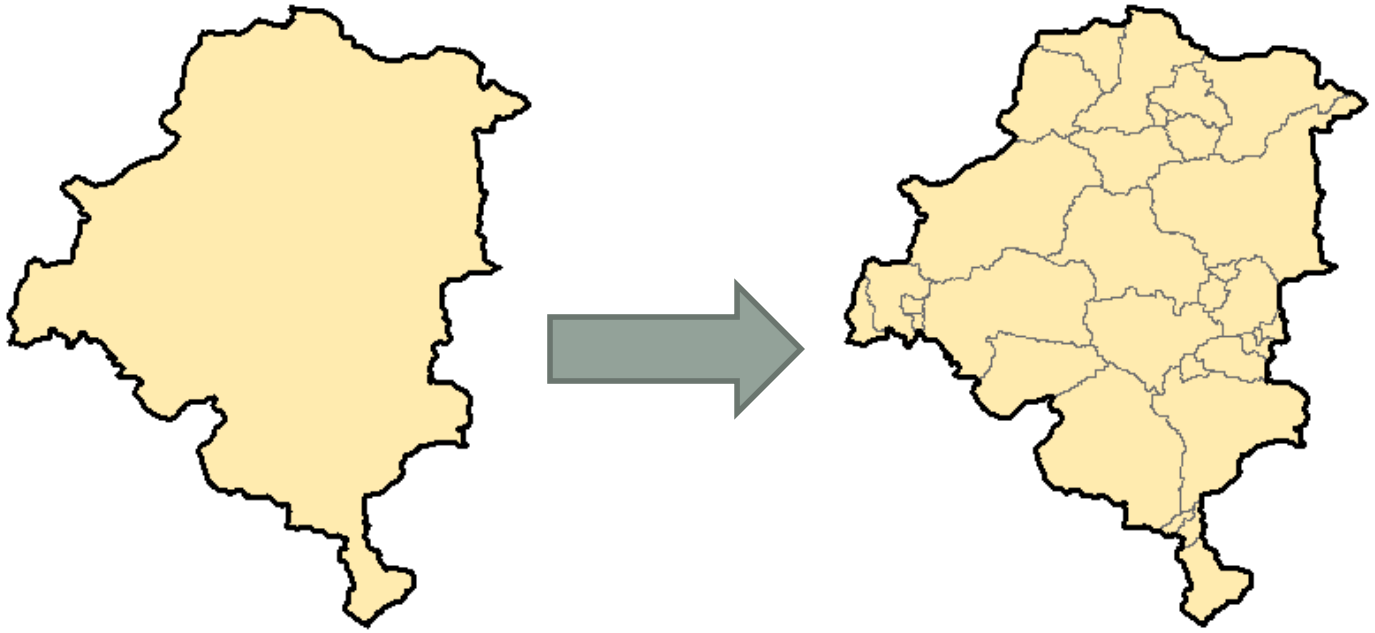
- Daily weather data input, SWAT tracks watershed response over time.



SWAT Modeling Process



Subwatershed Delineation



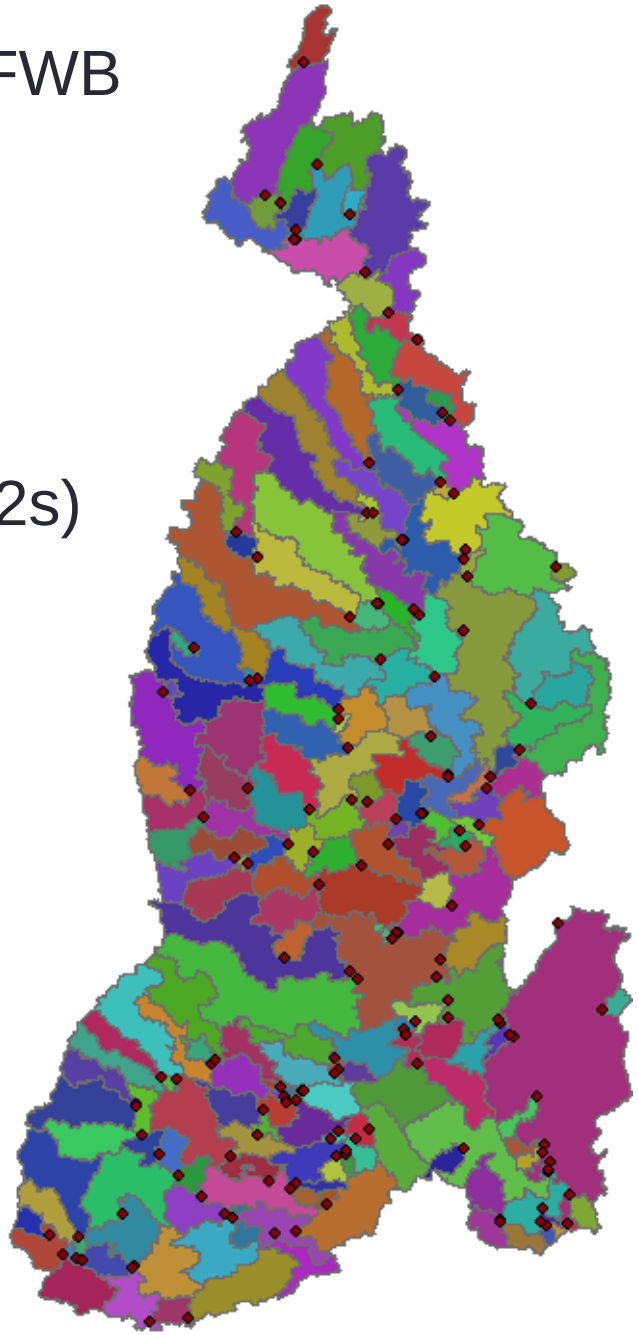
Partition UFWB into smaller drainage units. Done to:

- Obtain model predictions for specific outlet locations.
- Model variability in subwatershed-level parameters (climate, channel routing, etc.).

218 subwatersheds delineated for UFWB based on:

1. Impaired waters locations
2. Monitoring site locations
3. Contributing area threshold (~25 square miles; approximate HUC12s)

Draft subwatersheds posted on DNR website in October 2014 and refined based on feedback from Oshkosh & Fond du Lac.



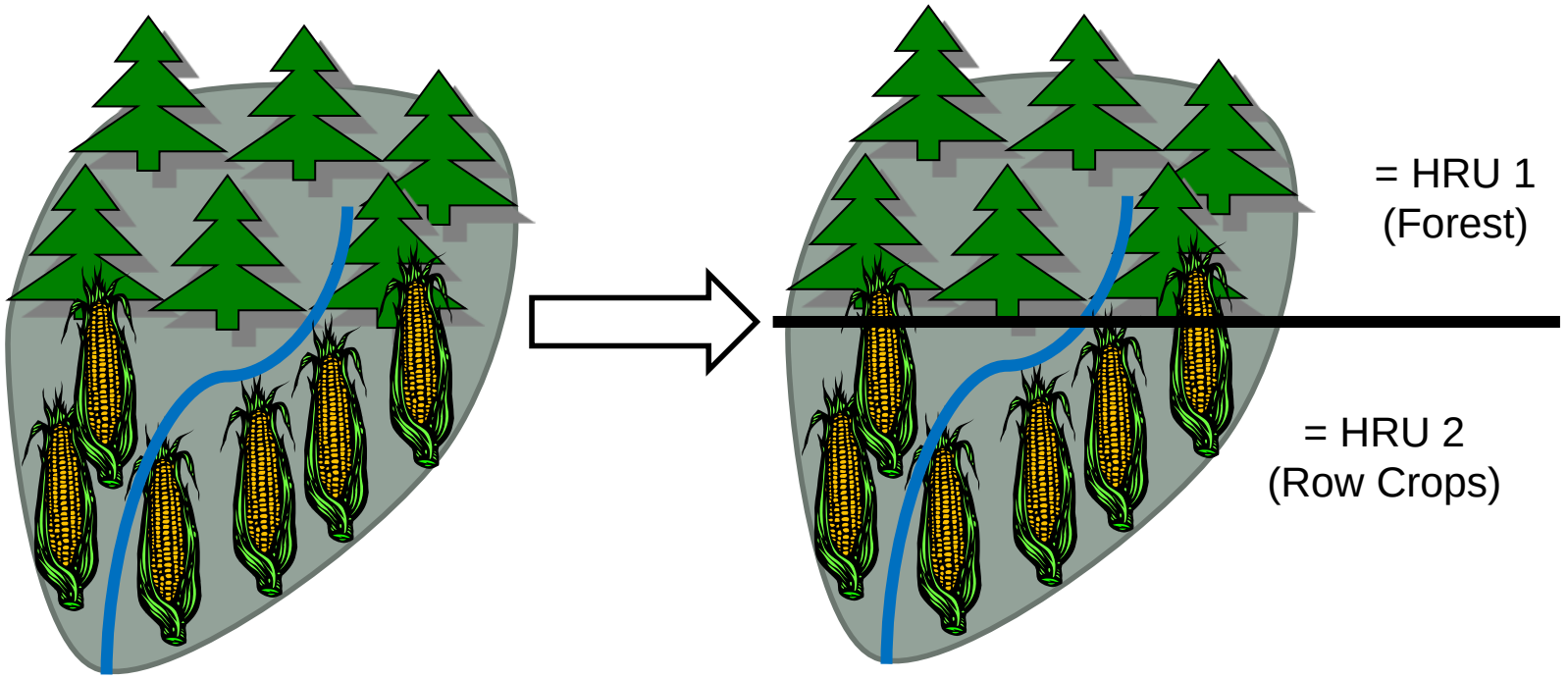
HRU Definition

HRU = Hydrologic Response Unit

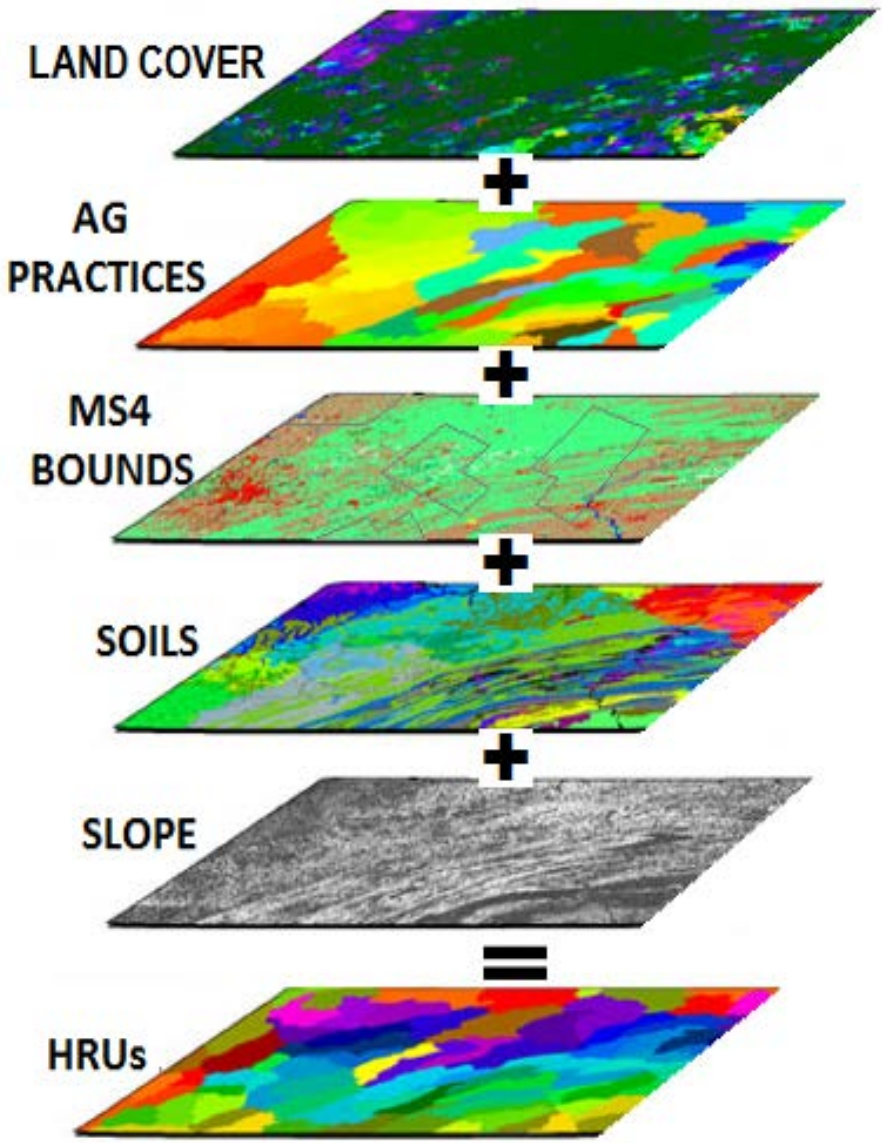
- “portions of a subwatershed that possess unique landuse, management, or soil attributes”

Second level of watershed division.

- Represent finer-scale variation in hydrologic and water quality parameters.



8,290 HRUs defined in UFWB SWAT model. Based on overlay of:

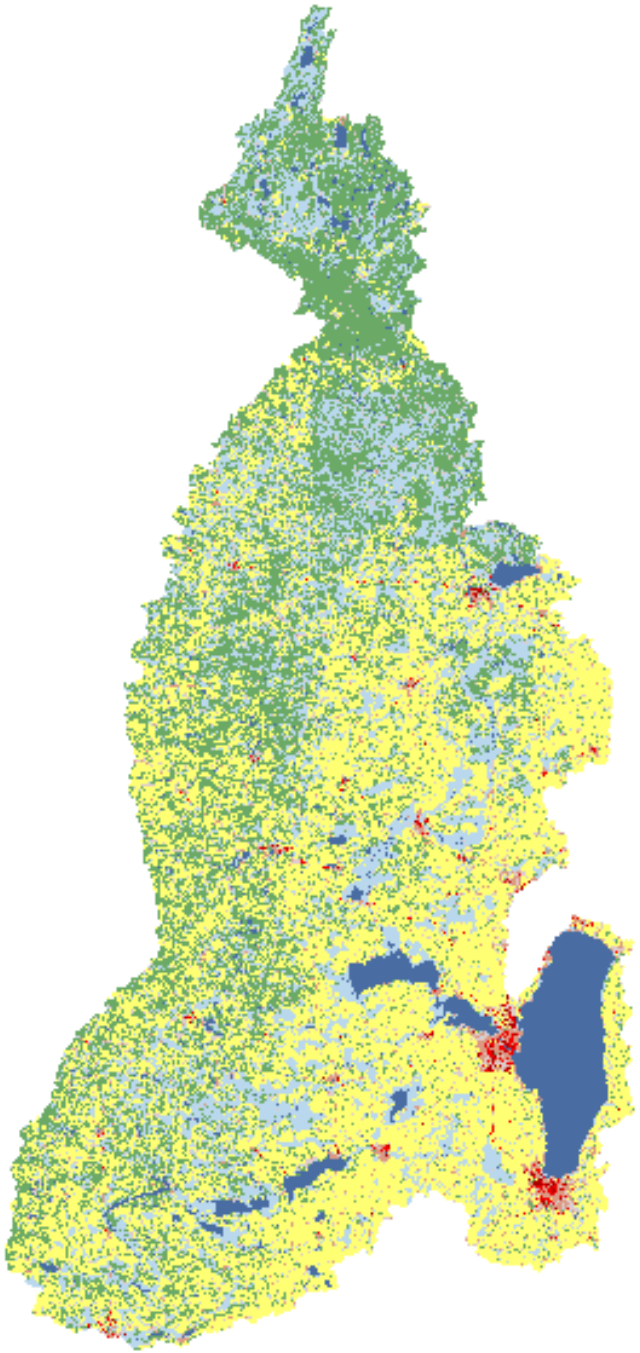


Land Use

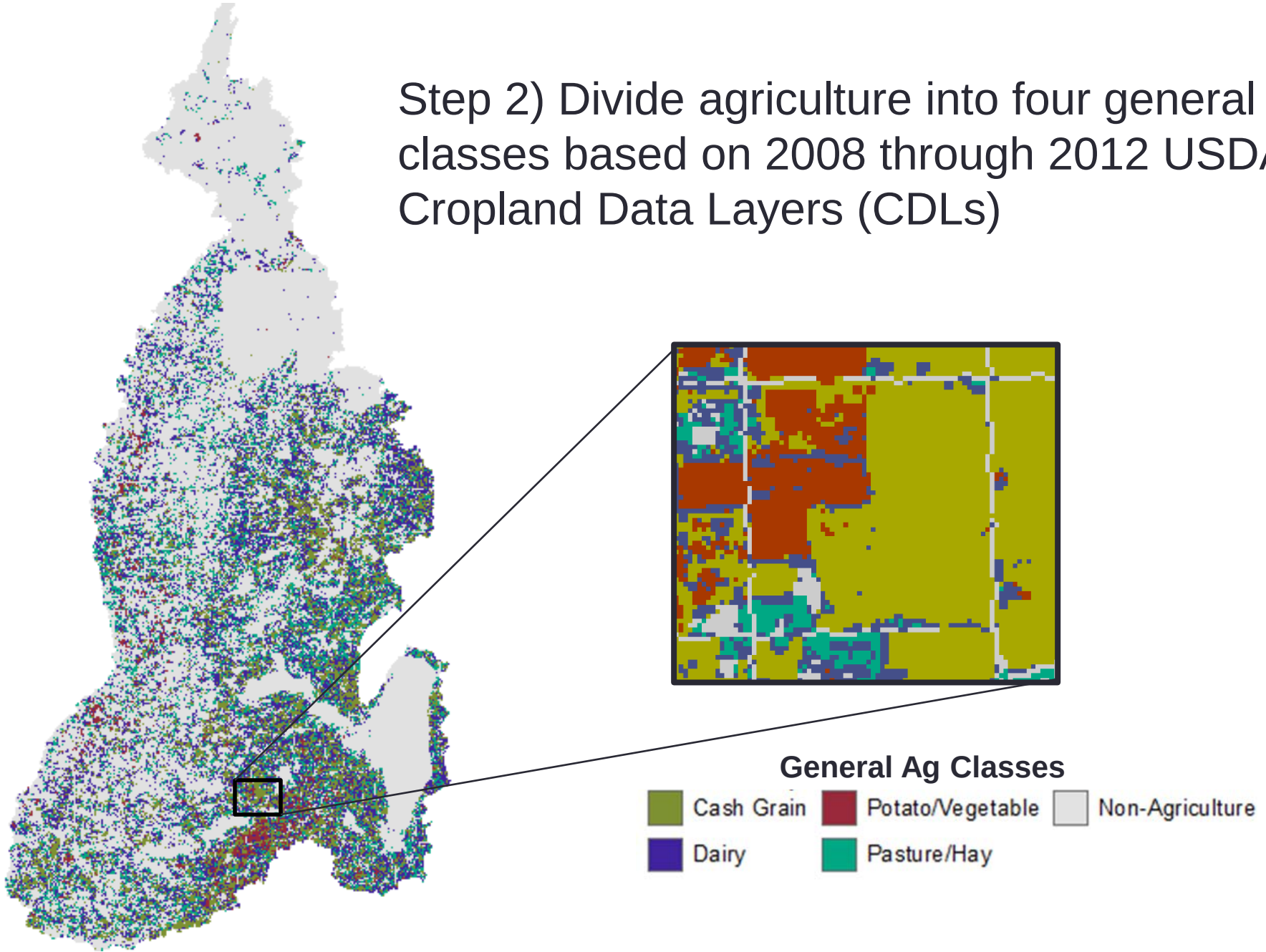
- Custom land use dataset

Step 1) Six land cover types mapped from 2006 National Land Cover Database

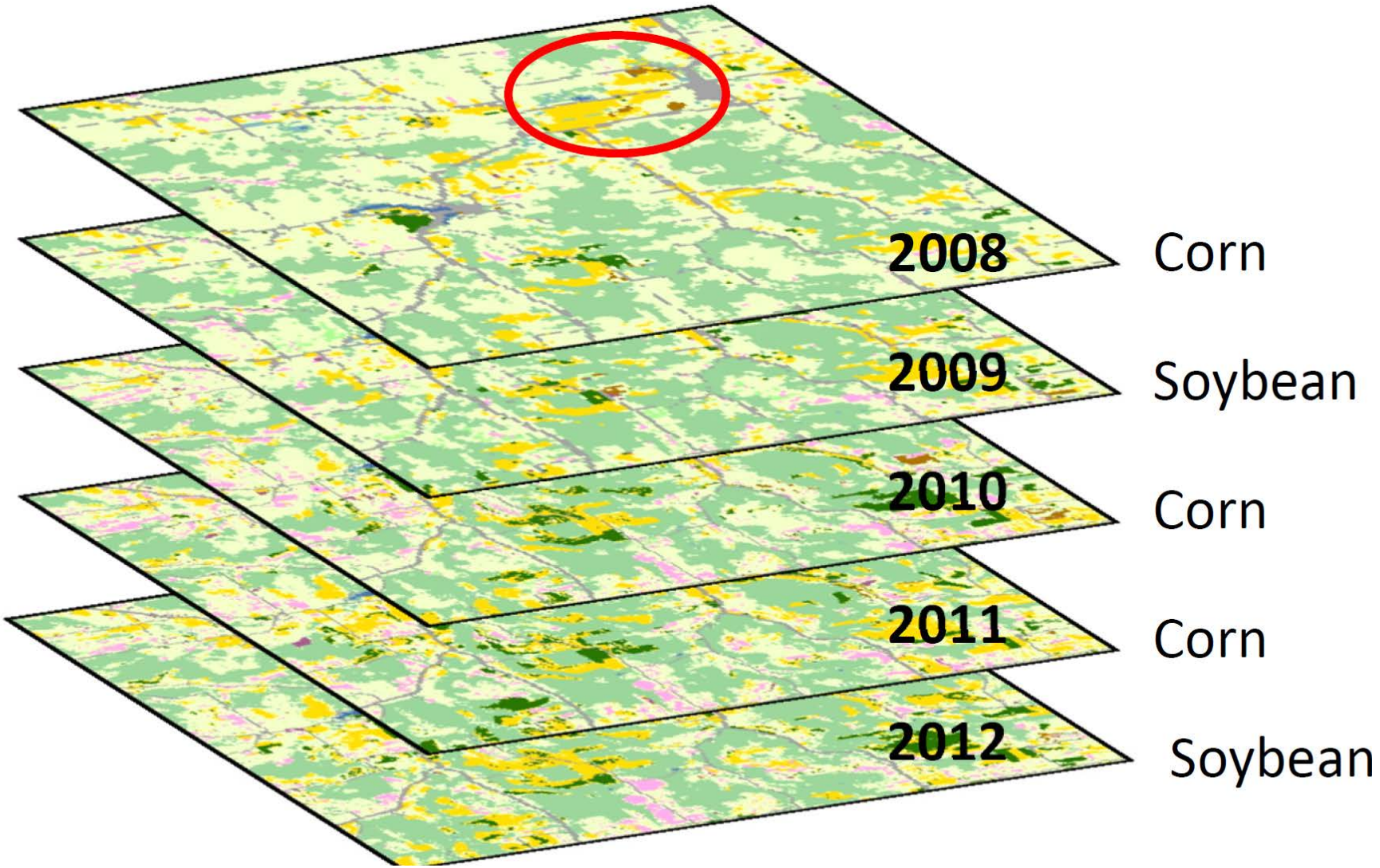
- Forest
- Herbaceous Wetland
- Forested Wetland
- Agriculture
- Developed, Low Density
- Developed, Medium Density
- Developed, High Density



Step 2) Divide agriculture into four general classes based on 2008 through 2012 USDA Cropland Data Layers (CDLs)



Cash Grain = Corn-Soybean Sequence
Dairy = Corn-Alfalfa Sequence

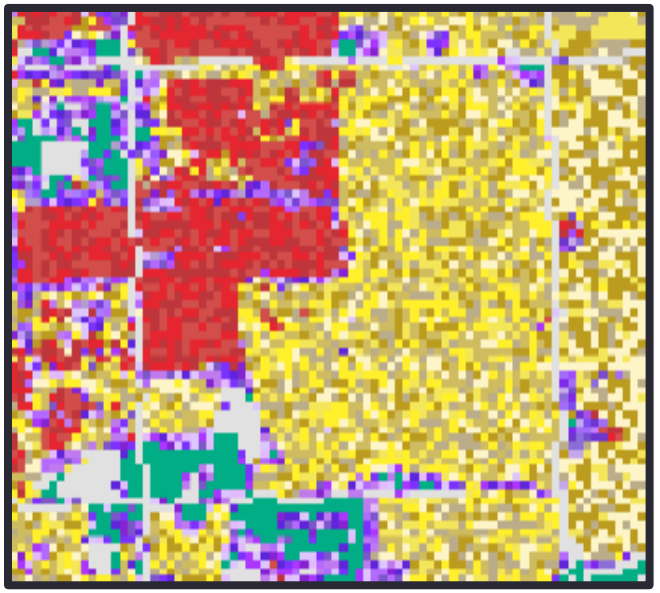


Step 3) Agriculture further refined into 46 detailed agriculture classes.

- Each has a specific set of farming practices programmed in SWAT (crops planted, tillage, fertilizer & manure application)

General Ag Classes

Cash Grain
Potato/Vegetable
Non-Agriculture
Dairy
Pasture/Hay



Detailed Ag Classes

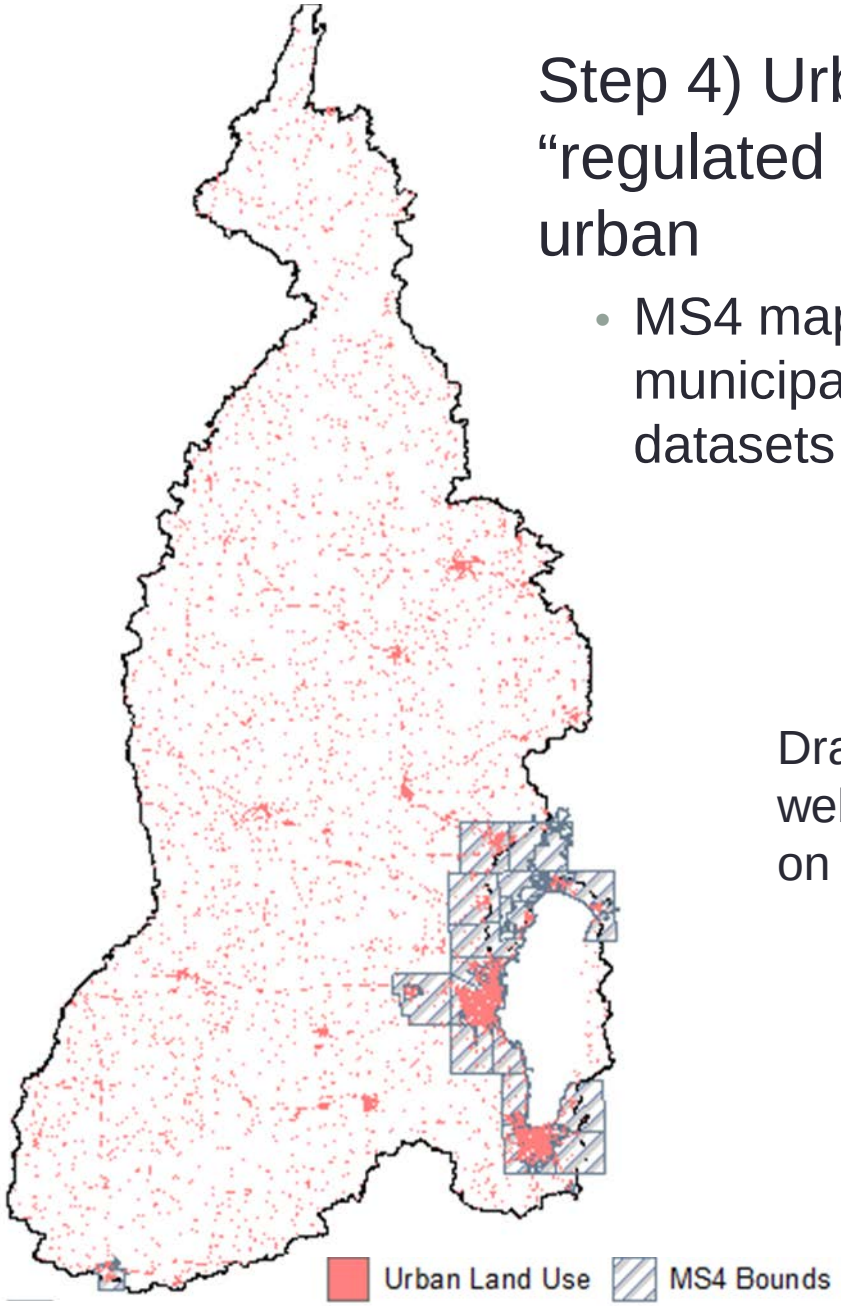
- County SWCDs surveyed for typical farming practices per HUC12 subwatershed.
- Feedback used to define and map detailed ag classes & prepare SWAT management tables.

Class Name	Crop Sequence	Tillage (% Residue Remaining)	Manure
Dairy 1	2 years corn silage followed by winter wheat and alfalfa	0-15%	Daily Haul
Dairy 2			Storage
Dairy 3		16-30%	Daily Haul
Dairy 4			Storage
Dairy 5		>30%	Daily Haul
Dairy 6			Storage
Dairy 7	1 year corn silage, 1 year corn grain followed by winter wheat and alfalfa	0-15%	Daily Haul
Dairy 8			Storage
Dairy 9		16-30%	Daily Haul
Dairy 10			Storage
Dairy 11		>30%	Daily Haul
Dairy 12			Storage
Cash Grain 1	Continuous corn	0-15%	-
Cash Grain 2		16-30%	-
Cash Grain 3		>30%	-
Cash Grain 4	Continuous soybean	0-15%	-
Cash Grain 5		16-30%	-
Cash Grain 6		>30%	-
Potato/Vegetable	1 year potato followed by 2 years vegetable	0-15%	-

Example SWAT Management Table for Detailed Ag Classes

Dairy Farm with:
Corn Silage
Conventional Tillage
Manure Storage

Year	Month	Day	Operation	Operation Type	Amount
1	4	25	Fertilizer	Dairy - Fresh Manure	3,083 kg/ha
1	4	26	Tillage	Field Cultivator Ge15ft	
1	5	1	Fertilizer	Elemental P	25 kg/ha
1	5	1	Plant	Corn Silage	
1	9	15	Harvest	Corn Silage	
1	10	1	Fertilizer	Dairy - Fresh Manure	3,083 kg/ha
1	10	2	Tillage	Generic Fall Plow Ge15ft	
2	4	25	Fertilizer	Dairy - Fresh Manure	3,083 kg/ha
2	4	26	Tillage	Field Cultivator Ge15ft	
2	5	1	Fertilizer	Elemental P	25
2	5	1	Plant	Corn Silage	
2	9	15	Harvest	Corn Silage	
2	10	1	Fertilizer	Manure	3,083 kg/ha
2	10	2	Tillage	Generic Fall Plow Ge15ft	
3	4	25	Fertilizer	Dairy - Fresh Manure	3,083 kg/ha
3	4	26	Tillage	Field Cultivator Ge15ft	
3	5	1	Fertilizer	Elemental P	25
3	5	1	Plant	Winter Wheat	
3	8	30	Harvest	Winter Wheat	
3	10	1	Fertilizer	Dairy - Fresh Manure	3,083 kg/ha
4	4	15	Tillage	Field Cultivator Ge15ft	
4	4	20	Plant	Alfalfa	
4	9	1	Harvest	Alfalfa	
5	5	15	Harvest	Alfalfa	
5	6	30	Harvest	Alfalfa	
5	8	15	Harvest	Alfalfa	
5	9	30	Harvest	Alfalfa	
6	5	15	Harvest	Alfalfa	
6	6	30	Harvest	Alfalfa	
6	8	15	Harvest	Alfalfa	
6	9	30	Harvest	Alfalfa	
6	10	15	Tillage	Generic Fall Plow Ge15ft	



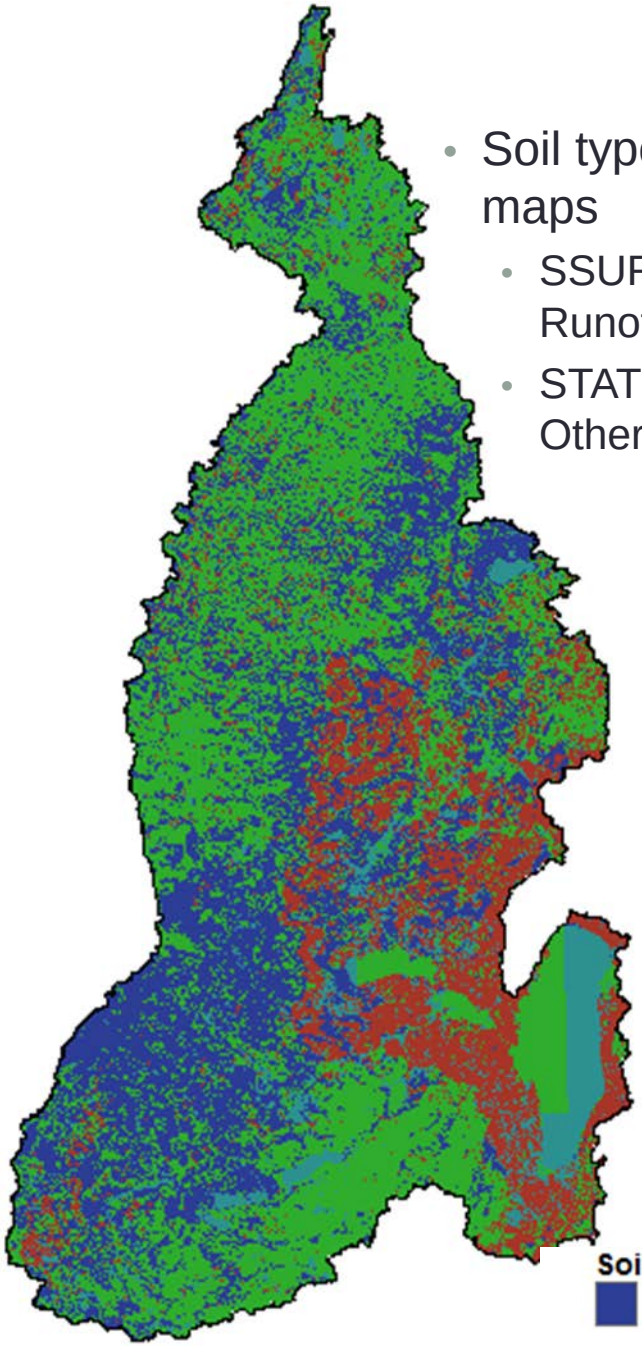
Step 4) Urban lands divided into "regulated MS4" and "non-regulated" urban

- MS4 mapping used US Census Bureau municipal and urbanized area boundary datasets

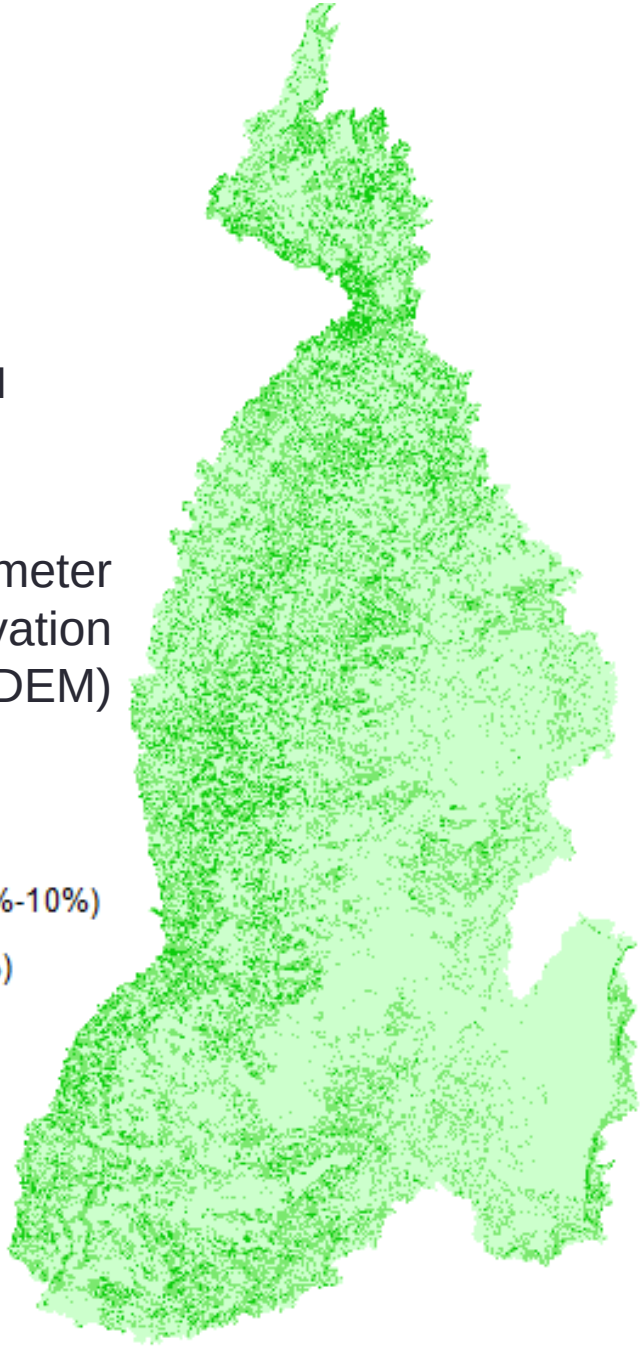
Draft MS4 boundaries posted on DNR website in October 2014 and refined based on feedback from Appleton & Fond du Lac.

Soils & Slopes

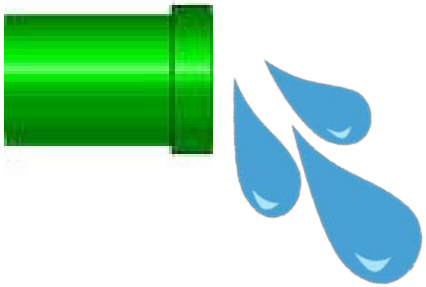
- Soil types defined from USDA soil maps
  - SSURGO = Detailed resolution = Runoff Potential
  - STATSGO2 = Coarse resolution = All Other Soil Parameters



- Slope mapped from 10 meter resolution Digital Elevation Model (DEM)

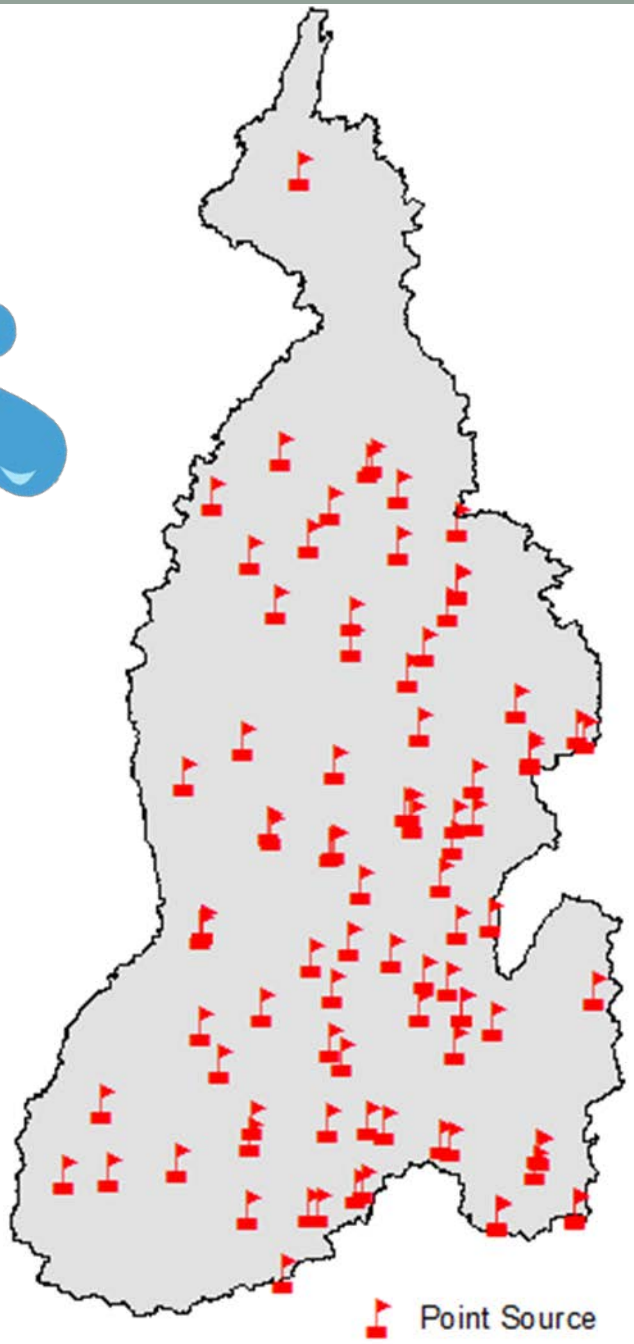


Other Model Inputs

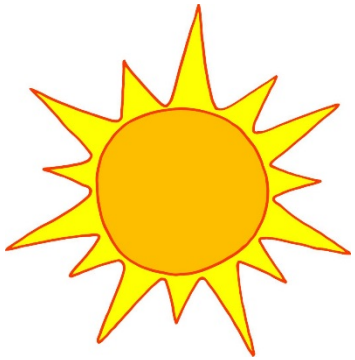


Point Source Discharges

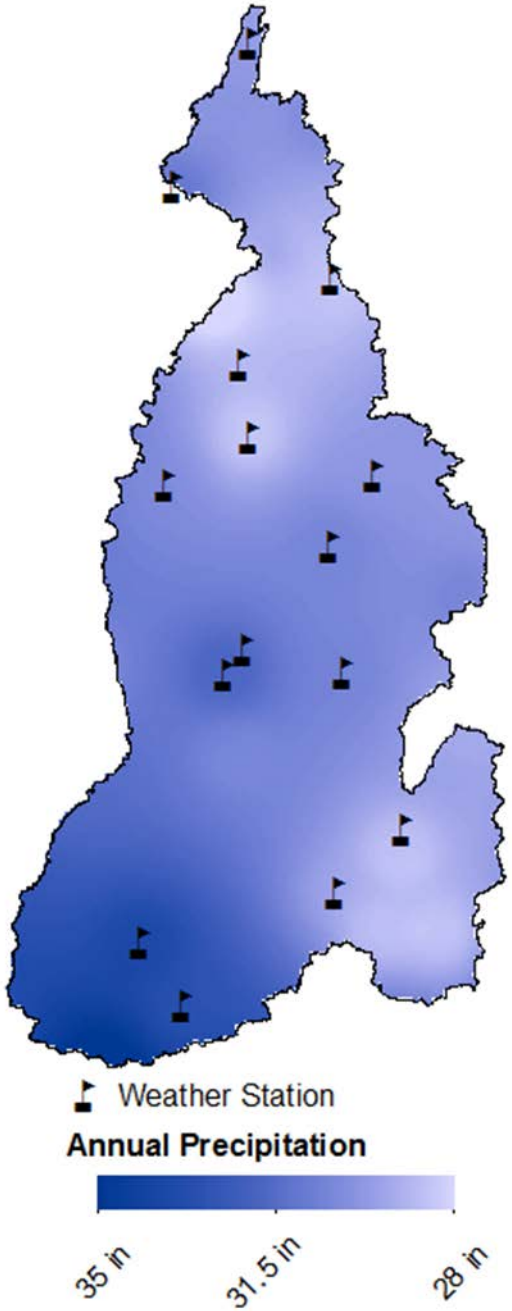
- 83 facilities
  - 60 municipal WWTFs
  - 23 industrial dischargers
- Annual effluent flows, phosphorus loads, and sediment loads estimated from discharge monitoring records



Other Model Inputs



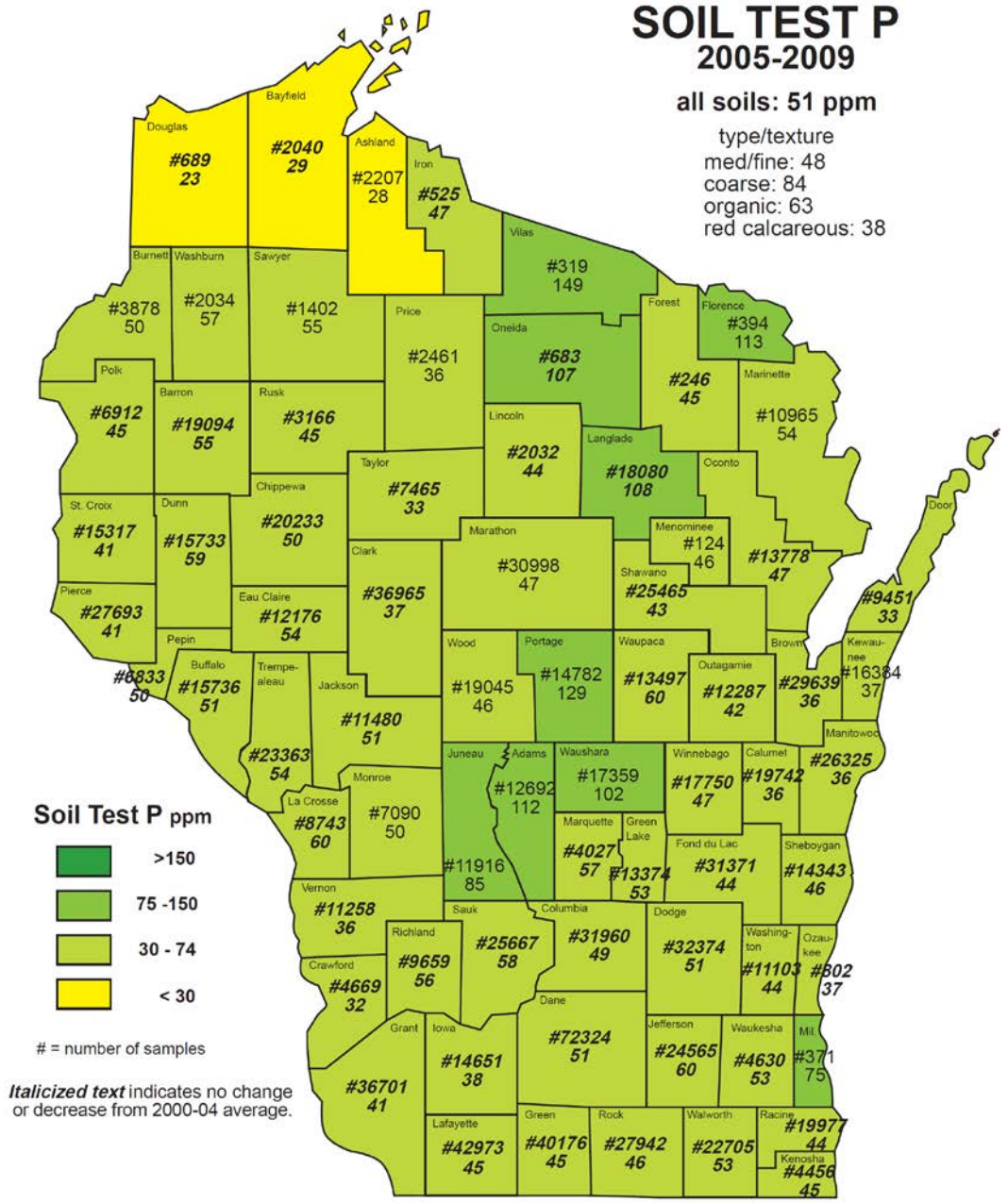
Daily precipitation & air temperature from 14 weather stations (NOAA National Climatic Data Center)



Other Model Inputs

Initial Soil Phosphorus

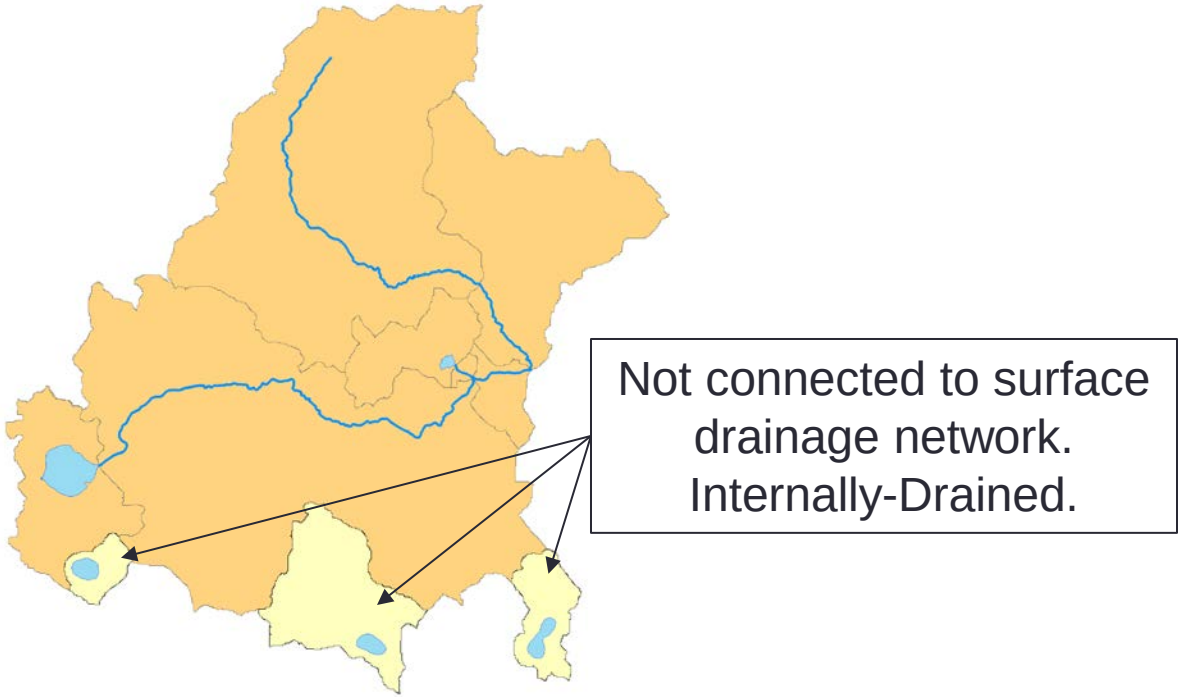
1) Reported by some county SWCDs from review of nutrient management plans
2) UW Soil Testing Lab summary

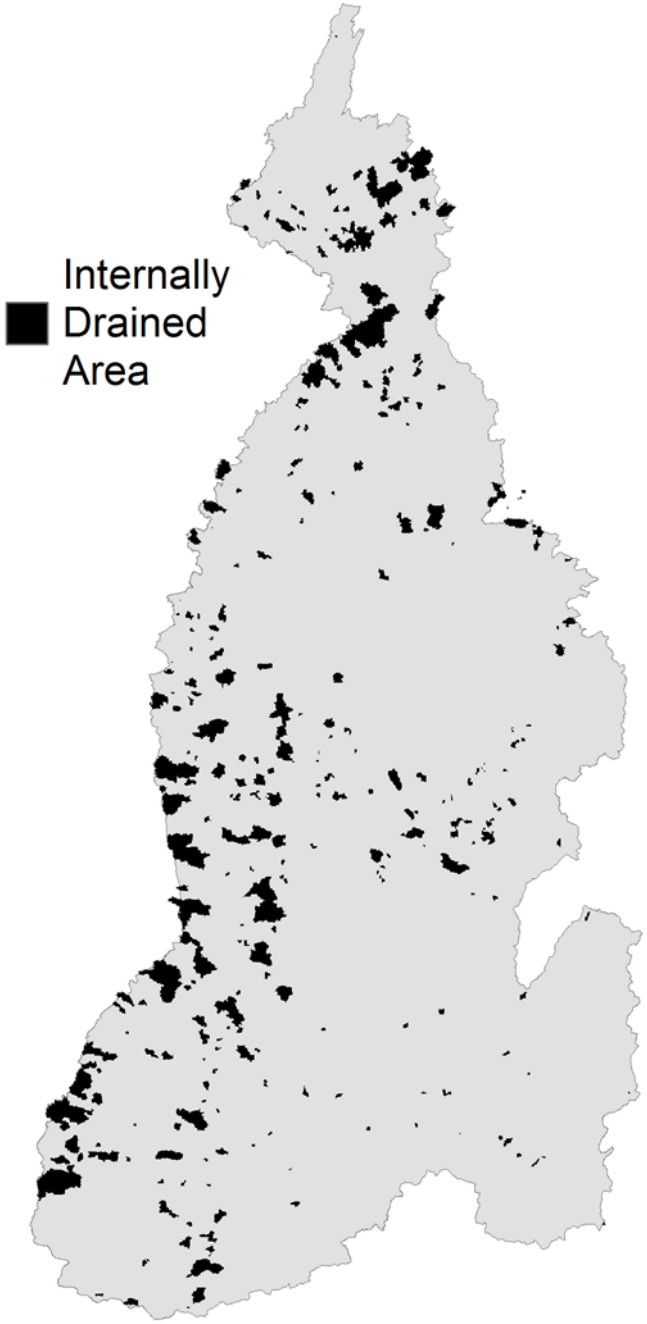


Other Model Inputs

Internally Drained Areas

- Mapped from isolated drainages in WDNR 1:24,000 hydrography database
- Internally drained area calculated for each SWAT subwatershed. Drain to pond with unlimited storage in SWAT.





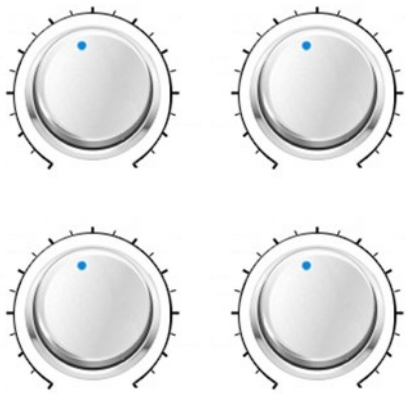
Other Model Inputs

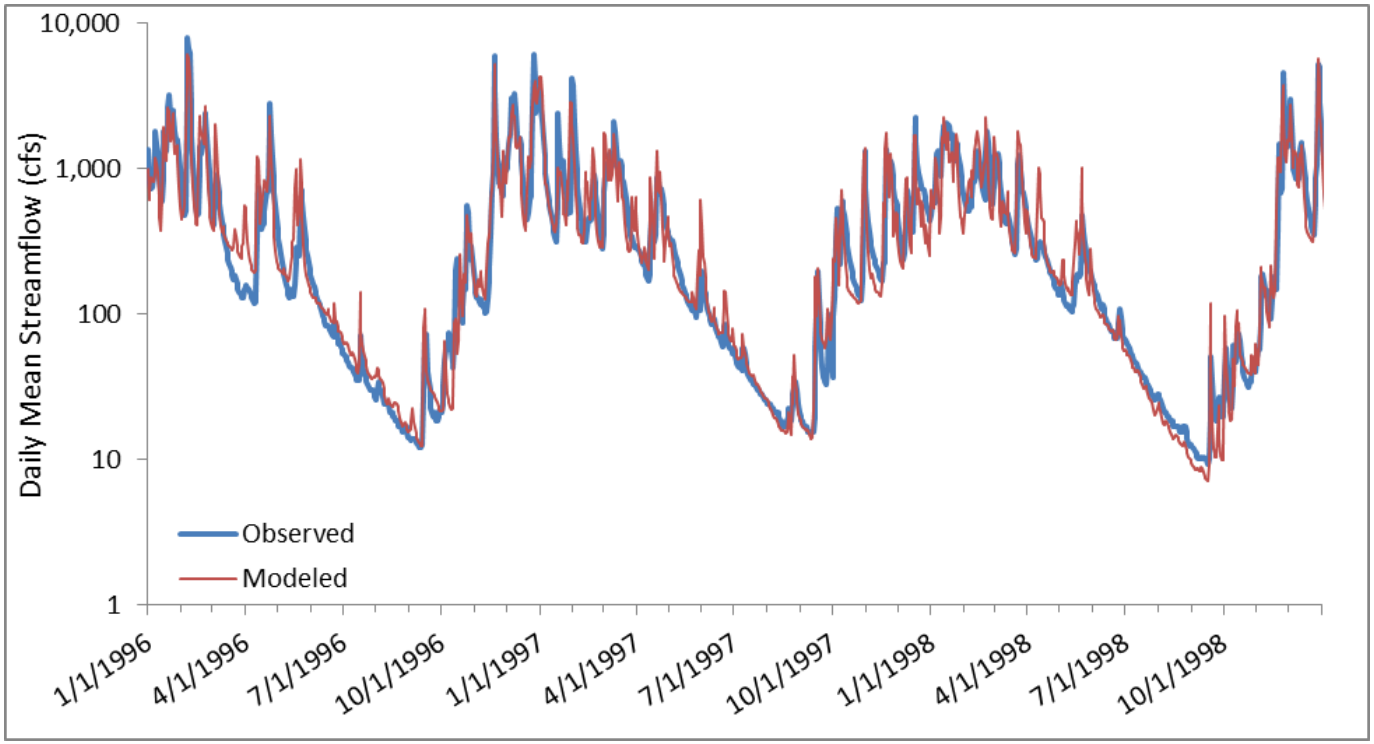
- Wetland dimensions
  - Based on wetland extent (2011 National Land Cover Database)
- Initial channel roughness (Manning's n) for main channels
  - Based on riparian buffer land cover (2011 National Land Cover Database)
- Other parameters automatically estimated from ArcSWAT software or set to default values
- Simulation period:
  - January 1, 1996 to December 31, 2013
  - 4 year warm-up

Model Calibration and Validation

Calibration = Tune model parameters so that predictions better match observations.

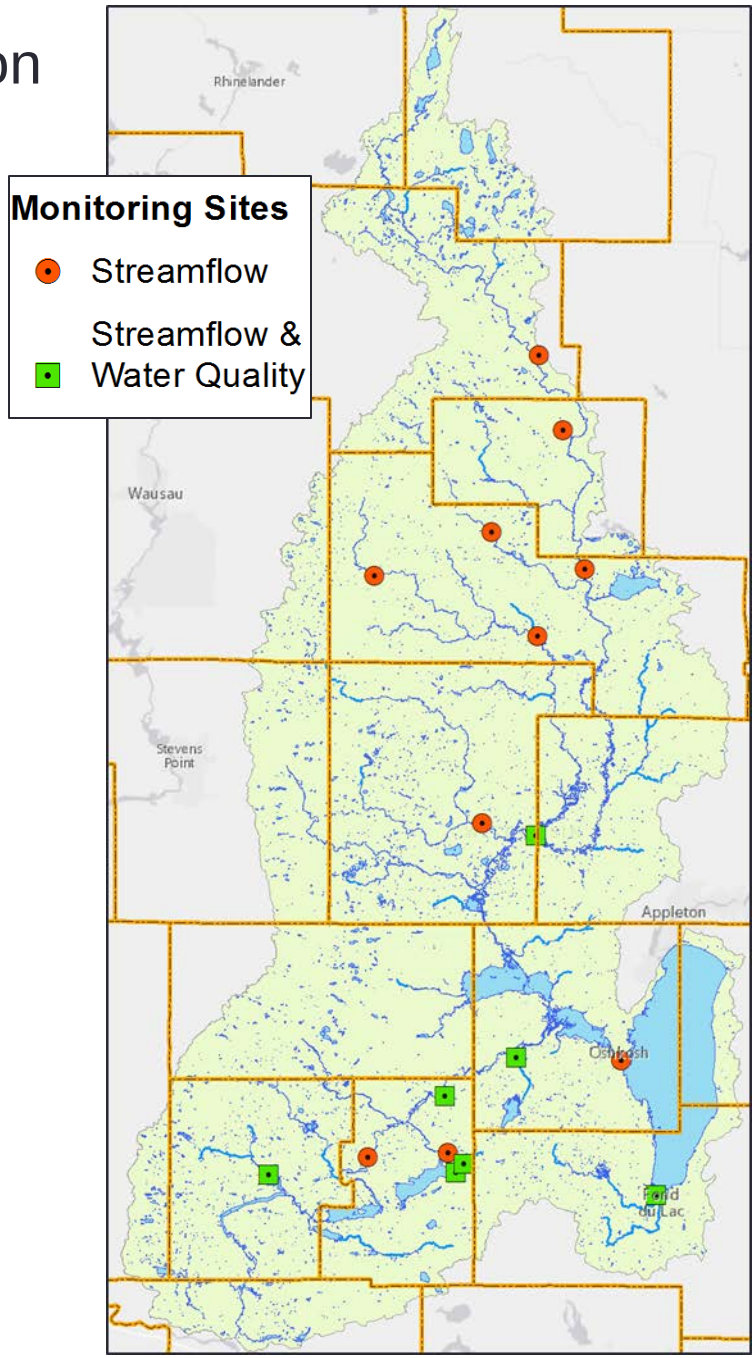
Validation = Compare calibrated model predictions to additional observations.





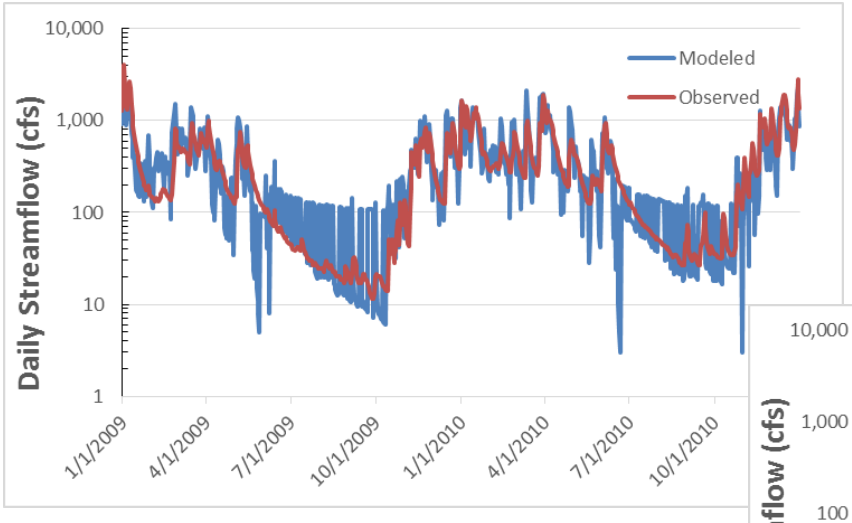
Observed data for calibration and validation

- County crop yields reported by USDA National Agricultural Statistics Service
- Monthly streamflow
  - 17 USGS gaging stations
- Monthly phosphorus & sediment loads
  - 7 USGS monitoring sites
- Datasets split into wet, average, and dry years; then assigned to calibration vs. validation



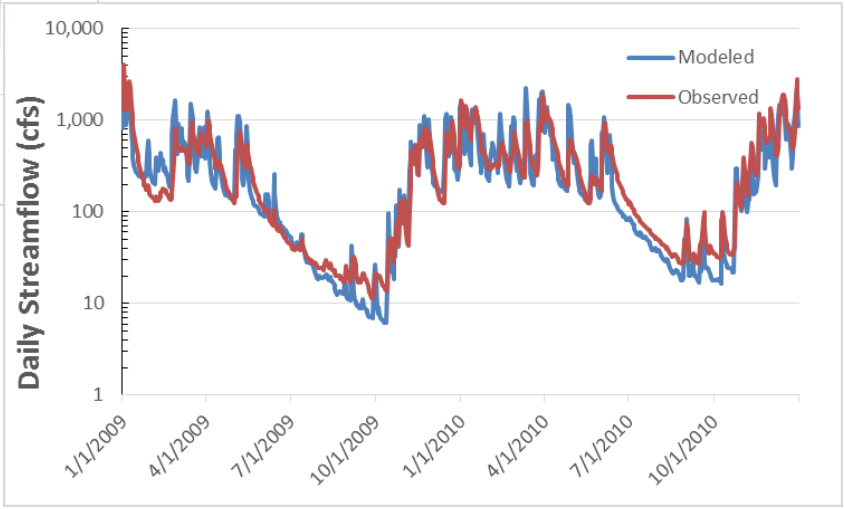
Calibration process

- Select goodness-of-fit measures
  - Nash-Sutcliffe Efficiency (NSE) & Percent Bias (PBIAS) for monthly streamflow, sediment loads, and phosphorus loads
- Sensitivity analysis
  - Which parameters affect measures?
- Adjust parameters to maximize goodness-of-fit



← Pre-Calibration

Post-Calibration →



Model Performance Measures

- Nash-Sutcliffe Efficiency = How accurately is month-to-month variation predicted?
- Percent Bias (aka Percent Difference) = Is the long-term average over- or under-predicted?
- Evaluation guidelines based on SWAT literature

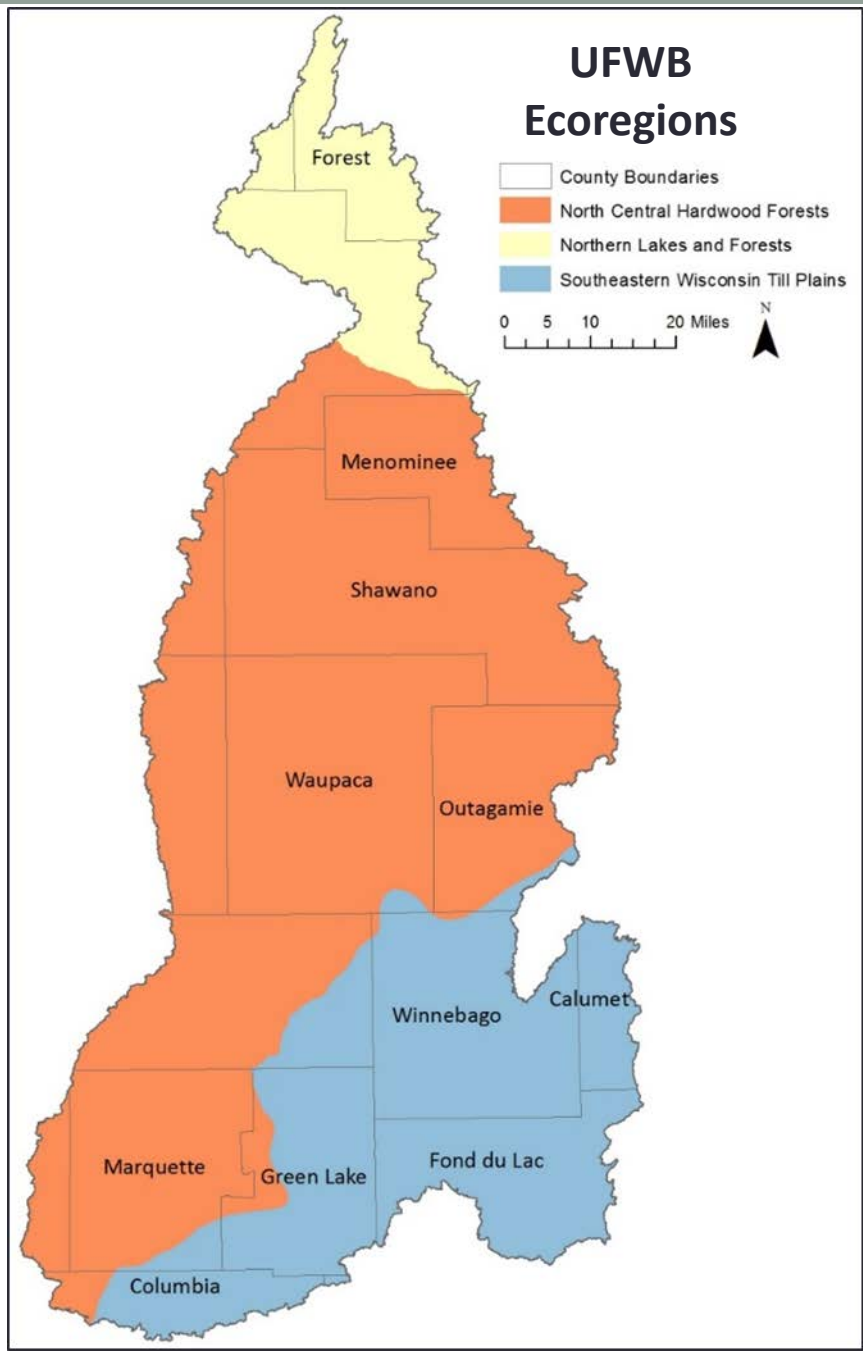
Performance Rating	NSE	PBIAS (%)		
		Streamflow	Sediment	P
Very good	0.75 < NSE ≤ 1.00	PBIAS < ±10	PBIAS < ±15	PBIAS< ±25
Good	0.65 < NSE ≤ 0.75	±10 ≤ PBIAS < ±15	±15 ≤ PBIAS < ±30	±25 ≤ PBIAS < ±40
Satisfactory	0.50 < NSE ≤ 0.65	±15 ≤ PBIAS < ±25	±30 ≤ PBIAS < ±55	±40 ≤ PBIAS < ±70

Moriasi et al. 2007. Model Evaluation Guidelines For Systematic Quantification Of Accuracy In Watershed Simulations. Transactions of the ASABE; 50(3).

Reflect estimates of error in monitoring data.

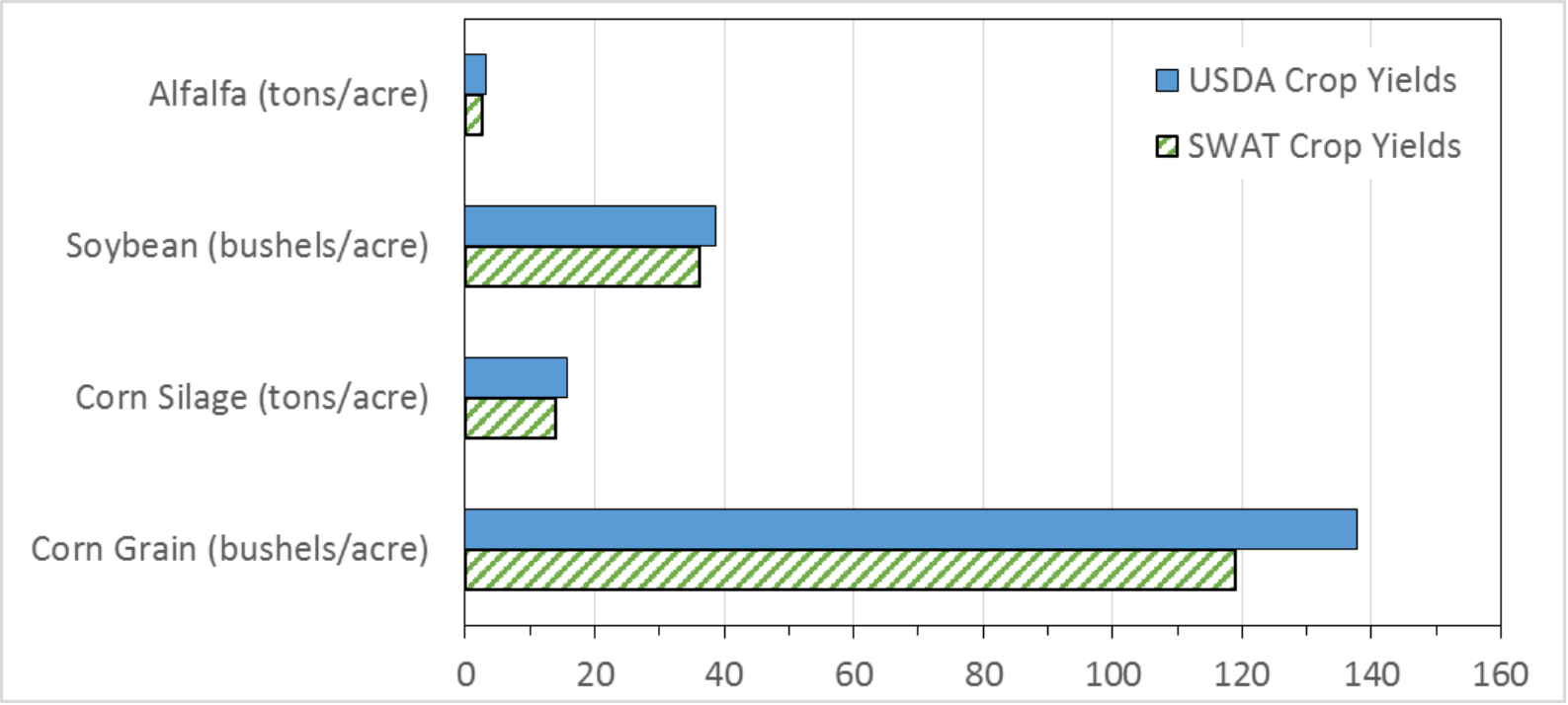
Calibration process

- Manual calibration
  - Visual assessment of predicted and observed plots & performance measures
- Automated calibration
  - SWAT-CUP software
  - Fine-tune parameters with hundreds of model runs
- Some parameters adjusted basin-wide
- Other parameters adjusted by ecoregion



Crop Yield/Plant Growth Calibration

- Compare SWAT crop yields to USDA reported yields
- Check plant growth on non-agricultural lands (forest, wetland, urban)
- Adjust plant growth parameters as needed



Streamflow Calibration

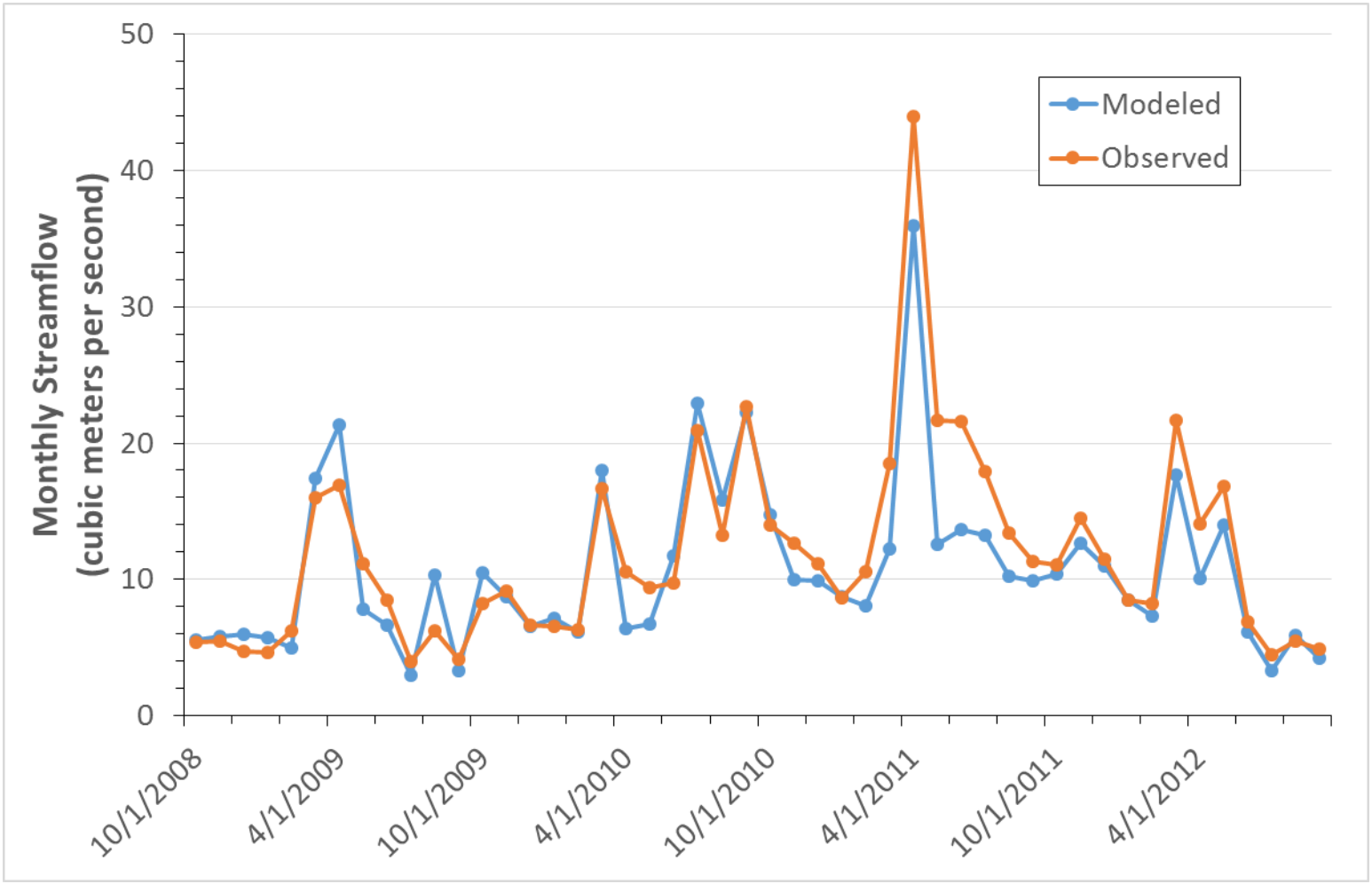
- Sensitive parameters affect surface runoff and storage and groundwater dynamics

Parameter Code	Description
CN2	SCS curve number
ESCO	Soil Evaporation Compensation Factor
SOL_Z	Soil depth
SOL_AWC	Soil available water capacity
SURLAG	Surface runoff lag coefficient
SMTMP, SFTMP, SMFMX, SMFMN, TIMP, SNOCOVMX	Snowmelt parameters
GW_DELAY	Groundwater delay
ALPHA_BF	Baseflow recession constant
GWQMN	Shallow aquifer return flow depth
GW_REVAP	Shallow aquifer transfer coefficient
REVAPMN	Shallow aquifer transfer depth

- Visually check water balance terms, baseflow magnitude and timing

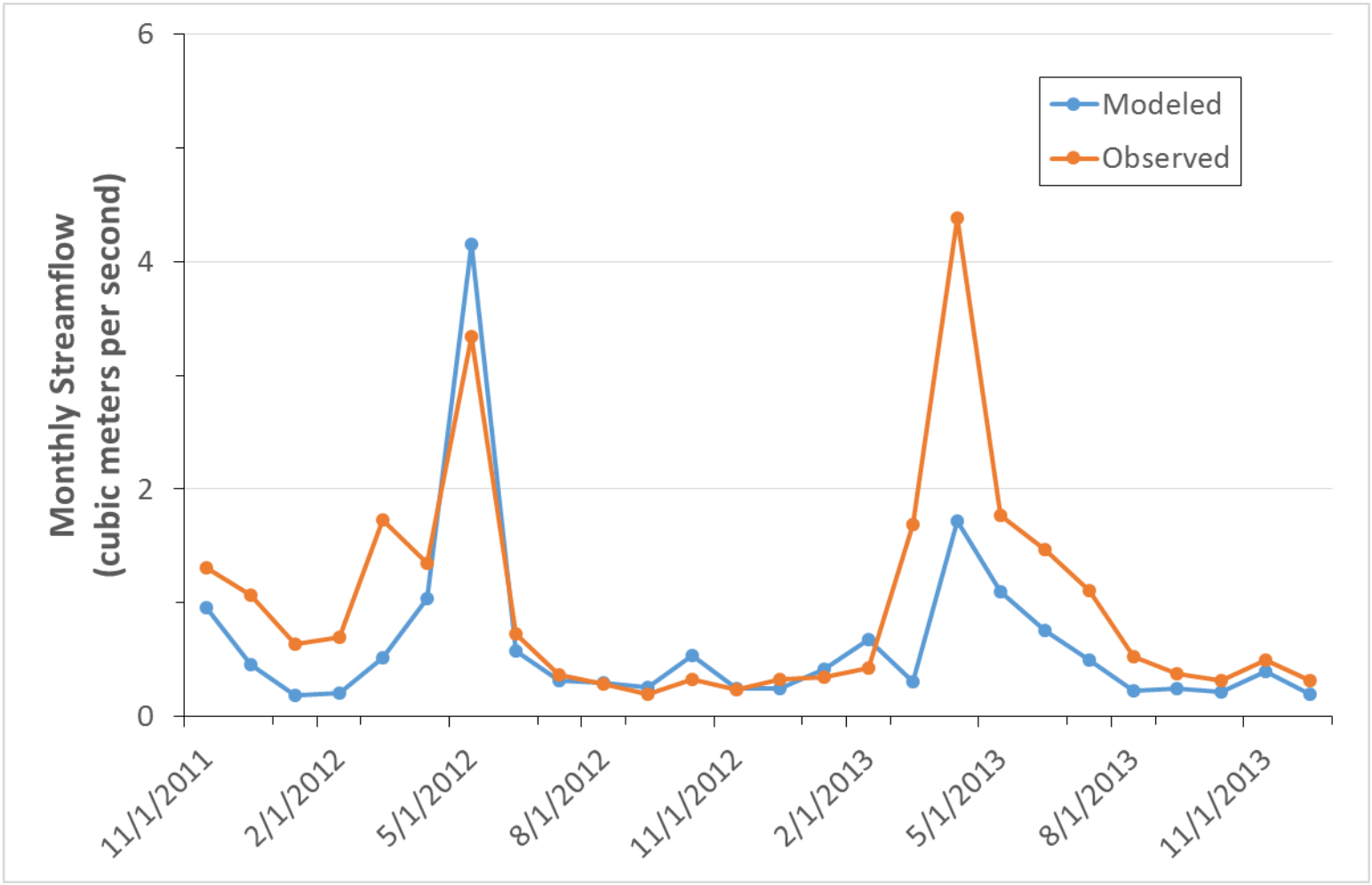
Streamflow Calibration

Little Wolf River At Royalton
NSE= 0.73 PBIAS = 10%

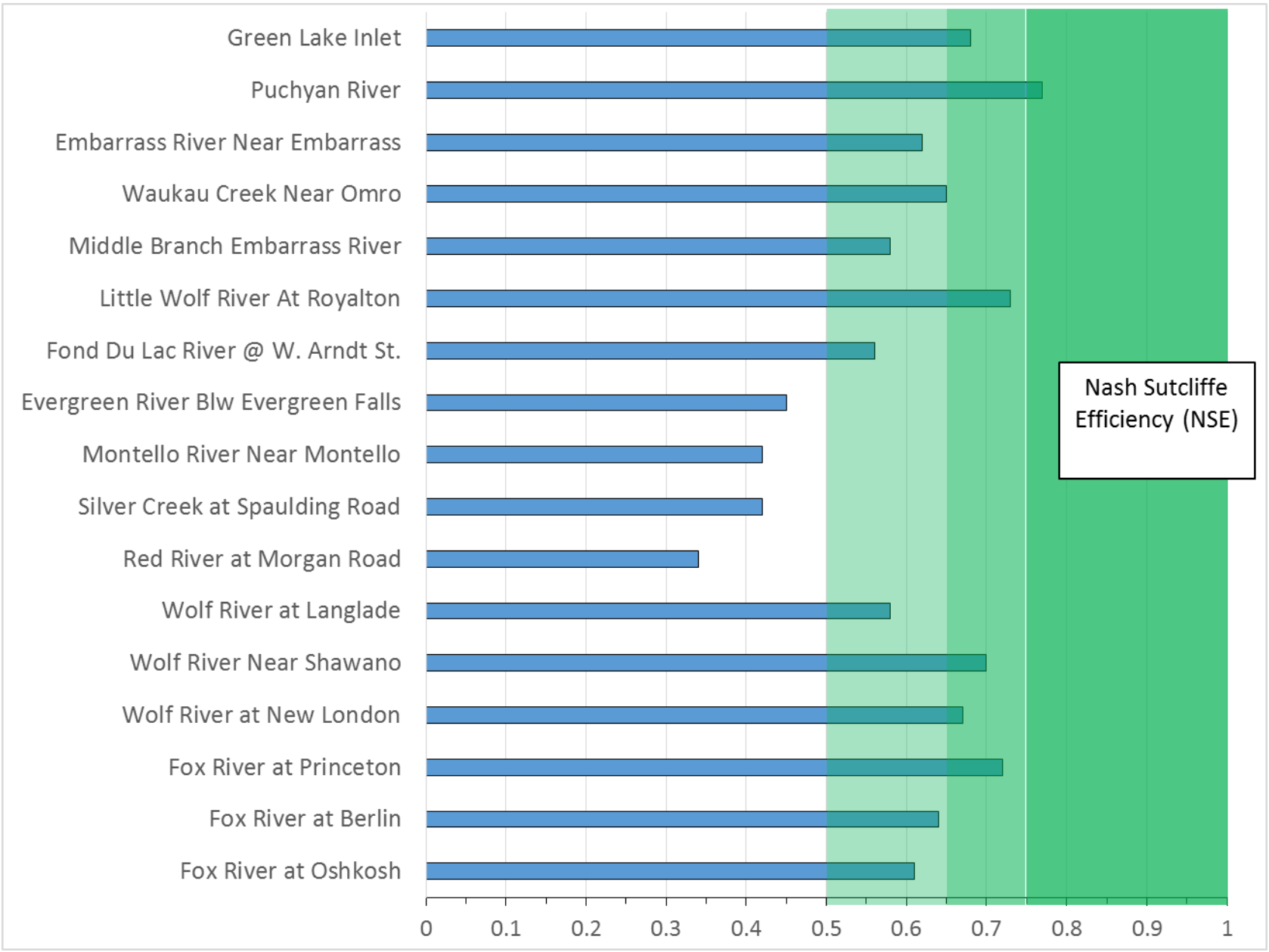


Streamflow Calibration

Silver Creek at Spaulding Road
NSE= 0.42 PBIAS = -32%



Streamflow Calibration Results



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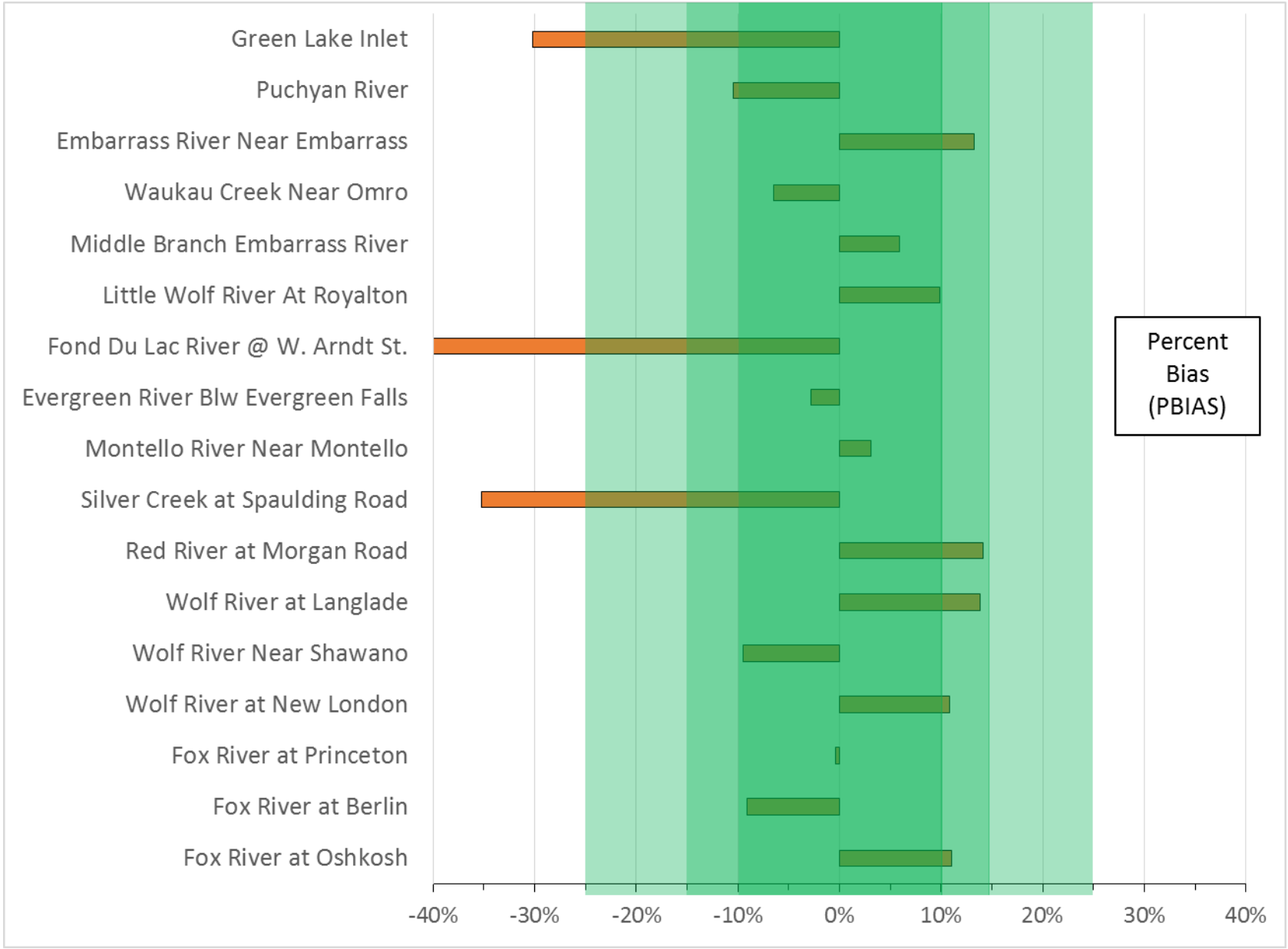
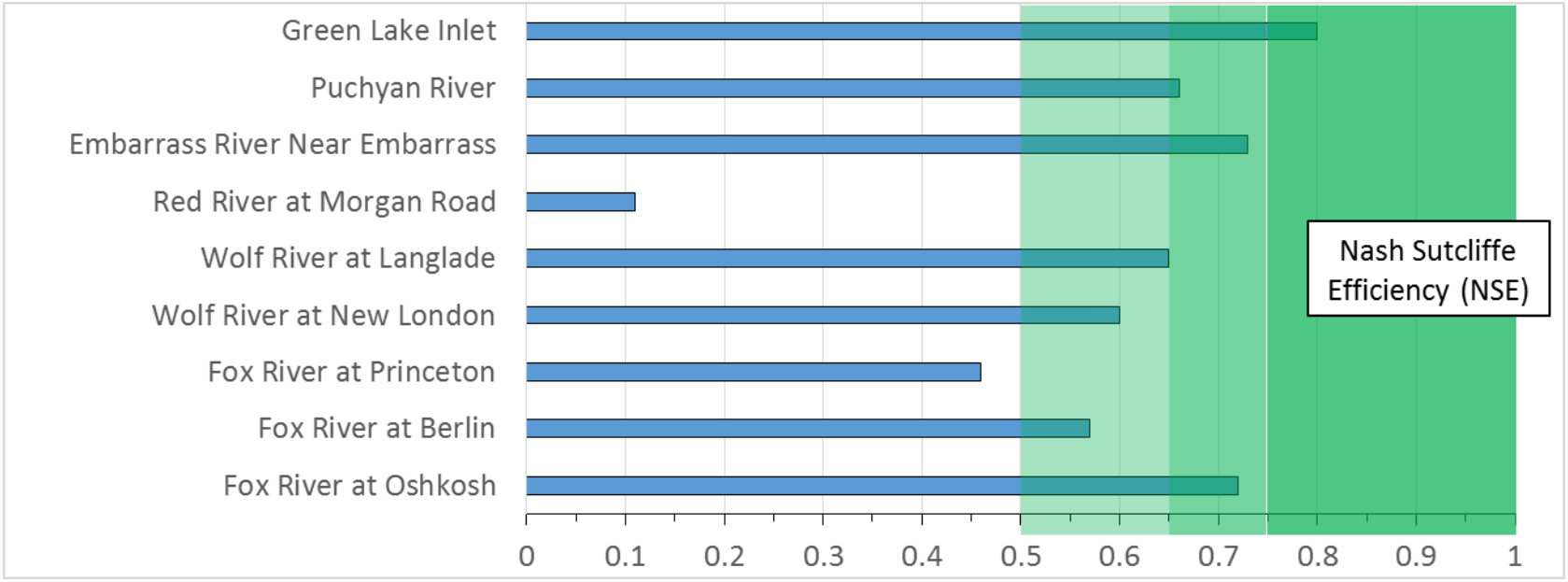
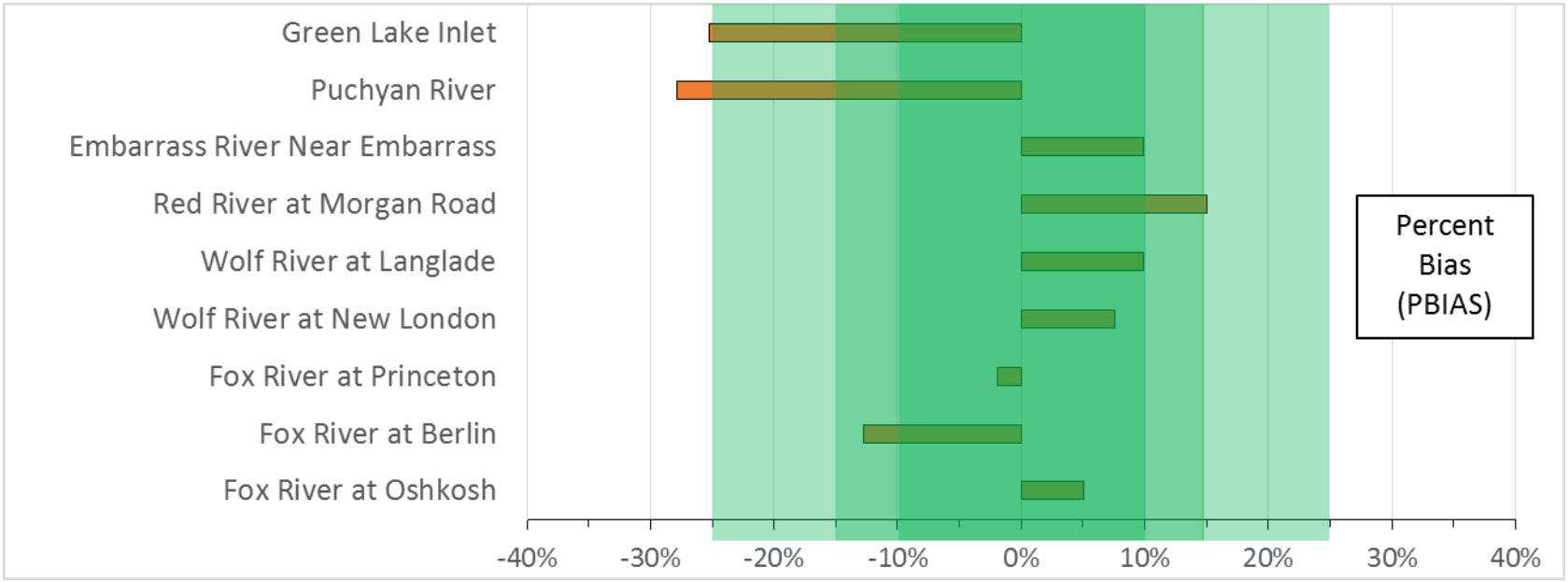


Streamflow Validation Results



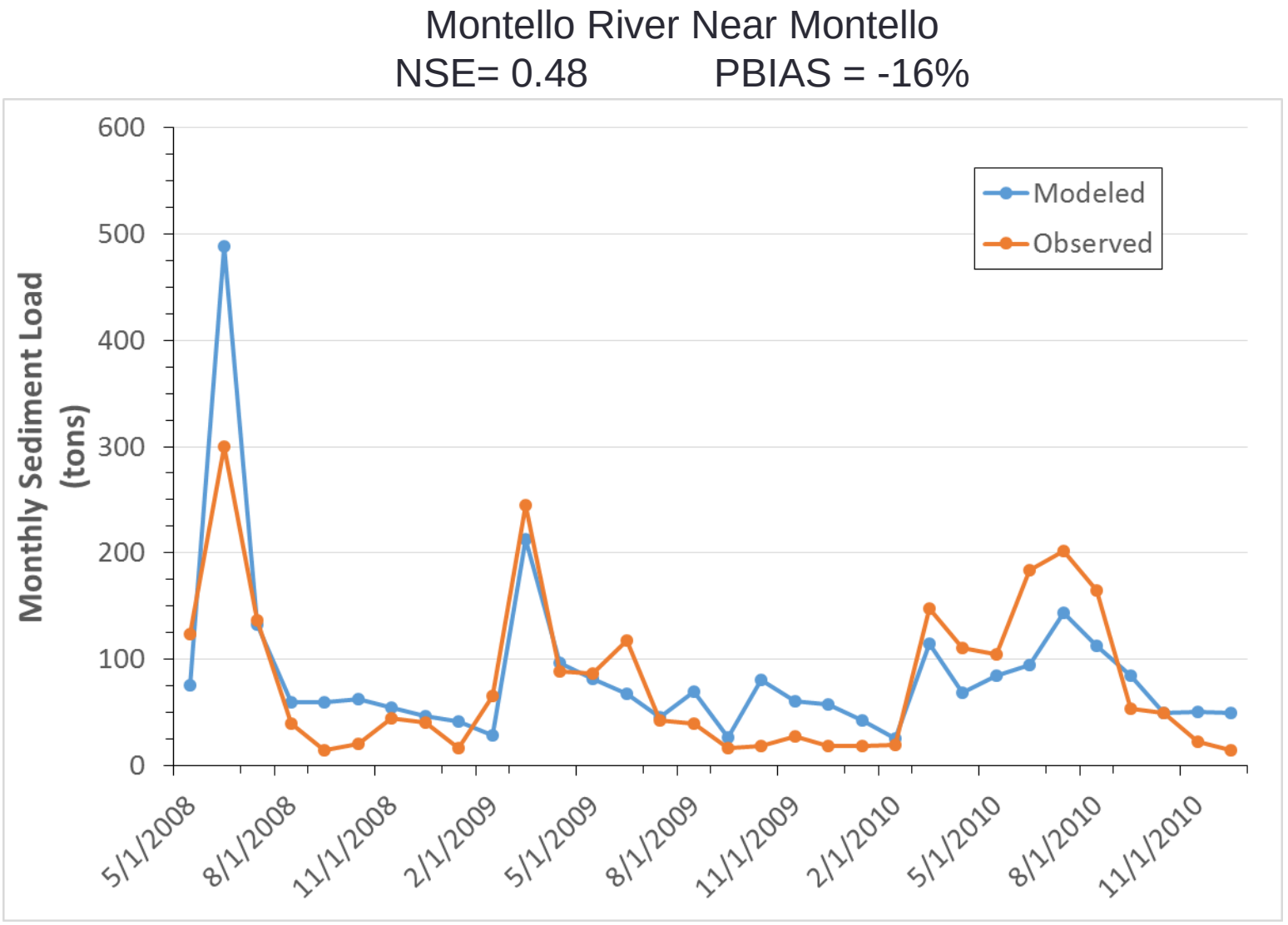


Sediment Calibration

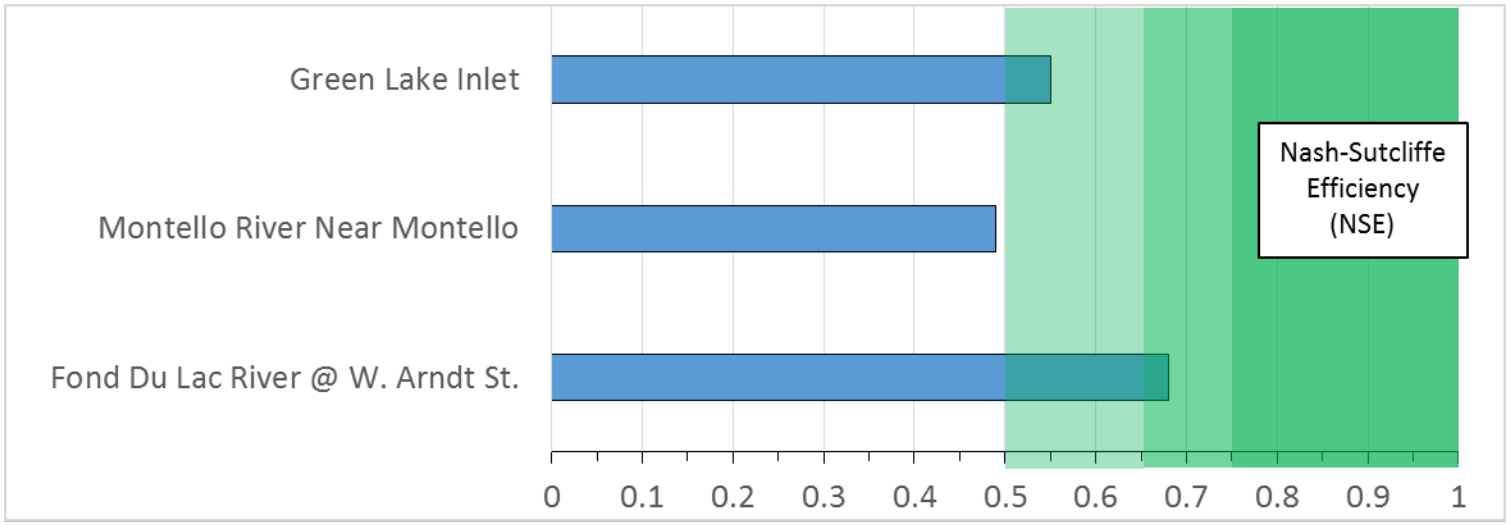
- Sensitive parameters affect landscape erosion and routing through stream channels/wetlands

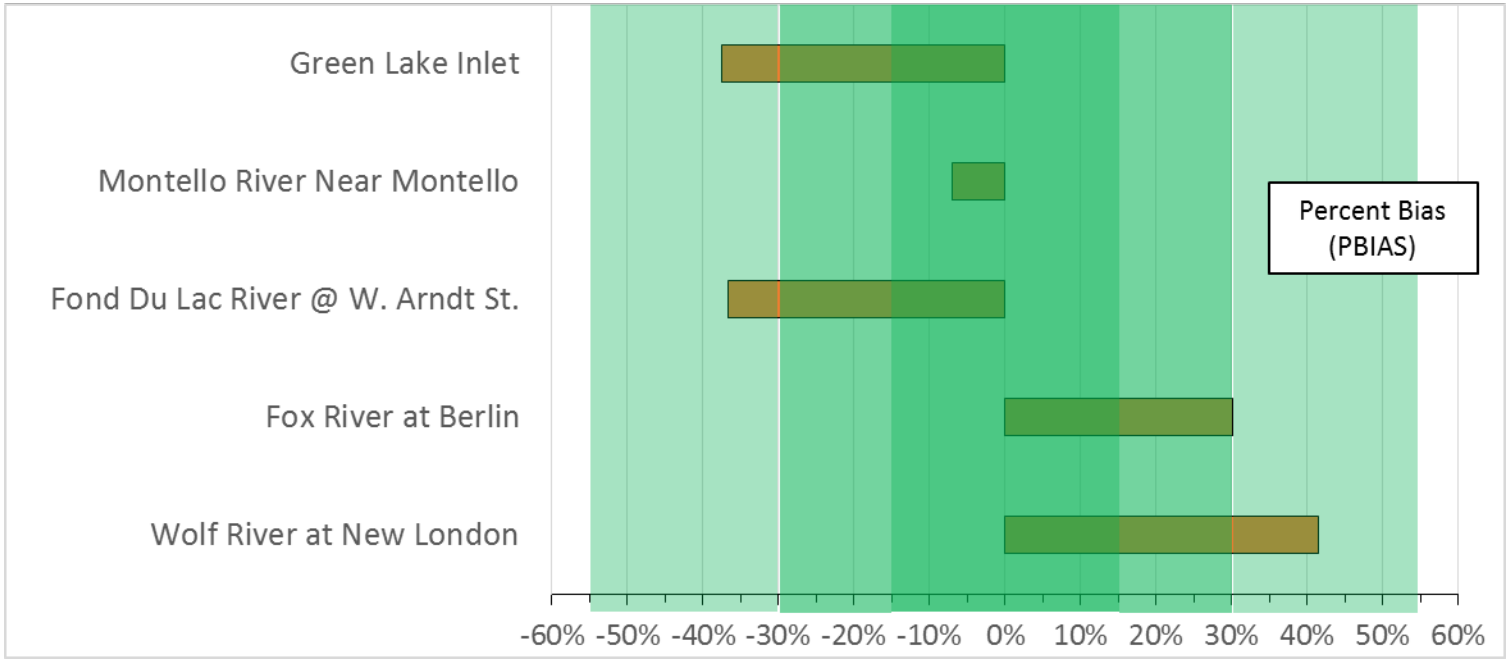
Parameter Code	Description
USLE_C	USLE Cover Factor
USLE_P	USLE Conservation Practice Factor
FILTERW	Edge-of field filter strip parameter
BIOMIX	Soil biological mixing efficiency
SPCON, SPEXP	Channel sediment transport coefficients
PRF_BSN, ADJ_PKR	Channel sediment transport peak rate adjustment factors
CH_COV1, CH_COV2	Channel erosion parameters
CH_N2	Channel roughness coefficient
CH_S2	Channel slope
CH_W2	Channel width
WET_NSED	Wetland equilibrium sediment concentrati
WET_SED	Wetland initial sediment concentration

Sediment Calibration

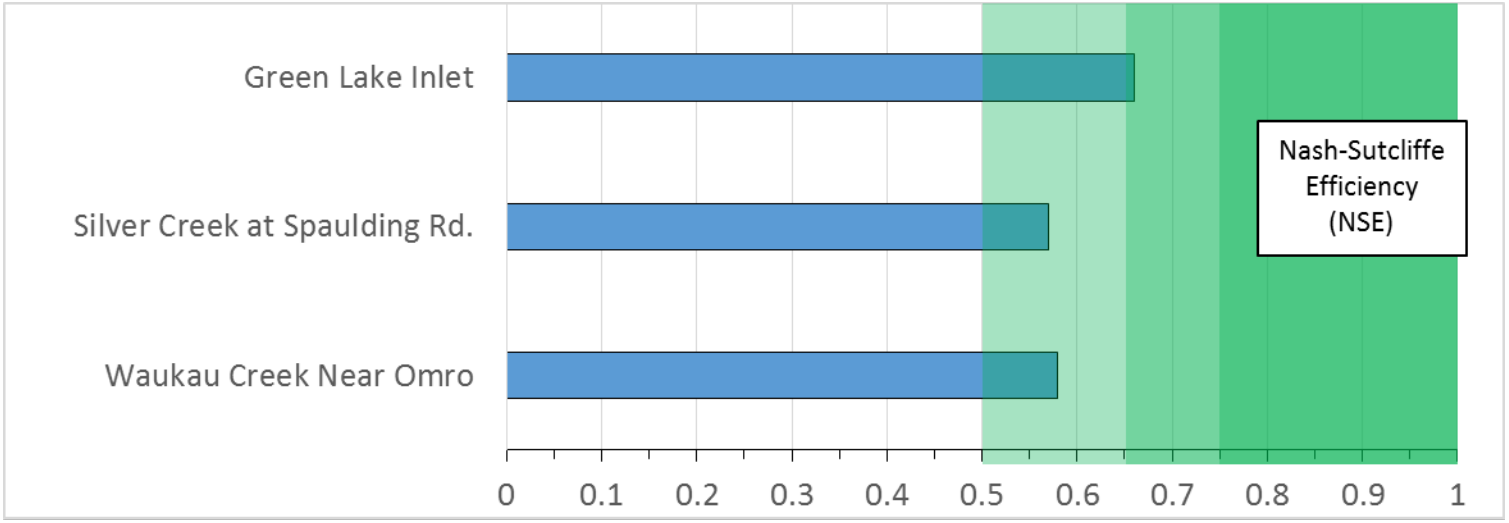


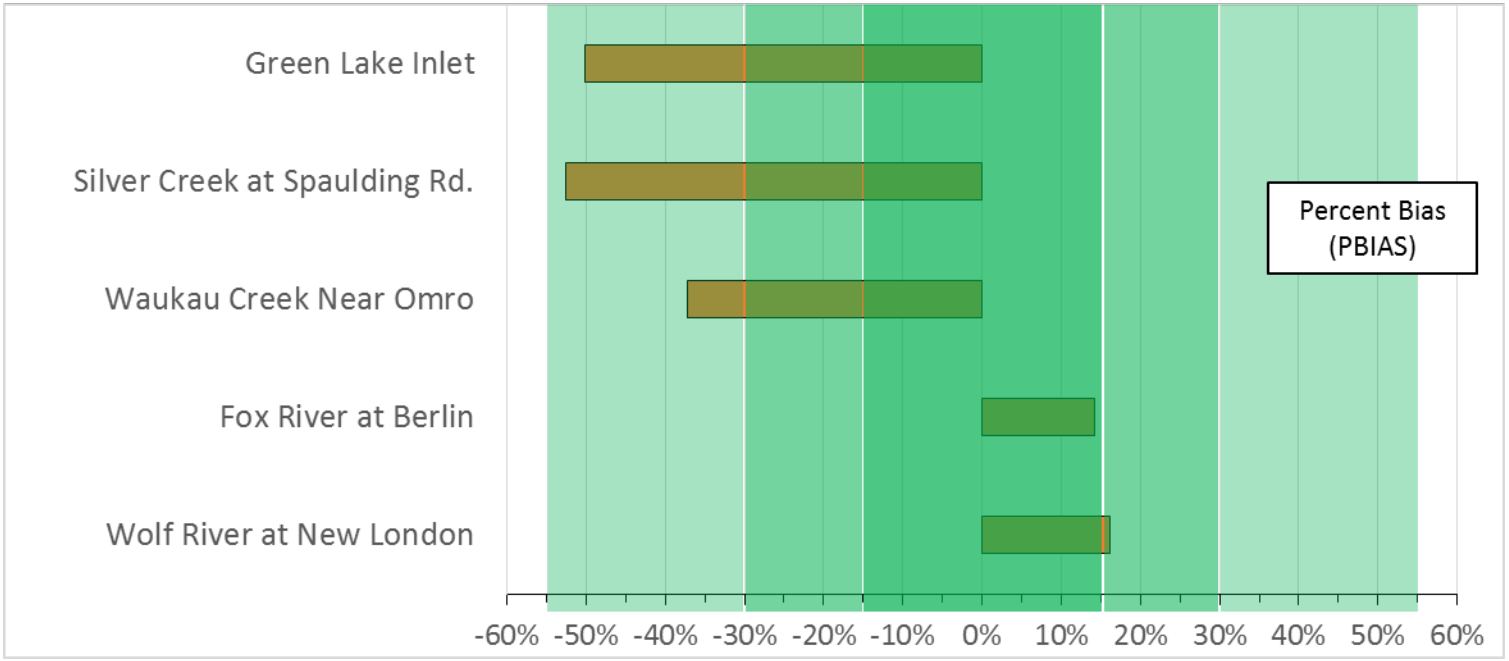
Sediment Calibration Results





Sediment Validation Results



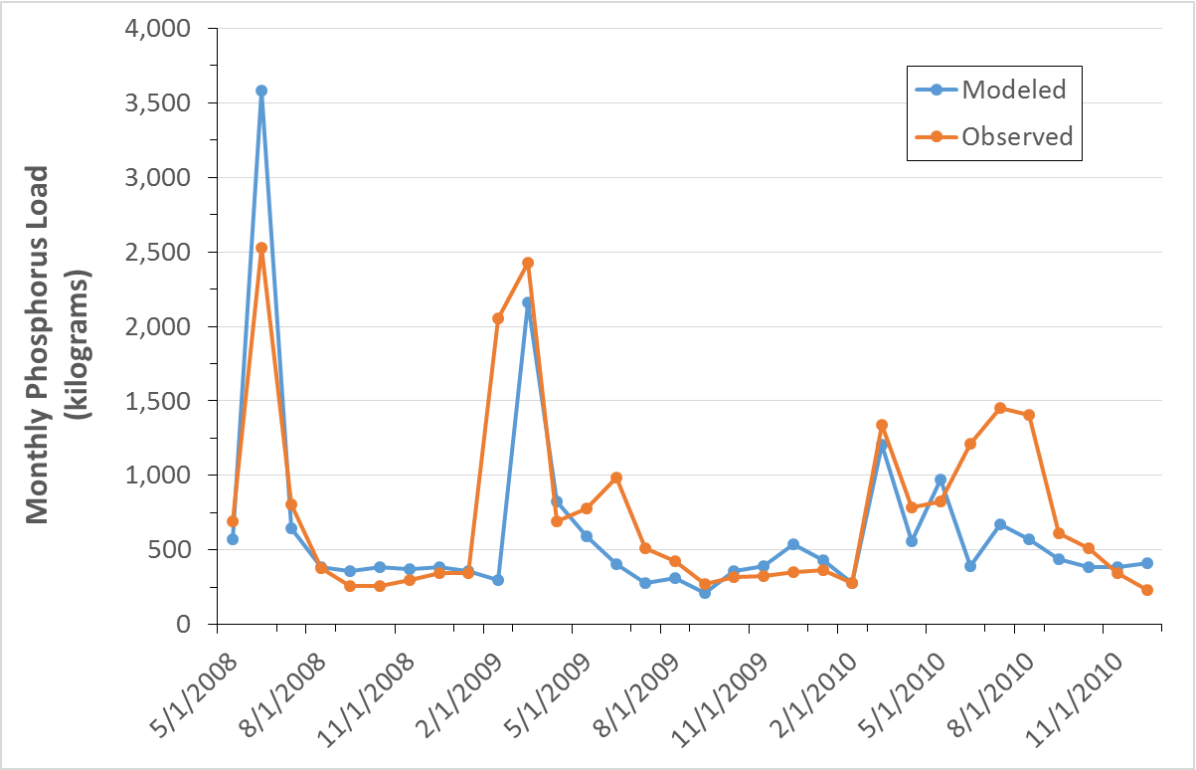


Phosphorus Calibration

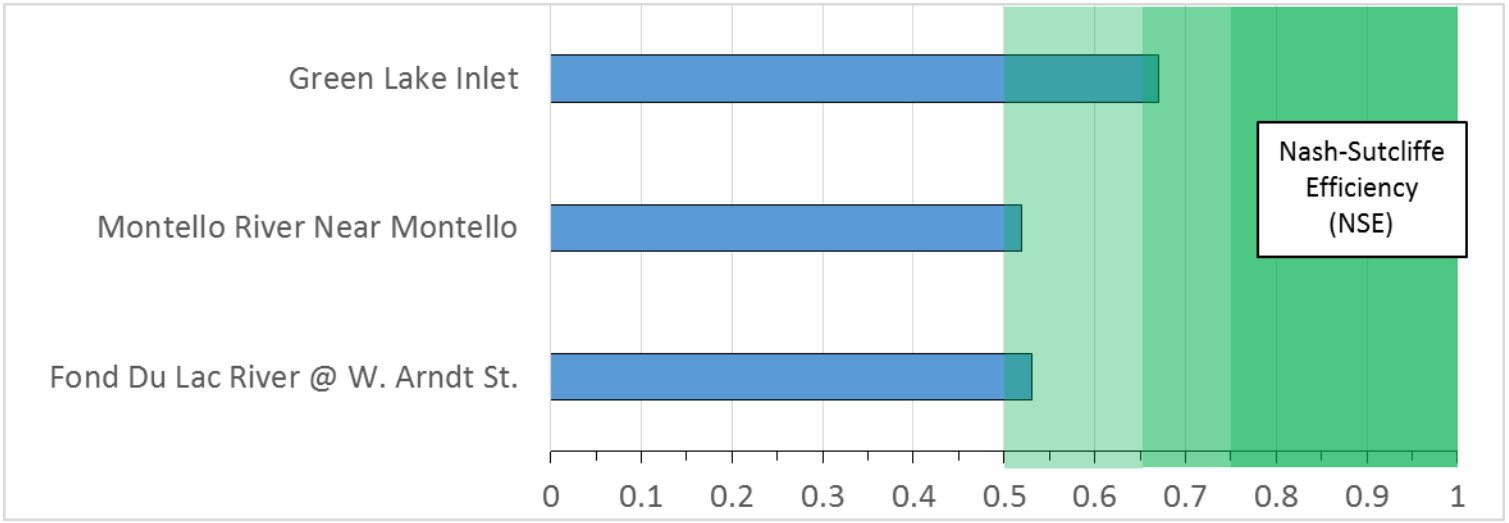
- Sensitive parameters affect phosphorus availability for washoff and routing through stream channels/wetlands

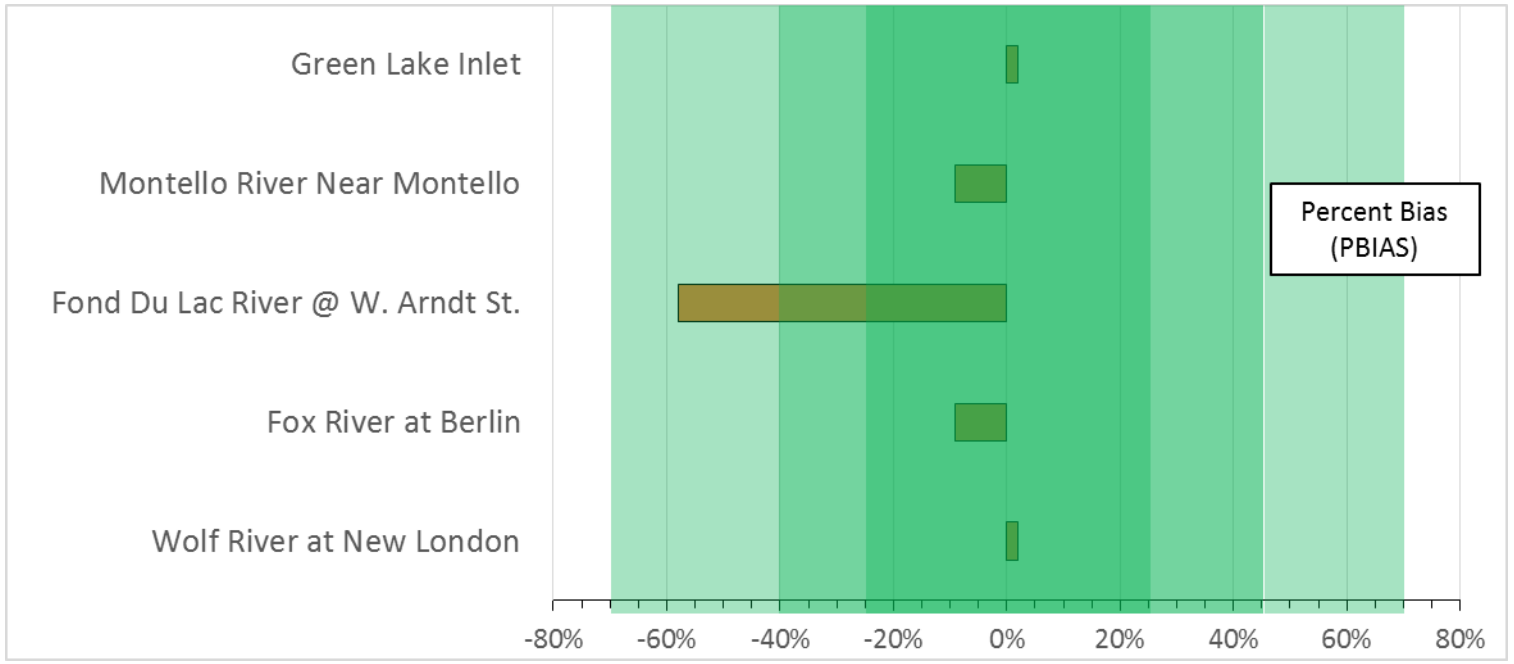
Parameter Code	Description
PSP	Phosphorus availability index
PHOSKD	Phosphorus soil partitioning coefficient
P_UPDIS	Phosphorus uptake distribution parameter
RSDCO	Residue Decomposition Coefficient
RS2, R25	Channel bedload phosphorus parameters
PSETLW1, PSETLW2	Phosphorus settling rate in wetlands

Montello River Near Montello
NSE= 0.52
PBIAS = -9%

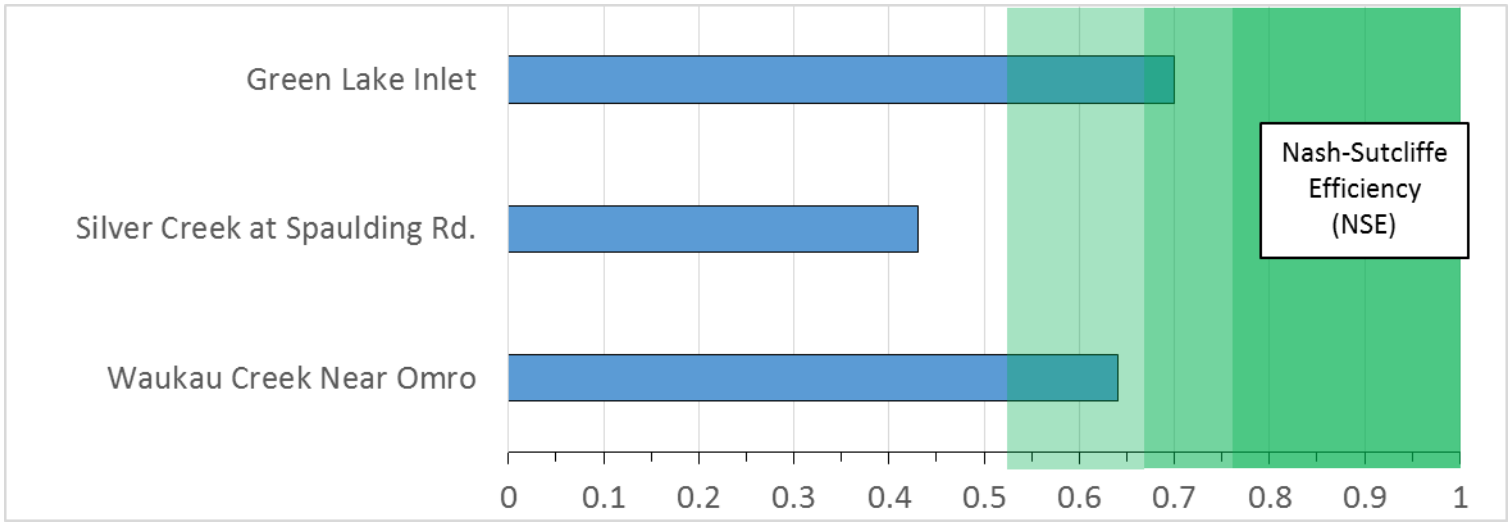


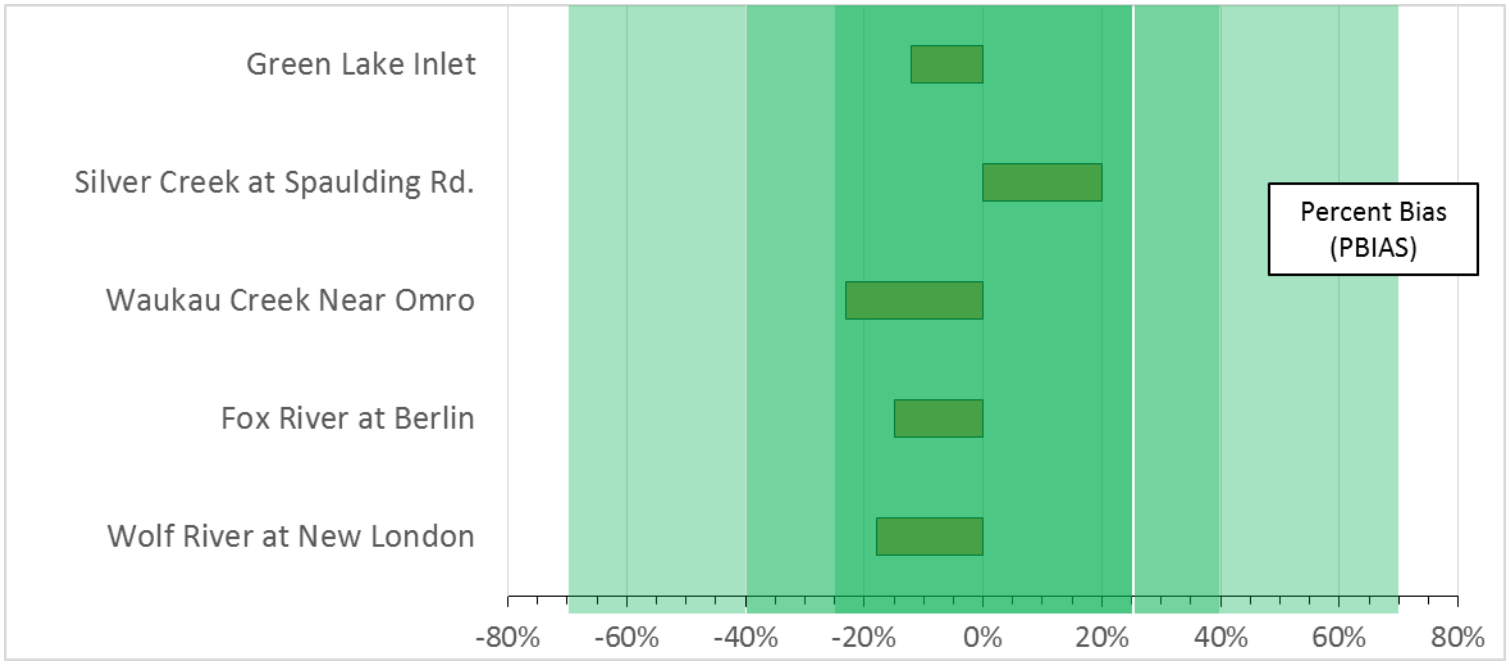
Phosphorus Calibration Results





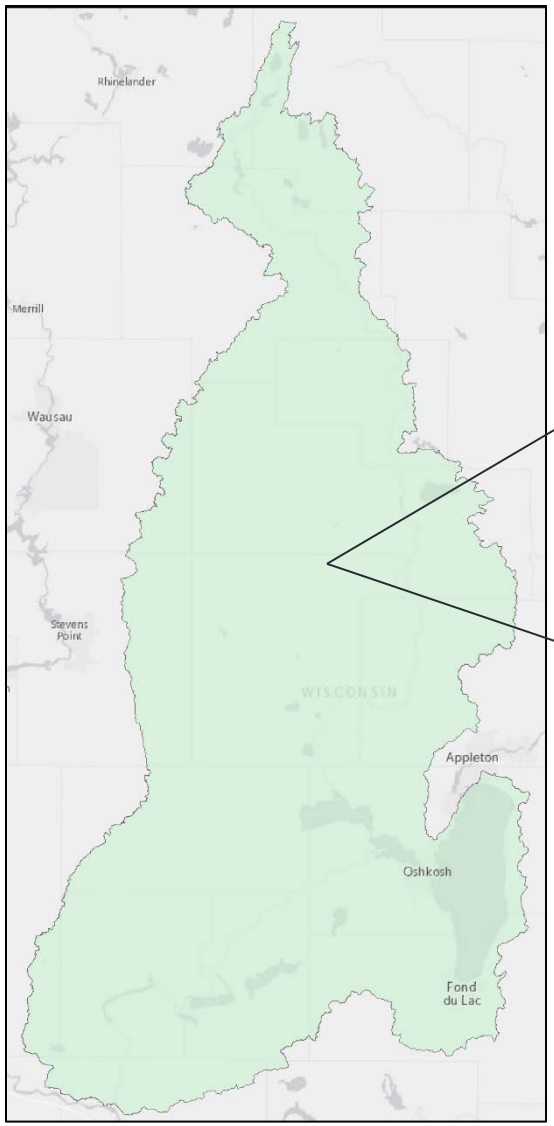
Phosphorus Validation Results

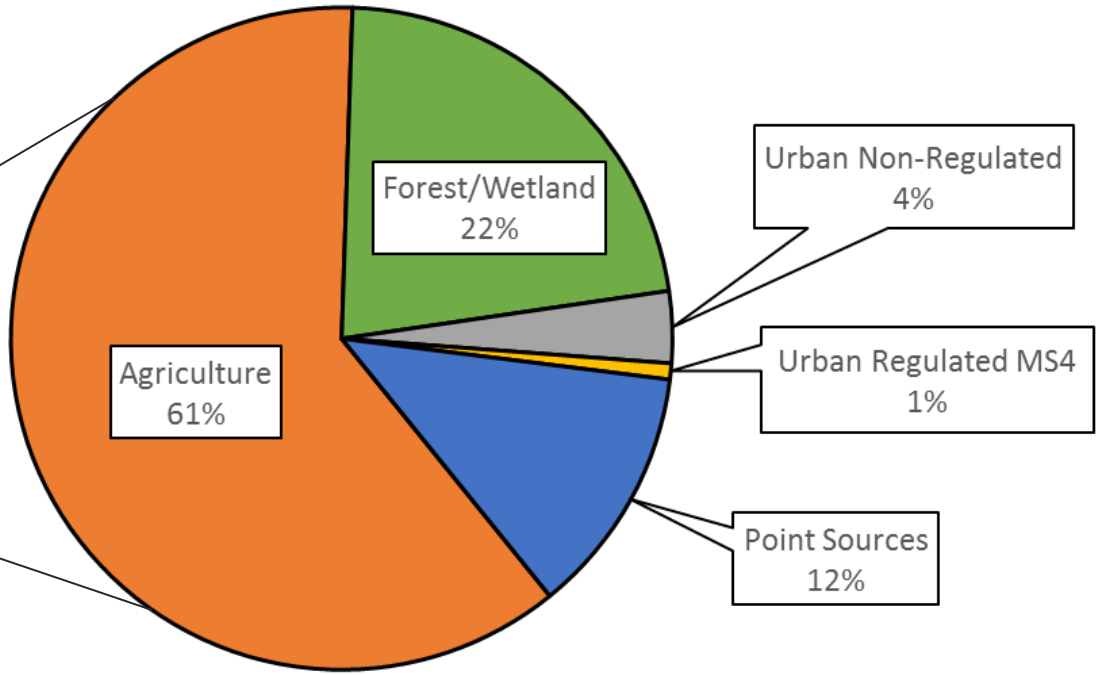


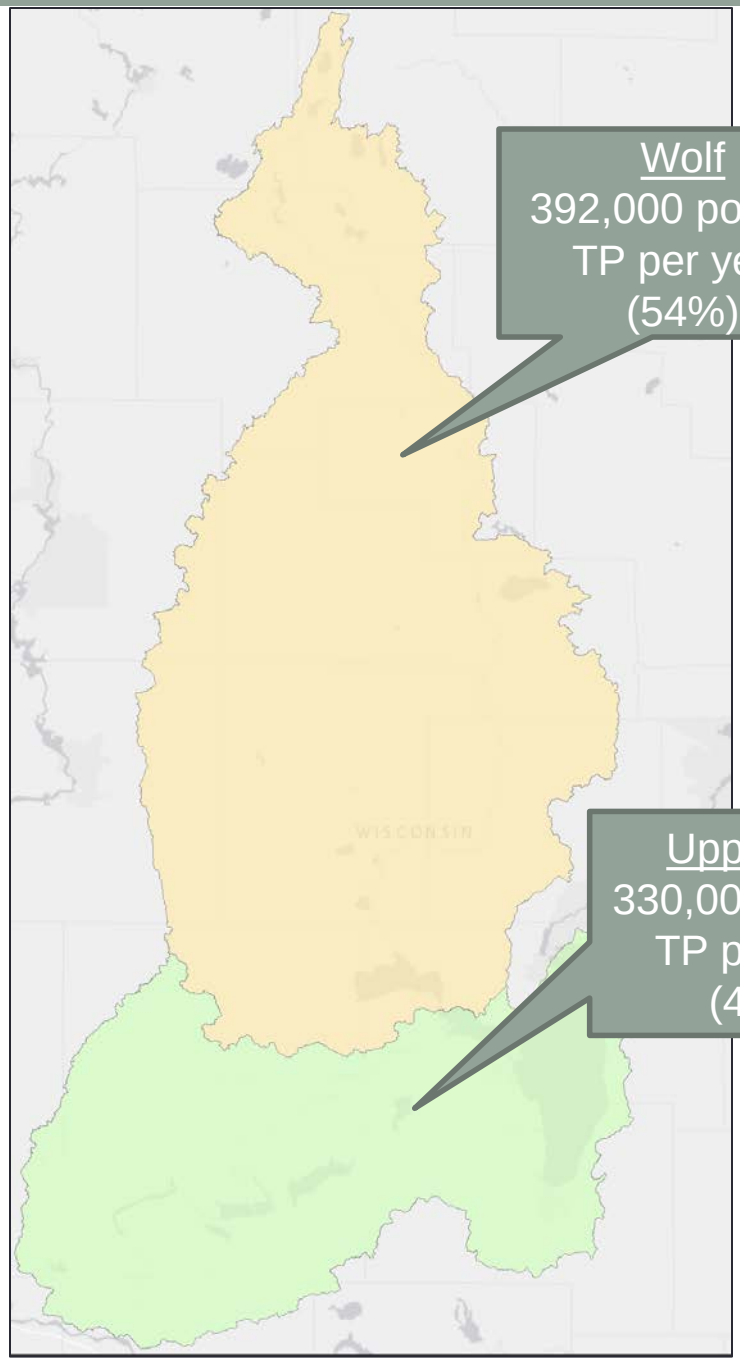


SWAT Model Results - Phosphorus

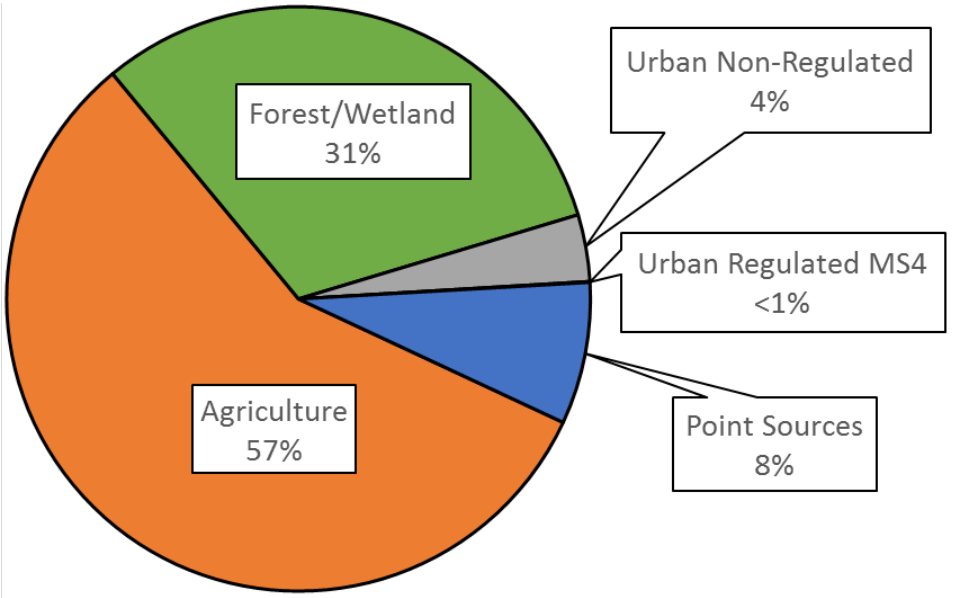
- Basin-wide 2000-2013 Annual TP Load = 722,000 Pounds



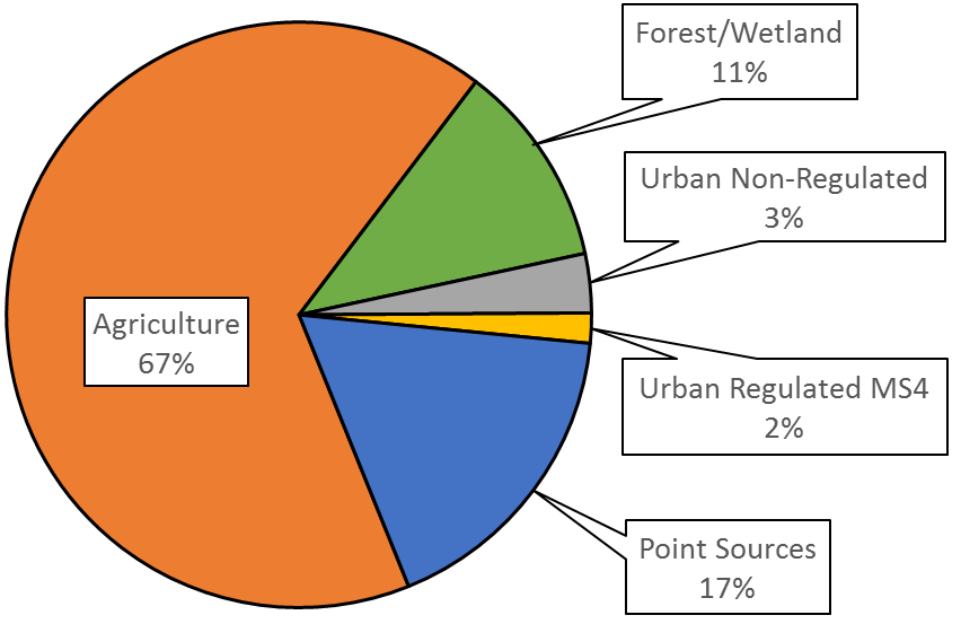


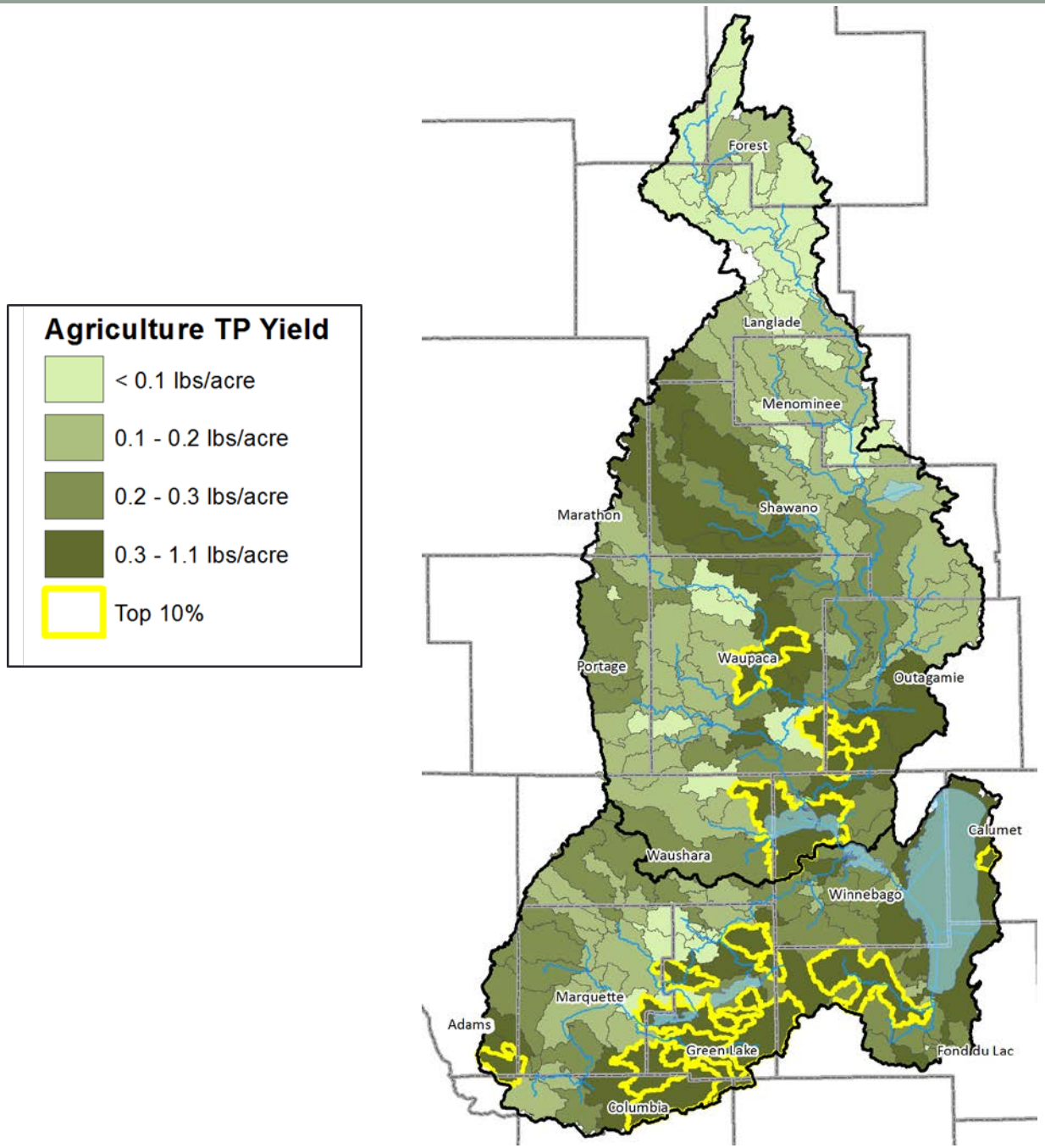


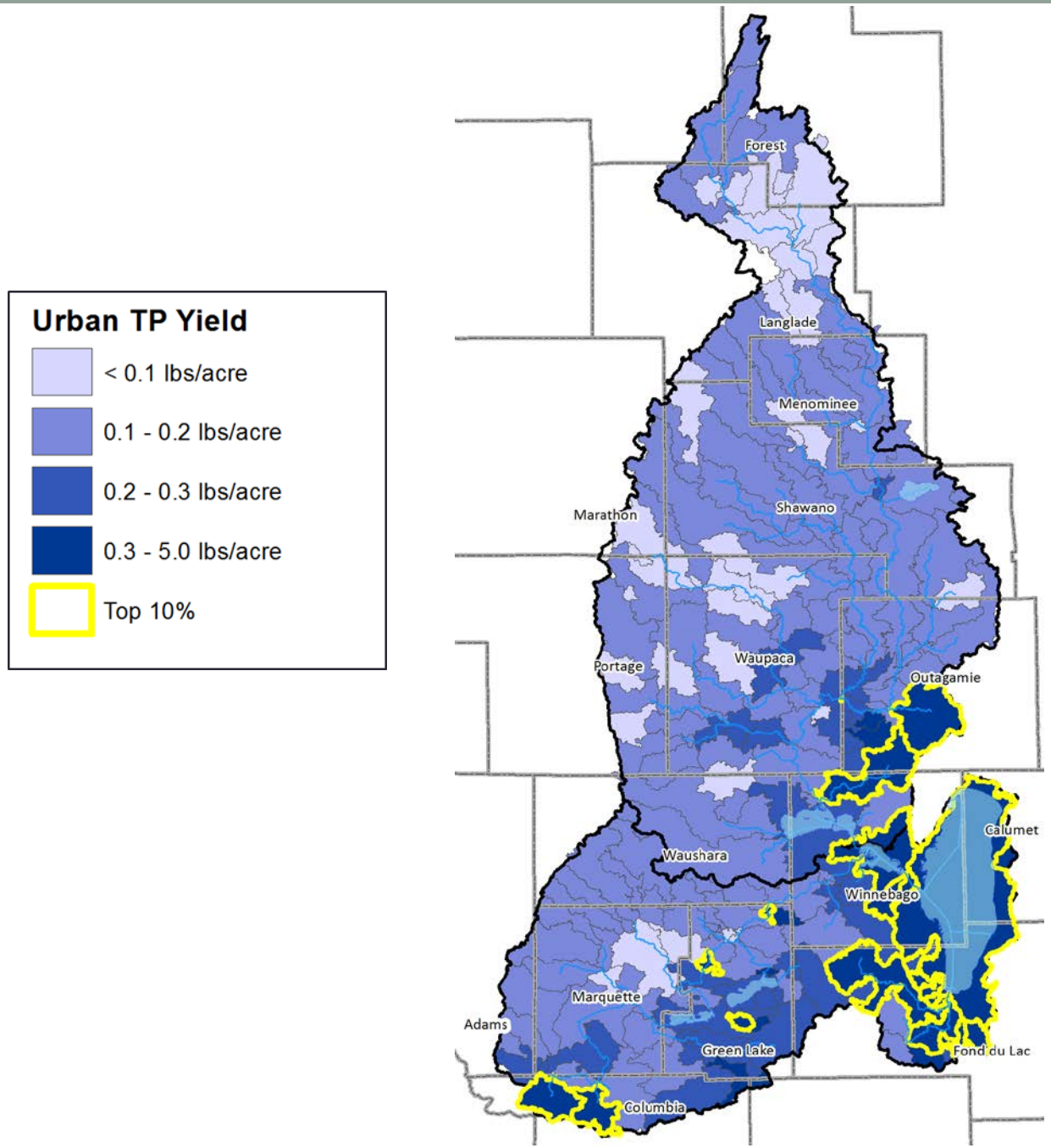
Wolf
392,000 pounds TP per year (54%)



Upper Fox
330,000 pounds TP per year (46%)

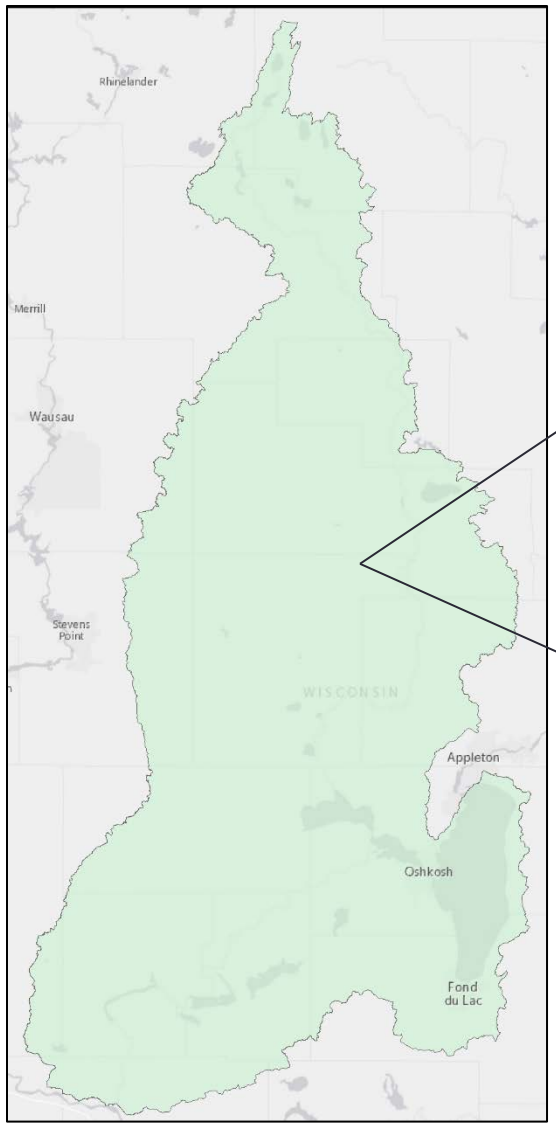


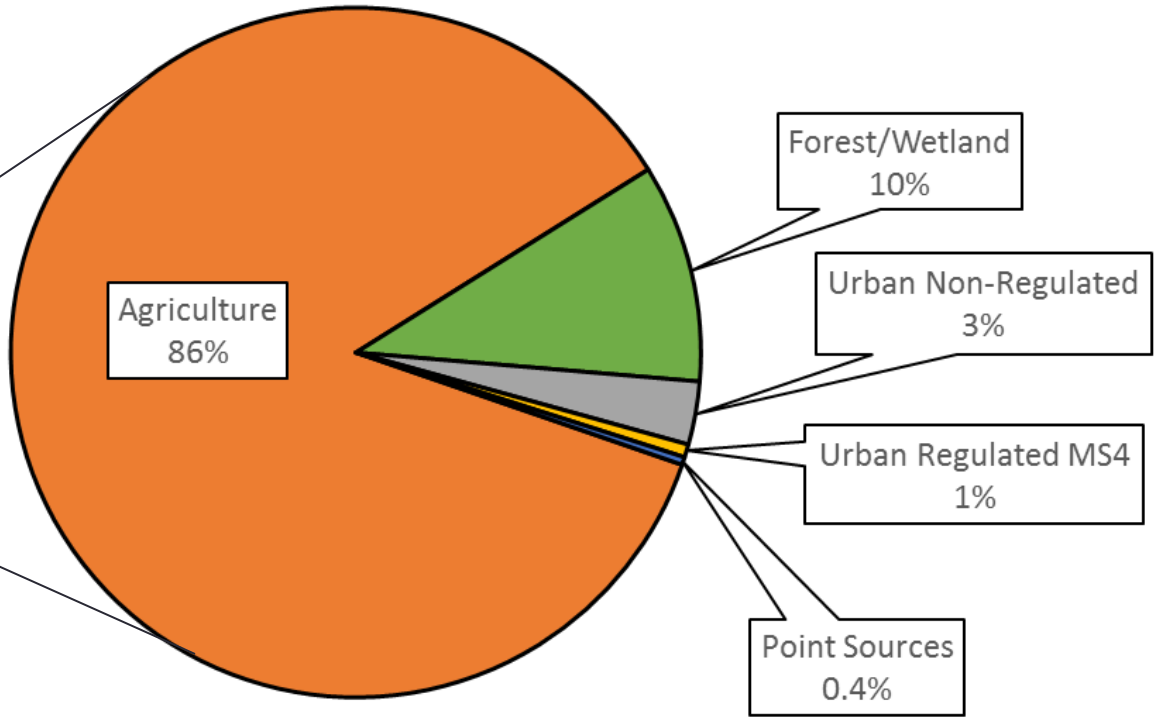

Agriculture TP Yield
< 0.1 lbs/acre
0.1 - 0.2 lbs/acre
0.2 - 0.3 lbs/acre
0.3 - 1.1 lbs/acre
Top 10%
Forest
Langlade
Menominee
Marathon
Shawano
Portage
Waupaca
Outagamie
Calumet
Waushara
Winnebago
Marquette
Adams
Green Lake
Fond du Lac
Columbia

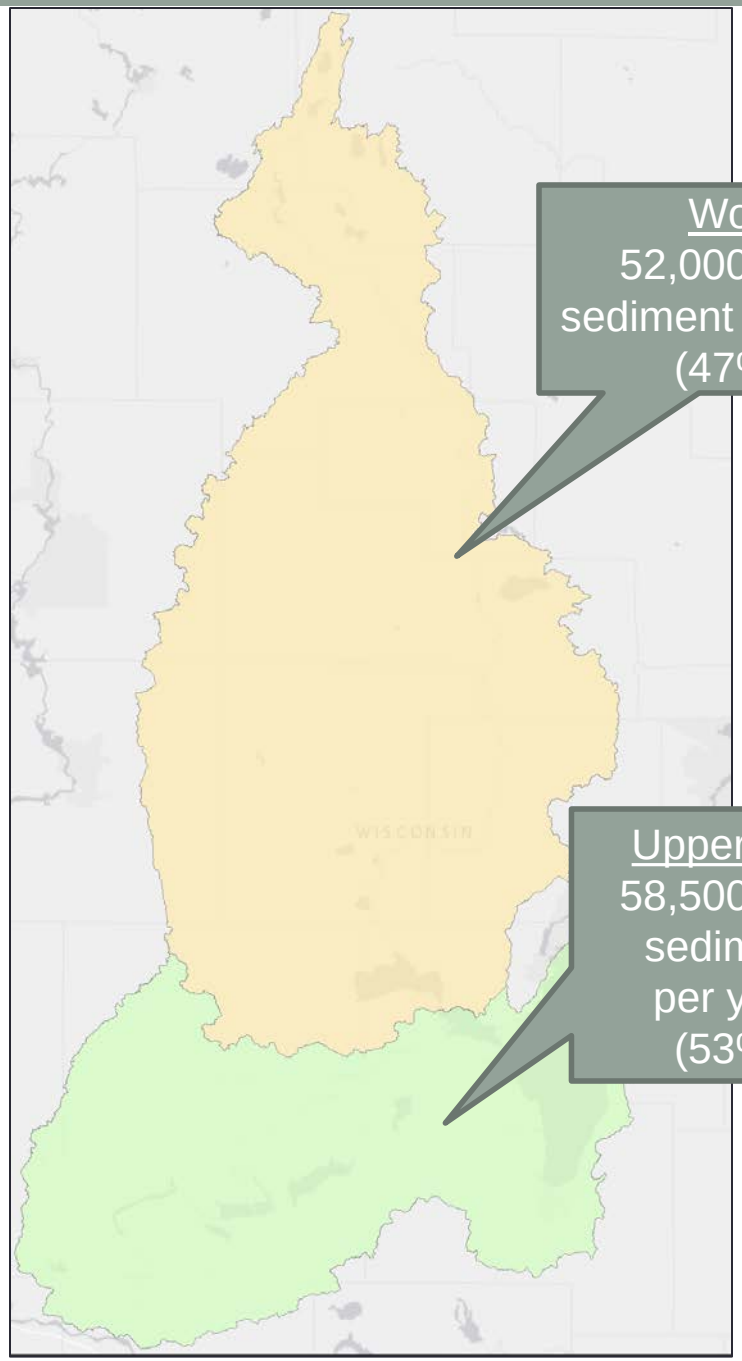

Urban TP Yield
< 0.1 lbs/acre
0.1 - 0.2 lbs/acre
0.2 - 0.3 lbs/acre
0.3 - 5.0 lbs/acre
Top 10%
Forest
Langlade
Menominee
Marathon
Shawano
Portage
Waupaca
Outagamie
Calumet
Waushara
Winnebago
Marquette
Adams
Green Lake
Fond du Lac
Columbia

SWAT Model Results - Sediment

- Basin-wide 2000-2013 Annual Sediment Load = 110,500 Tons

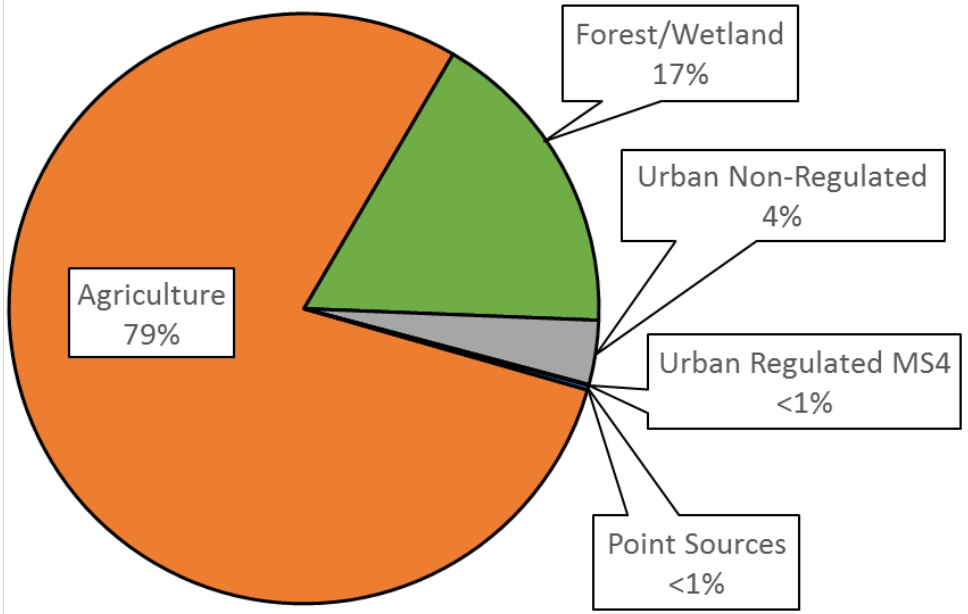


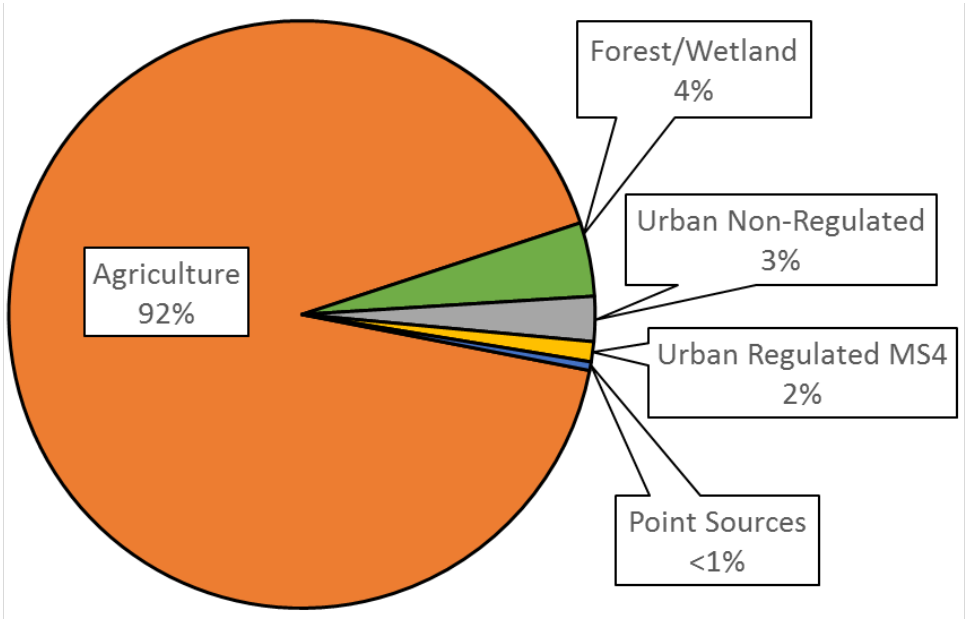


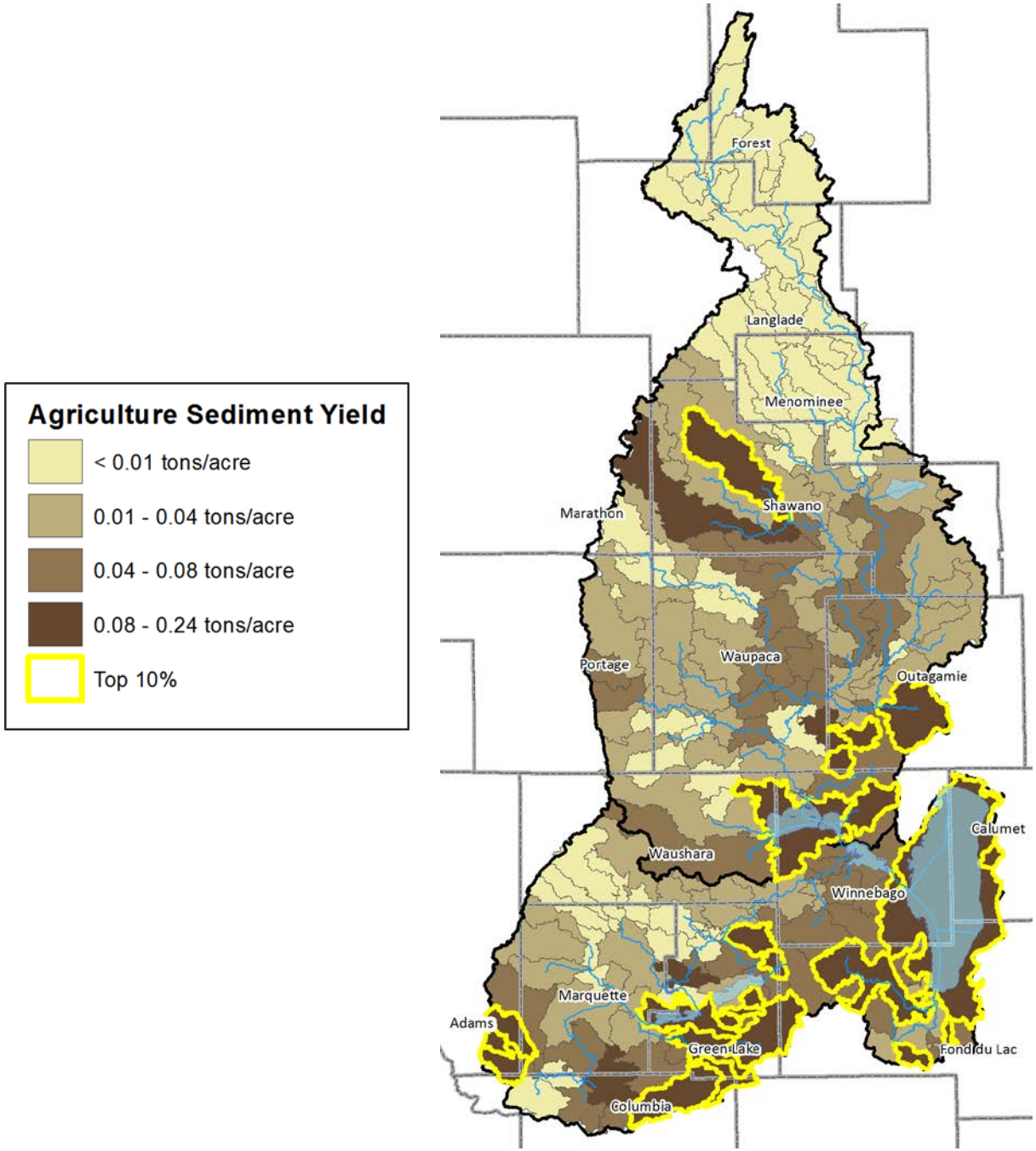


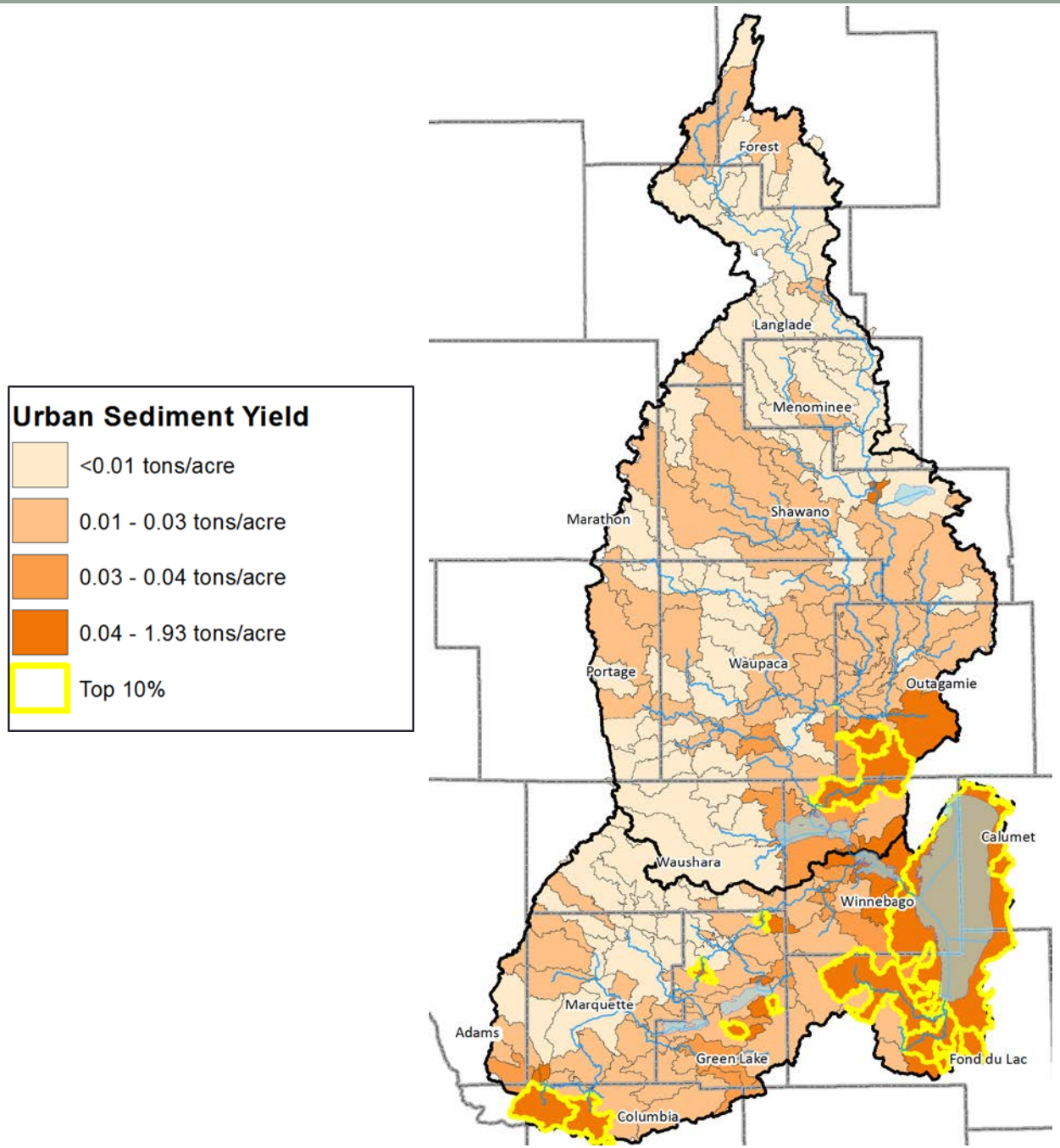
Wolf
52,000 tons sediment per year (47%)

Upper Fox
58,500 tons sediment per year (53%)






Agriculture Sediment Yield
< 0.01 tons/acre
0.01 - 0.04 tons/acre
0.04 - 0.08 tons/acre
0.08 - 0.24 tons/acre
Top 10%
Forest
Langlade
Menominee
Marathon
Shawano
Portage
Waupaca
Outagamie
Calumet
Waushara
Winnebago
Marquette
Adams
Green Lake
Fond du Lac
Columbia


Urban Sediment Yield
<0.01 tons/acre
0.01 - 0.03 tons/acre
0.03 - 0.04 tons/acre
0.04 - 1.93 tons/acre
Top 10%
Forest
Langlade
Menominee
Marathon
Shawano
Portage
Waupaca
Outagamie
Calumet
Waushara
Winnebago
Marquette
Adams
Green Lake
Fond du Lac
Columbia

Next Steps…

- Calculate sediment and phosphorus loading capacity for each SWAT subwatershed.
  - Maximum load while still achieving water quality standards.
  - Use SWAT flow predictions and phosphorus/sediment concentration targets.
- Allocate loading capacity to sources of phosphorus and sediment.

Questions?