WISCONSIN DNR
Department of Natural Resources

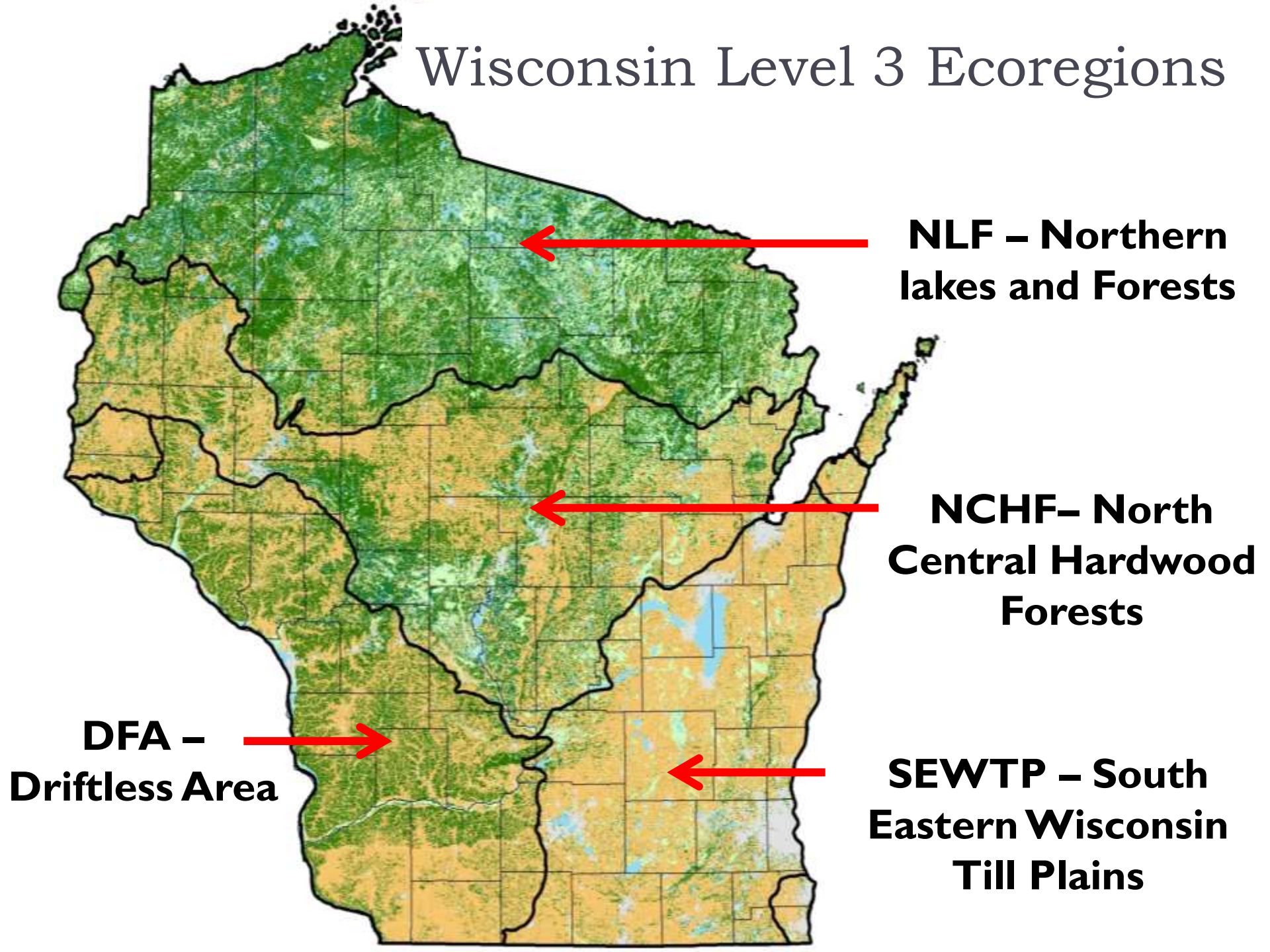
Predicting Natural Background Phosphorus in Wisconsin Streams Using a Geostatistical Model

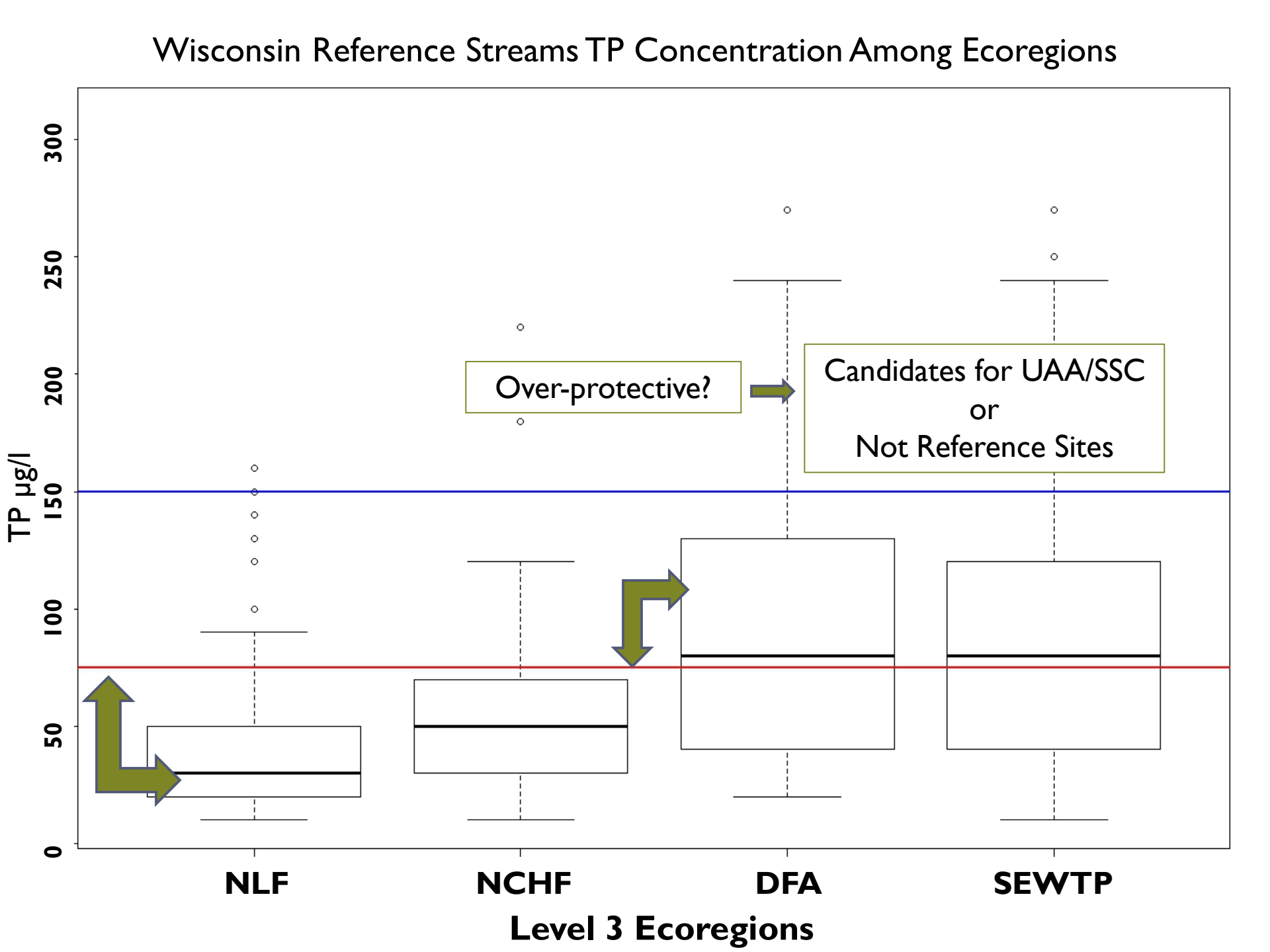
Shupryt, M.P. and Ruesch A.S.

Background: Numeric Nutrient Criteria

- 6 States with one aquatic media with numeric phosphorus criteria
- 16 additional States have numeric N or P criteria for specific waterbodies
- Criteria are often developed from stressor-response analysis
- Stressor-response relationships do not consider natural background spatial distributions of N or P

Wisconsin Level 3 Ecoregions




Wisconsin Reference Streams TP Concentration Among Ecoregions
TP µg/l
0
50
100
150
200
250
300
Over-protective?
Candidates for UAA/SSC
or
Not Reference Sites
NLF
NCHF
DFA
SEWTP
Level 3 Ecoregions

Site-Specific Criteria for Phosphorus (SSC)

Use SSC if the statewide phosphorus criteria are over- or under- protective; modify accordingly

- Range of natural TP concentrations
- Range of waterbody responses to TP levels, based on physical/chemical factors
- Enables more appropriate assessments & permit limits

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Developing site-specific nutrient criteria from empirical models

John R. Olson[1] AND Charles P. Hawkins[2]
Department of Watershed Sciences, Western Center for Monitoring and Assessment of Freshwater Ecosystems, and the Ecology Center, Utah State University, Logan, Utah 84322-5210 USA

- Site-specific model to predict natural background TP
- Create Random Forest model at reference watersheds then transfer to all watersheds
  - ***Use only natural landscape variables***

- Poor model performance among Wisconsin streams
- Other model possibilities?

Spatial Stream Networks (SSN)

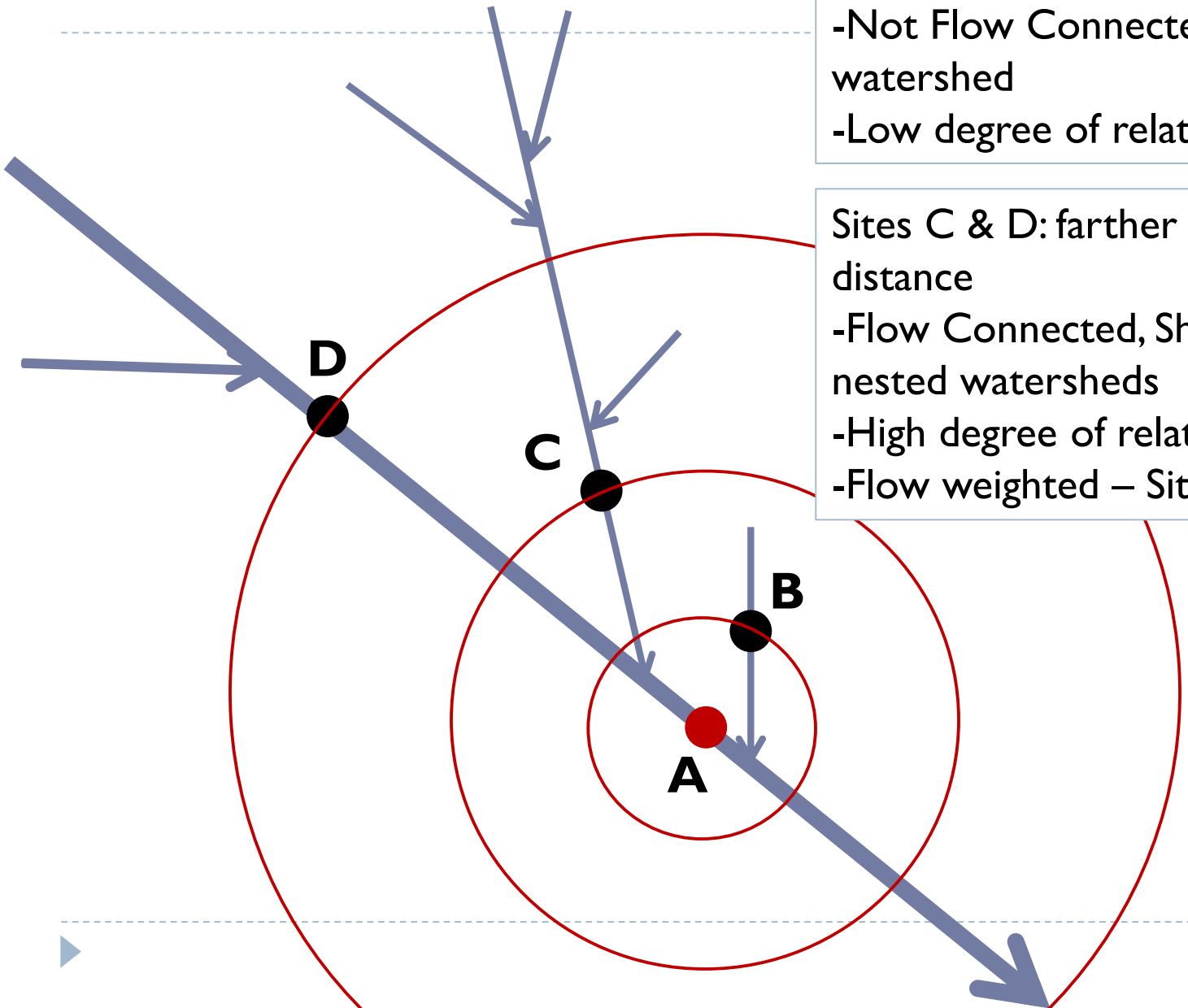
- Incorporates a linear model and accounts for spatial autocorrelation
- Replaces Euclidean distance with hydrologic network distances
- Accounts for direction and flow within network
- Ideal for modeling materials transport

A mixed-model moving-average approach to geostatistical modeling in stream networks

Erin E. Peterson[1,3] and Jay M. Ver Hoef[2]

Ecology, 2010

Hydrologic Network Distance vs Euclidean Distance



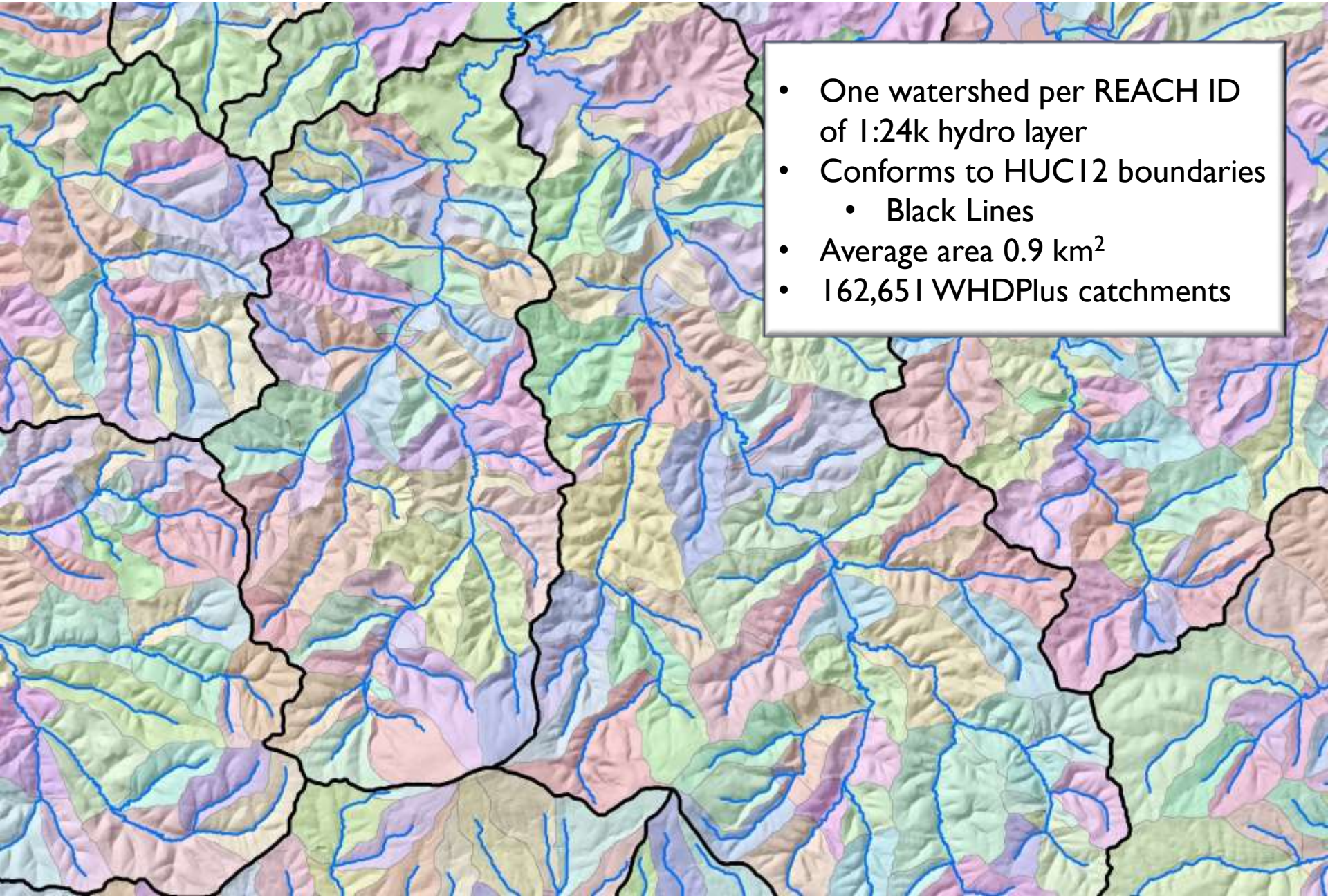
Sites A-B: closest in Euclidean distance
-Not Flow Connected, no shared watershed
-Low degree of relationship

Sites C & D: farther in Euclidean distance
-Flow Connected, Shared water and nested watersheds
-High degree of relationship
-Flow weighted – Site D

Model Process

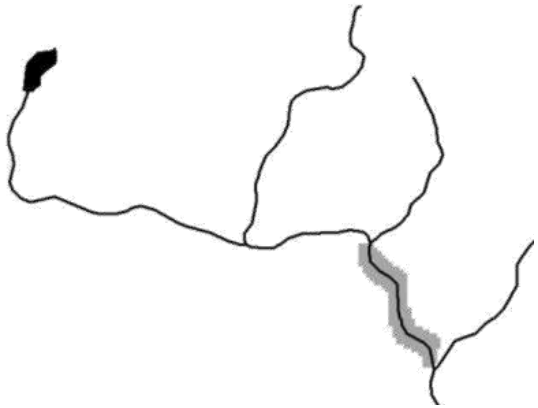
- Develop Hydrologic Network with Natural Landscape Variables
  - WI DNR WHDPlus database
- Select Reference Watersheds
- All TP in WI DNR database from 2000-2013
  - May 15th to October 15th
  - Average across time and within WHDPlus catchment
- Develop an linear model with spatial covariance (SSN)
- Apply predictive model to non-reference watersheds

Wisconsin's Watershed (WHDPlus) Delineation

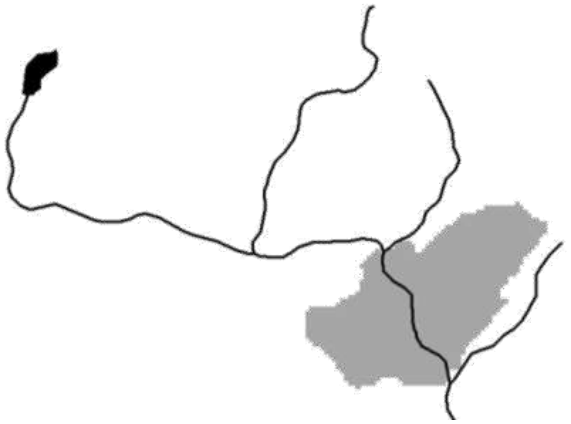


WHDPlus Attribute Dimensions

Local Riparian



Local Watershed



60 m on both sides of feature

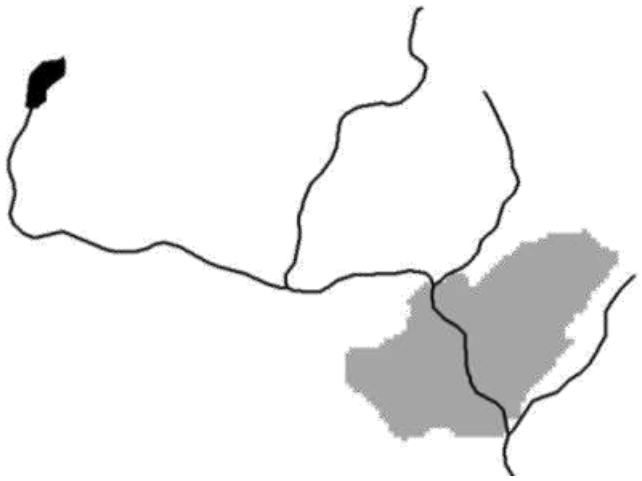
Riparian Watershed Trace

Watershed Trace

WHDPlus Attribute Dimensions

- Two most important for model development:

Local Watershed



Watershed Trace

Watershed Attributes

Hydrology/Temperature

- Groundwater potential
- Stream discharge (10, 50 & 90% Exceedence flows)
- Stream temperature*
- Watershed Area

Stream Network

- Connectivity to Great Lakes, inland lakes, large rivers
- Stream gradient and sinuosity

Land Cover

- NLCD 2006
- Pre-settlement*

Climate

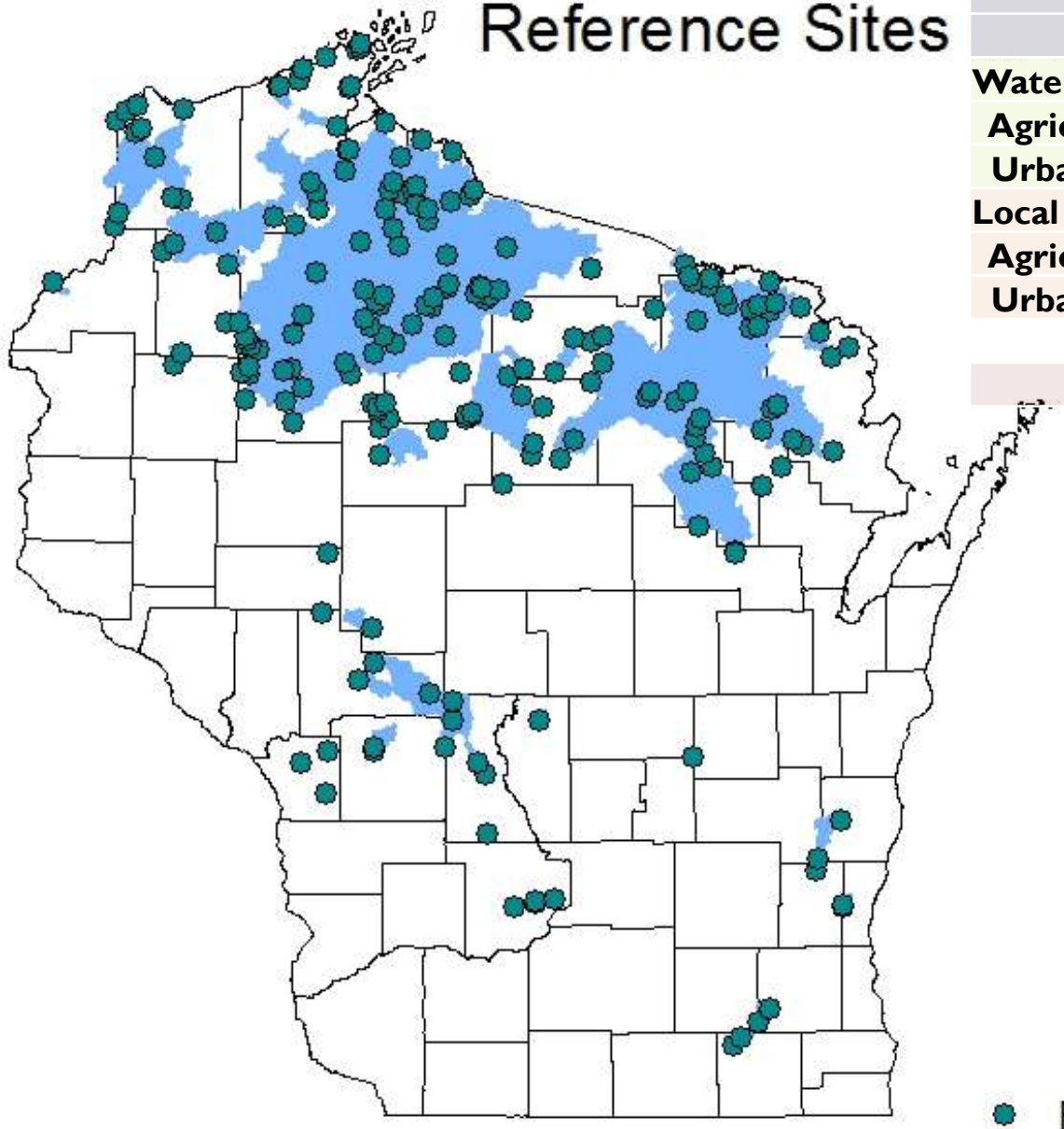
- Annual precipitation
- Annual, growing season, and monthly temperature

Geology/Soils/Topography

- Soil permeability
- Surficial geology type
- Bedrock depth and type
- Internally drained areas
- Slope
- Runoff curve number*

*Modeled attribute

Reference Sites



	Percent Land Use Criteria for Reference by Level 3 Ecoregion			
	NLF	NCHF	DFA	SEWTP
Watershed				
Agriculture	6	8	25	35
Urban	4	5	8	9
Local				
Agriculture	20	25	35	78
Urban	20	20	20	25
n=	133	18	12	10

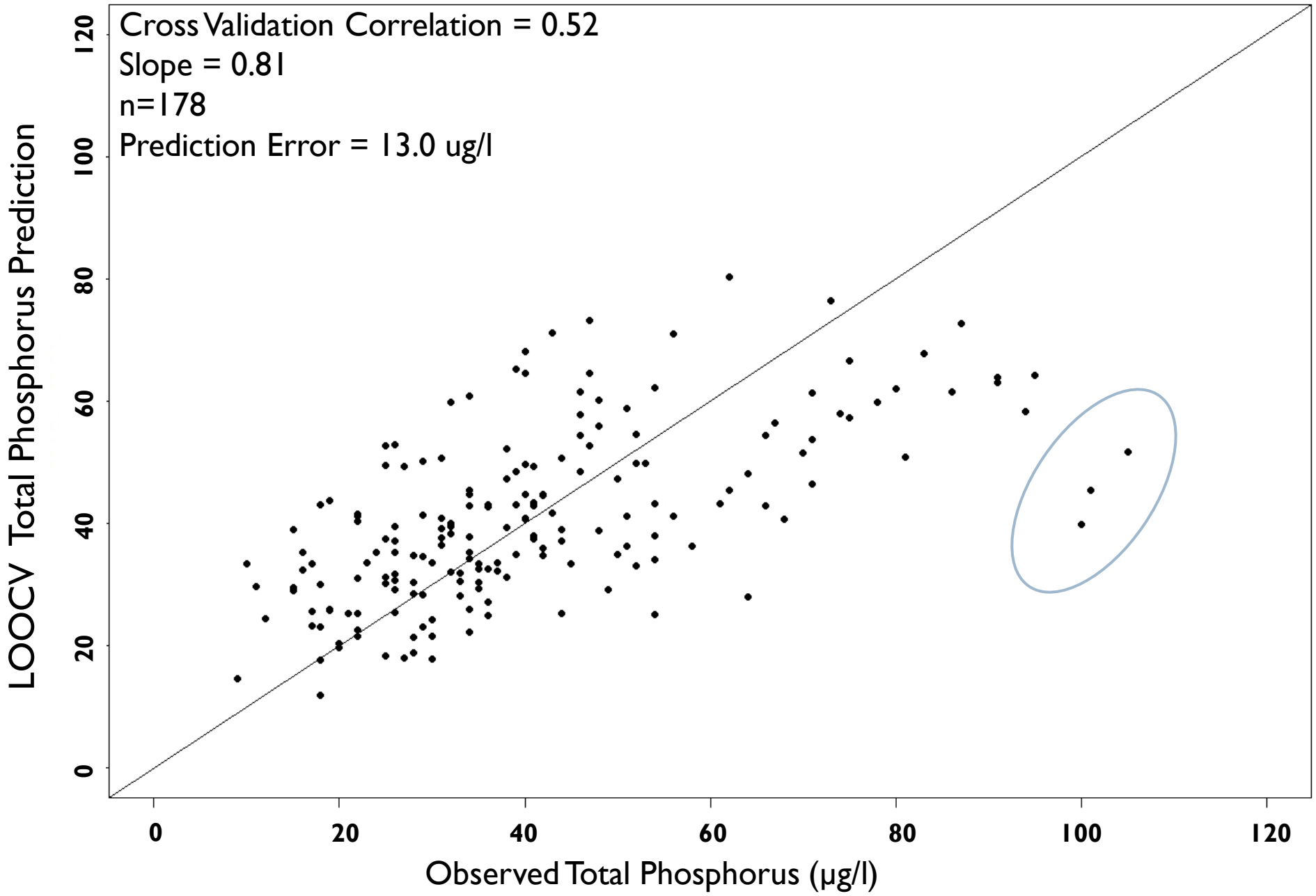
Linear Model: Parameters

Parameter	Response	P-value
Soil Permeability	Negative	<0.001
Soil pH	Negative	<0.001
Percent Forests (pre-settlement)	Negative	0.07
Percent Sand Soils	Positive	<0.001
Temp Growing Season	Positive	<0.002
Percent Clay Soils	Positive	0.009
Depth to Water Table	Positive	0.022
Soil Erodibility	Positive	0.054

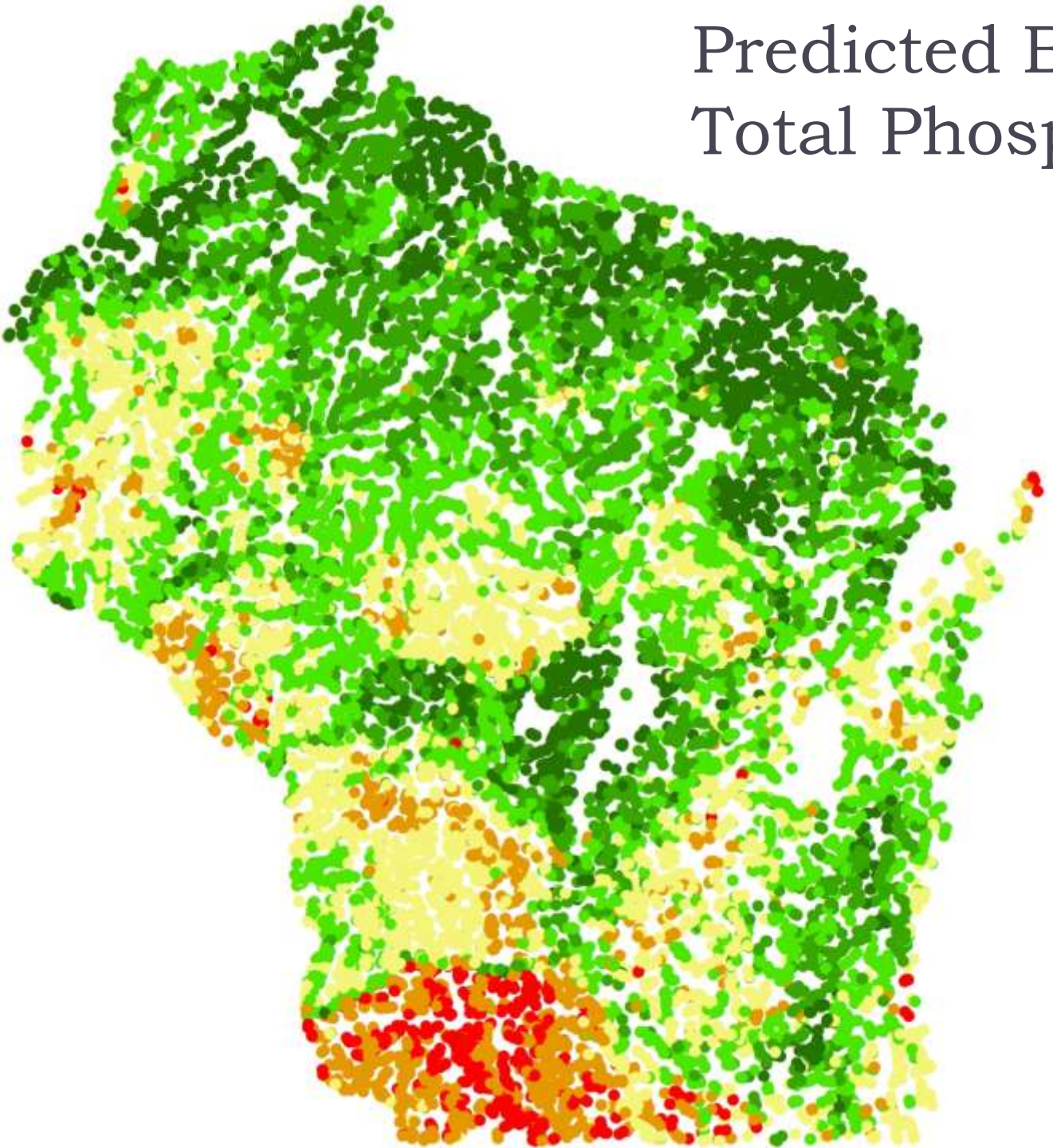
Model Diagnostics

Proportion of Error Explained
Modeled Parameters: 0.39
Tail-Up Spatial Model: 0.39
Tail-Down Spatial Model: 0.08
Nugget: 0.14 (unexplained spatial error)

Leave One Out Cross Validation of Reference Sites



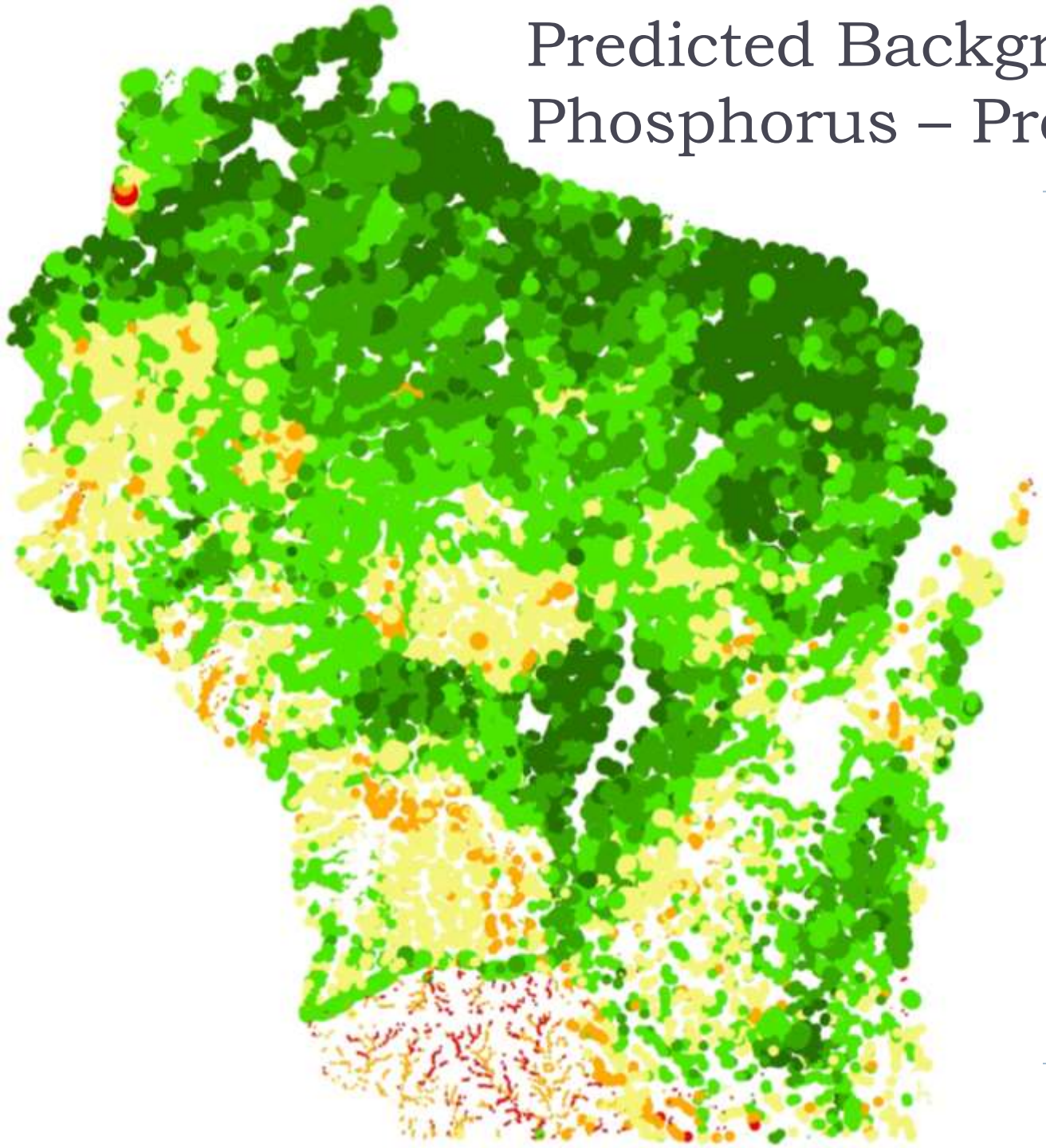
Predicted Background Total Phosphorus



Predicted TP (µg/l)

- 4.0– 35.0
- 36.0 – 45.0
- 46.0 – 55.0
- 56.0 – 65.0
- 66.0 – 75.0
- 76.0 – 113.0

Predicted Background Total Phosphorus – Prediction Errors



Larger Bubble Size = more confidence

Percentile Prediction Errors (µg/l)
5th – 14.0
95th – 17.0

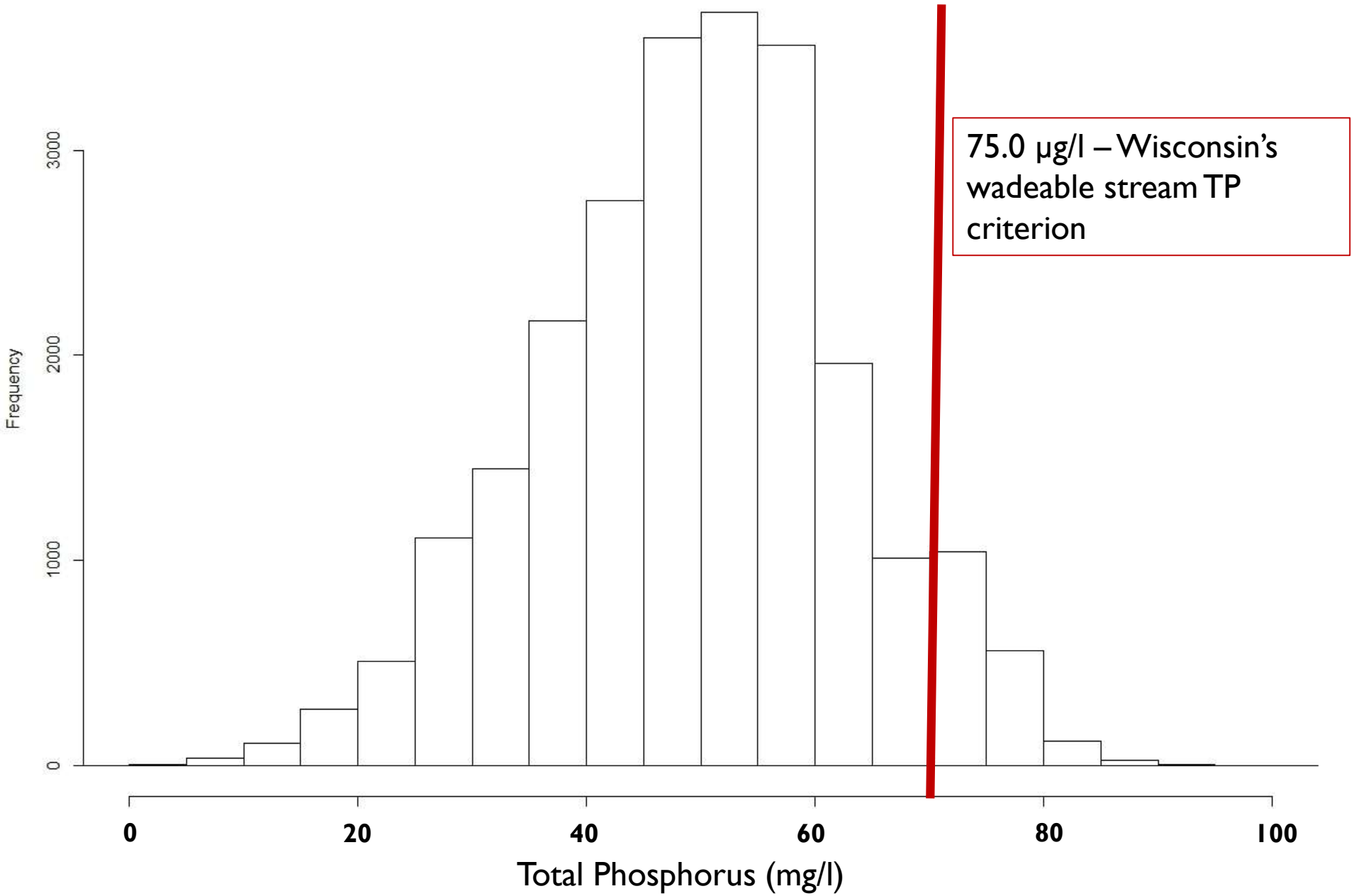
Predicted TP (µg/l)

- 4.0– 35.0
- 36.0 – 45.0
- 46.0 – 55.0
- 56.0 – 65.0
- 66.0 – 75.0
- 76.0 – 113.0

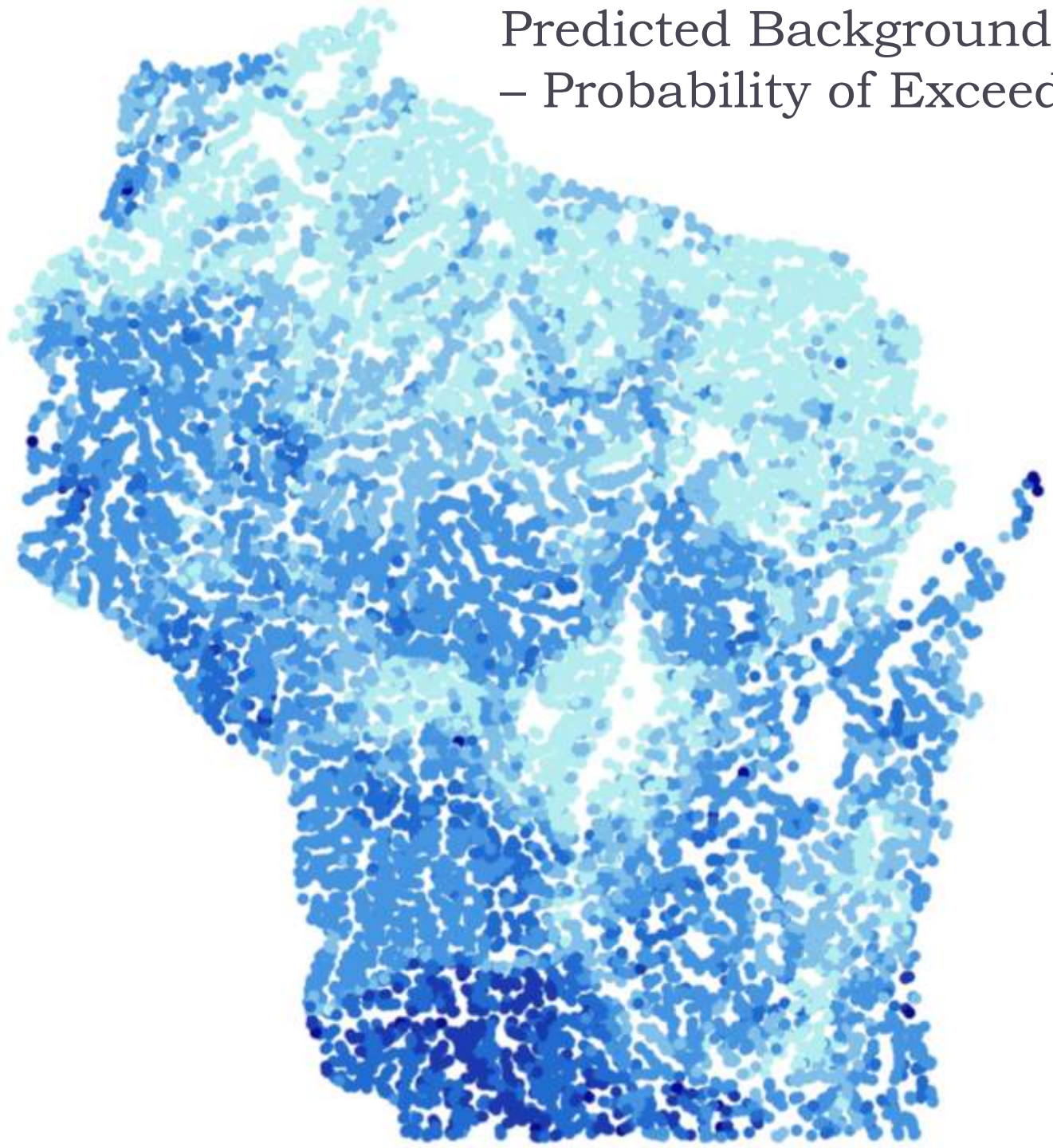
Summary

- Stream network modeling shows promise to predict chemical constituents in streams
- Median background TP concentration in Wisconsin is ~50 ug/l
  - Range: 27 to 72 ug/l (5^{th} – 95^{th} percentile)
- Model Predicts ~ 3% of streams exceed the WQS (75 ug/l)
  - Strong spatial relationship (SW WI)
  - Highest prediction error among these sites
- Currently, WI is testing the ability of the model to inform TMDL development.

Statewide Predicted Total Phosphorus



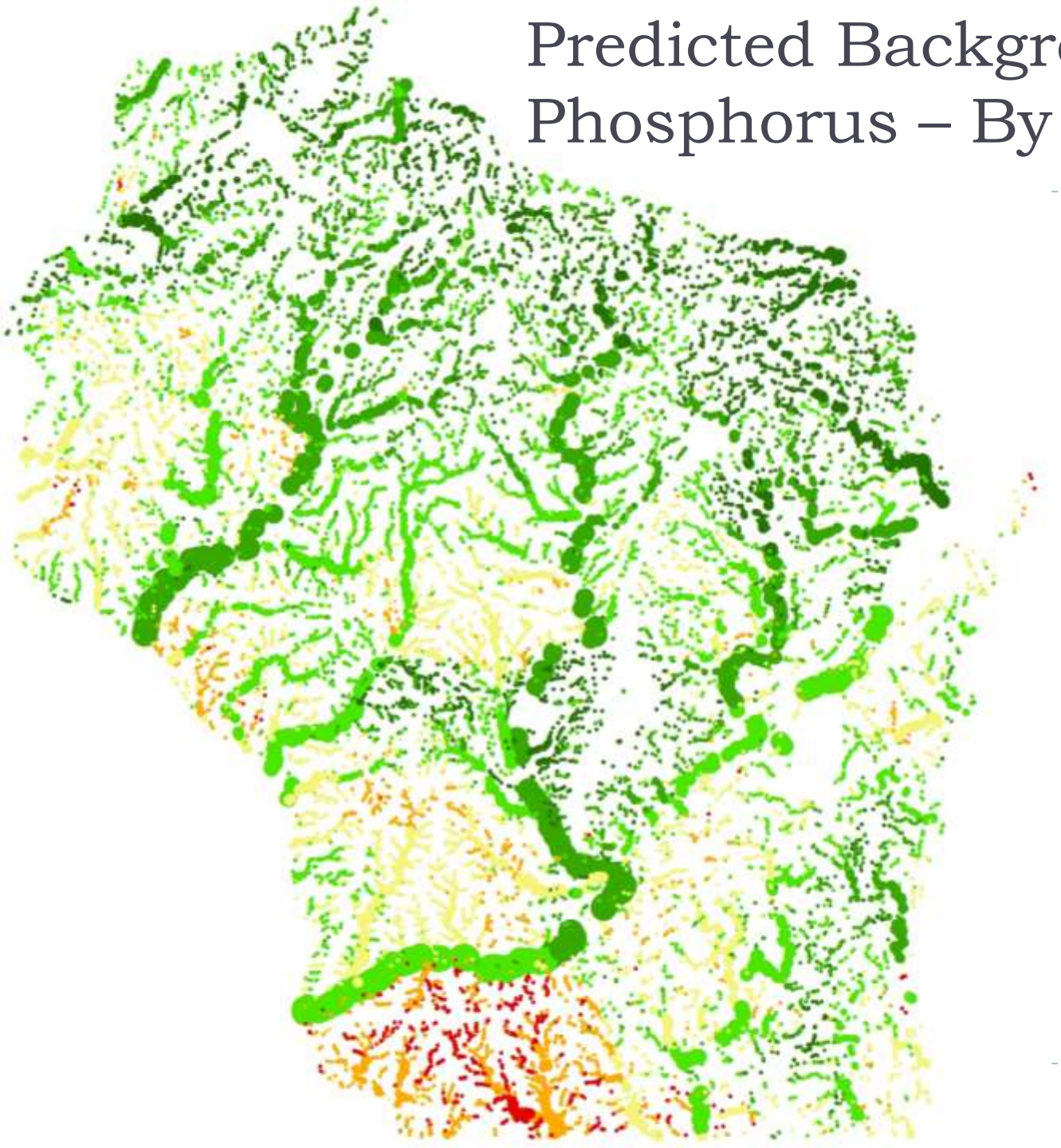
Predicted Background Total Phosphorus – Probability of Exceeding WQS



Probability of Exceeding TP criterion

- 0.0– .01
- 0.02 – 0.05
- 0.06 – 0.10
- 0.11 – 0.25
- 0.26 – 0.50
- 0.51 – 0.97

Predicted Background Total Phosphorus – By Stream Flow



Larger Bubbles = Watershed Area

Predicted TP (µg/l)

- 4.0– 35.0
- 36.0 – 45.0
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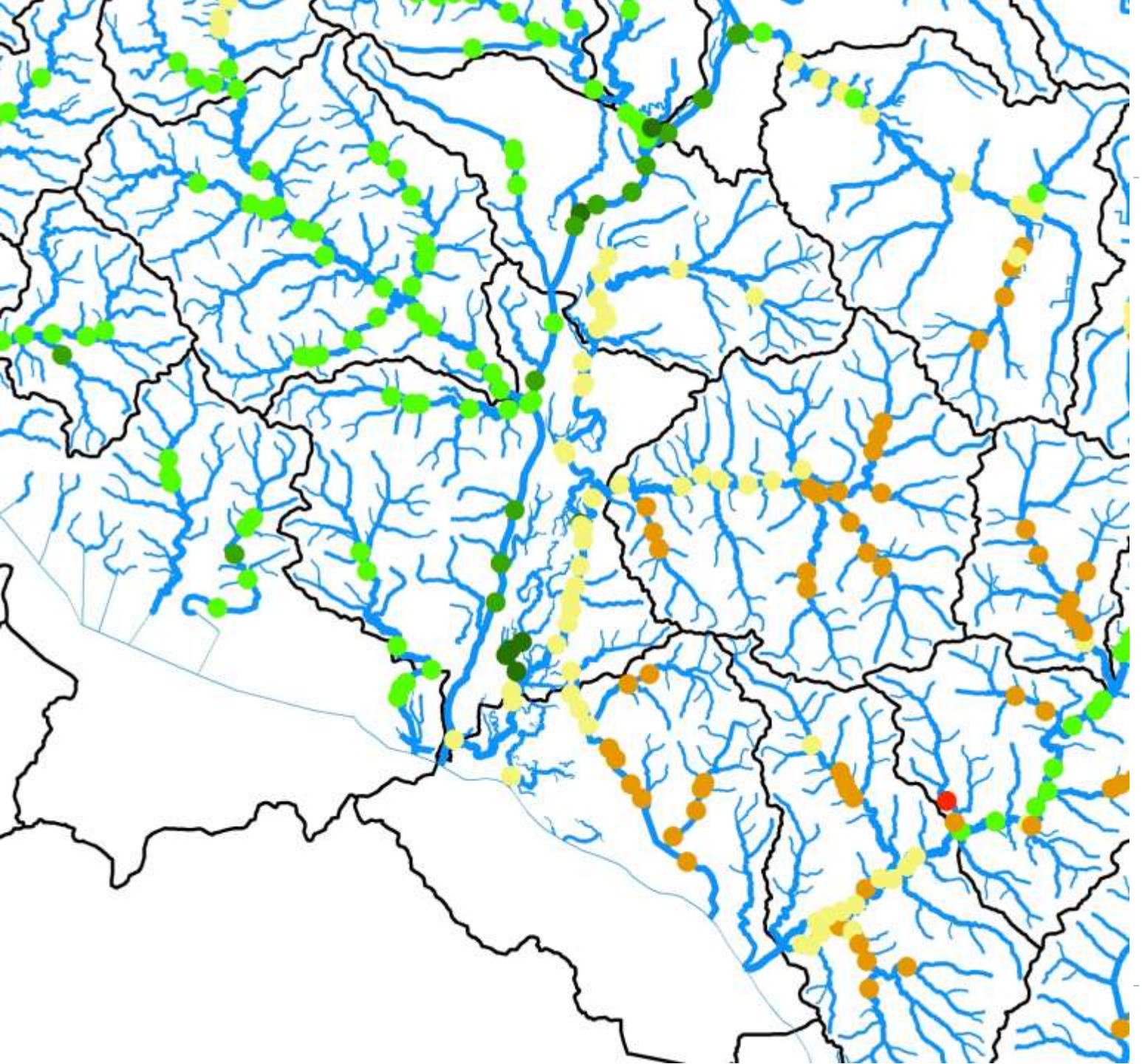
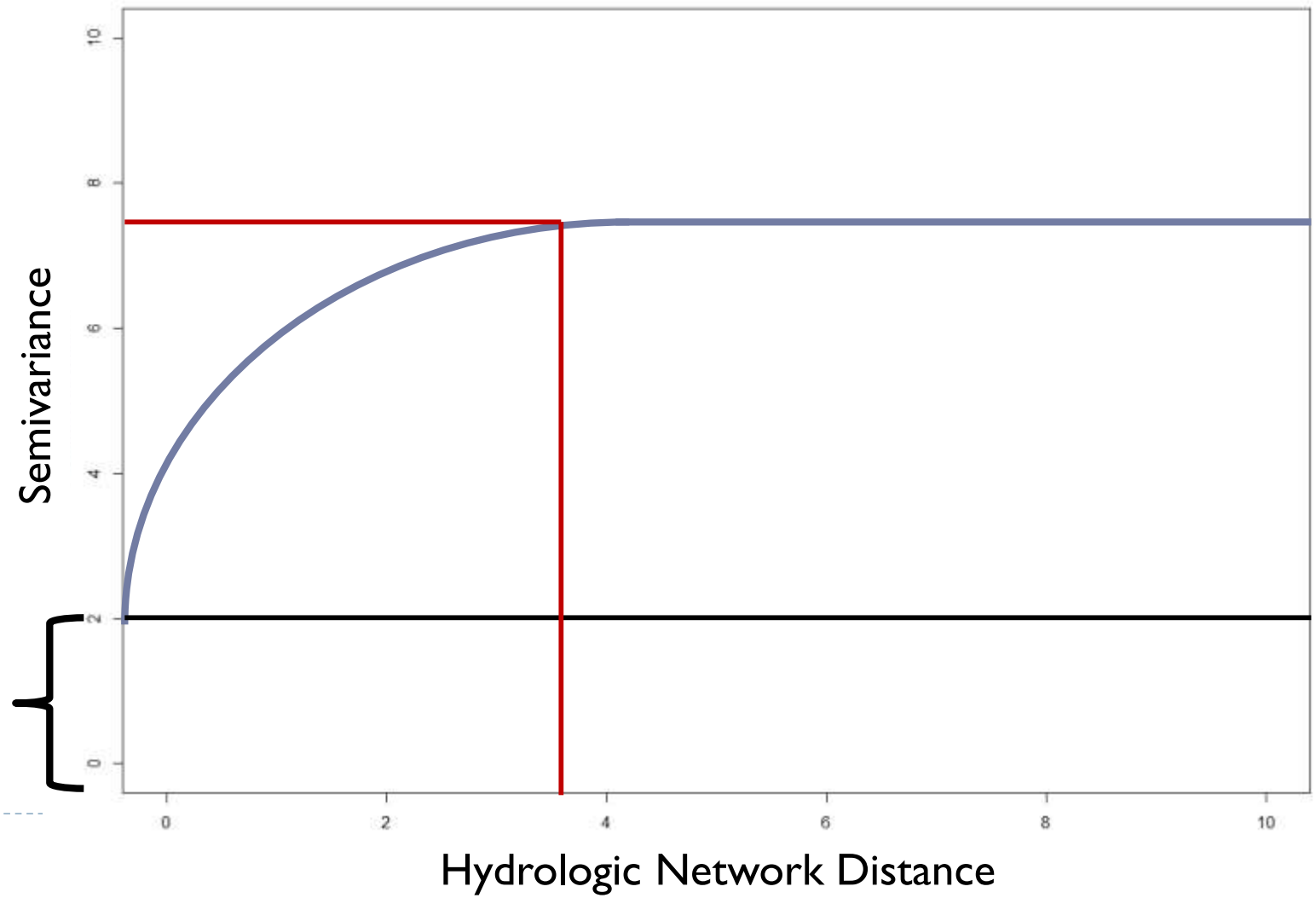


Semivariogram



Nugget Effect:
Unexplained
Spatial Variance