UNRBA Monitoring Program Development and Implementation

PFC Meeting
March 4, 2014

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Unrba

Monitoring objectives

- Falls Lake EFDC Model improvement
- Demonstrate response of Falls Lake chlorophyll a and TOC to changes in nitrogen and phosphorus concentrations and loading
- Determine Jurisdictional Loading
- Regulatory compliance
- Link water quality and designated uses
- Prioritize BMP implementation
- Support regulatory options

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Updates

- Main focus of current analyses is to use and create models that can predict water quality or flow
  - Develop adaptive monitoring plan
  - Reduce future monitoring effort where possible
  - Optimize the level of monitoring effort and cost

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Statistical Model Development

Statistical Model Development Objectives

- ***Inform monitoring design*** (locations and frequency of sampling)
- Assess degree to which models could be used to ***estimate water quality parameters***
  - > at locations without data (or very little data)
  - > for dates without measurements

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Future Use of Water Quality Statistical Prediction Models

- Fill in data gaps with model predictions
  - > EFDC model requires daily inputs of nutrients
    - – measurements occur less frequently than daily
    - – models should provide unbiased estimates (linear interpolation is likely biased, e.g. Ferguson 1987).
- Statistically test hypotheses about changes in WQ post management action (e.g. WWTP upgrades).
- Estimate trends in WQ through time (e.g. gradual effects from multiple BMP implementations).

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Use of Statistical Models to Support Design of Monitoring Program

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Monitoring Implications

- If a site of interest is well predicted* by models, UNRBA may not need to sample that location as frequently as others (but still enough to verify model predictions).
- If a site of interest is poorly predicted by models, sampling may need to occur more frequently.

*Estimates are unbiased with narrow confidence intervals

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Monitoring Implications

- Statistical model provides the ***expected daily mean*** nutrient concentrations
  - Adjust sampling frequency based on the expected mean concentrations.
    - For example, sites with high nutrient loading are more influential to the Falls Lake Nutrient Response model than sites with low nutrient loading.
  - Sample sites more frequently where expected (modeled) values are significantly different from those assumed by NC-DWR in the current version of the Falls Lake Nutrient Response model.

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Monitoring Implications

- Model provides estimates of the **prediction interval** around the estimate of the daily mean
  > sites with narrow prediction intervals may not need to be sampled as frequently as sites with wide CIs

  > may want to sample sites with narrow prediction intervals quarterly and use model to statistically test whether samples are significantly different from predictions. If so, adjust frequency of sampling accordingly.

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Monitoring Implications

- Decisions to use models in place of sampling can be adaptive; new data which validate (or do not validate) the models for specific sites can support decisions to reduce (or increase) sampling frequency at any point in time.
- Sampling frequency in year-one need not dictate frequency in all subsequent years; as data accumulate and the models' predictive capacities are reassessed, UNRBA may be able to sample less frequently.

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Model Overview

Model 1: applies to locations for which we have historical data. The model predictions are informed by the historical data specific to the location of interest.

Model 2: applies to locations for which we do not have historical data. Predictions are informed by spatial relationships among locations and water quality.

Statistical Model for Sites with Existing Data (Model 1)

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Model 1 Overview

- Model 1 is a standard regression model that predicts WQ as a function of location, time and predictors such as precipitation and stream flow
- Model 1 applies a natural log transformation to WQ and assumes normally distributed errors

$$\ln(WQ) = \mu + \gamma_l + \tau_y + \delta_m + \boldsymbol{x\beta} + \varepsilon$$

where μ is the **intercept** parameter, γ_l is a **<u>location</u>** effect, τ_y is a **<u>year</u>** effect, δ_m is a **<u>month</u>** effect , $\boldsymbol{x\beta}$ are the effects of **<u>predictors</u>** (next slide) and ε is the **error** term

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Model Predictors for TN, TP, TSS and TOC

TN	TP	TSS	TOC
Precipitation	Precipitation	Precipitation	Precipitation
Precipitation* Catchment Area	Precipitation* Catchment Area	Precipitation* Catchment Area	Precipitation* Catchment Area
ln(Flow)	ln(Flow)	ln(Flow)	ln(Flow)
[ln(Flow)]2	$[\ln(Flow)]^2$	$[\ln(Flow)]^2$	$[\ln(Flow)]^2$
Maximum Daily Temperature	Maximum Daily Temperature	Maximum Daily Temperature	
Precipitation on Day Prior	Precipitation on Day Prior	Precipitation on Day Prior	
Precipitation Two Days Prior	Precipitation Two Days Prior	Precipitation Two Days Prior	

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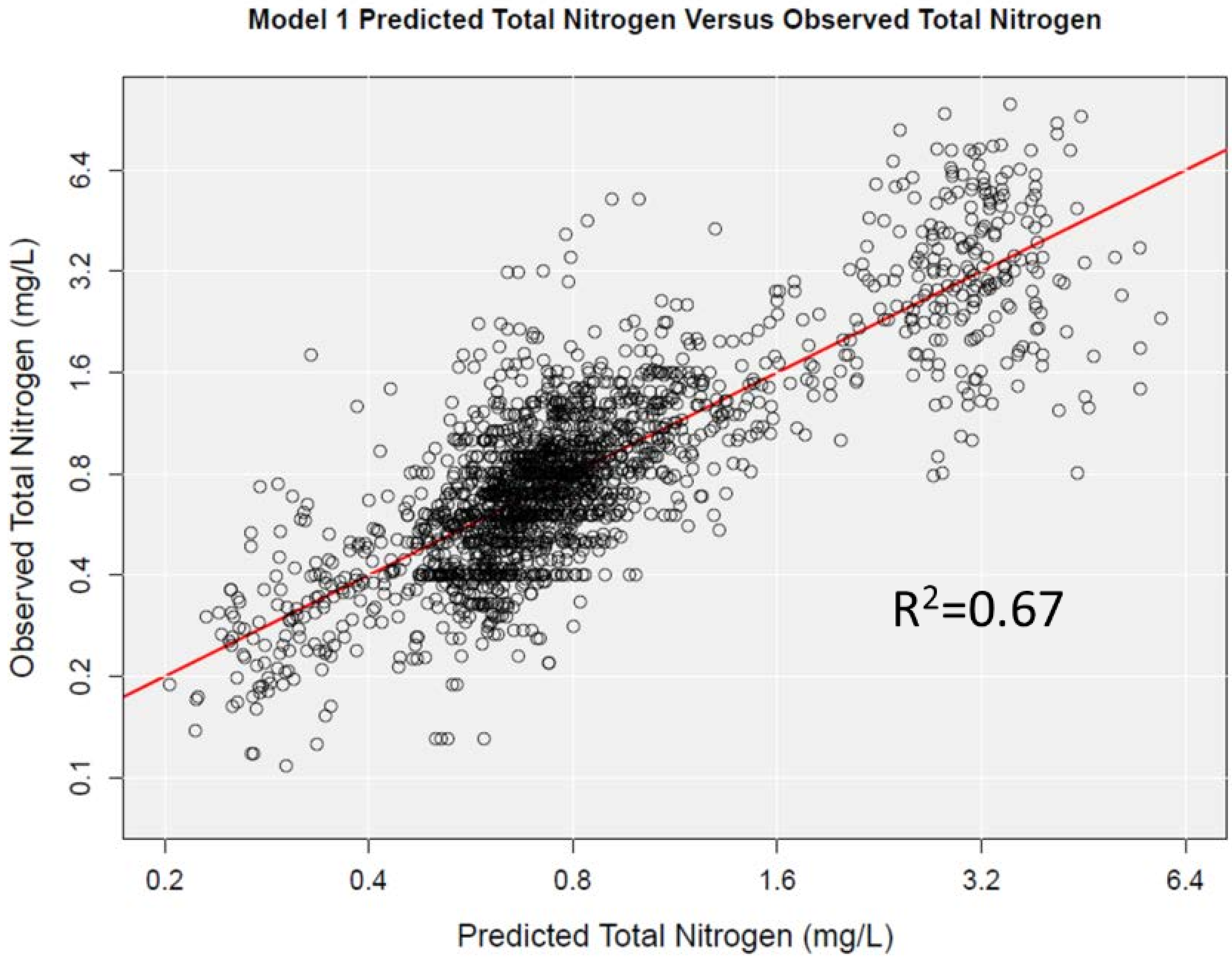
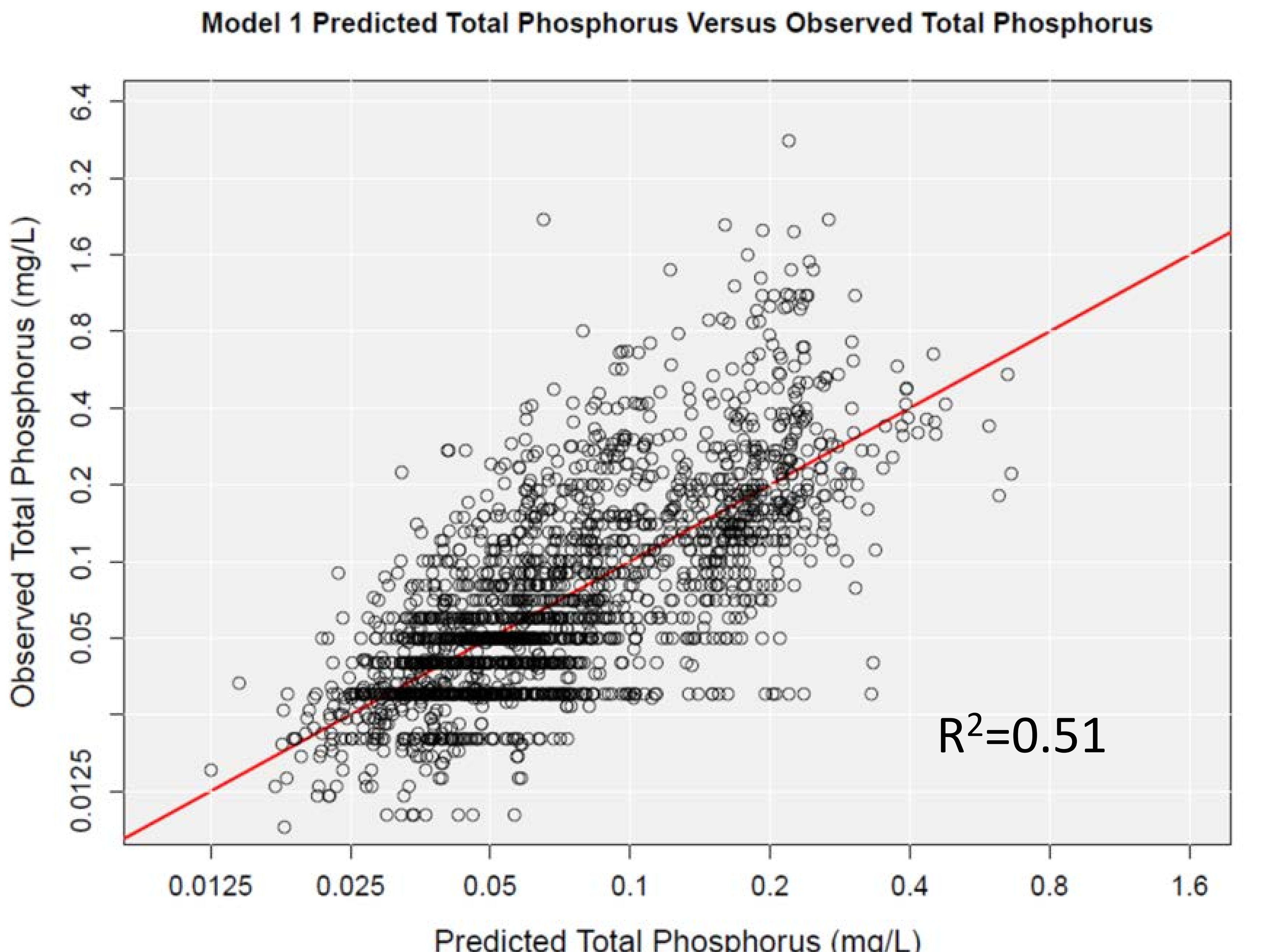
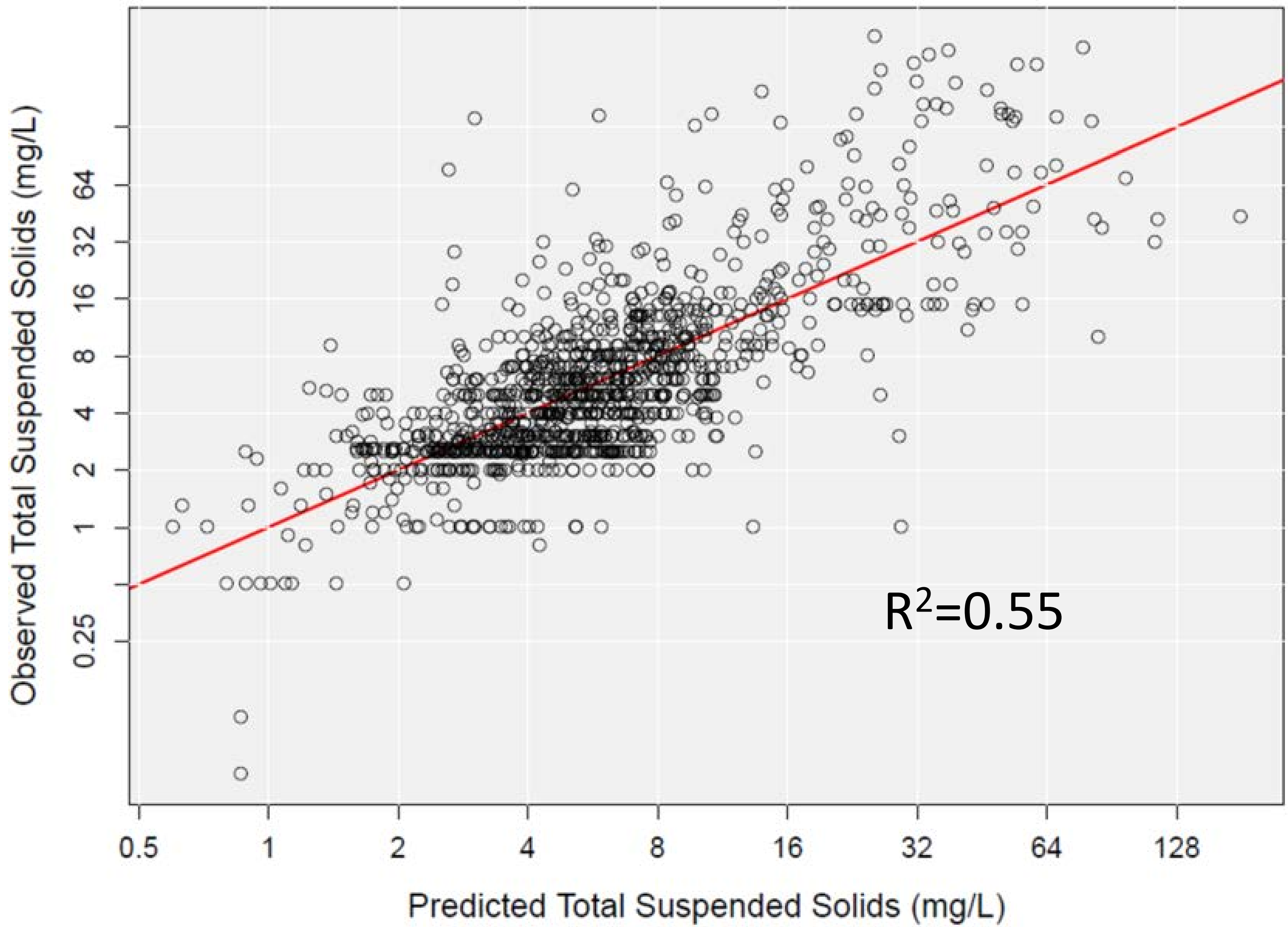
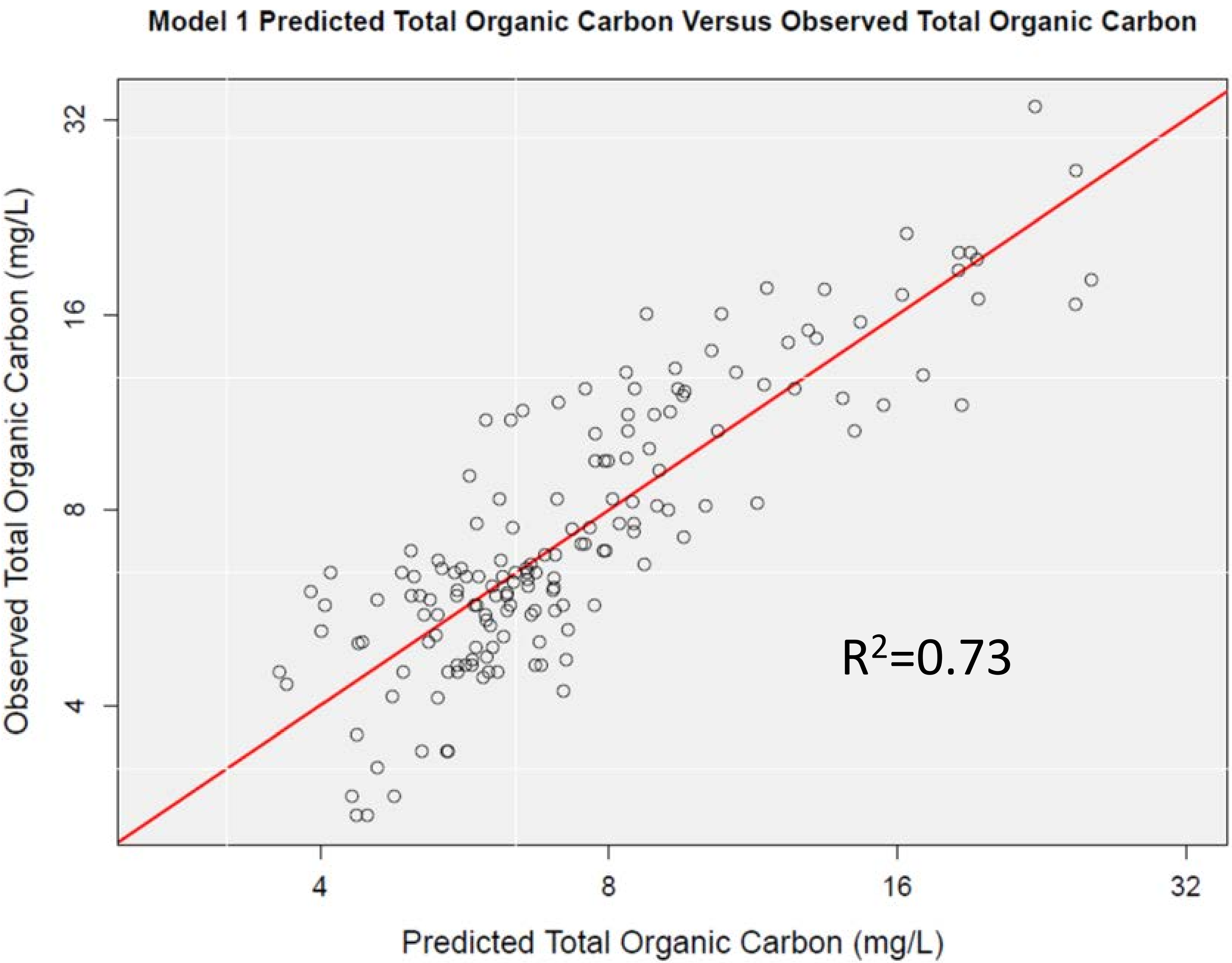

Model 1 Predicted Total Nitrogen Versus Observed Total Nitrogen
Observed Total Nitrogen (mg/L)
6.4
3.2
1.6
0.8
0.4
0.2
0.1
0.2
0.4
0.8
1.6
3.2
6.4
Predicted Total Nitrogen (mg/L)
R2=0.67

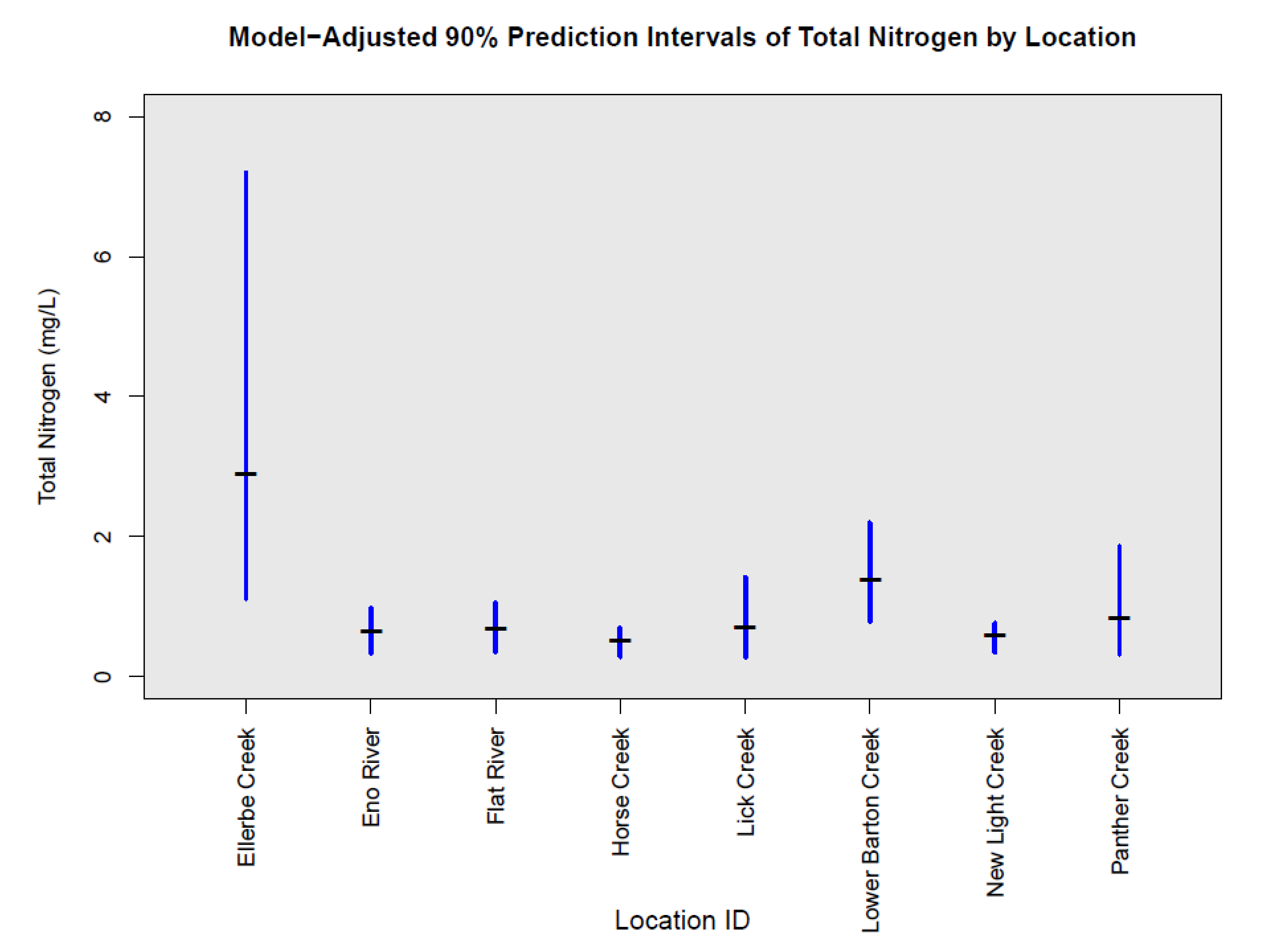

Model 1 Predicted Total Phosphorus Versus Observed Total Phosphorus
Observed Total Phosphorus (mg/L)
6.4
3.2
1.6
0.8
0.4
0.2
0.1
0.05
0.0125
0.0125
0.025
0.05
0.1
0.2
0.4
0.8
1.6
Predicted Total Phosphorus (mg/L)
R2=0.51

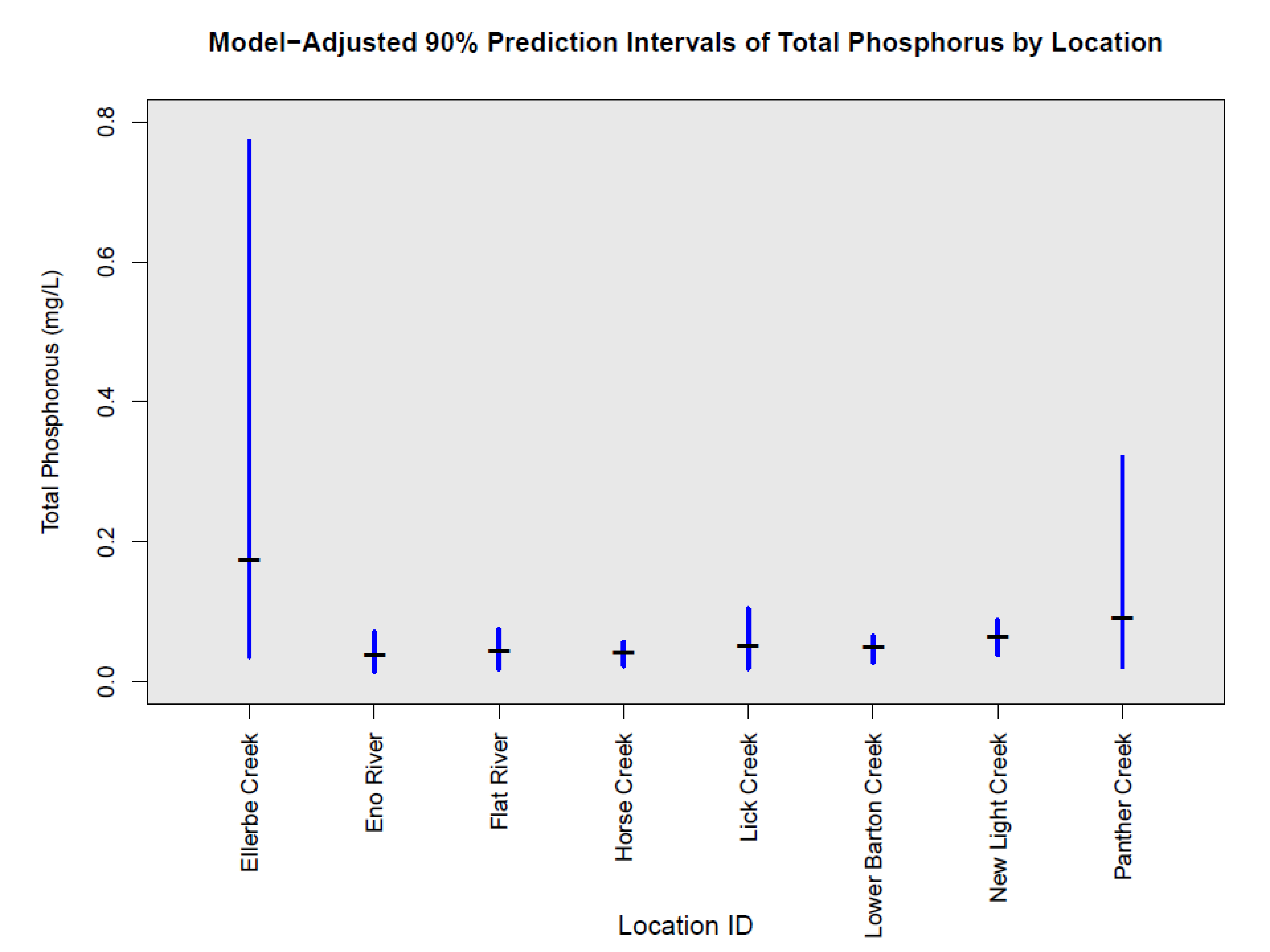
Model 1 Predicted Total Suspended Solids Versus Observed Total Suspended Solids

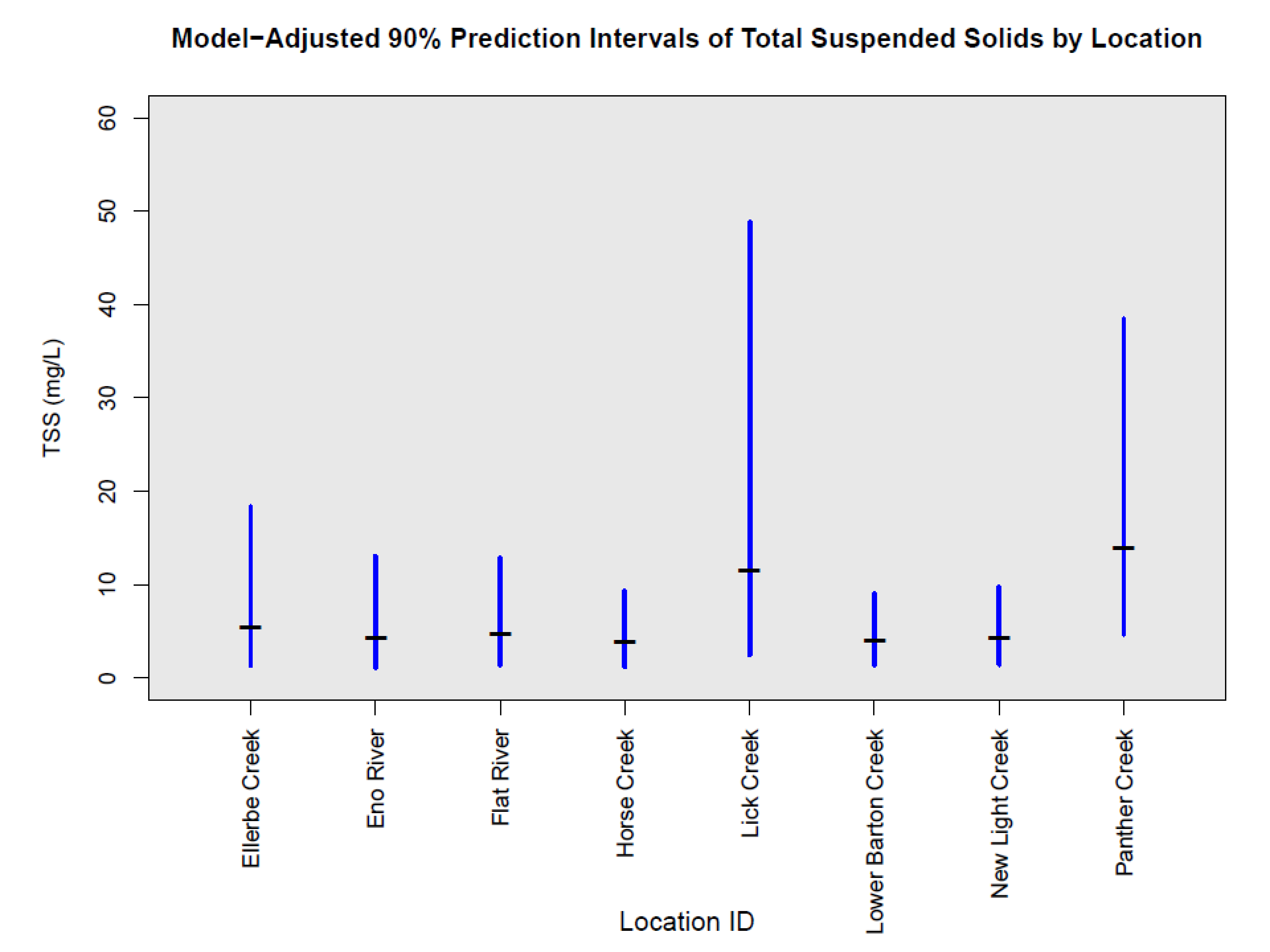




Model 1 Predicted Total Organic Carbon Versus Observed Total Organic Carbon
Observed Total Organic Carbon (mg/L)
32
16
8
4
4
8
16
32
Predicted Total Organic Carbon (mg/L)
R2=0.73


Model−Adjusted 90% Prediction Intervals of Total Nitrogen by Location
Total Nitrogen (mg/L)
0
2
4
6
8
Ellerbe Creek
Eno River
Flat River
Horse Creek
Lick Creek
Lower Barton Creek
New Light Creek
Panther Creek
Location ID


Model−Adjusted 90% Prediction Intervals of Total Phosphorus by Location
Total Phosphorous (mg/L)
0.0
0.2
0.4
0.6
0.8
Ellerbe Creek
Eno River
Flat River
Horse Creek
Lick Creek
Lower Barton Creek
New Light Creek
Panther Creek
Location ID


Model−Adjusted 90% Prediction Intervals of Total Suspended Solids by Location
TSS (mg/L)
0
10
20
30
40
50
60
Ellerbe Creek
Eno River
Flat River
Horse Creek
Lick Creek
Lower Barton Creek
New Light Creek
Panther Creek
Location ID

Using results to inform sampling frequency

- Some sites have large prediction intervals for all three parameters, for example **Panther Creek**, and may be candidates for more frequent sampling than other sites.
- Some sites are well predicted for all three parameters, for example **Horse Creek**, and may not need to be sampled as frequently as other sites.
- Samples can be continually compared to model predictions and sampling frequency adjusted accordingly.

Using Statistical Model 1 to Determine Monitoring Frequency

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Sampling Frequency Analysis

- The relationship between the number of samples used in model development and uncertainty in model predictions of water quality parameters can be obtained from Model 1
- The uncertainty calculation occurs as follows:

Percent relative error =

$$\frac{Upper\ bound\ of\ X\%\ CI\ for\ WQ_{predicted} - average\ WQ}{average\ WQ} \times 100\%$$

where the upper bound is from a Confidence Interval on the model estimated WQ

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For example

- If average WQ is 10 and for a given sample size we expect a 90% CI from 5 to 15, then the expected relative error rate (for 90% confidence) is:

$$\left(\frac{15-10}{10}\right)\times 100\% = 50\%\ error$$

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Total number of samples needed

Approximate number of samples needed to achieve specified confidence/relative error rates

			Relative Error Rate			
		10%	20%	30%	40%	50%
	TN	99	27	13	8	6
90% Confidence	TP	218	60	29	18	13
	TSS	>260	105	51	31	22
			Relative Error Rate			
		10%	20%	30%	40%	50%
	TN	140	39	19	12	8
95% Confidence	TP	>260	85	41	25	18
	TSS	>260	149	72	44	30

Example: monthly sampling for 5 years (n=60) would allow the model to estimate daily values of TP (and TN) for which we could be 90% certain that the predictions are within 20% of the true value. For TSS the same monitoring frequency would result in estimates which have a higher (30%) relative error.

Statistical Model for Prediction of Water Quality at Locations with No Data (Model 2)

Model 2 Characteristics

- Model 2 extends Model 1
- Instead of location-specific parameters, Model 2 is a spatial model able to consider historically unmonitored location
- Model incorporates thin-plate splines which are used in spatial statistical modeling
- Spline modeling is a modern alternative to kriging methods

Model 2 Characteristics

The model is similar to Model 1:

$$\ln(WQ) = f(lat, long) + \tau_y + \delta_m + \boldsymbol{x\beta} + \varepsilon$$

where now $f(lat, long)$ is the spatial component, modeling WQ as a function of latitude and longitude; the other components are analogous to Model 1

Model 2 includes additional physical predictor variables that were not useful for Model 1

Precipitation
Precipitation*Catchment Area
ln(Flow)
$[\ln(\text{Flow})]^2$
Terrain slope index 1
Terrain slope index 2
Elevation index 1
Elevation index 2
Percent impervious surface in 2006
Percent wetlands in 2006
5-year peak flow level
Percent forest in 2006

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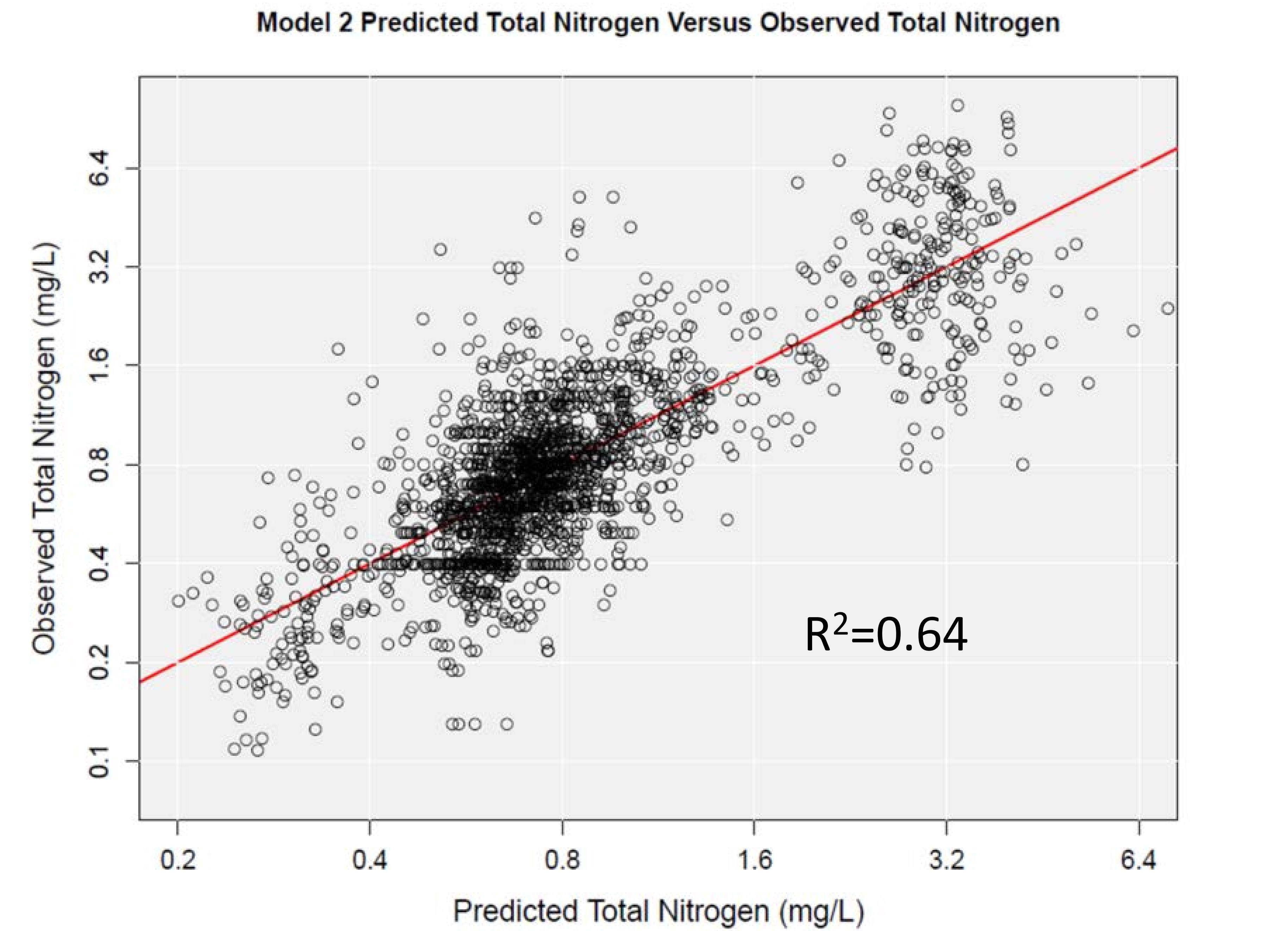
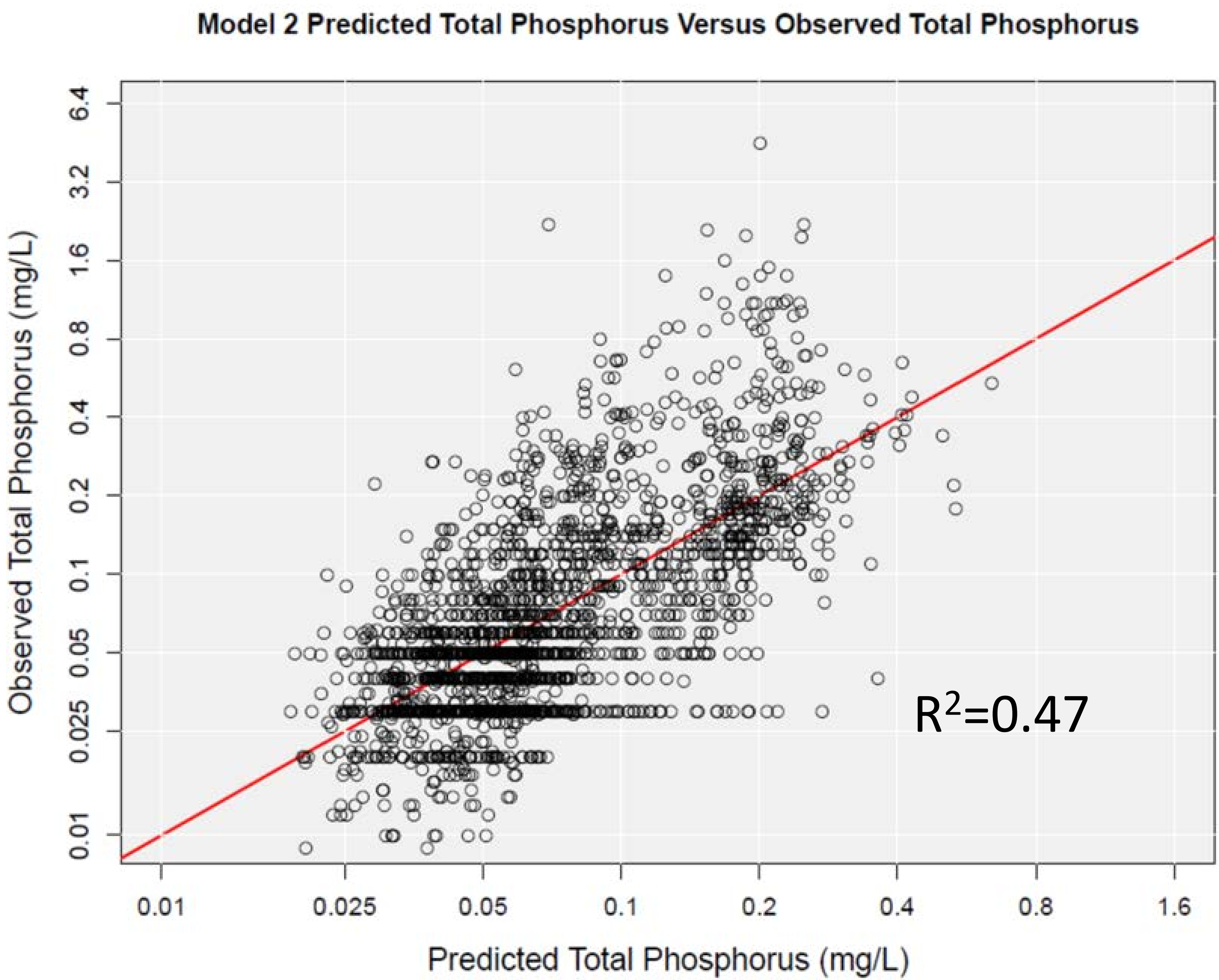
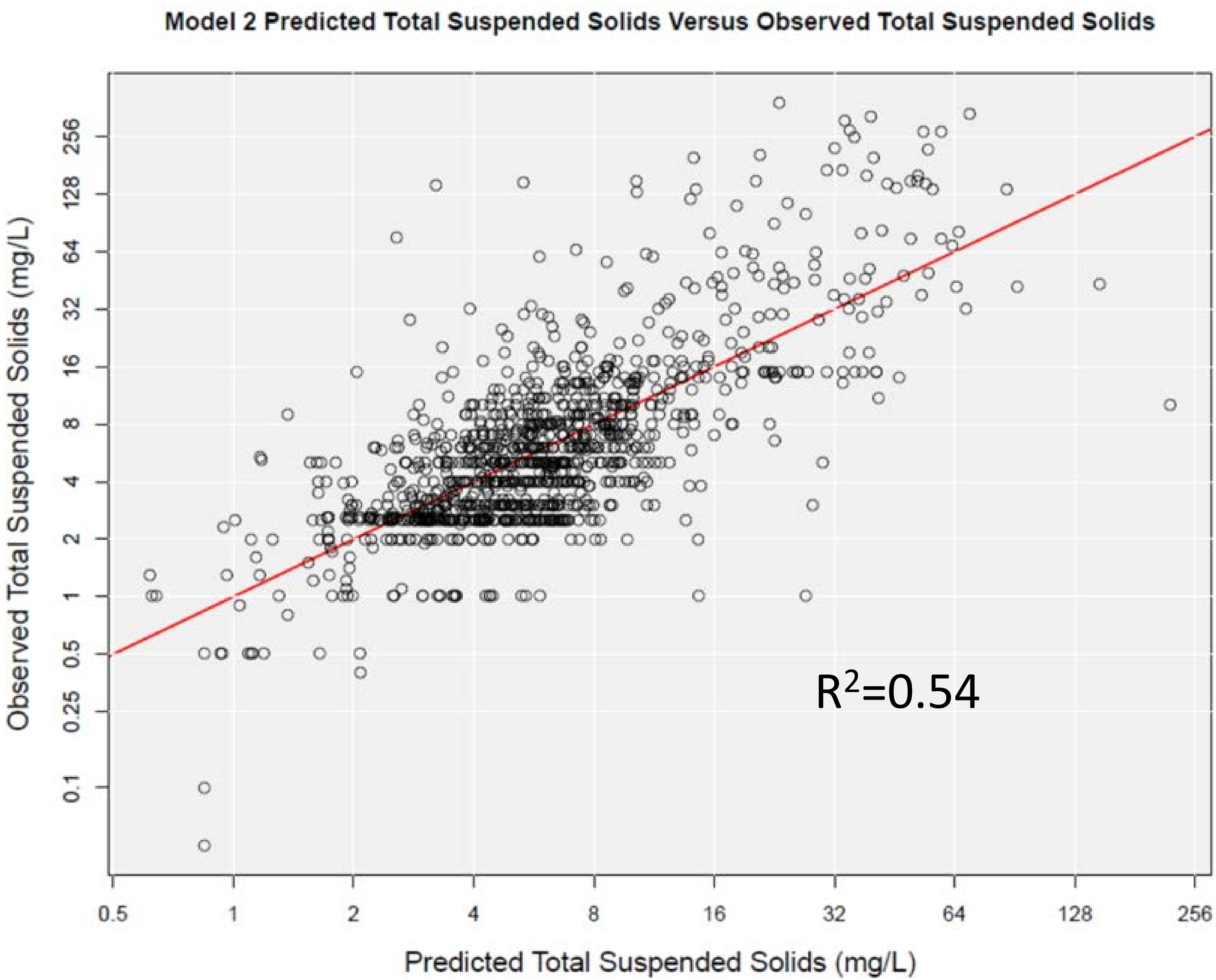
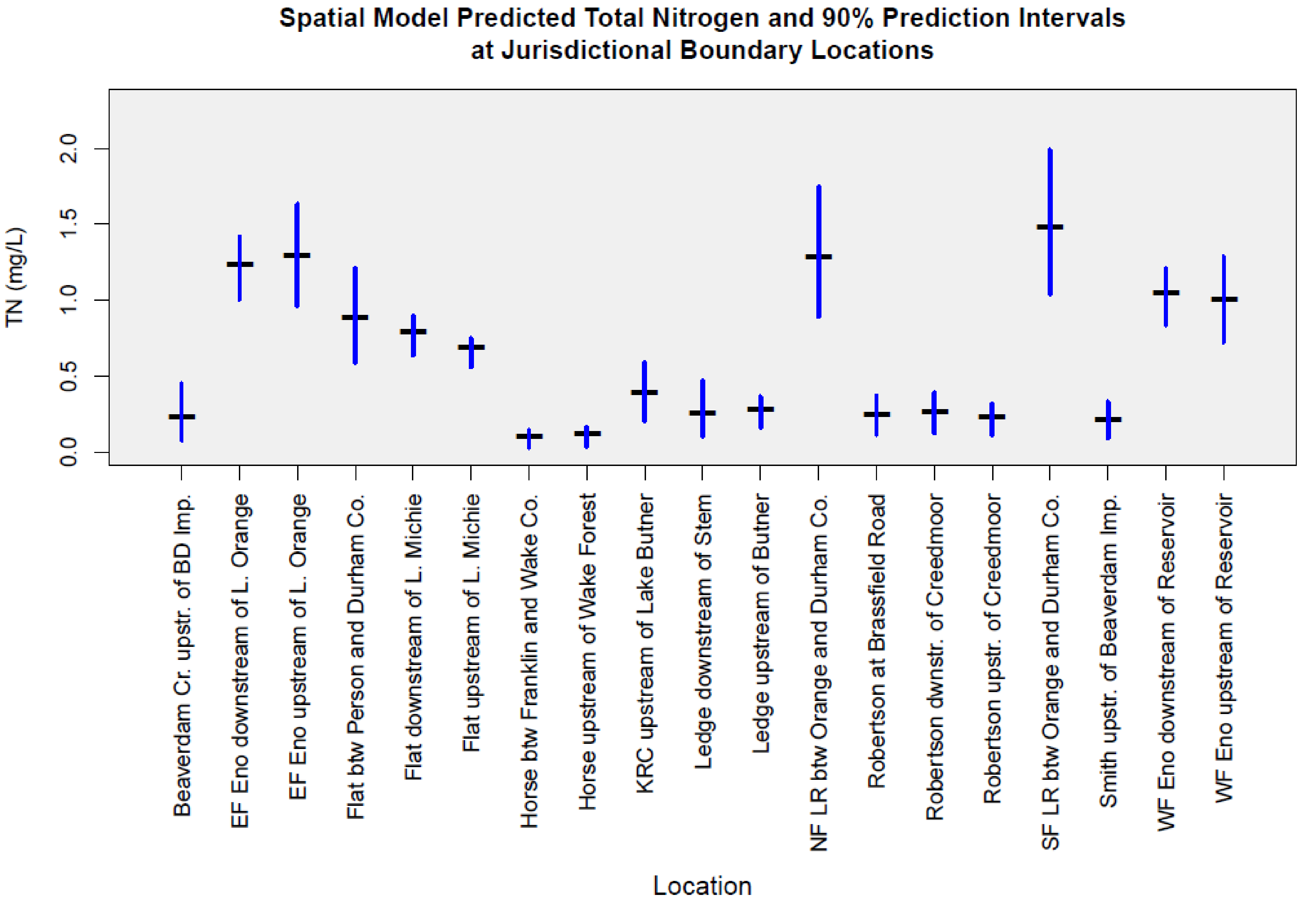

Model 2 Predicted Total Nitrogen Versus Observed Total Nitrogen
Observed Total Nitrogen (mg/L)
0.1
0.2
0.4
0.8
1.6
3.2
6.4
Predicted Total Nitrogen (mg/L)
0.2
0.4
0.8
1.6
3.2
6.4
R2=0.64



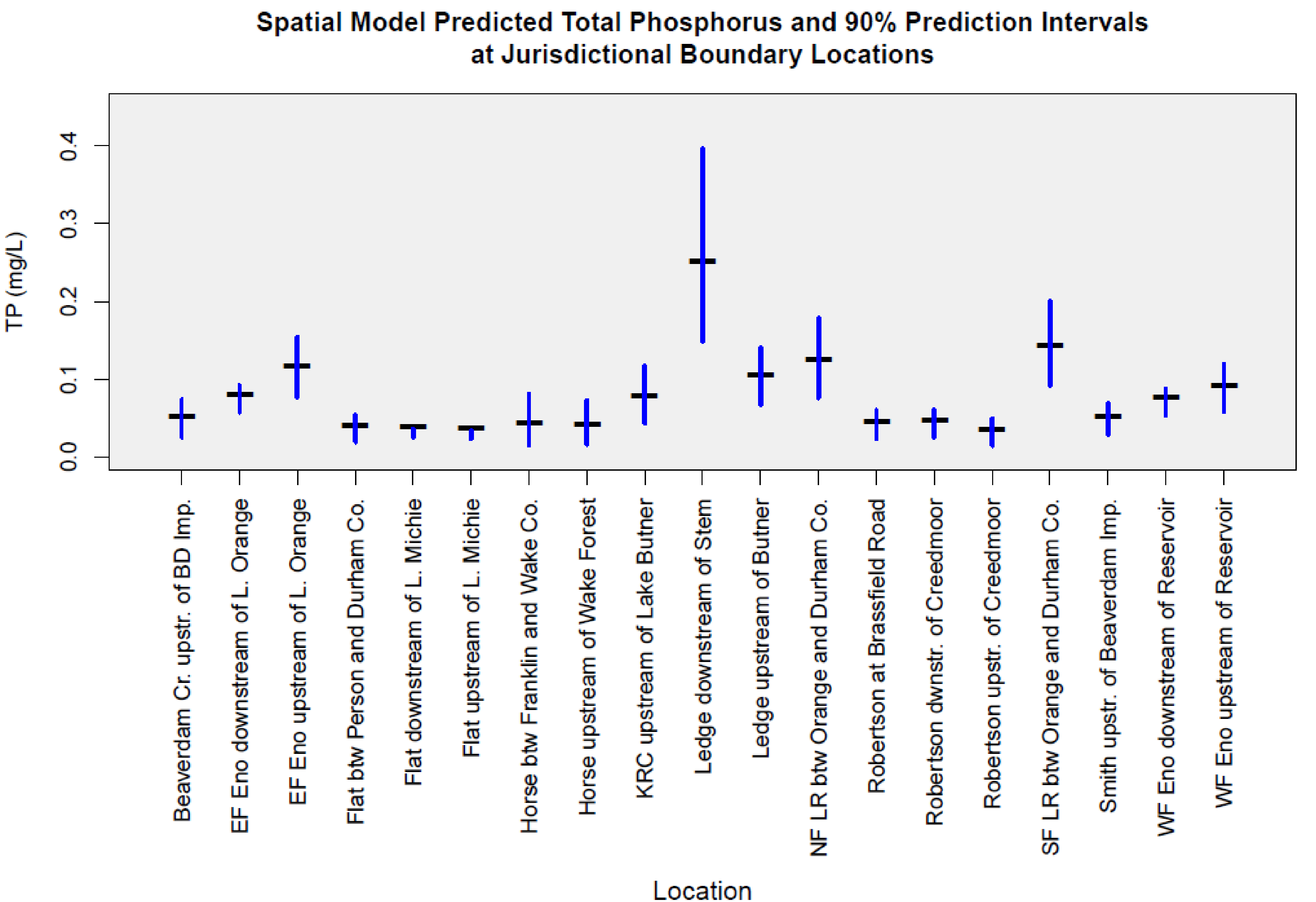
Model 2 Predicted Total Phosphorus Versus Observed Total Phosphorus
Observed Total Phosphorus (mg/L)
6.4
3.2
1.6
0.8
0.4
0.2
0.1
0.05
0.025
0.01
0.01
0.025
0.05
0.1
0.2
0.4
0.8
1.6
Predicted Total Phosphorus (mg/L)
R2=0.47



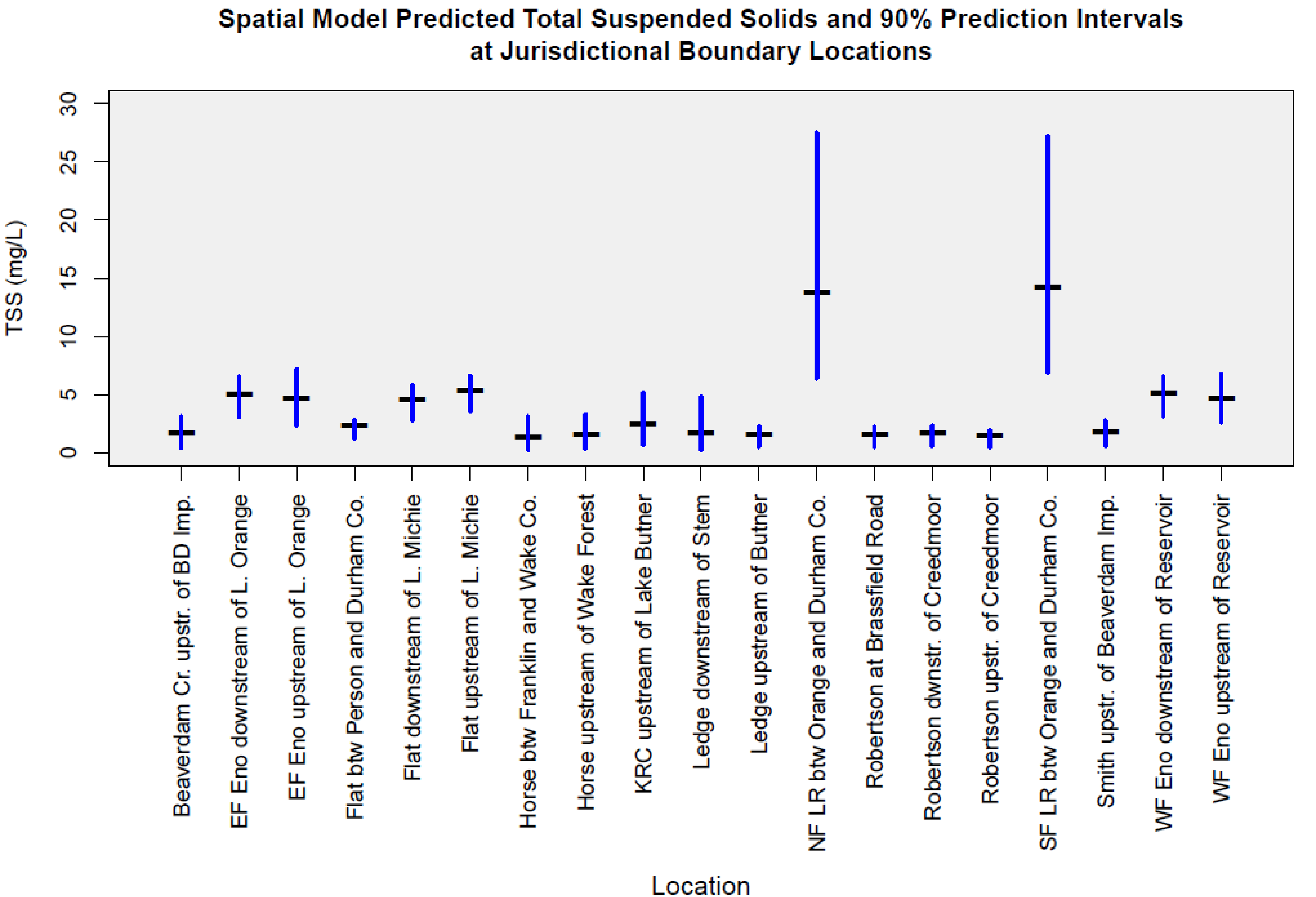
Model 2 Predicted Total Suspended Solids Versus Observed Total Suspended Solids
Observed Total Suspended Solids (mg/L)
0.1
0.25
0.5
1
2
4
8
16
32
64
128
256
0.5
1
2
4
8
16
32
64
128
256
Predicted Total Suspended Solids (mg/L)
R2=0.54



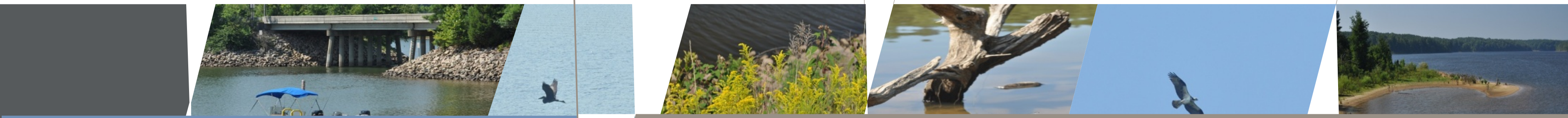
Spatial Model Predicted Total Nitrogen and 90% Prediction Intervals
at Jurisdictional Boundary Locations
TN (mg/L)
0.0
0.5
1.0
1.5
2.0
Beaverdam Cr. upstr. of BD Imp.
EF Eno downstream of L. Orange
EF Eno upstream of L. Orange
Flat btw Person and Durham Co.
Flat downstream of L. Michie
Flat upstream of L. Michie
Horse btw Franklin and Wake Co.
Horse upstream of Wake Forest
KRC upstream of Lake Butner
Ledge downstream of Stem
Ledge upstream of Butner
NF LR btw Orange and Durham Co.
Robertson at Brassfield Road
Robertson dwnstr. of Creedmoor
Robertson upstr. of Creedmoor
SF LR btw Orange and Durham Co.
Smith upstr. of Beaverdam Imp.
WF Eno downstream of Reservoir
WF Eno upstream of Reservoir
Location



Spatial Model Predicted Total Phosphorus and 90% Prediction Intervals
at Jurisdictional Boundary Locations
TP (mg/L)
0.0
0.1
0.2
0.3
0.4
Beaverdam Cr. upstr. of BD Imp.
EF Eno downstream of L. Orange
EF Eno upstream of L. Orange
Flat btw Person and Durham Co.
Flat downstream of L. Michie
Flat upstream of L. Michie
Horse btw Franklin and Wake Co.
Horse upstream of Wake Forest
KRC upstream of Lake Butner
Ledge downstream of Stem
Ledge upstream of Butner
NF LR btw Orange and Durham Co.
Robertson at Brassfield Road
Robertson dwnstr. of Creedmoor
Robertson upstr. of Creedmoor
SF LR btw Orange and Durham Co.
Smith upstr. of Beaverdam Imp.
WF Eno downstream of Reservoir
WF Eno upstream of Reservoir
Location



Spatial Model Predicted Total Suspended Solids and 90% Prediction Intervals
at Jurisdictional Boundary Locations
TSS (mg/L)
0
5
10
15
20
25
30
Beaverdam Cr. upstr. of BD Imp.
EF Eno downstream of L. Orange
EF Eno upstream of L. Orange
Flat btw Person and Durham Co.
Flat downstream of L. Michie
Flat upstream of L. Michie
Horse btw Franklin and Wake Co.
Horse upstream of Wake Forest
KRC upstream of Lake Butner
Ledge downstream of Stem
Ledge upstream of Butner
NF LR btw Orange and Durham Co.
Robertson at Brassfield Road
Robertson dwnstr. of Creedmoor
Robertson upstr. of Creedmoor
SF LR btw Orange and Durham Co.
Smith upstr. of Beaverdam Imp.
WF Eno downstream of Reservoir
WF Eno upstream of Reservoir
Location



Comparisons of Model Predictions with Input Nutrient Concentrations for the DWR Falls Lake Nutrient Response Model (EFDC)

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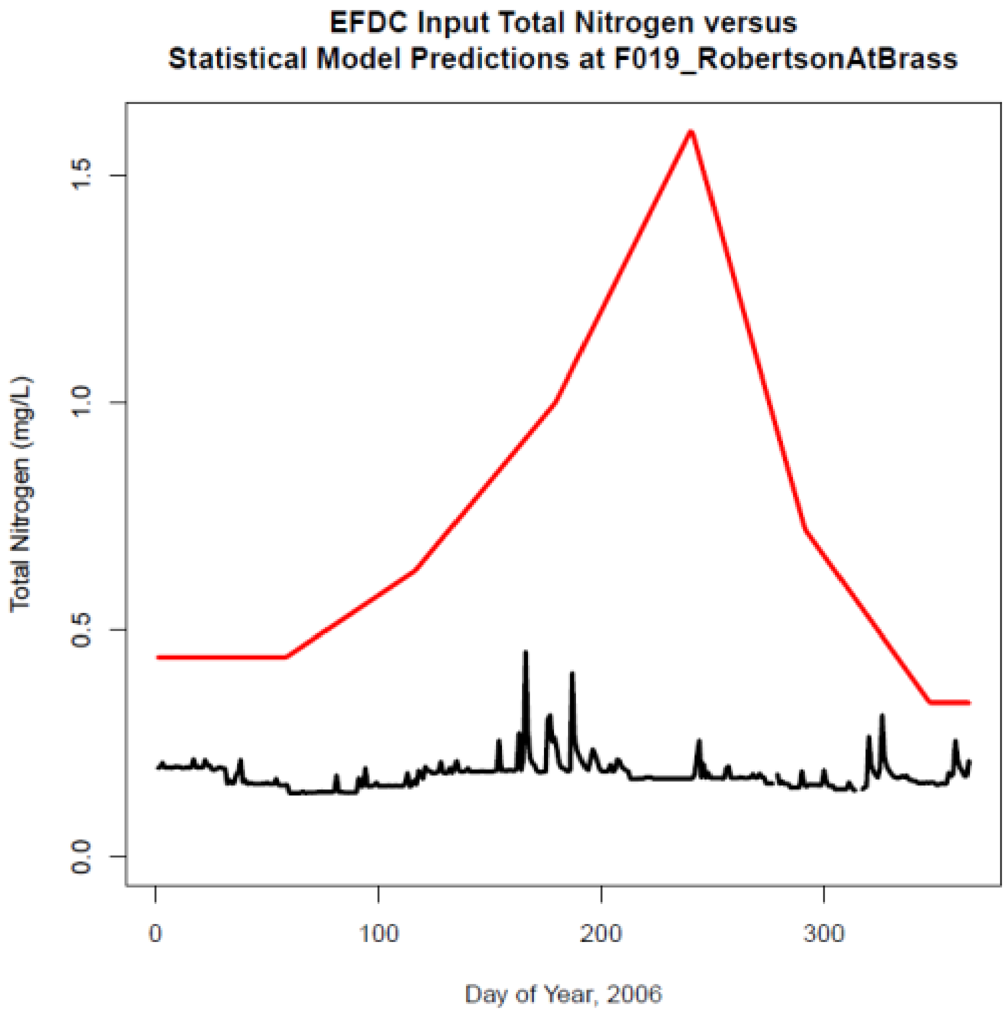

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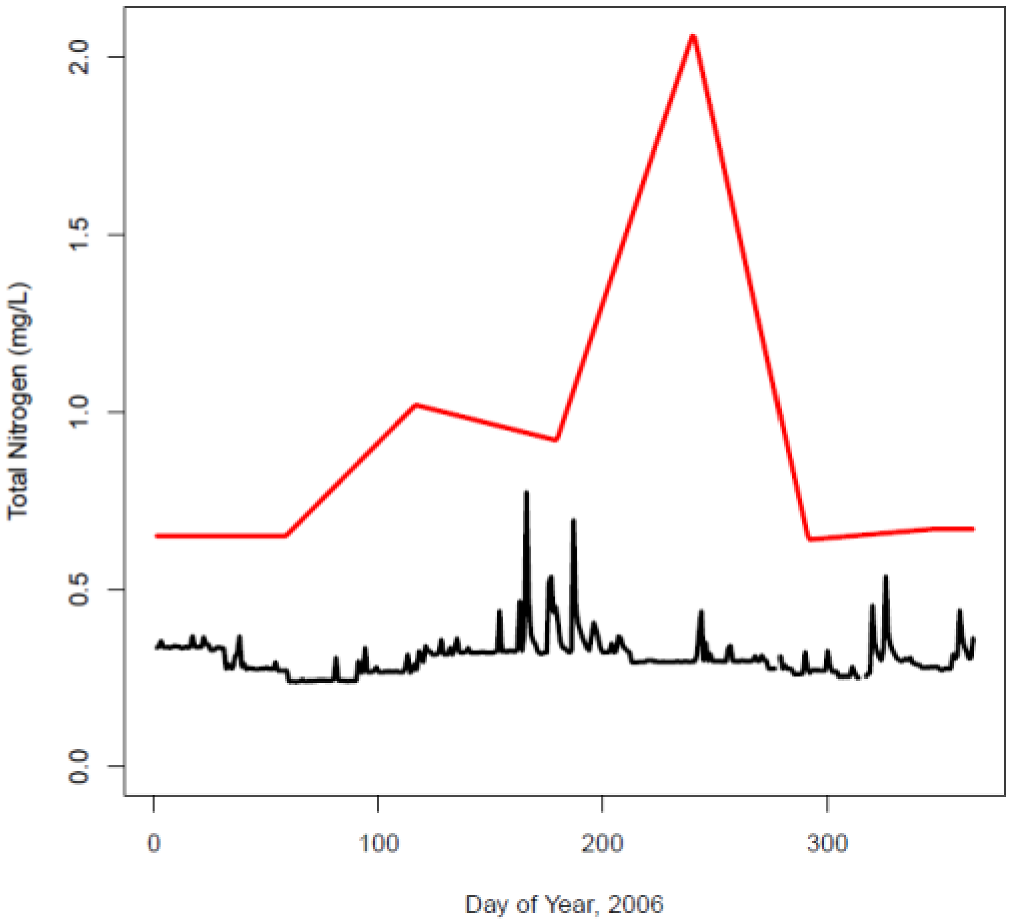
EFDC Input Total Nitrogen versus Statistical Model Predictions at F021_LedgeCr



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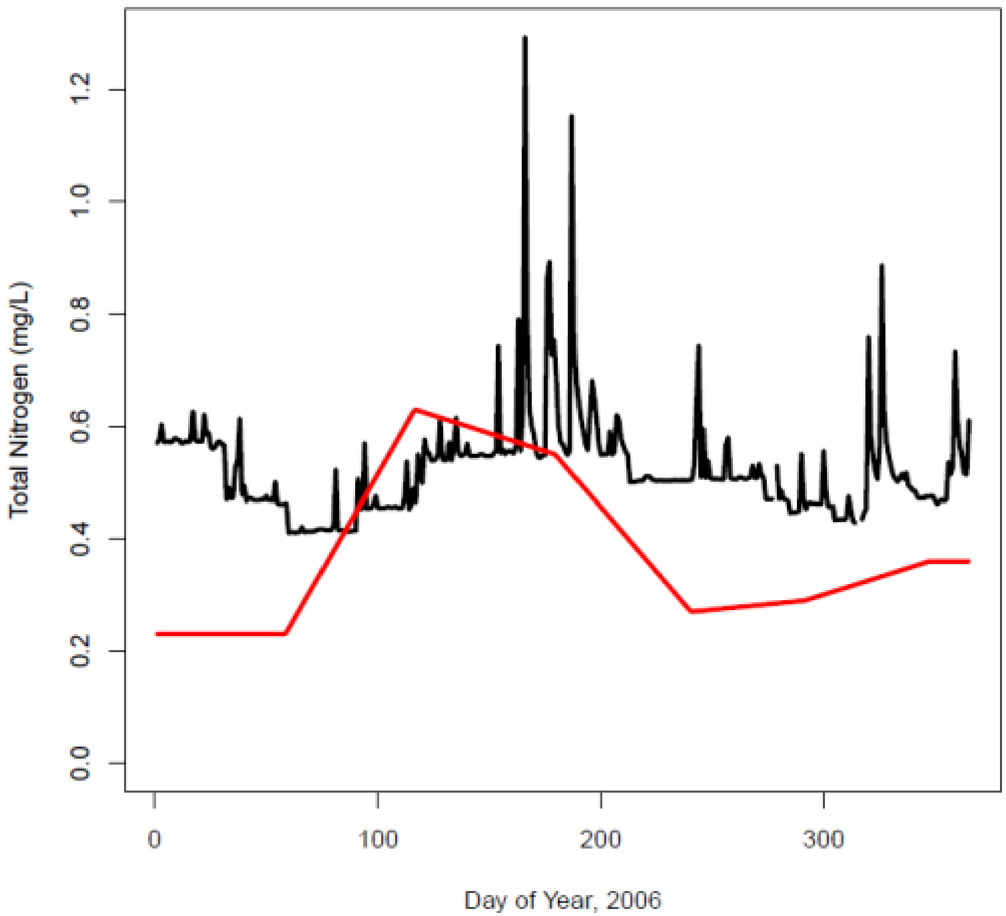
EFDC Input Total Nitrogen versus Statistical Model Predictions at F025_HoneycuttCr



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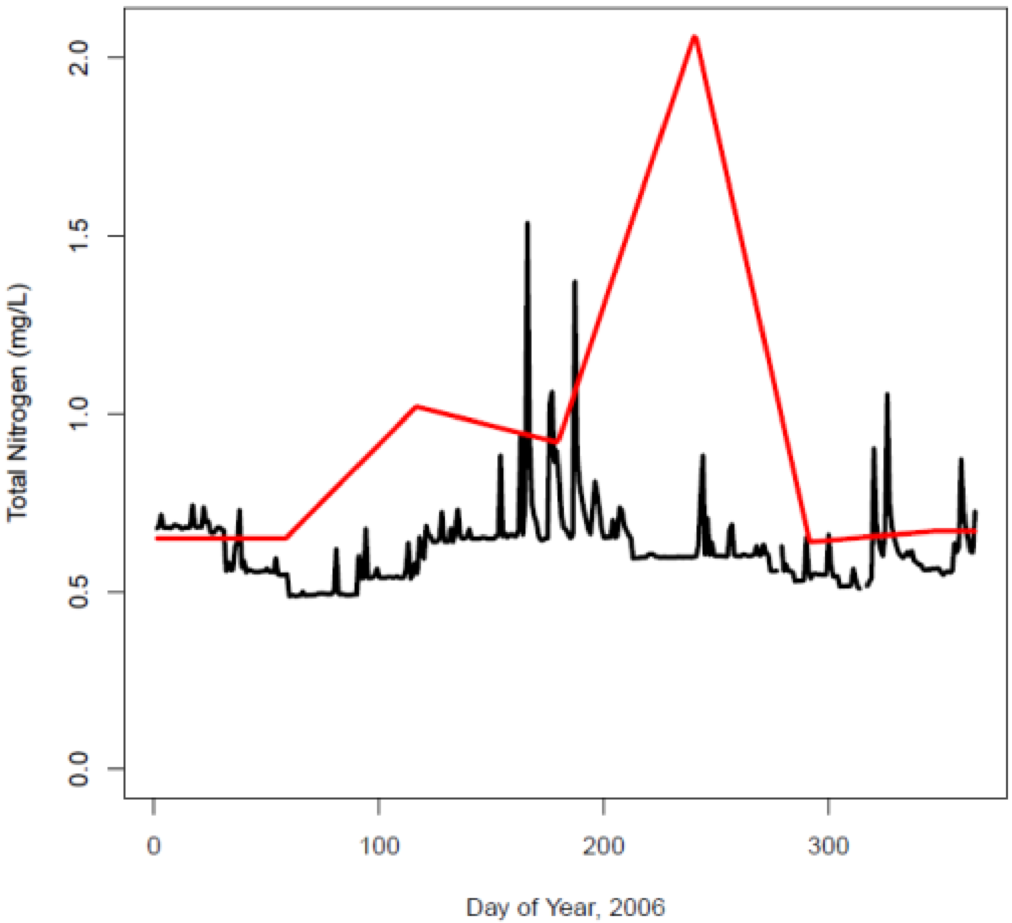
EFDC Input Total Nitrogen versus Statistical Model Predictions at F020_UnnamedTrib



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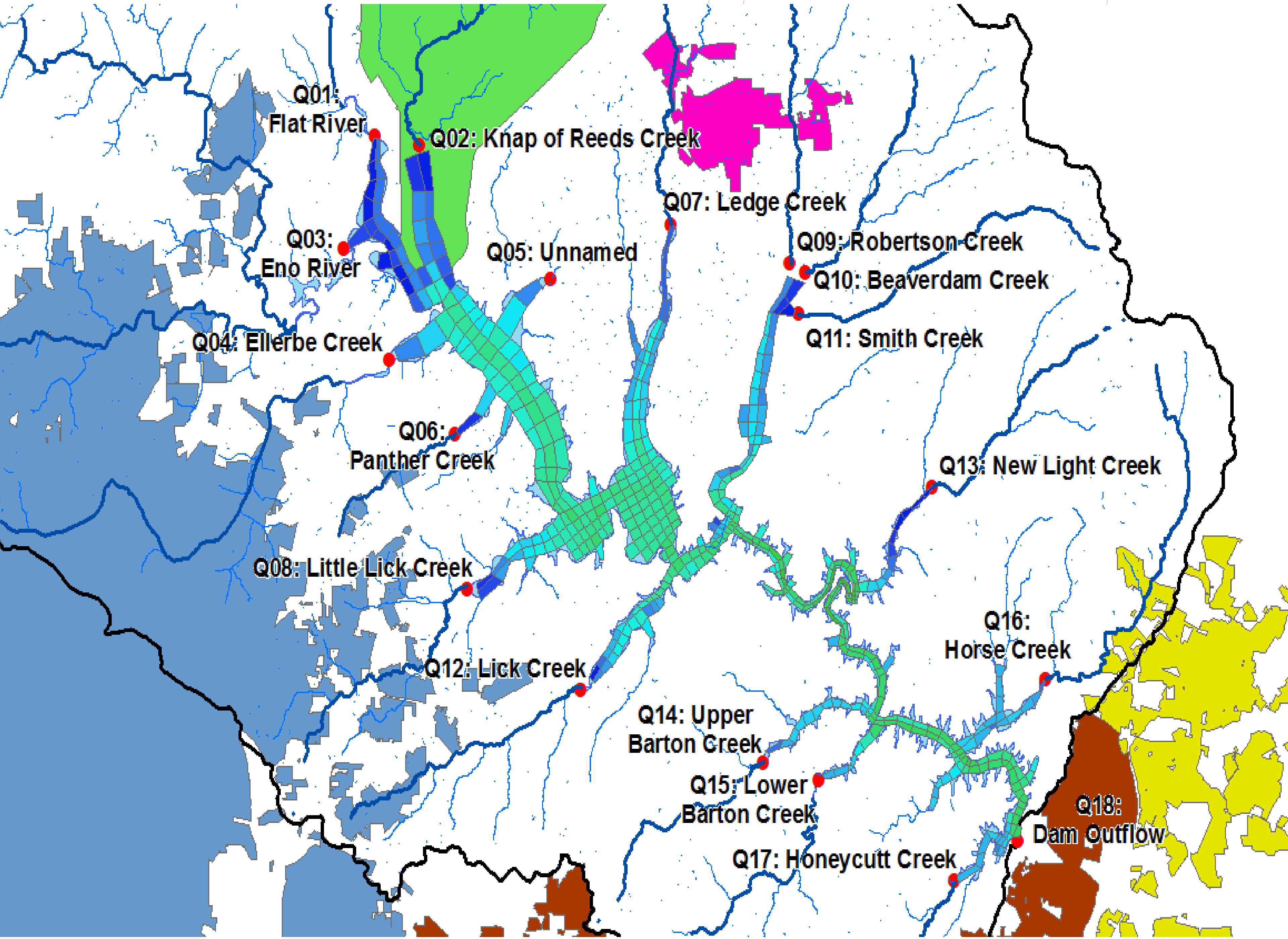
Q01: Flat River
Q02: Knap of Reeds Creek
Q03: Eno River
Q04: Ellerbe Creek
Q05: Unnamed
Q06: Panther Creek
Q07: Ledge Creek
Q08: Little Lick Creek
Q09: Robertson Creek
Q10: Beaverdam Creek
Q11: Smith Creek
Q12: Lick Creek
Q13: New Light Creek
Q14: Upper Barton Creek
Q15: Lower Barton Creek
Q16: Horse Creek
Q17: Honeycutt Creek
Q18: Dam Outflow