Fox Illinois River Basin TMDL Watershed Modeling

A Framework for Surface Water Quality Improvement

September 25, 2024

Online Webinar

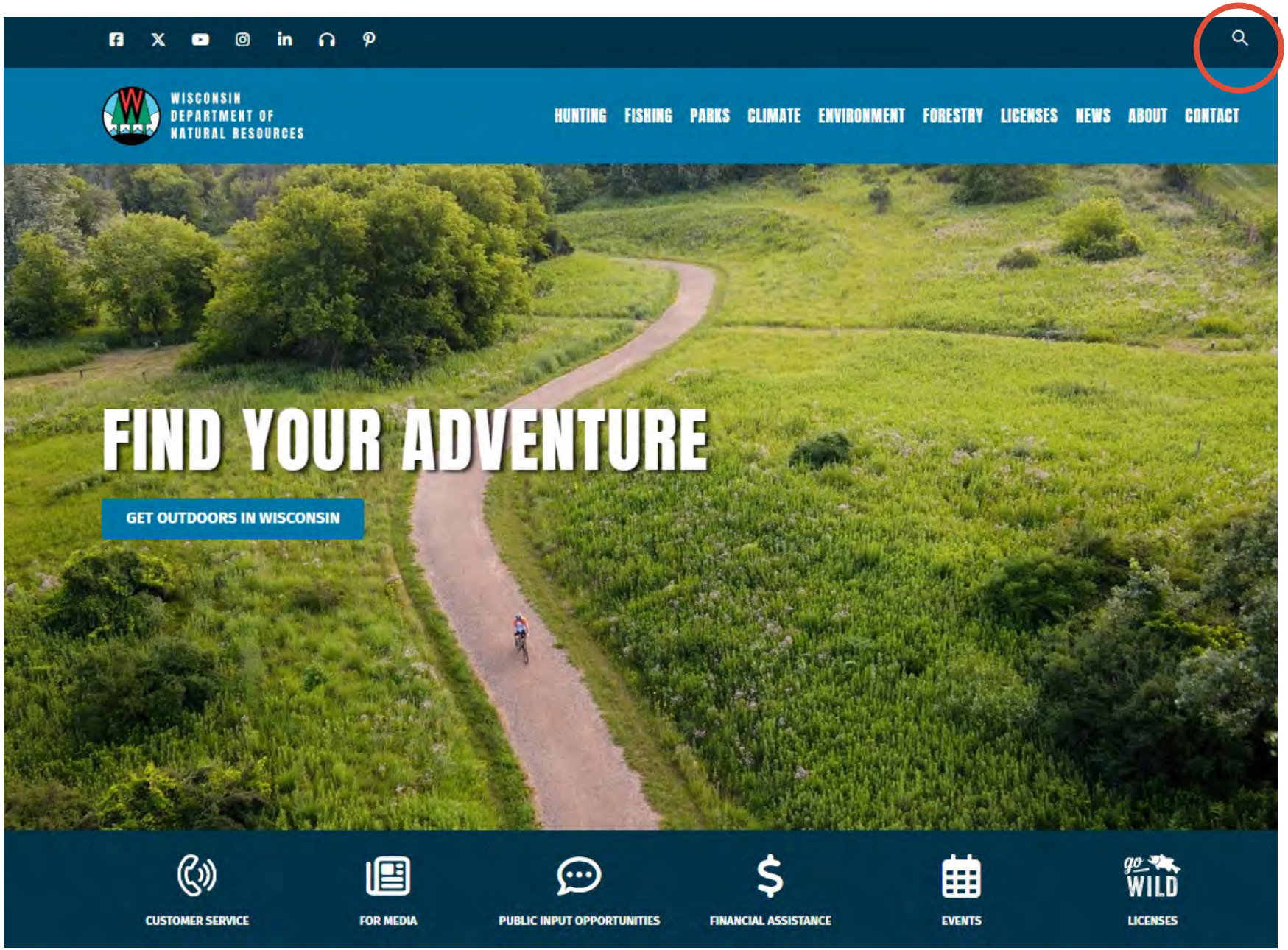
Today's Format

- Introductions
- Presentation covering the development, calibration, and validation of the watershed model
- Panel to address questions

- Both the recorded presentation and slides will be available on the DNR website

https://dnr.wi.gov/topic/TMDLs/FoxIllinois.html

or search "Fox Illinois River TMDL"



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Click magnifying glass and type “Fox Illinois River TMDL” into the search bar

WISCONSIN DEPARTMENT OF NATURAL RESOURCES

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» TOPIC » TMDLS

FOX ILLINOIS RIVER BASIN TMDL

A FRAMEWORK FOR WATER QUALITY IMPROVEMENT

Fox River at Waterford

Total Maximum Daily Loads (TMDLs)

- Overview
- TMDLs In Development
- Approved TMDLs
- Implementation
- Point Source
- Nonpoint Source
- Map and Projects

For more information, contact:

Eric Hettler
TMDL Modeler
Water Quality Program

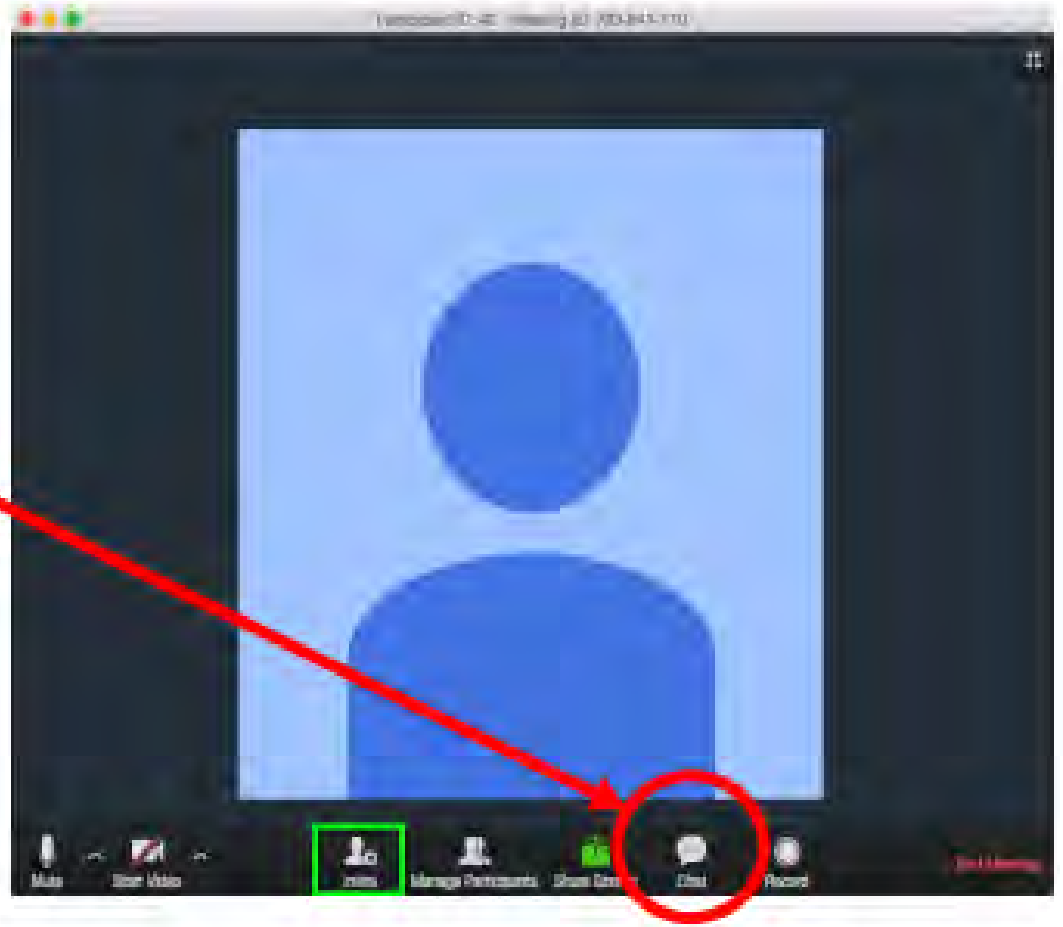
GovDelivery Sign-up

Subscribe to receive updates about the Fox Illinois River Basin TMDL.

Zoom

Click **Chat** in the meeting controls.

NOTE: If don't see controls, tap screen and they will pop up.



Kevin Kirsch
Statewide TMDL Coordinator

Eric Hettler, PE
TMDL Modeler

Aaron Fisch
Water Quality Modeler

DNR Project Team and Sector Leads

Project Coordination: Eric Hettler[1] & Kevin Kirsch[1]

Monitoring: Rachel Sabre[1]

Wastewater: Nick Lent[1] & Nicole Krueger[1]

Stormwater: Samantha Katt[2] & Pete Wood[2]

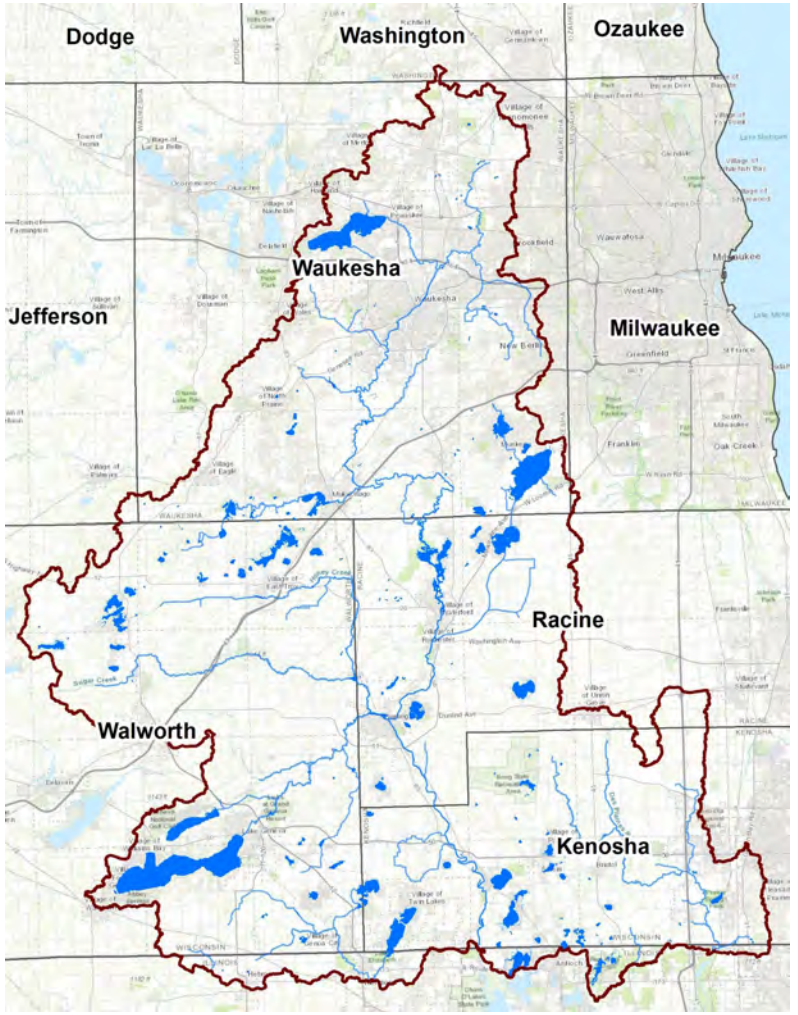
Agriculture & Urban Nonpoint: Jesse Bennett[2]

Modeling: Eric Hettler[1]

1. Bureau of Water Quality (WY)
2. Bureau of Watershed Management (WT)

Key Partners in the TMDL Development Process

SEWRPC
Serving the counties of Kenosha, Milwaukee, Ozaukee, Racine, Walworth, Washington, and Waukesha



Presentation Outline

Fox Illinois River Basin TMDL Background

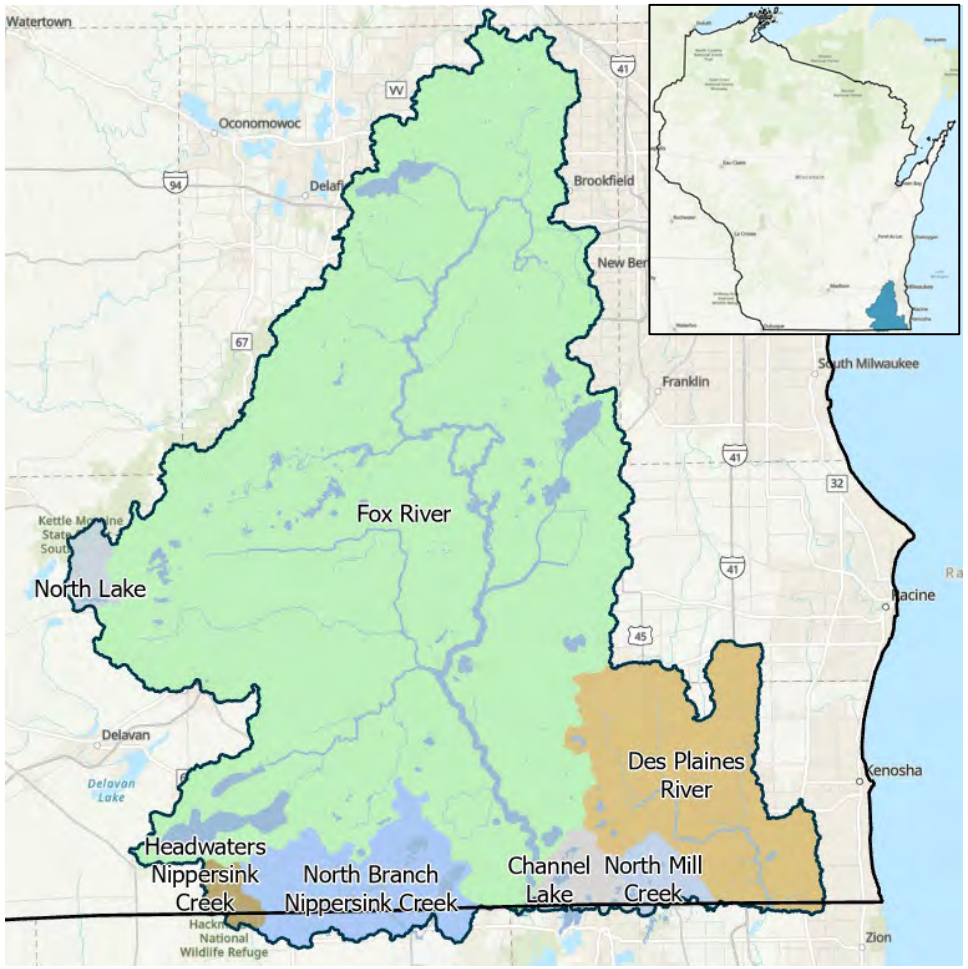
TMDL Model Development

- Monitoring
- Conceptualization
- Model Setup
- Model Validation/Calibration
- Model Performance and Results

Next Steps: Allocation and Implementation

Fox Illinois River Basin TMDL Watershed Modeling

FOXIL TMDL Project Extents

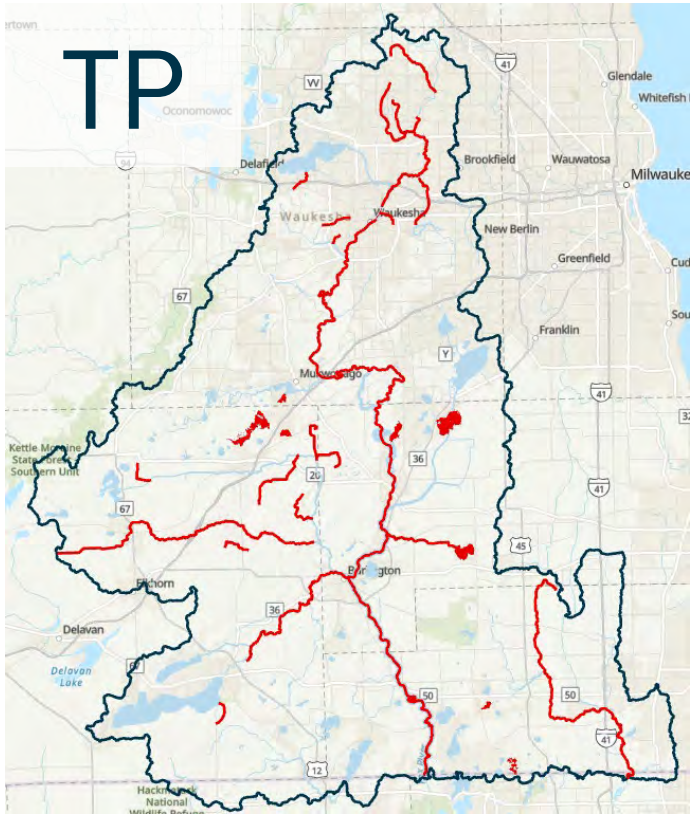


Located in Southeast Wisconsin

Seven Distinct Watersheds

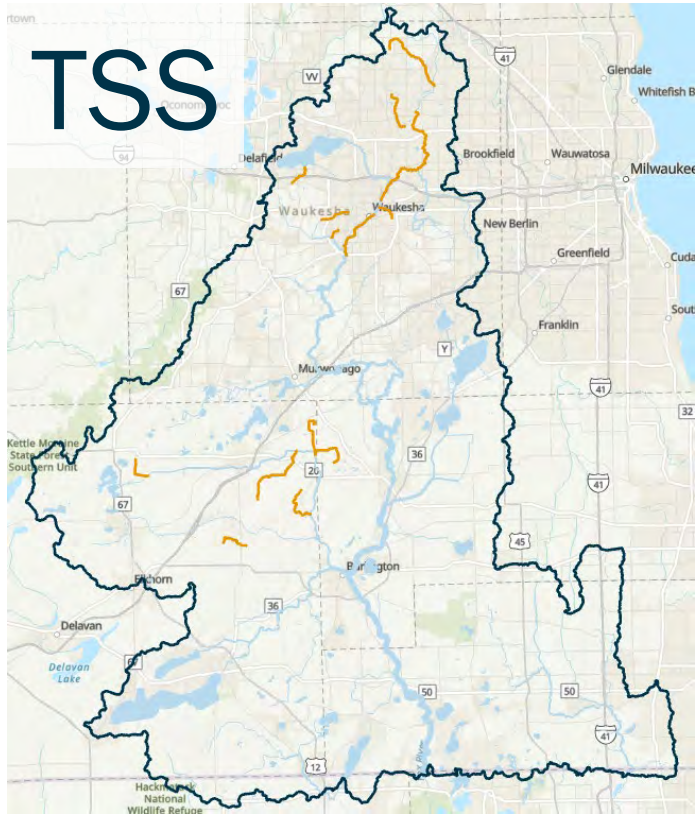
- Fox River
- North Lake
- Headwaters Nippersink Creek
- North Branch Nippersink Creek
- Channel Lake
- North Mill Creek
- Des Plaines River

TP & TSS Impairments – 303(d) List



11 named streams/rivers

9 lakes

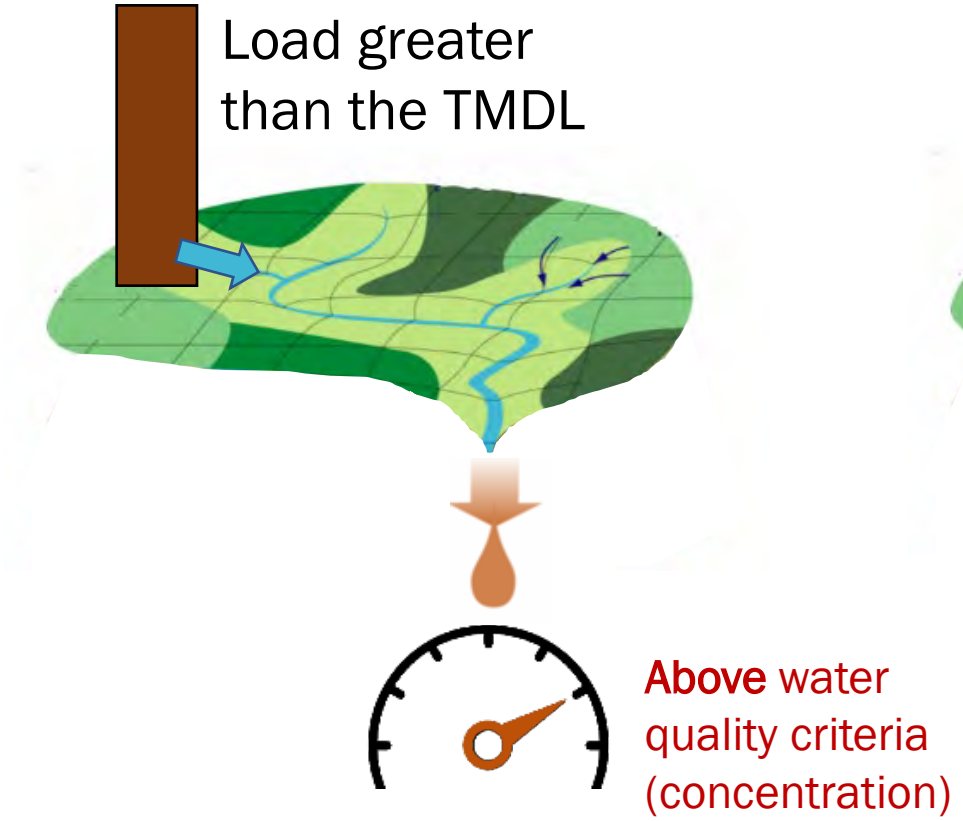


7 named streams/rivers

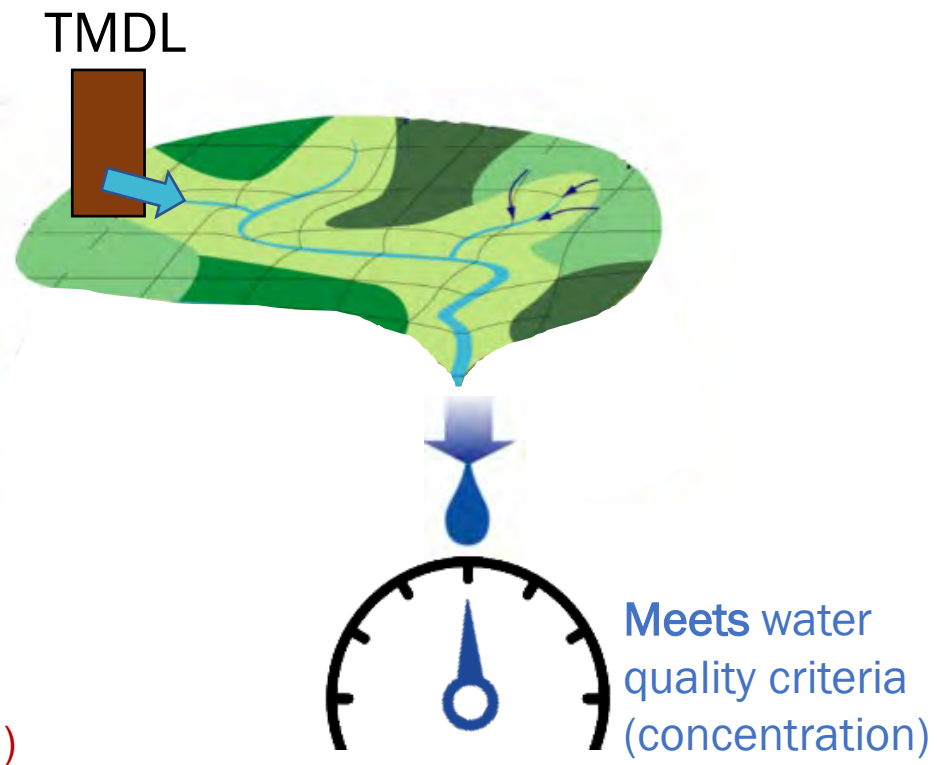
1 impoundment (Fox River)

Total Maximum Daily Load (TMDL)

TMDL: Amount of a pollutant a waterbody can receive and still meet water quality standards



Above water quality criteria (concentration)



Meets water quality criteria (concentration)

Total Maximum Daily Load (TMDL)

EPA requires that waters listed as impaired on Wisconsin's 303d list have TMDLs developed

TMDL =

Load Allocation

Nonpoint loads

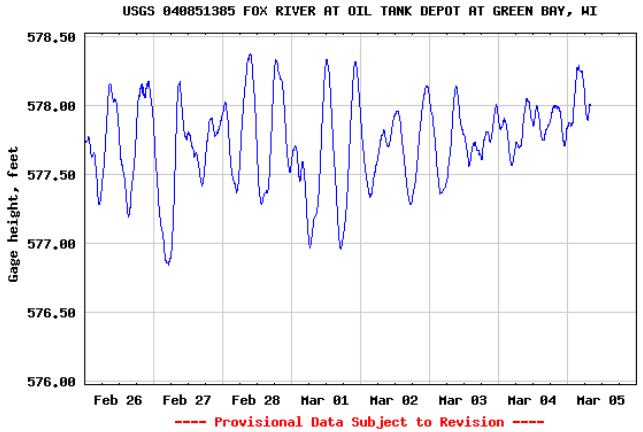
+

Wasteload Allocation

Permitted point sources

+

Margin of Safety



Modeling assumptions

Fox Illinois TMDL Development

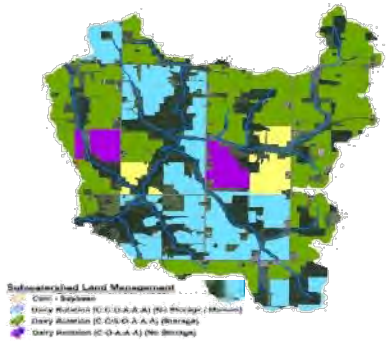
TMDL Development Overview

Monitoring
Conceptualization

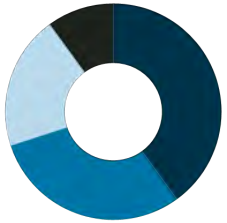
Modeling

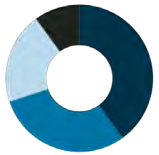
Allocations

Implementation



Baseline





TMDL

Monitoring

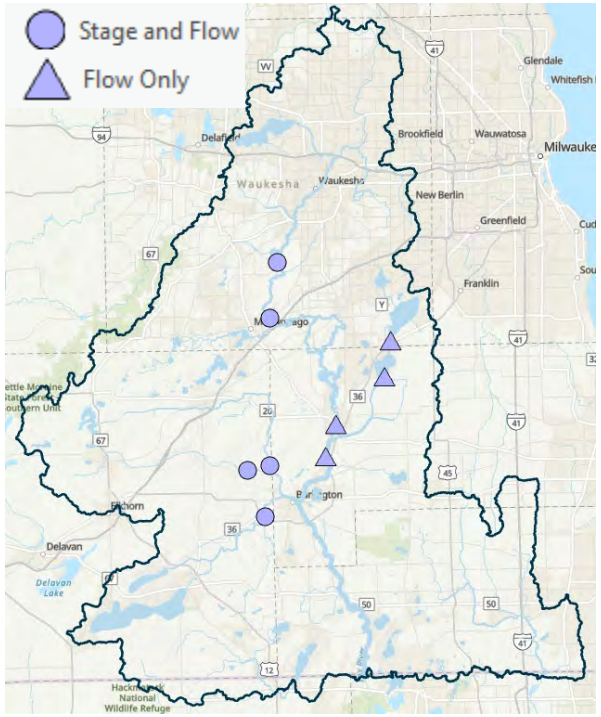

Monitoring
Conceptualization
Modeling
Allocations
Implementation

Stage and Flow Monitoring

Project-Specific Monitoring

Nov. 2019 – Jun. 2022

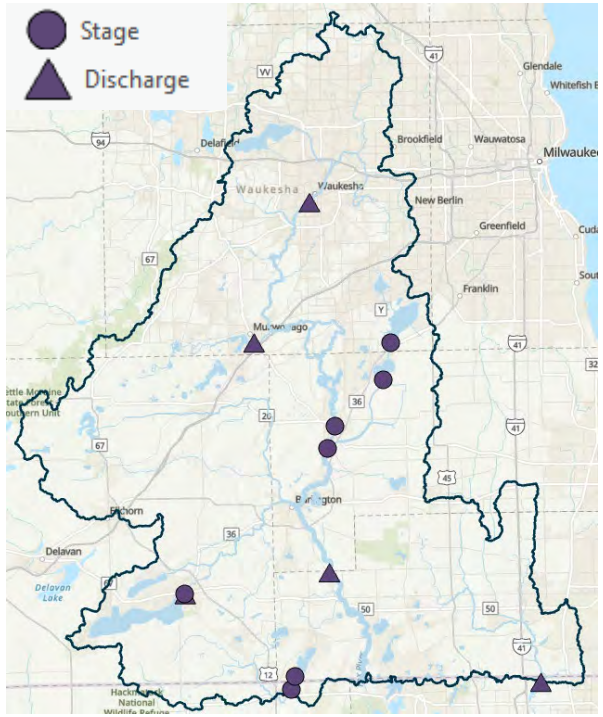
Continuous stage, periodic flow



USGS Monitoring Stations

2001-2022 *(where available)*

Stage and discharge

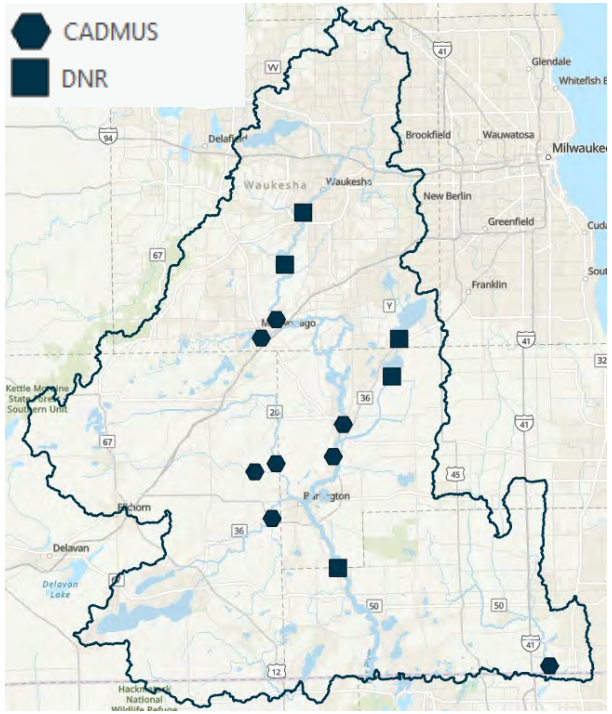


Chemistry Monitoring

Project-Specific Monitoring

Nov. 2019 – Jun. 2022

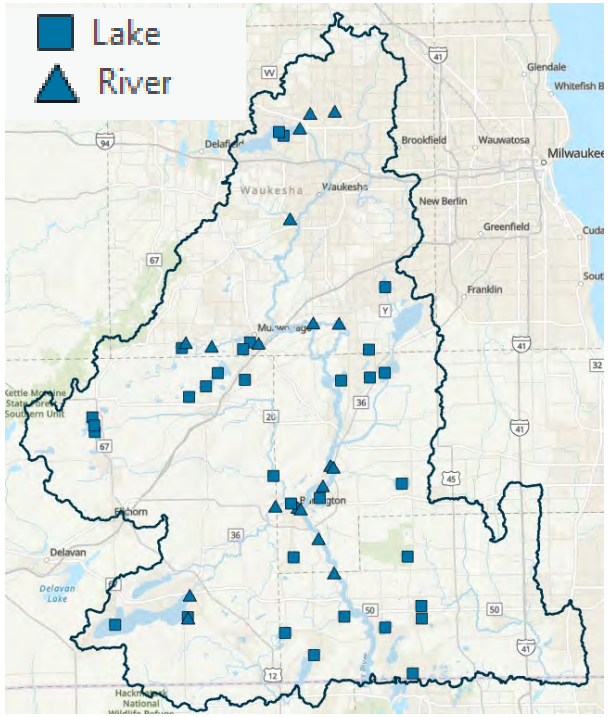
TP, TSS, Ortho-P



Supplemental Data

Availability varies

TP, TSS, Ortho-P



Calibration and Validation Datasets

Draft Calibration and Validation Dataset Report

Contents:

Summary of monitoring efforts

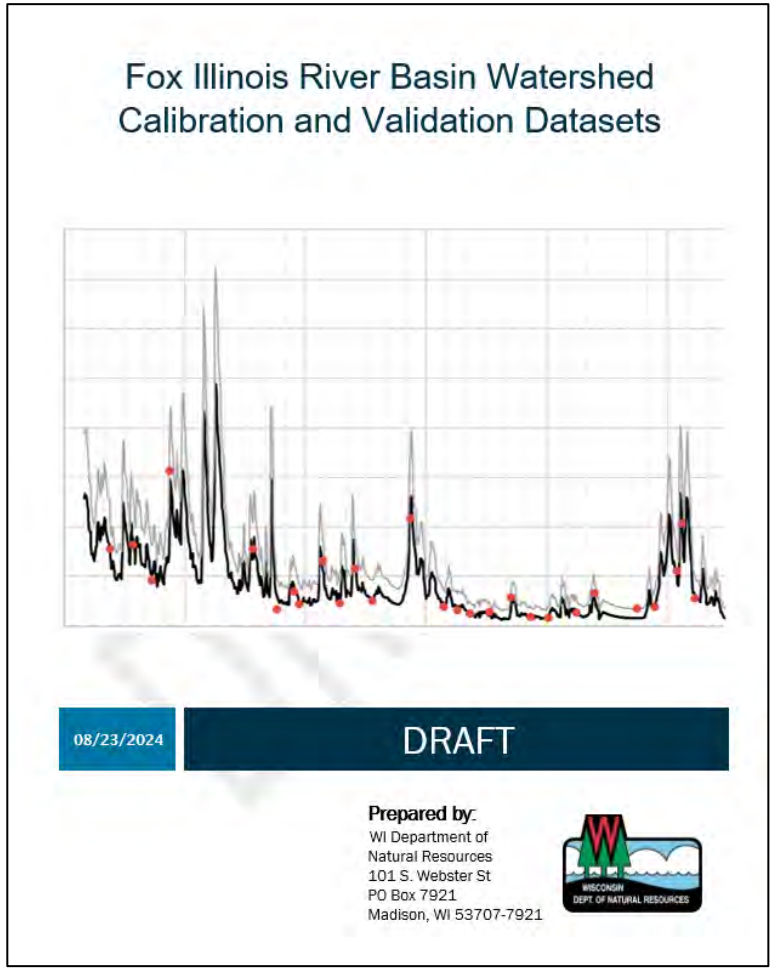
Estimation of continuous flows

Estimation of daily flux/load

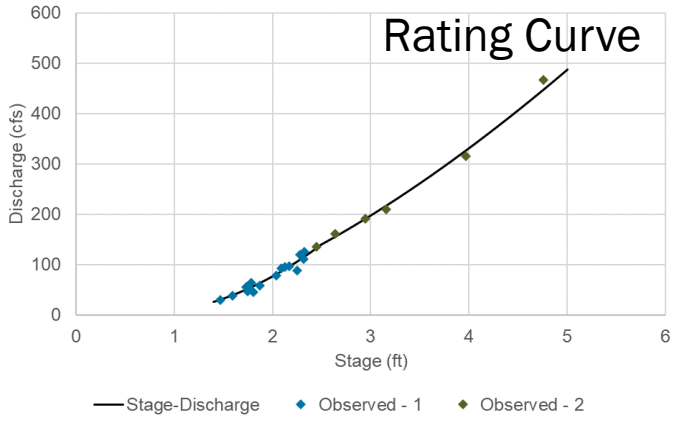
Outcome:

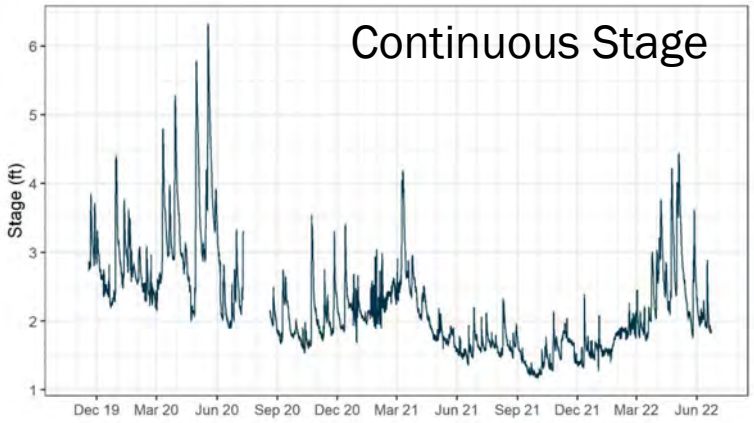
Continuous dataset of **flow** and **load**

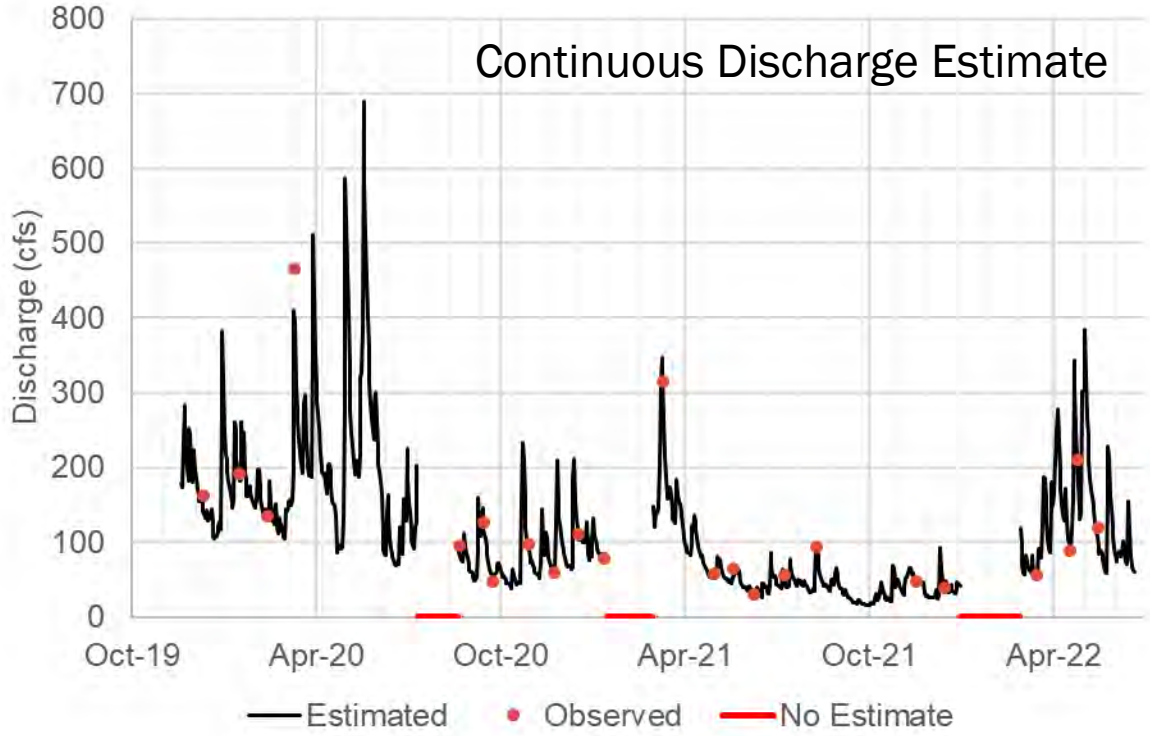
Report will be posted on Fox Illinois River TMDL website for review and feedback



Continuous Flow Dataset: Rating Curves

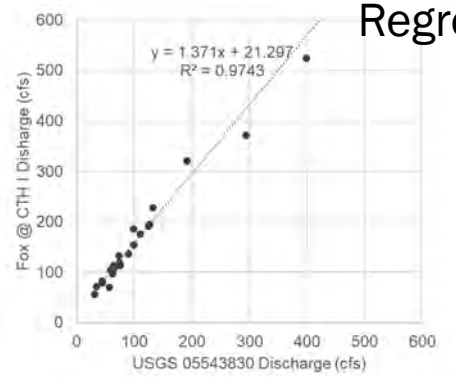




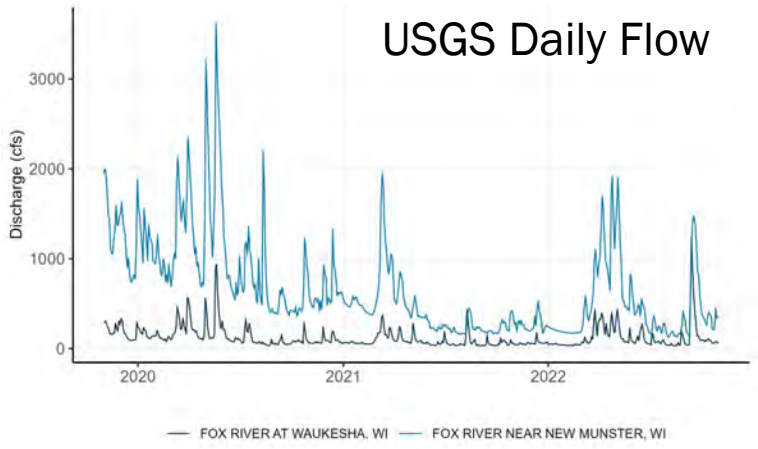


Continuous Flow Dataset: Regression

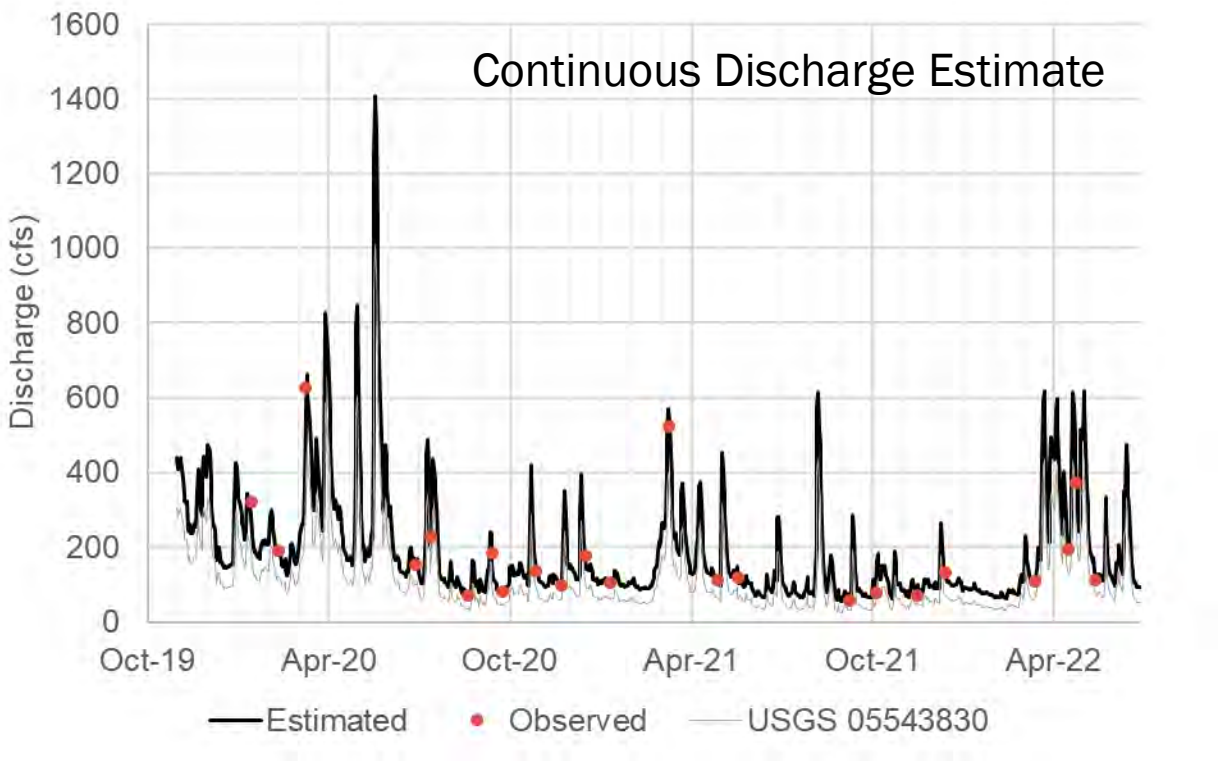
Regression Curve



USGS Daily Flow



Continuous Discharge Estimate

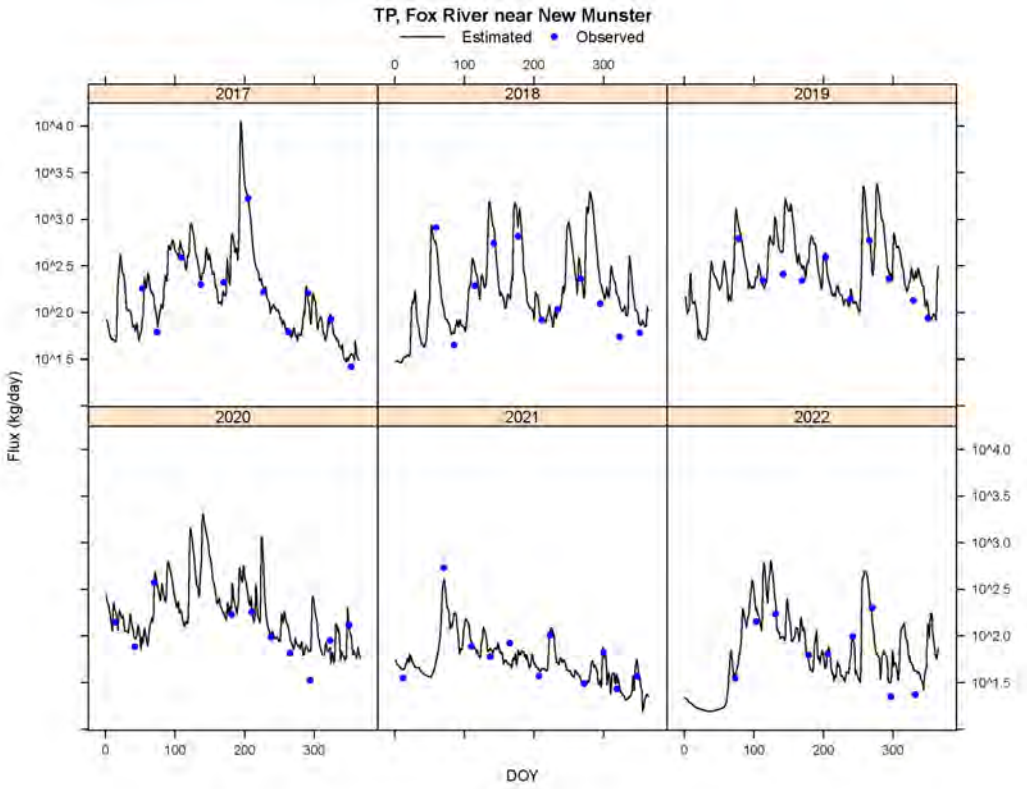


Continuous Load Dataset: Flux Models

Approach: Linear Mixed Effects model based on modified LOADEST

**Developed by Aaron Fisch at WDNR*

Outcome: Continuous flux dataset from continuous flow data and periodic monitoring data



$$\ln(\boldsymbol{\rho}_m) = \beta_0 + [\beta_f] * \begin{bmatrix} \ln(\boldsymbol{Q_m}) \\ \ln(\boldsymbol{Q_m^2}) \\ \sin(2\pi \boldsymbol{T_m}) \\ \cos(2\pi \boldsymbol{T_m}) \end{bmatrix} + \gamma_0 + [\gamma_{f,m}] * \begin{bmatrix} \ln(\boldsymbol{Q_m}) \\ \ln(\boldsymbol{Q_m^2}) \\ \sin(2\pi \boldsymbol{T_m}) \\ \cos(2\pi \boldsymbol{T_m}) \end{bmatrix} + \boldsymbol{e}_m$$

Conceptualization

TMDL Process: Conceptualization

What's happening in the watershed?

- Point sources
- Land use/management
- Climate
- Soils, topography, slope
- Hydrography

Agricultural Survey

Agricultural Surveys

- Questions to summarize agricultural practices in HUC 12s
- Submitted to 4 counties

Topics

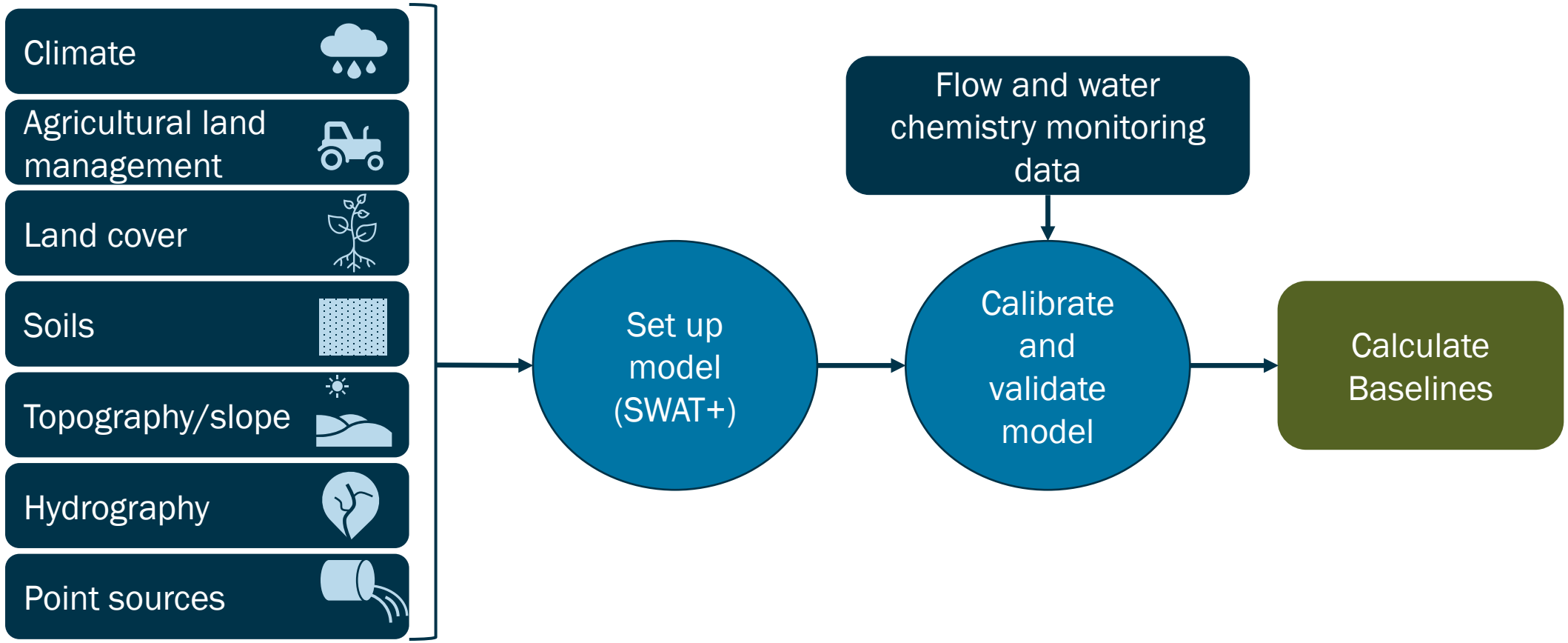
- Land use and land cover
- Crop rotations
- Tillage practices
- Soil phosphorus
- Fertilizer management
- Tile drainage

	Rotations with Tillage							
County	Dairy		Cash Grain		Cont. Corn		Sod	
Kenosha	D1-T2		CG-T5		CC-T1	CC-T3		
Racine	D1-T1	D1-T2	CG-T4	CG-T5			Sod	
Walworth	D1-T1	D2-T1	CG-T1	CG-T3	CC-T1			
Waukesha	D1-T2		CG-T1	CG-T5	CC-T1			

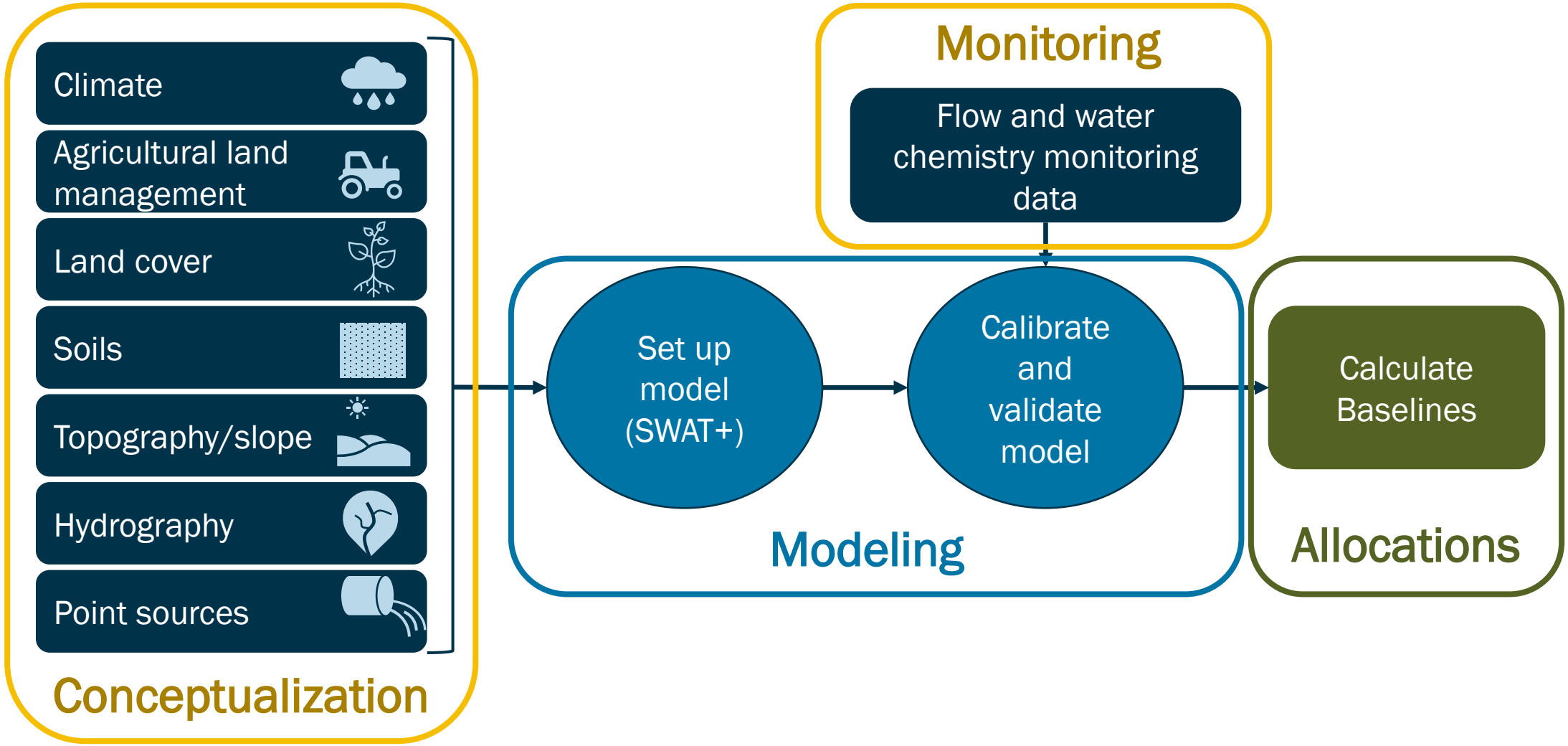
Modeling


Monitoring
Conceptualization
Modeling
Allocations
Implementation

Watershed Model Setup



Watershed Model Setup

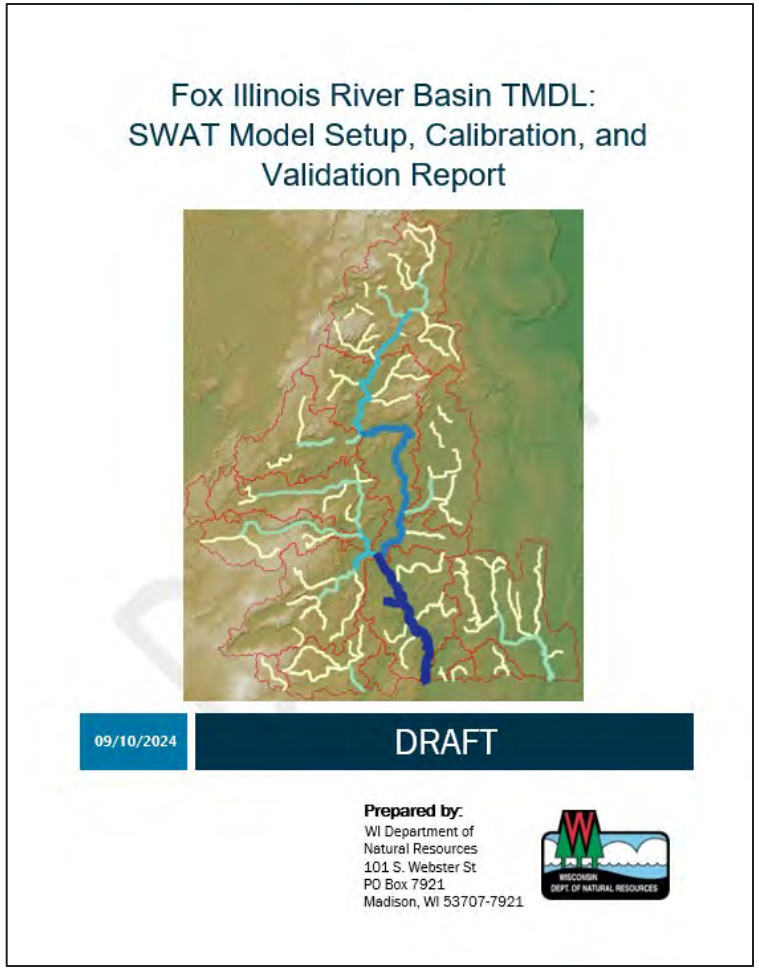


Draft Watershed Model Report

Contents

- Model setup
- Calibration and validation
- Performance
- Results

Report will be posted on Fox Illinois River TMDL website for review and feedback



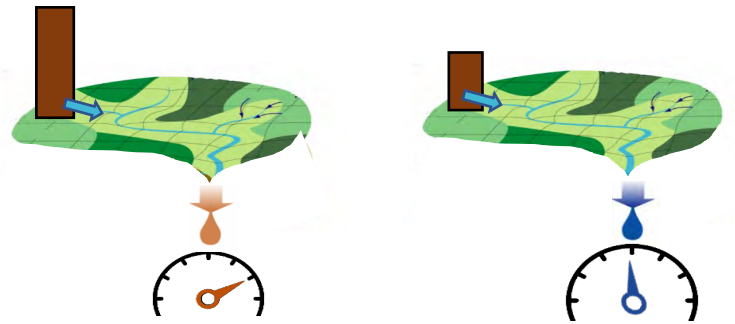
Goals of Watershed Modeling

Why do we develop a watershed model for TMDLs?

- Estimate flows and loads at ungauged and unmonitored systems
- Estimate flows and loads for a wide range of conditions
- Quantify loads from nonpoint and background sources

How will results be used?

- Establish loading capacity
- Estimate baseline loads
- Determine allocations



Soil and Water Assessment Tool (SWAT)

"The Soil & Water Assessment Tool is a small watershed to river basin-scale model used to simulate the **quality and quantity of surface and ground water** and predict the environmental impact of **land use, land management practices**, and **climate change**. SWAT is widely used in assessing soil erosion prevention and control, non-point source pollution control and regional management in watersheds."

SWAT+: Restructured Version of SWAT

Same Basic Algorithms

Model Changes

- Watershed configuration
- Aquifer configuration
- Reservoir configuration
- Decision tables

File Management Changes

- QGIS interface
- SQLite database files
- Input and output files aggregation

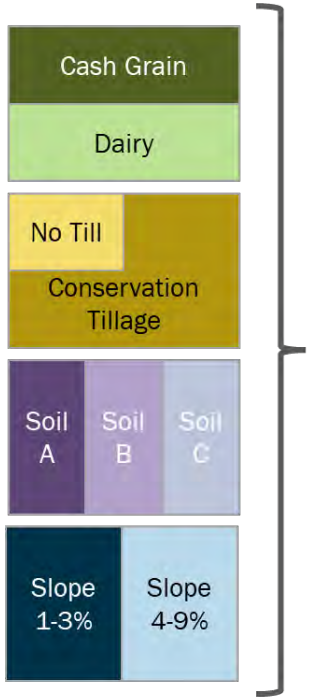
SWAT+ Model Development

SWAT+ Model Setup

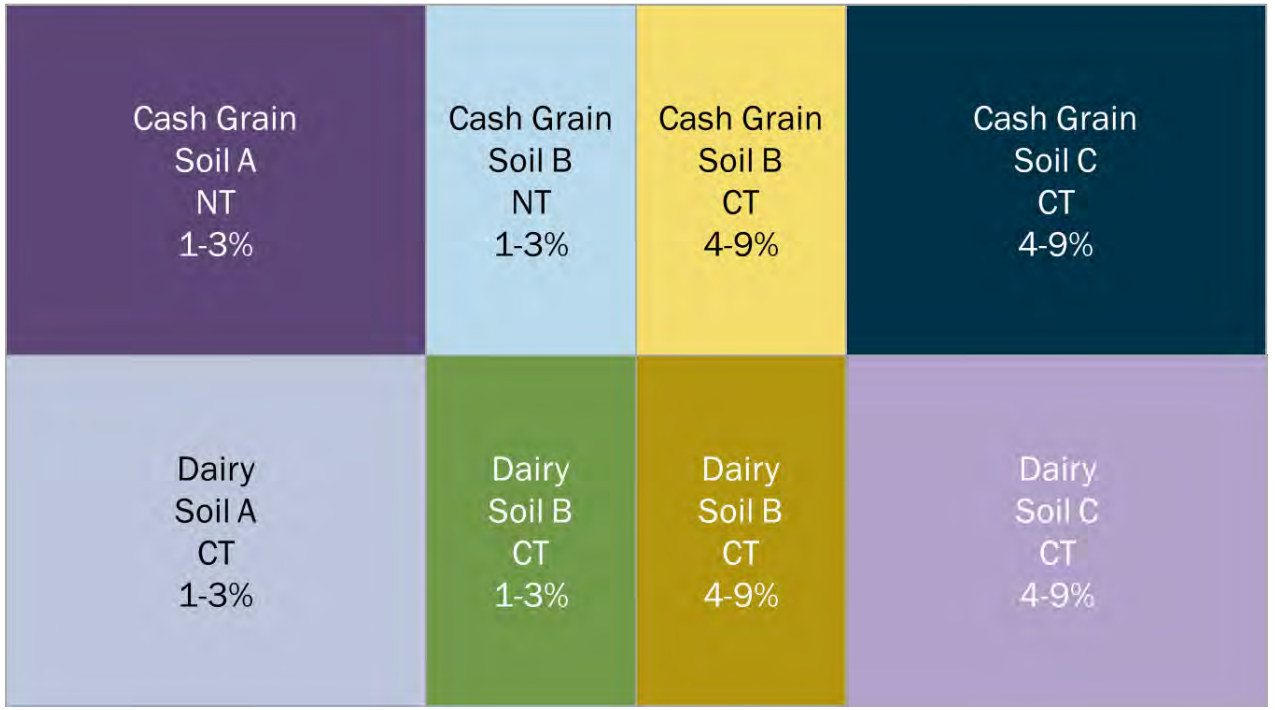
Hydrologic Response Units (HRUs)

HRUs are a unique combination of

- Subbasin
- Land use
- Soils
- Slope



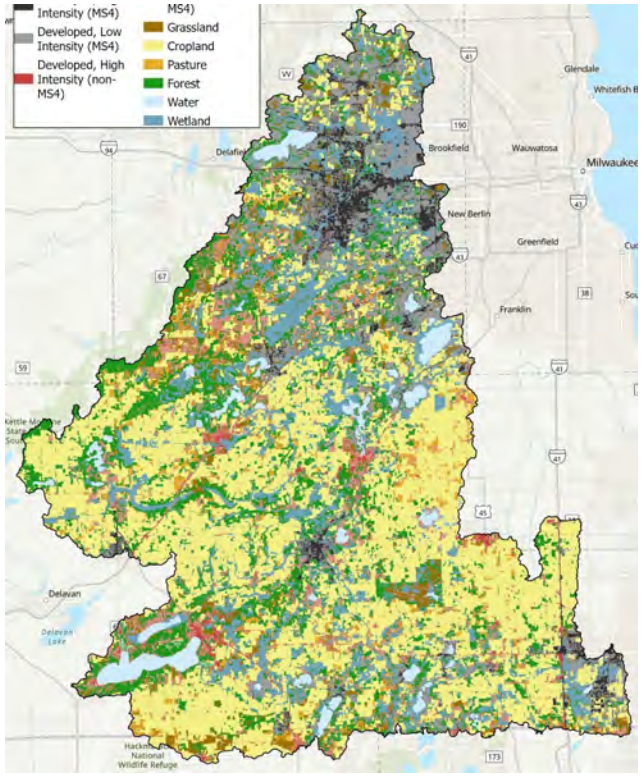
One subbasin



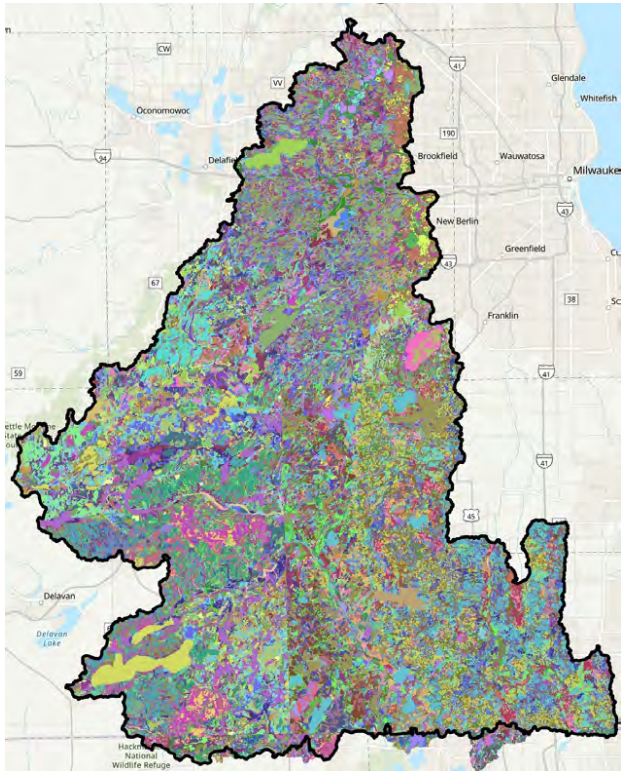
Eight unique combinations (HRUs)

FOXIL HRU Datasets

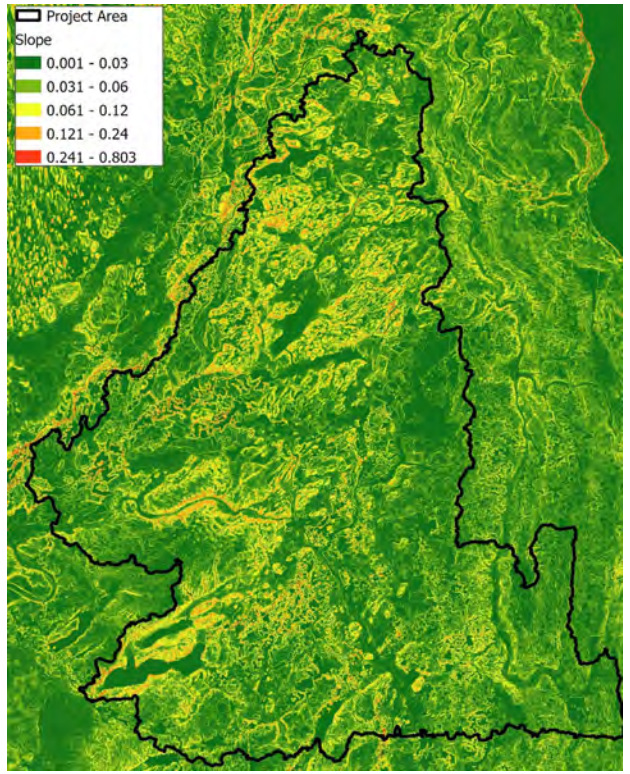
Land Use



Soils



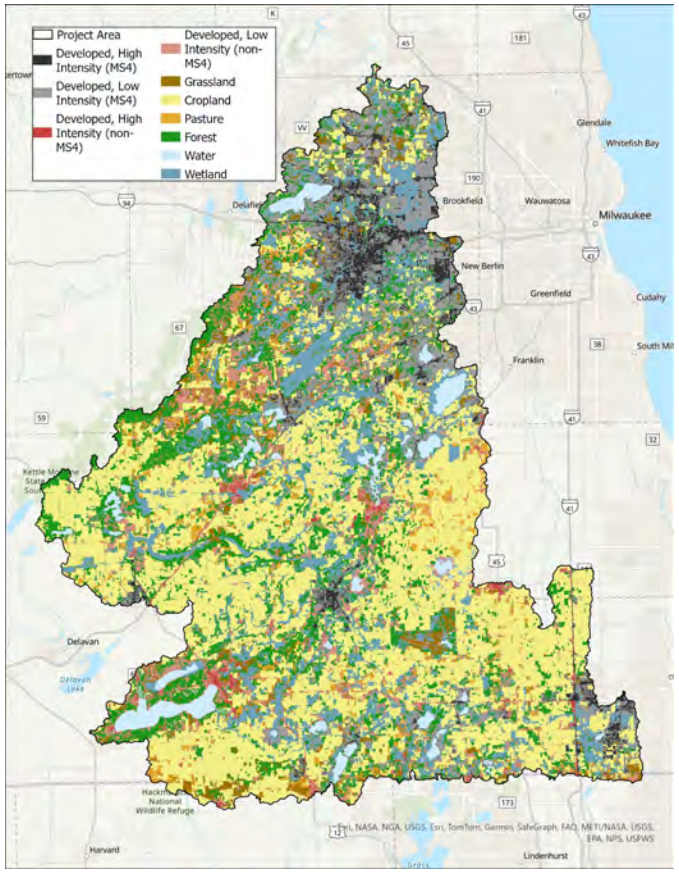
Slopes



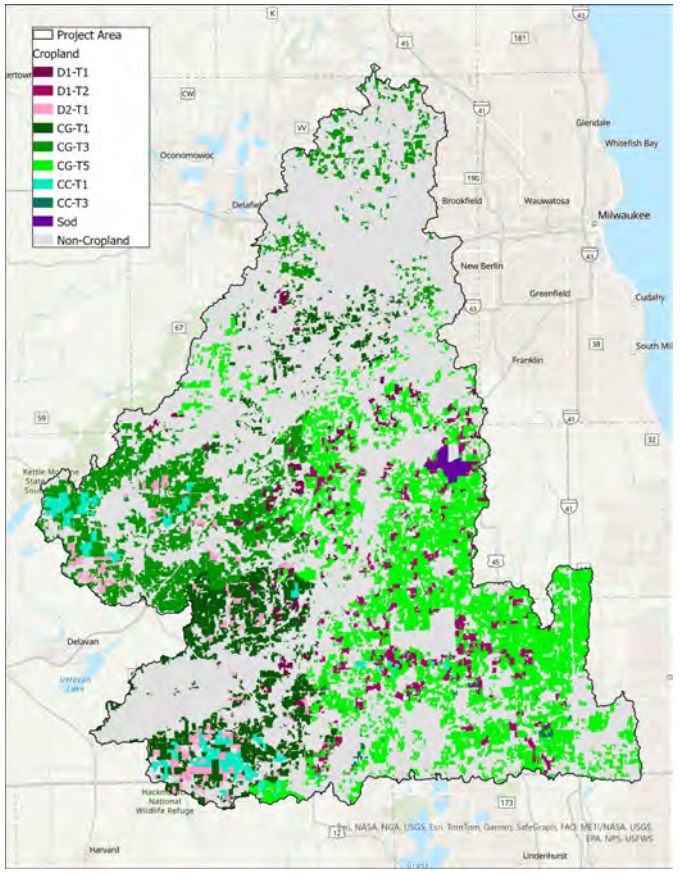
Land Use Dataset

1. Started with Wiscland 2 database
2. Incorporated comments from ag. surveys to update land use categories
3. Assigned crop rotation & tillage combinations to crop types

All Land Use



Cropland



Soils Dataset

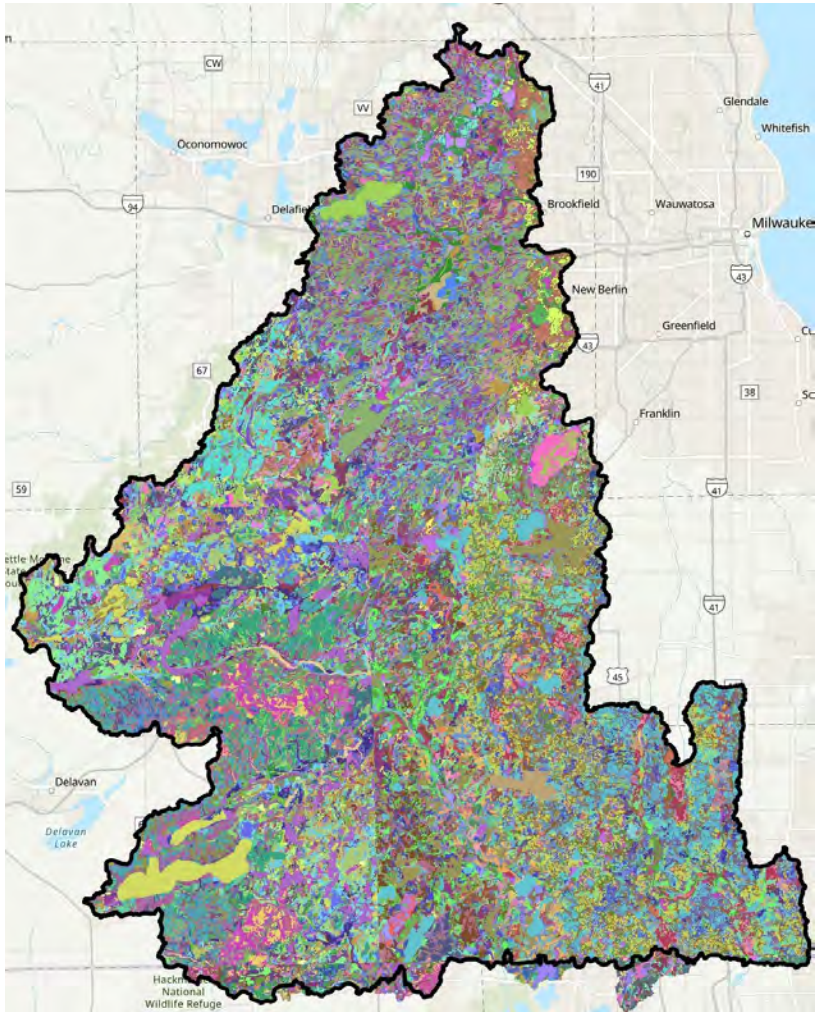
Source

NRCS gridded Soil Survey Geographic Database (gSSURGO)

Map Units

Collection of soils with similar characteristics; hydrologic properties assigned to unique map units

>600 unique map units in project area



Slope Dataset

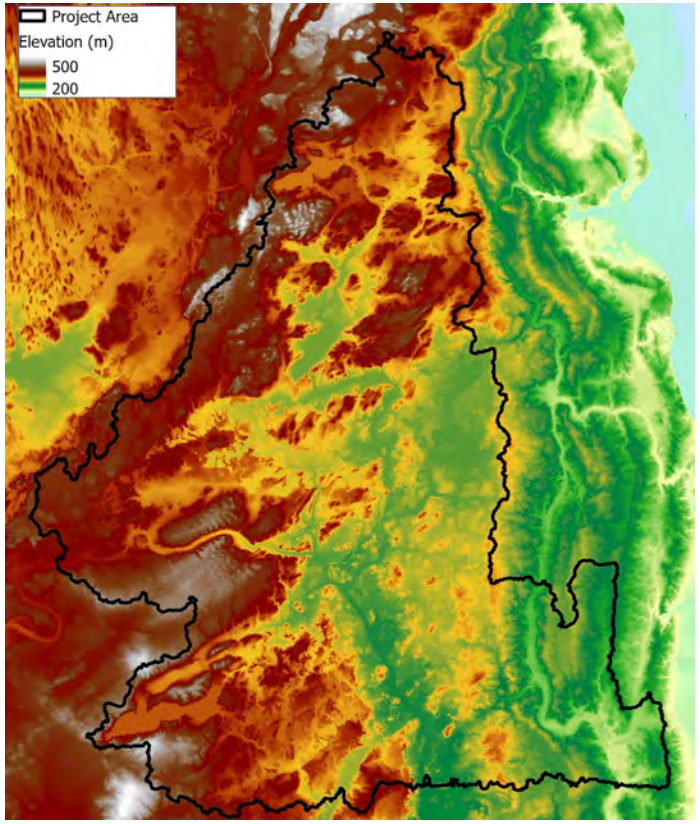
Source

30m DEM for study area

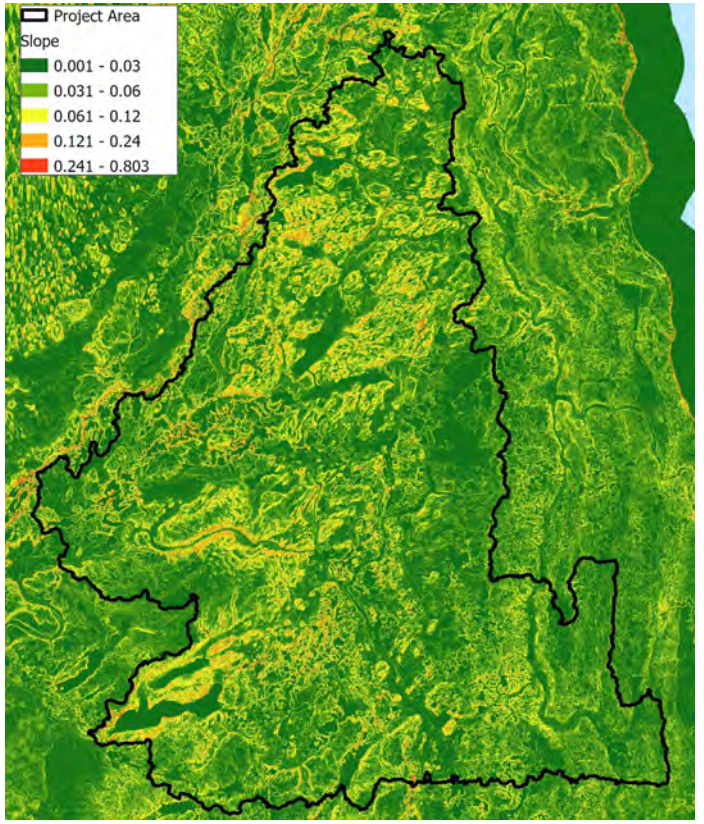
Processing

Built-in tools in SWAT+

Elevation

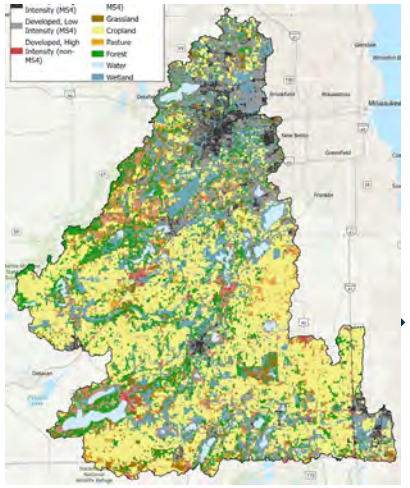


Slopes



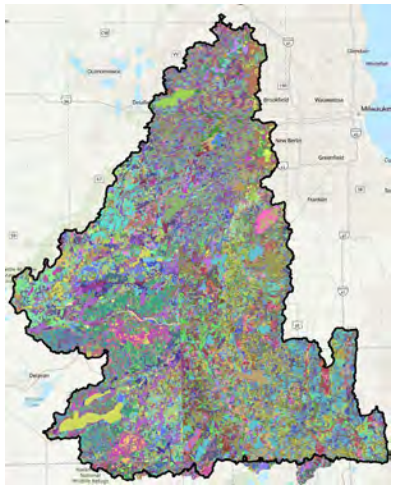
Initial HRU Definition

Land Use



+

Soils



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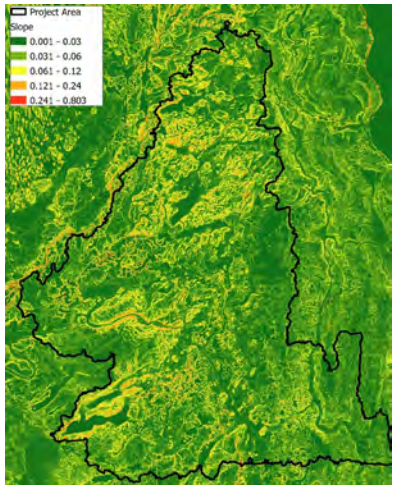
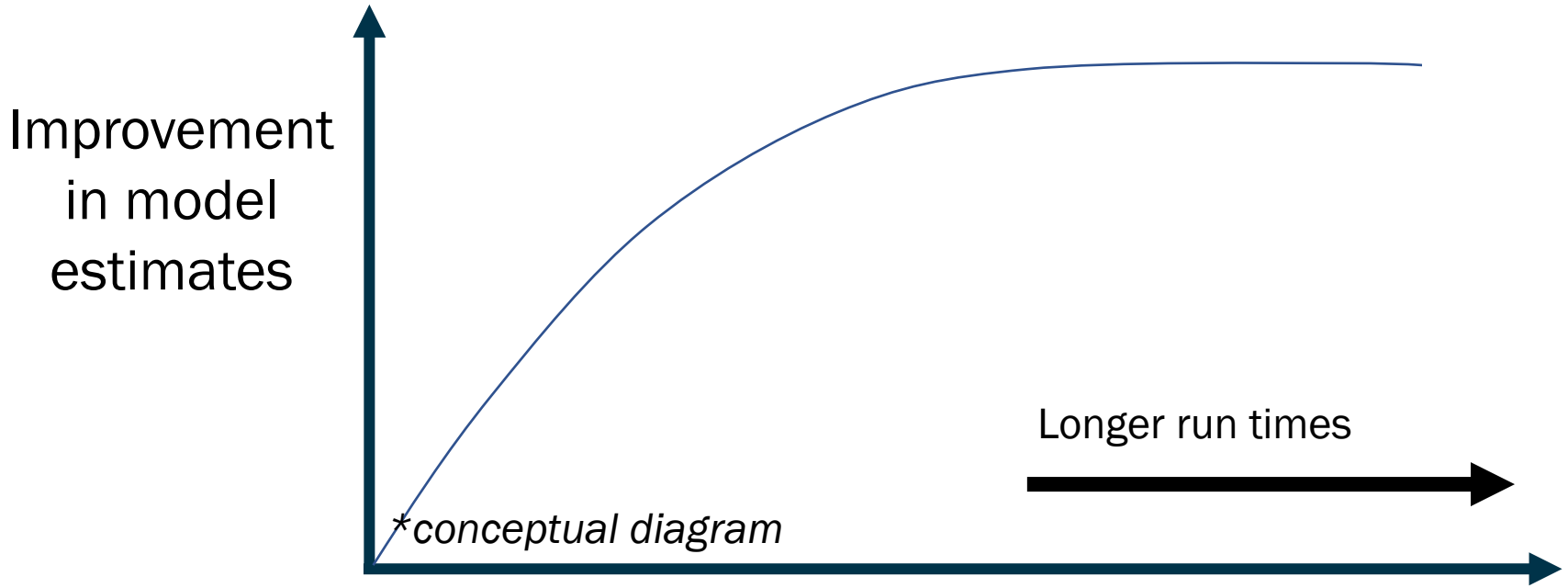
Slope



46,317 HRUs

HRU Tradeoffs

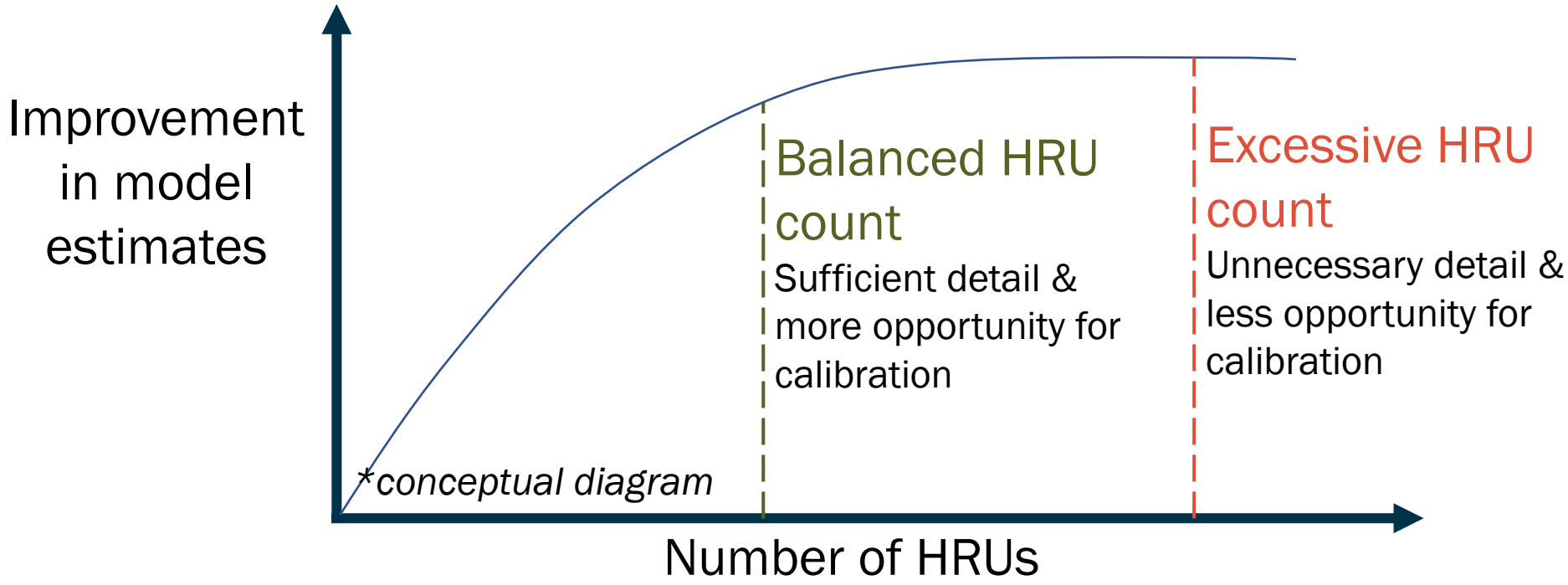
After a certain number of HRUs, the additional HRU details do not significantly improve the the model's estimates



(unique land use & soil & slope combinations per subbasin)

HRU Tradeoffs

After a certain number of HRUs, the additional HRU details do not significantly improve the the model's estimates



(unique land use & soil & slope combinations per subbasin)

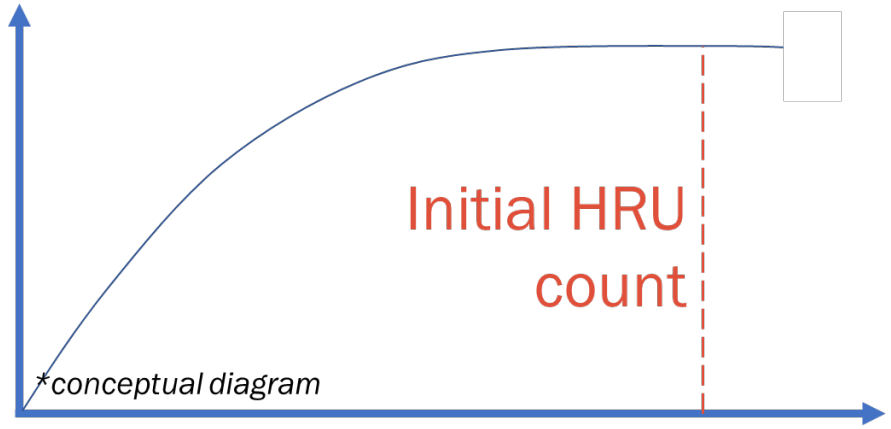
HRU Refinement

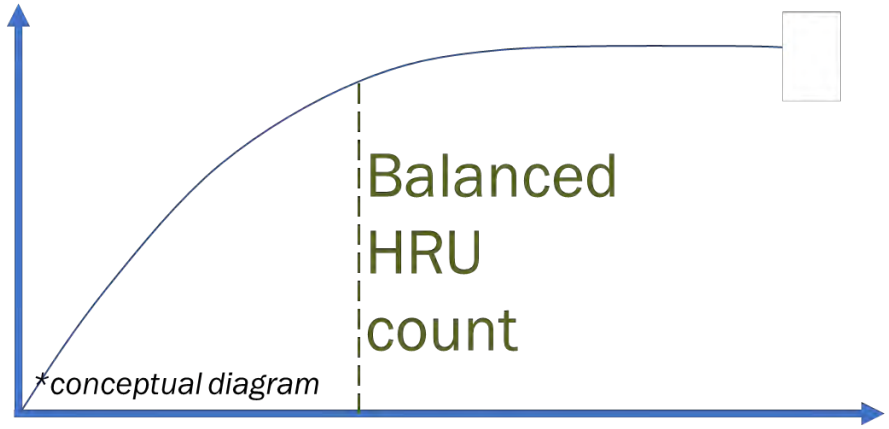
Initial Definition
46,317 HRUs

Refine HRUs using area thresholds

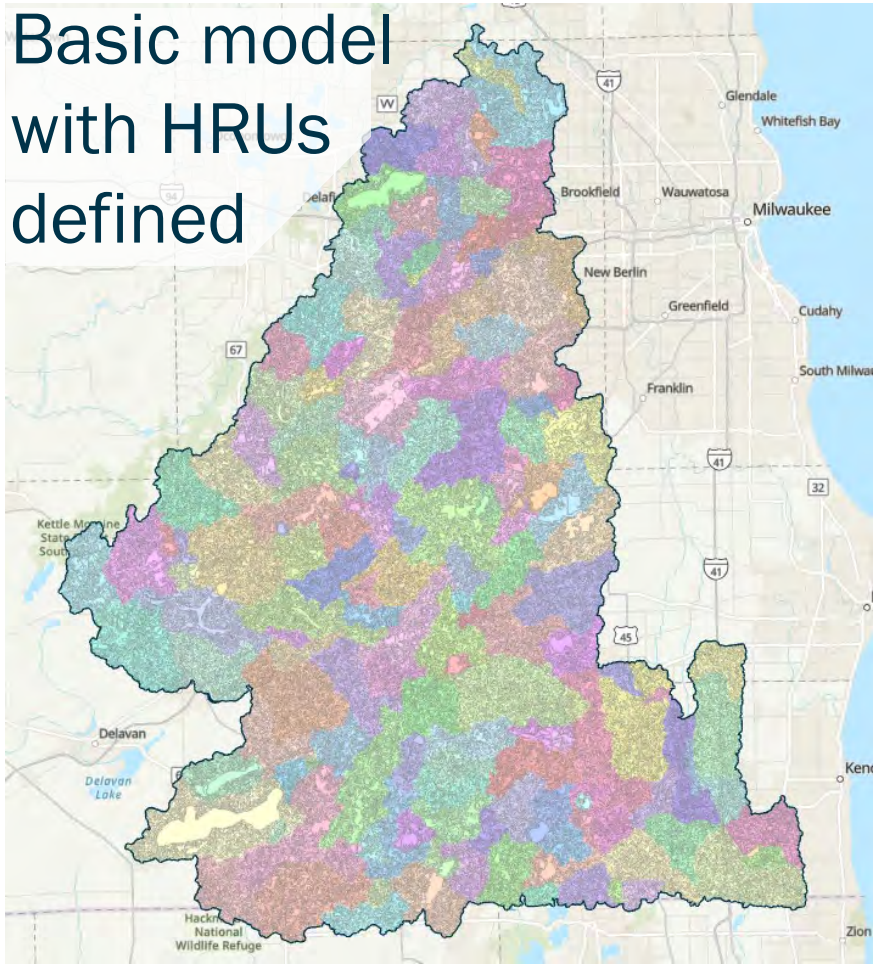
- Land use
- Soils
- Slopes

Final Definition
6,735 HRUs





Additional Model Parameters



- Weather
- Point Sources
- Management
- Lake & reservoir properties
- Aquifer properties
- Channel properties
- P Soil phosphorus

Watershed Model Calibration/Validation

What is Model Calibration?

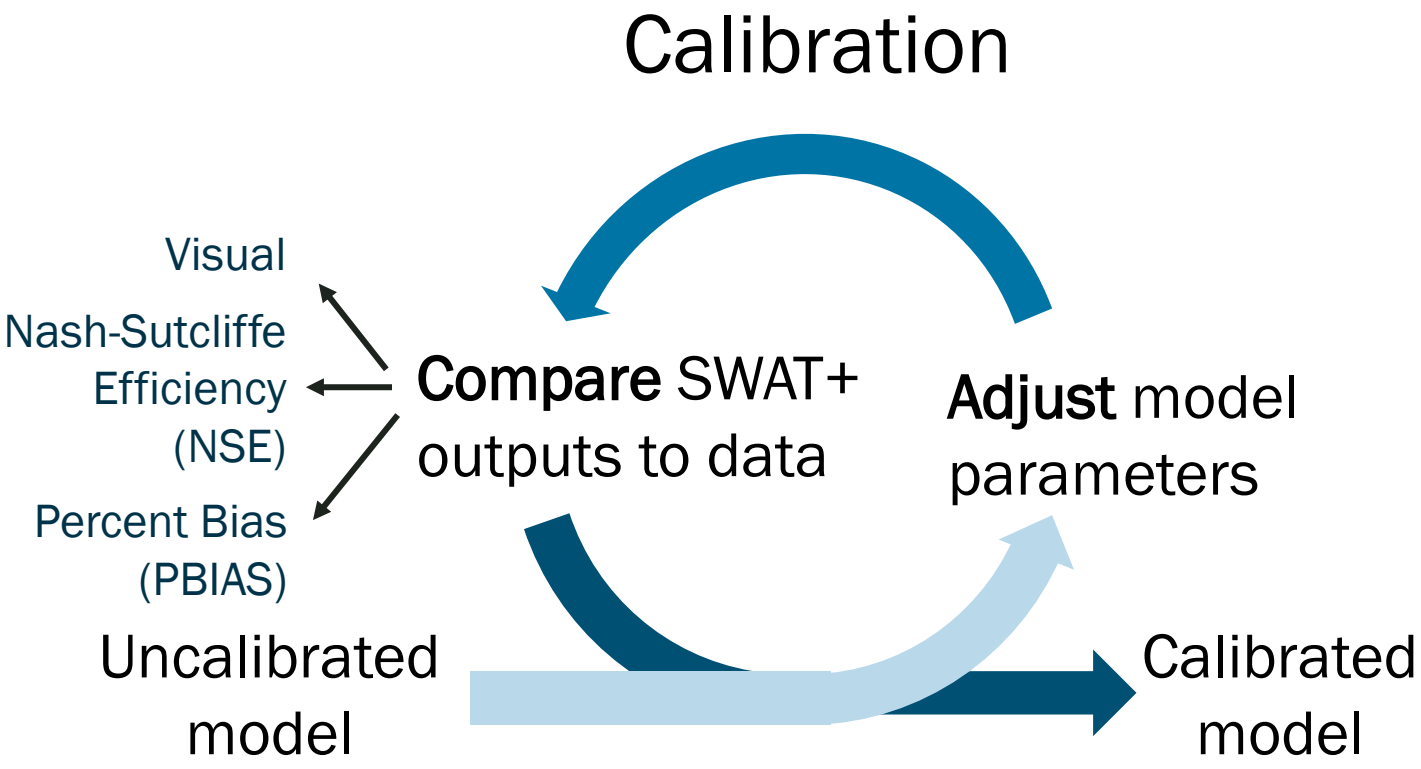
Process

- Compare model results to fitted flow and load datasets
- Adjust model parameters until modeled results reasonably match fitted flow and load datasets

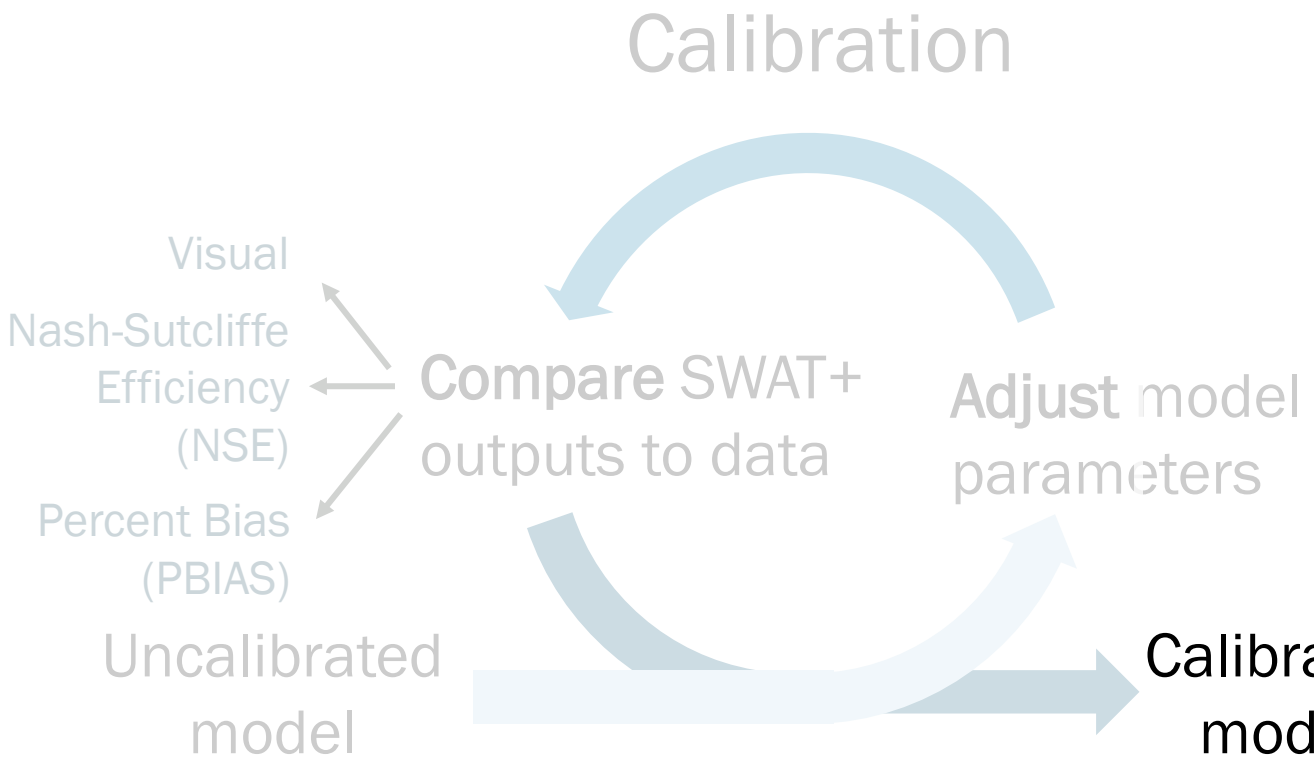
Objective

- Improve the agreement of modeled outputs and real-world measurements
- Increase confidence in model estimates in subbasins without monitoring data

Calibration and Validation Process



Calibration and Validation Process



Validation

- Uses monitoring data not used for calibration
- Demonstrates that the model is accurately predicting through time

Calibrated model → **Compare** SWAT+ outputs to data → Validated model

SWAT+ Model Calibration/Validation

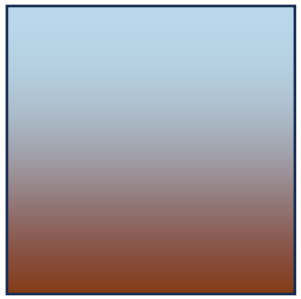
Calibration Steps

1. Crop Yield*

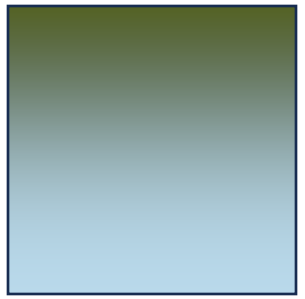
*Calibrated for entire model period

2. Flows

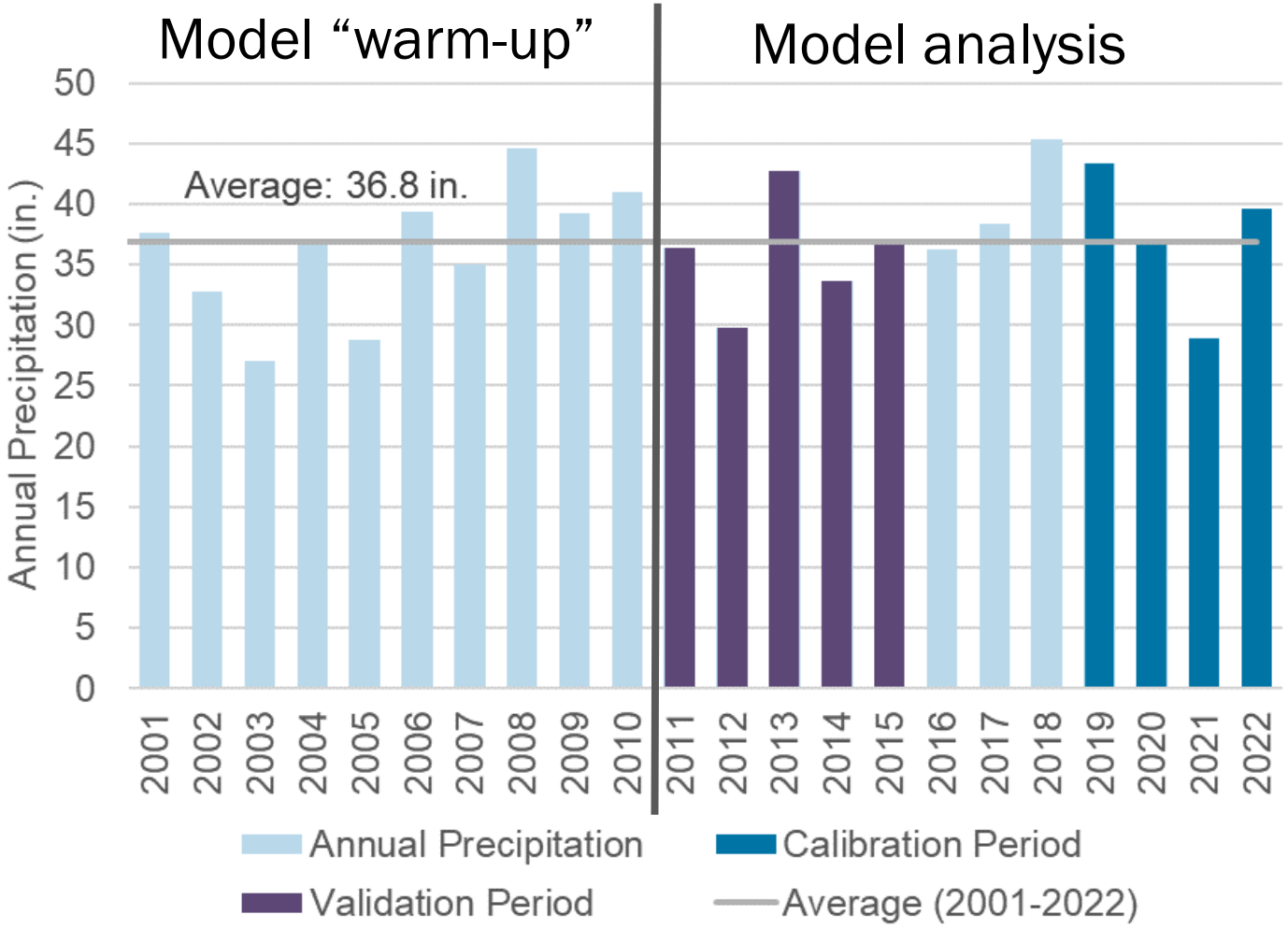
3. Sediment



4. Phosphorus



FOXIL Calibration and Validation Periods



Parameters Adjusted

Target	Parameter Description
Crop Growth	harv_idx, tmp_opt, tmp_base, lai_pot, bm_e
Evapotranspiration	esco, epco, petco
Runoff	cn2, cn3_swf, awc, surlag, canmx, chs
Groundwater	alpha, latq_co, soil_k, perco, flo_min, revap_min, revap_co, deep_seep
Snowmelt	snomelt_tmp, snomelt_min, snomelt_max, tmp_lag, sno_h2o
Reservoirs	evap_co, drawdown_days, sed_amt, stl_vel, p_conc_min, mid_p_stl, p_stl
Sediment	usle_k, rock, adj_pkrt_sed, slp_len, bed_load, cons_prac, biomix, rsd_init, rsd_decay, plnt_decomp, rsd_pctcov, rsd_ovfac, bm_dieoff
Phosphorus	p_avail, p_soil, p_perc, p_uptake, lat_orgp, ero_grp, frac_p, pltp_stl, ptl_p, ben_disp

SWAT+ Model Results

Performance and Loads

SWAT+ Model Performance

Average Annual Crop Yield (2011-2022)

Crop Name	SWAT+ Yield (Mg/ha)	NASS Yield (Mg/ha)	% Difference
Corn	9.6	9.0	7%
Corn silage	15.9	15.2	4%
Soybean	2.7	2.8	-4%
Alfalfa, hay	6.0	6.4	-6%
Winter wheat	4.3	4.3	-1%

Performance Metrics for Model Fit

Moriasi et al. (2007)

Percent Bias: "Tendency of the simulated data to be larger or smaller than observations"

Nash Sutcliffe Efficiency (NSE): "Normalized statistic that determines the relative magnitude of residual variance"

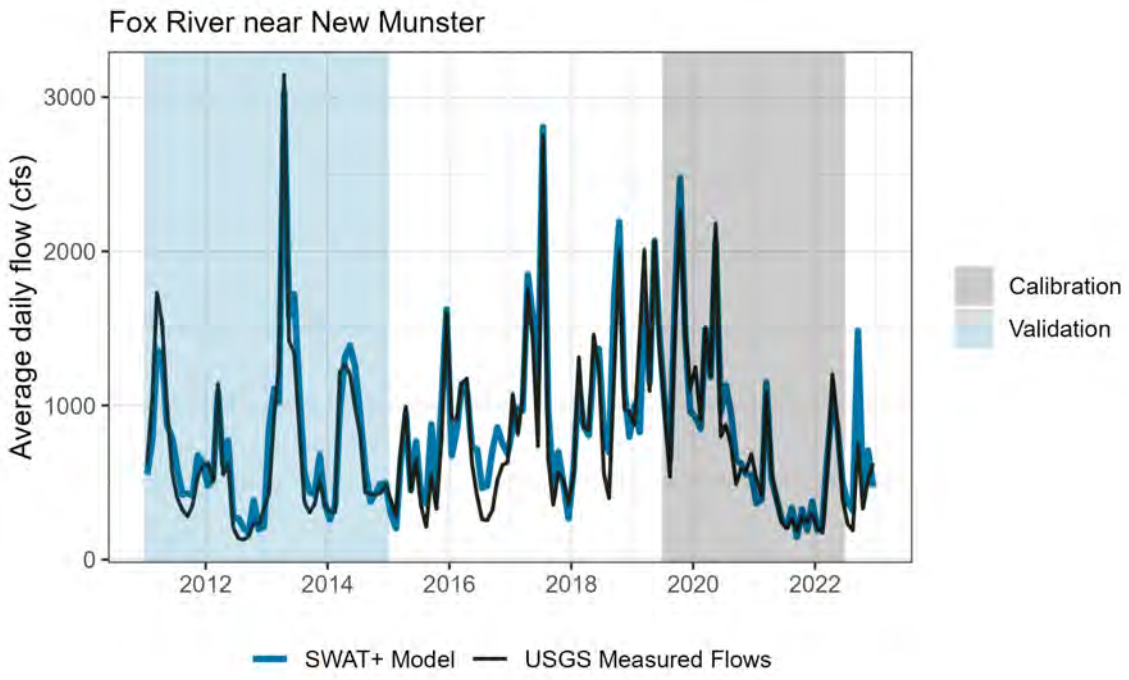
Interpretation	Constituent	NSE	PBIAS
Very Good	Flow	0.75 or greater	±10 % or less
	TP	0.75 or greater	±15 % or less
	TSS	0.75 or greater	±25 % or less
Good	Flow	0.65 or greater	±15 % or less
	TP	0.65 or greater	±30 % or less
	TSS	0.65 or greater	±40 % or less
Satisfactory	Flow	0.5 or greater	±25 % or less
	TP	0.5 or greater	±55 % or less
	TSS	0.5 or greater	±70 % or less

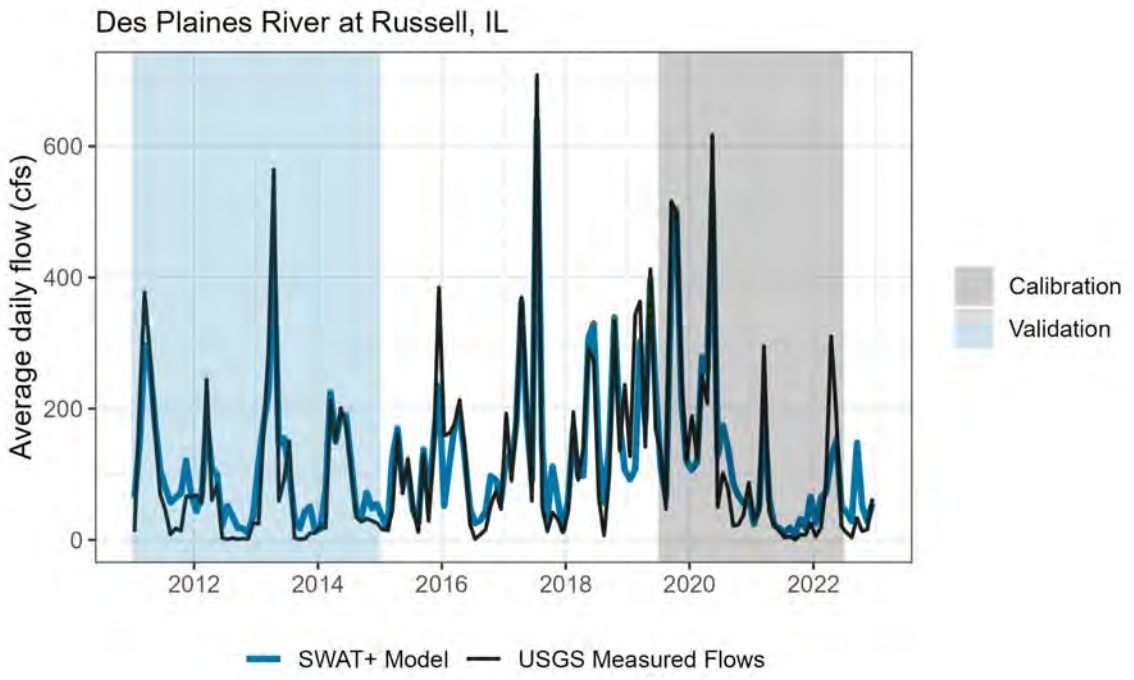
Performance: Flow

Calibration Site	Calibration		Validation	
	NSE	PBIAS	NSE	PBIAS
Fox River at Waukesha	0.89	-2.0	0.92	4.6
Fox River at CTH I	0.92	-6.2	0.93	0.1
Mukwonago River	0.84	1.1	0.49	14.1
Fox River at Waterford	0.94	-5.1	0.84	2.4
Muskego Lake	0.88	0.8		
Wind Lake	0.66	-1.1		
Fox River at Rochester Dam	0.91	-9.8	0.91	0.3
Honey Creek	0.74	-7.6		
Sugar Creek	0.72	1.1		
Lake Geneva	0.71	-13.0	0.52	12.8
White River	0.80	-14.6		
Fox River at New Munster	0.95	2.2	0.90	7.7
Des Plaines River	0.88	-0.9	0.83	12.1

Performance Metrics
Very Good
Good
Satisfactory
Not Satisfactory

Performance: Flow



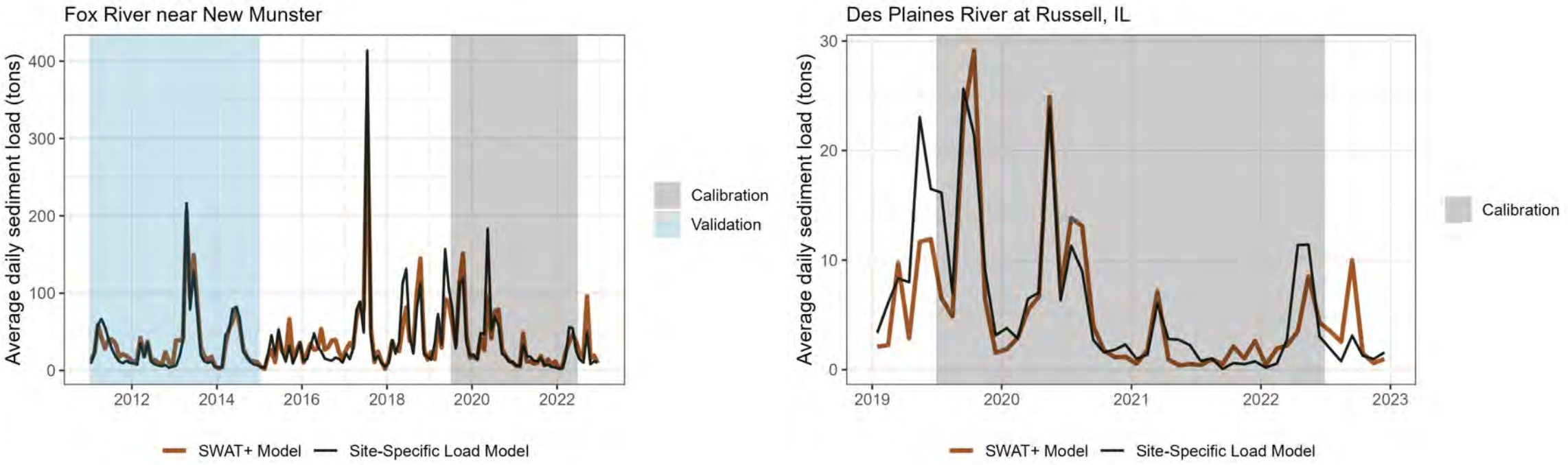


Performance: Sediment

Calibration Site	Calibration NSE	Calibration PBIAS	Validation NSE	Validation PBIAS
Fox River at Waukesha	0.41	7.5		
Fox River at CTH I	0.43	-23.6	0.71	-10.6
Fox River at Waterford	0.68	-16.9		
Fox River at Rochester Dam	0.67	-18.4	0.85	2.8
Honey Creek	0.84	-4.9		
Sugar Creek	0.69	10.3		
White River	0.85	-10.7		
Fox River at New Munster	0.79	-4.4	0.90	9.7
Des Plaines River	0.81	-7.3		

Performance Metrics
Very Good
Good
Satisfactory
Not Satisfactory

Performance: Sediment

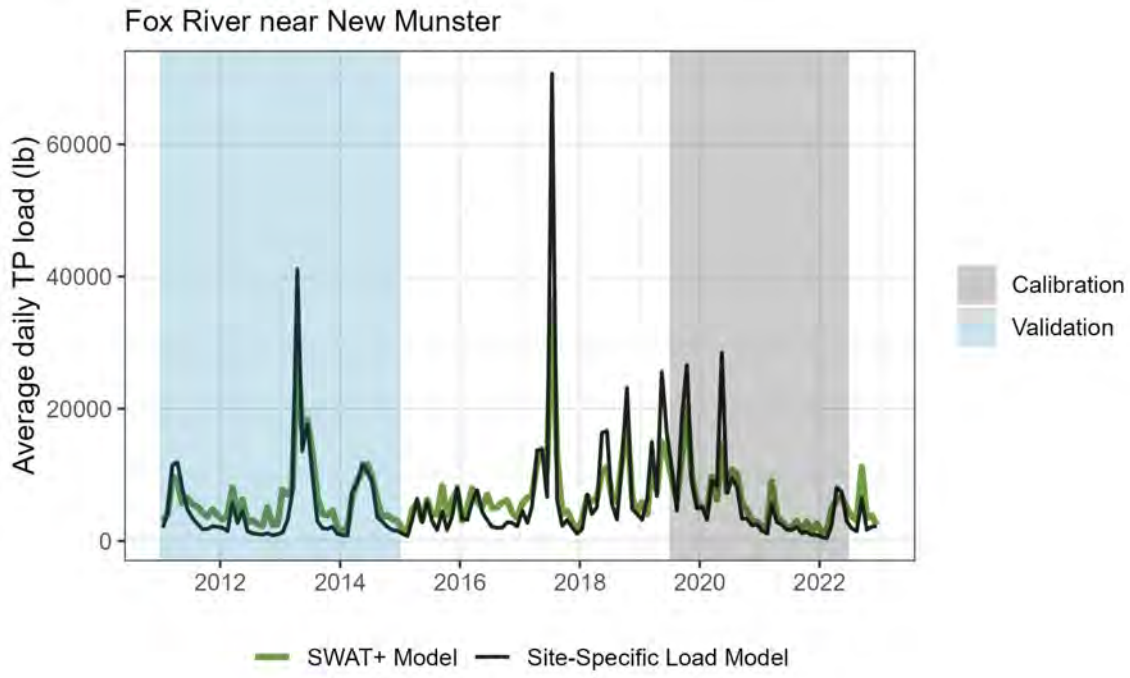


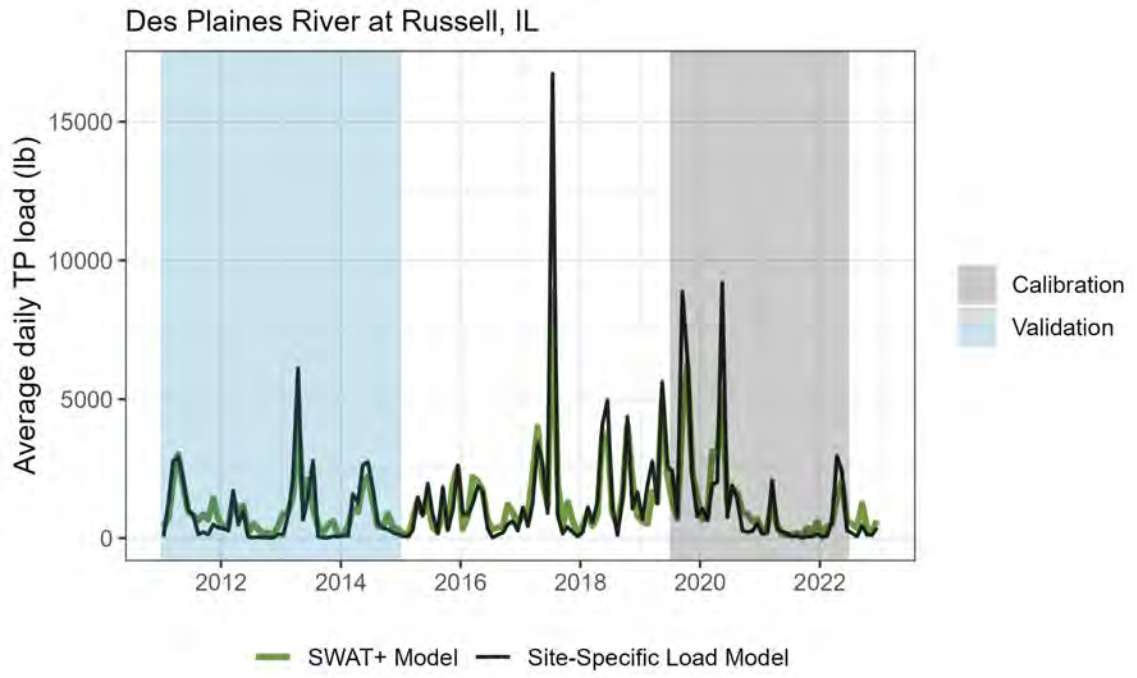
Performance: Phosphorus

Calibration Site	Calibration		Validation	
	NSE	PBIAS	NSE	PBIAS
Fox River at Waukesha	0.66	6.9		
Fox River at CTH I	0.67	4.2	0.50	40.1
Mukwonago River	0.36	13.5		
Fox River at Waterford	0.57	24.7		
Muskego Lake	0.86	1.2		
Wind Lake	0.54	24.3		
Fox River at Rochester Dam	0.66	-5.9	0.74	28.9
Honey Creek	0.81	6.8		
Sugar Creek	0.61	19.6		
Lake Geneva	0.30	9.6	0.53	5.9
White River	0.77	-4.8		
Fox River at New Munster	0.79	-0.3	0.80	24.9
Des Plaines River	0.75	-10.2	0.77	3.5

Performance Metrics
Very Good
Good
Satisfactory
Not Satisfactory

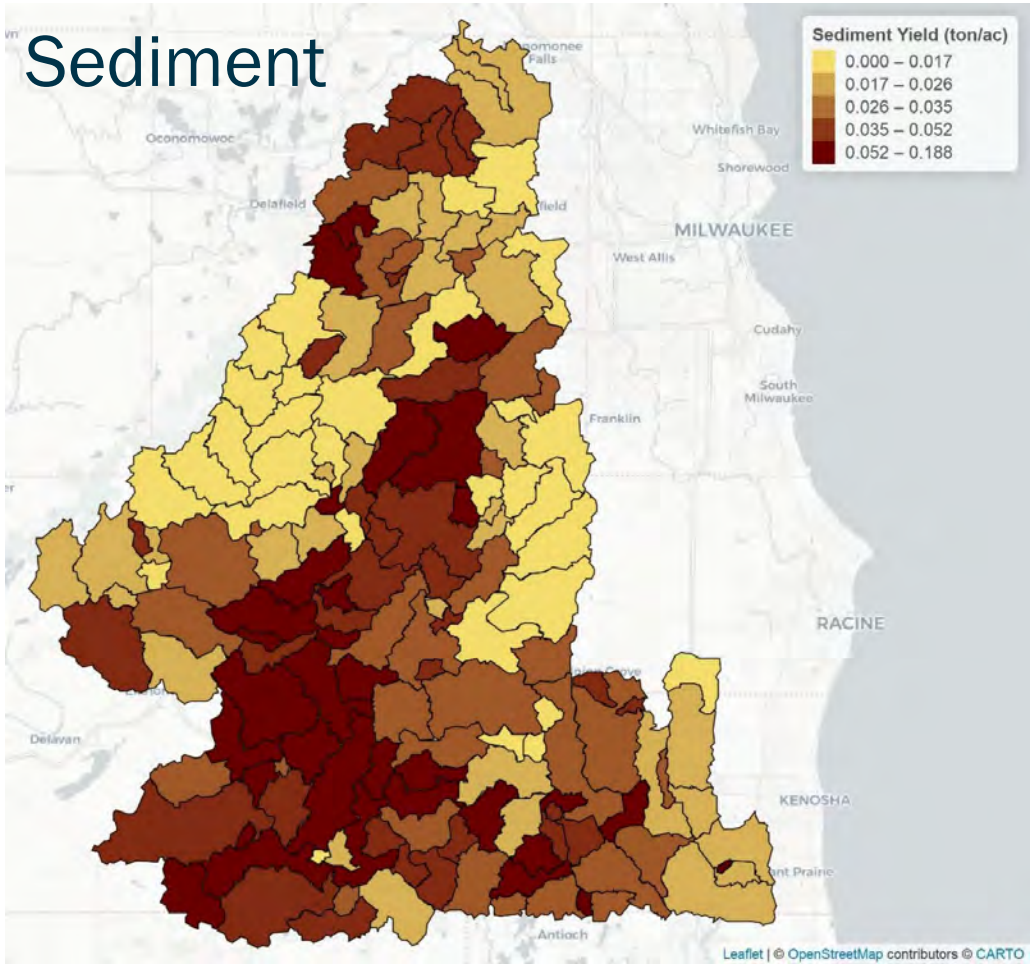
Performance: Phosphorus

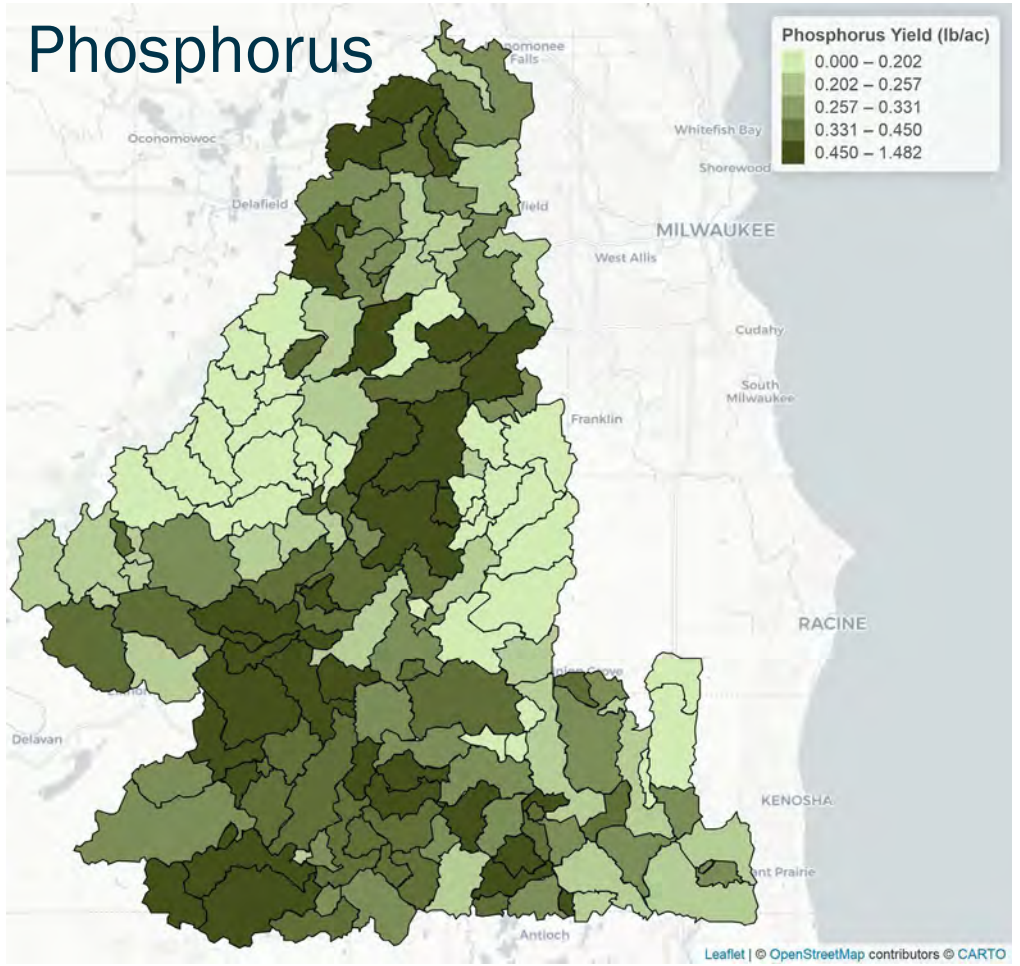




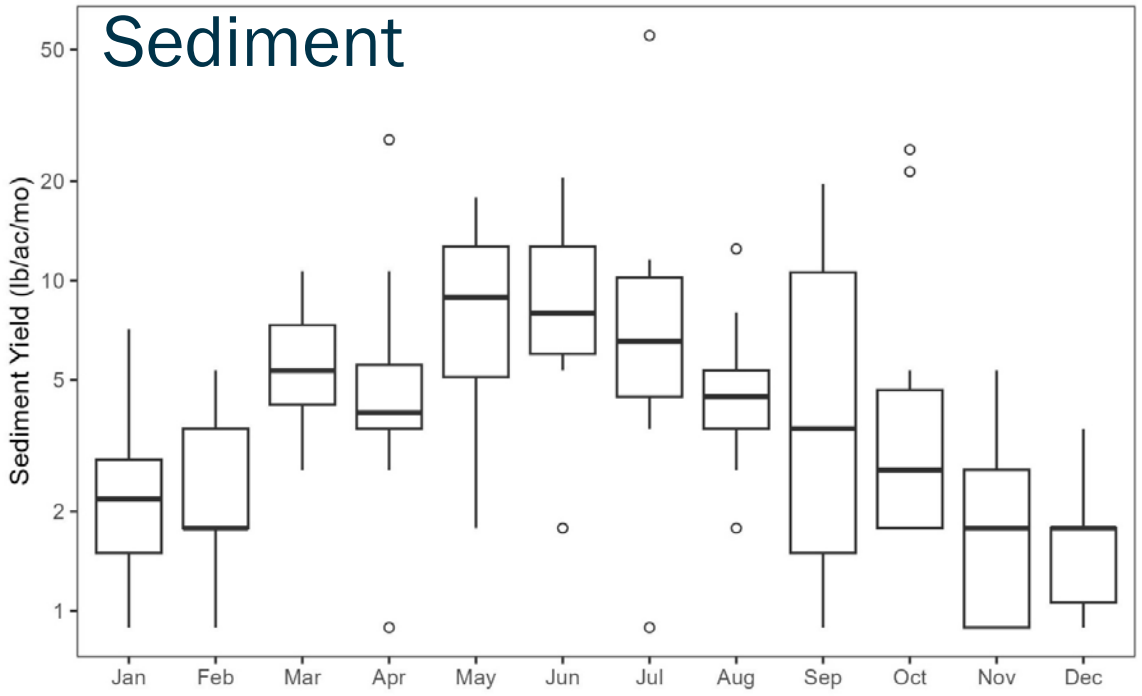
SWAT+ Model Load Estimates

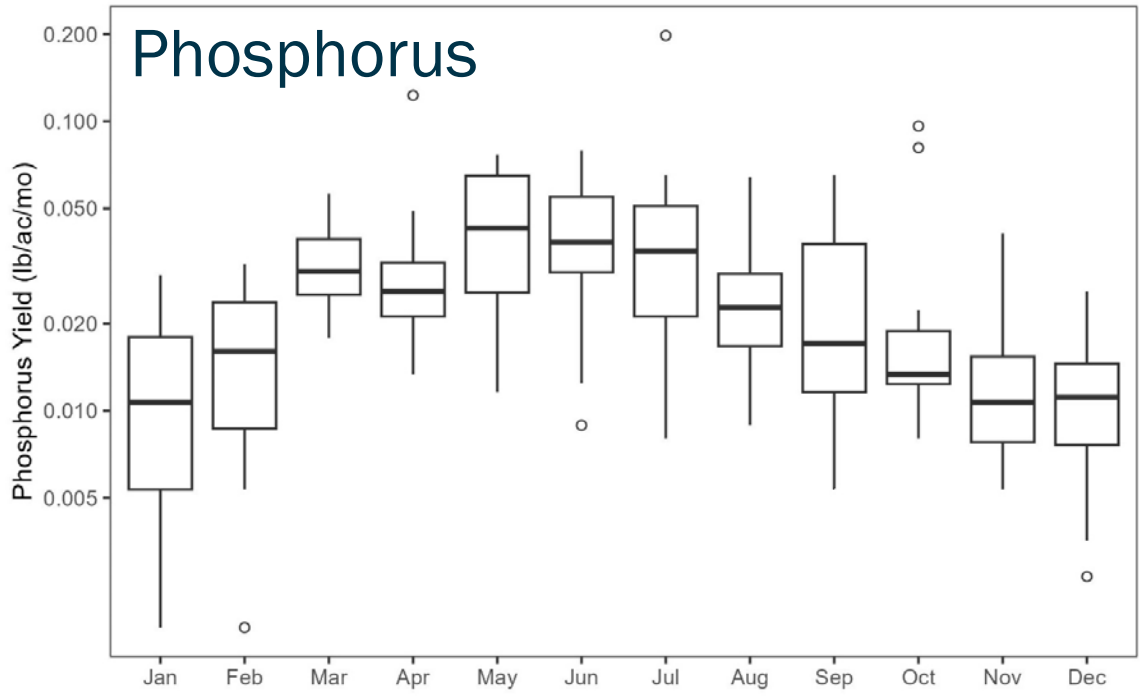
Spatial Distribution





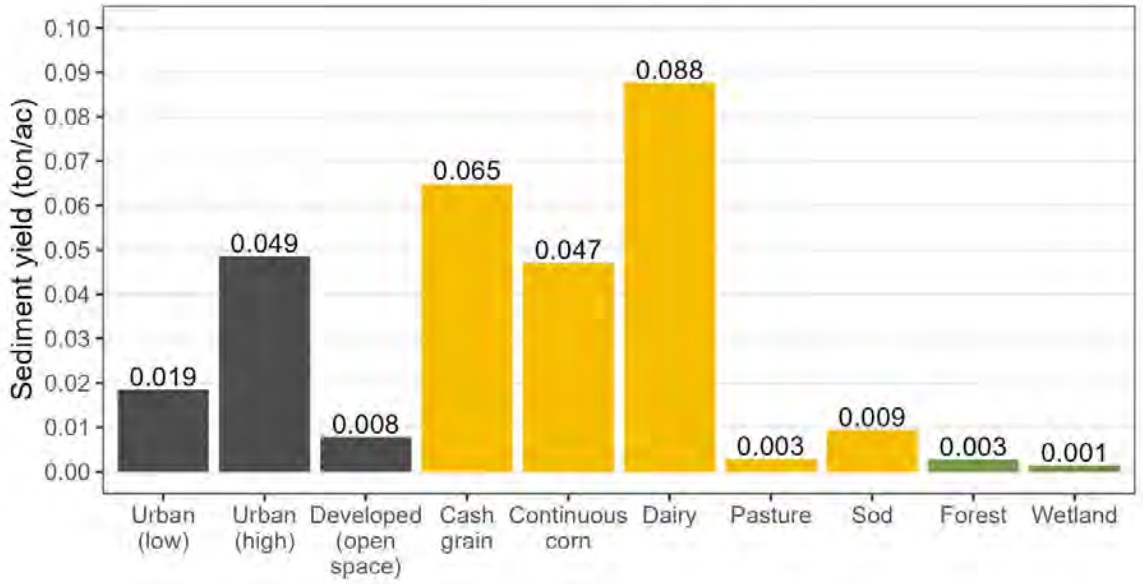
Temporal Distribution



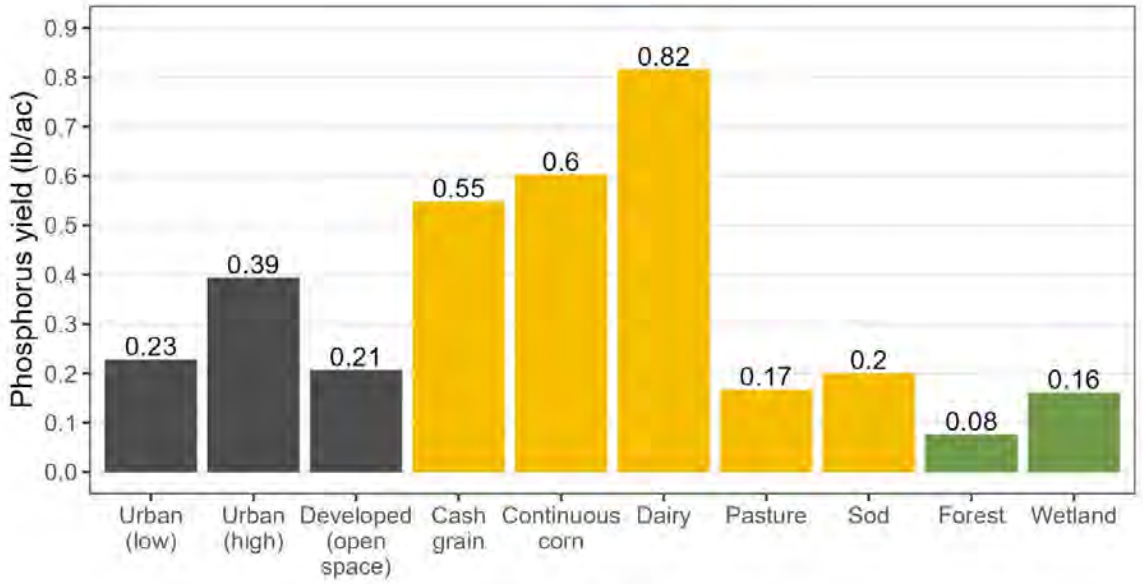


Yields by Land Use Category

Sediment



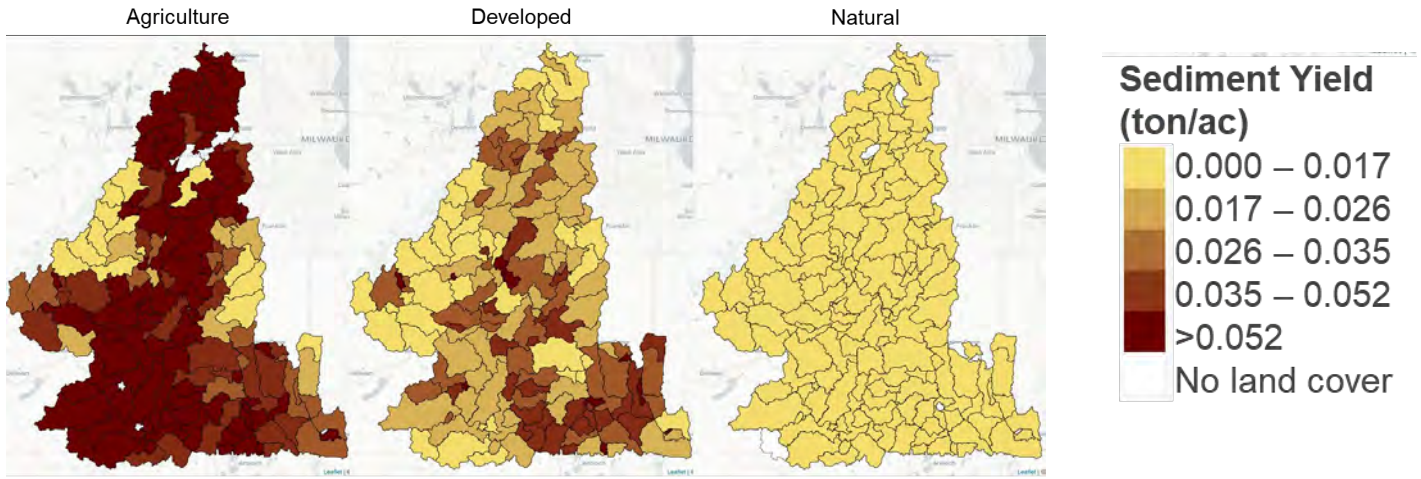
Phosphorus



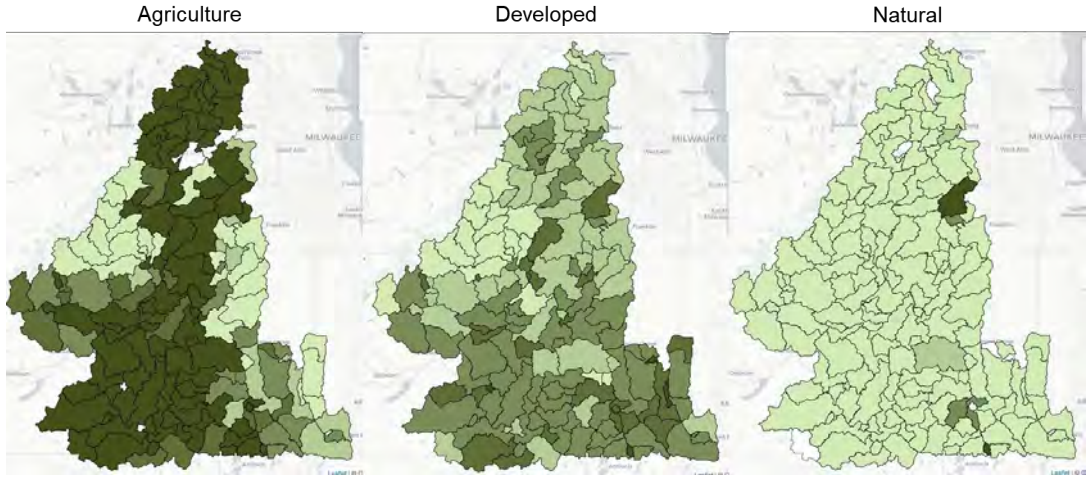
Developed Agriculture Natural

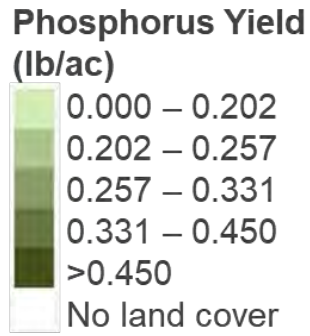
Total Yield by Land Use Category

Sediment



Phosphorus

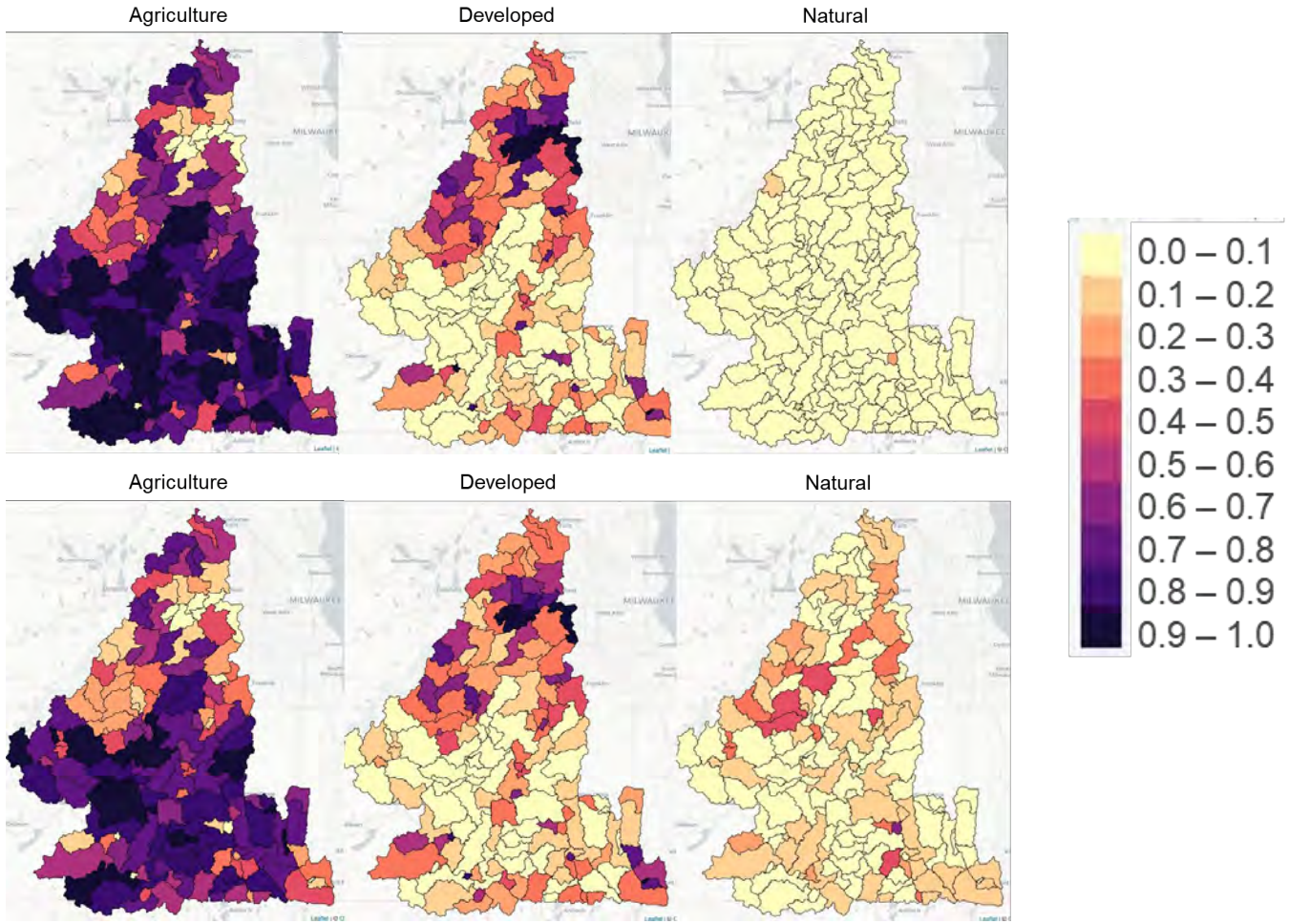




Fraction of Yield by Land Use Category

Sediment

Phosphorus



Fraction of Total Yield

Allocations

Allocations Using Model Outputs

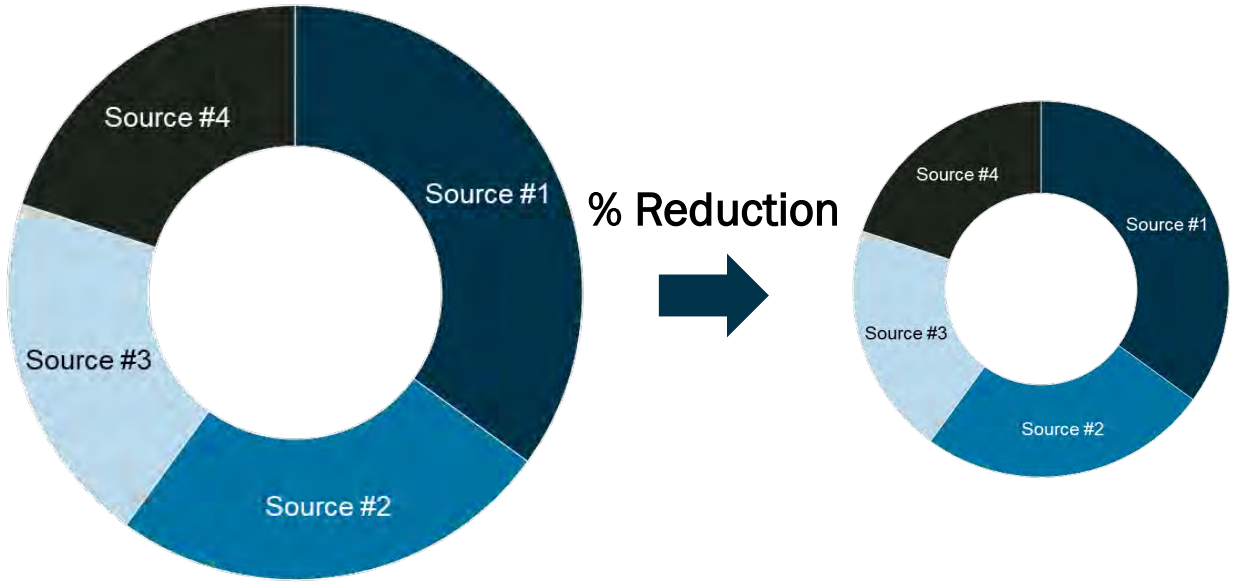
Point source baselines + **nonpoint loads from SWAT+ model**

Baseline Load
Model

Allowable Load
Criteria and Flows

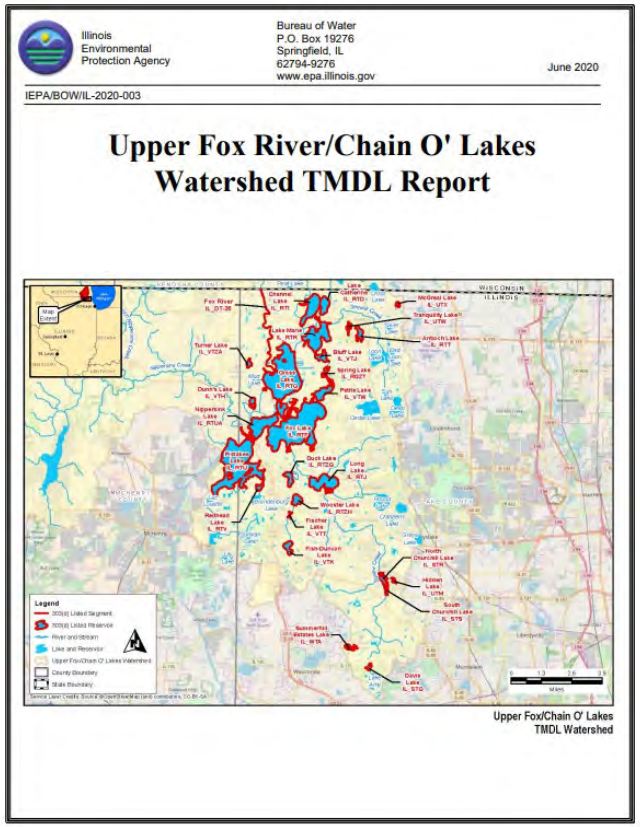
Reduction

Water quality criteria **x** **SWAT+ model flows**



Evaluate Illinois Chain O’ Lakes TMDL

Approved by EPA in 2020



Illinois Environmental Protection Agency

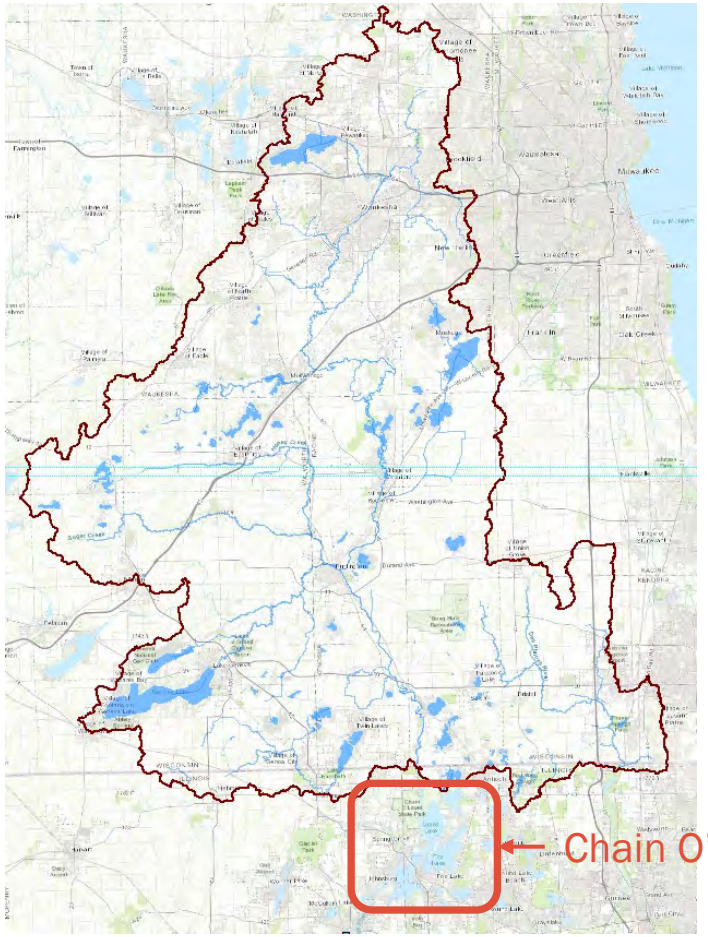
Bureau of Water
P.O. Box 19276
Springfield, IL
62794-9276
www.epa.illinois.gov

June 2020

IEPA/BOW/IL-2020-003

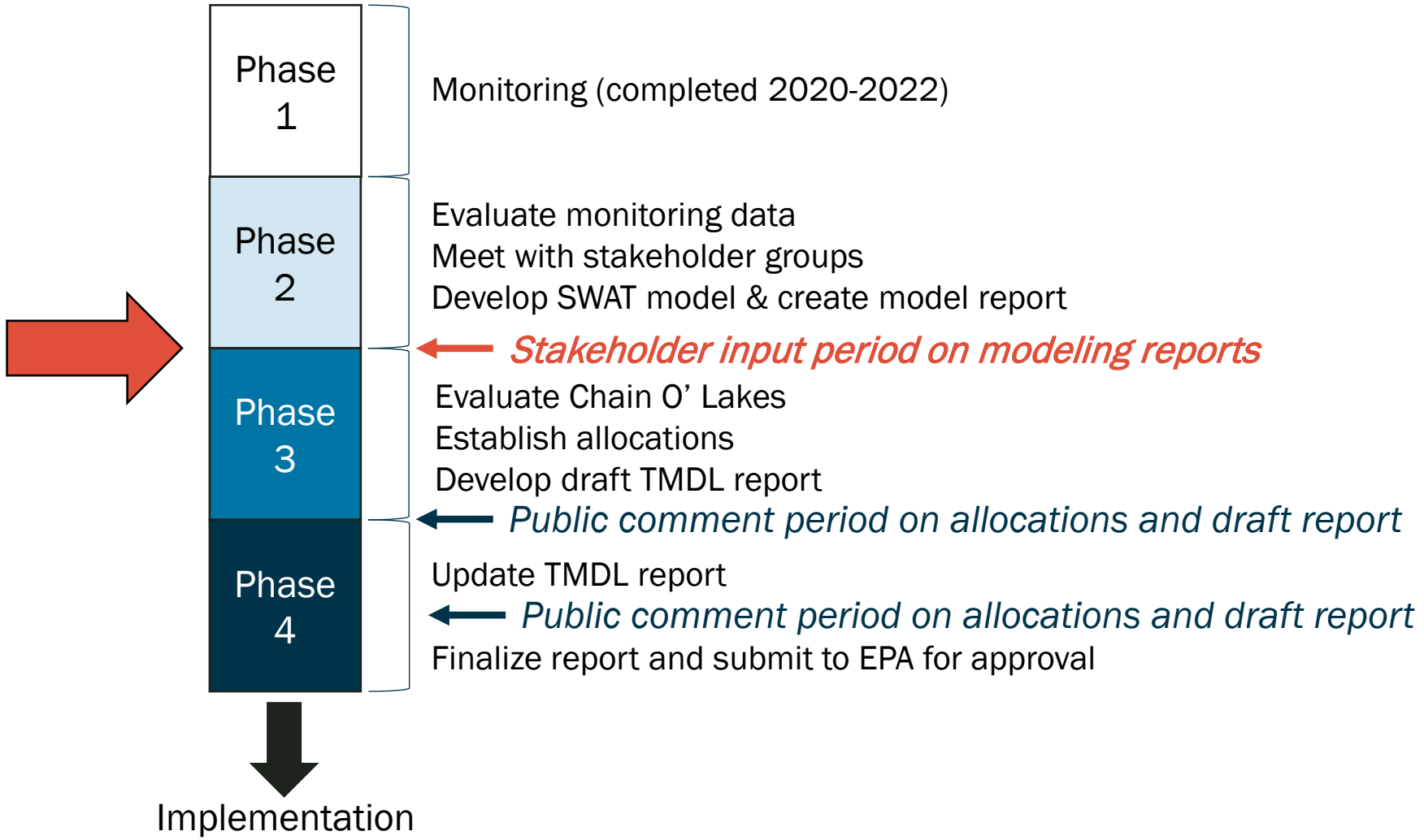
Upper Fox River/Chain O' Lakes Watershed TMDL Report

Upper Fox/Chain O' Lakes TMDL Watershed



Next Steps

Summary of Next Steps

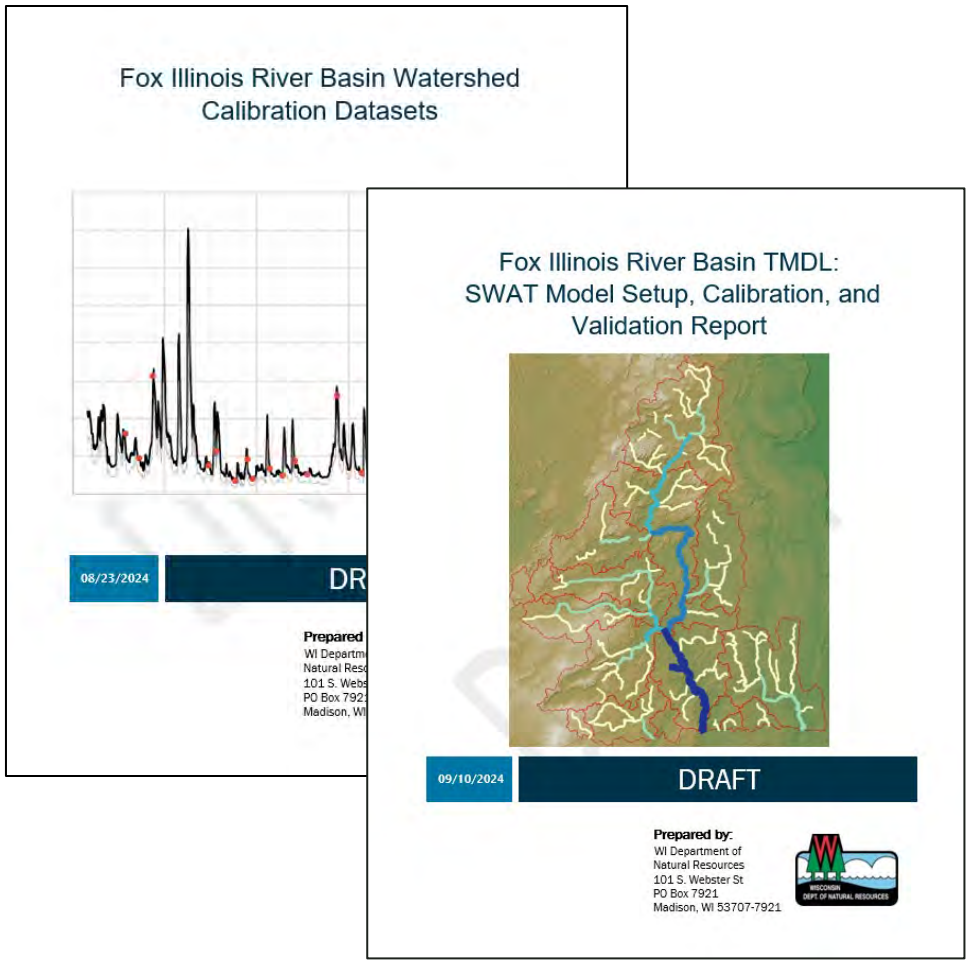


Stakeholder Input on Draft Reports

Draft reports will be posted to FOXIL TMDL project website

Provide feedback to Eric Hettler (eric.hettler@wisconsin.gov) by **December 6, 2024**

Input will be incorporated into the model, and the model will be finalized in early 2025



CONNECT WITH US

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Project Website:
https://dnr.wisconsin.gov/topic/TMDLs/FOXIL

or search for “Fox Illinois TMDL” on dnr.wi.gov

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"WILD WISCONSIN:
OFF THE RECORD"