NC STATE UNIVERSITY

Jordan Lake Watershed Model

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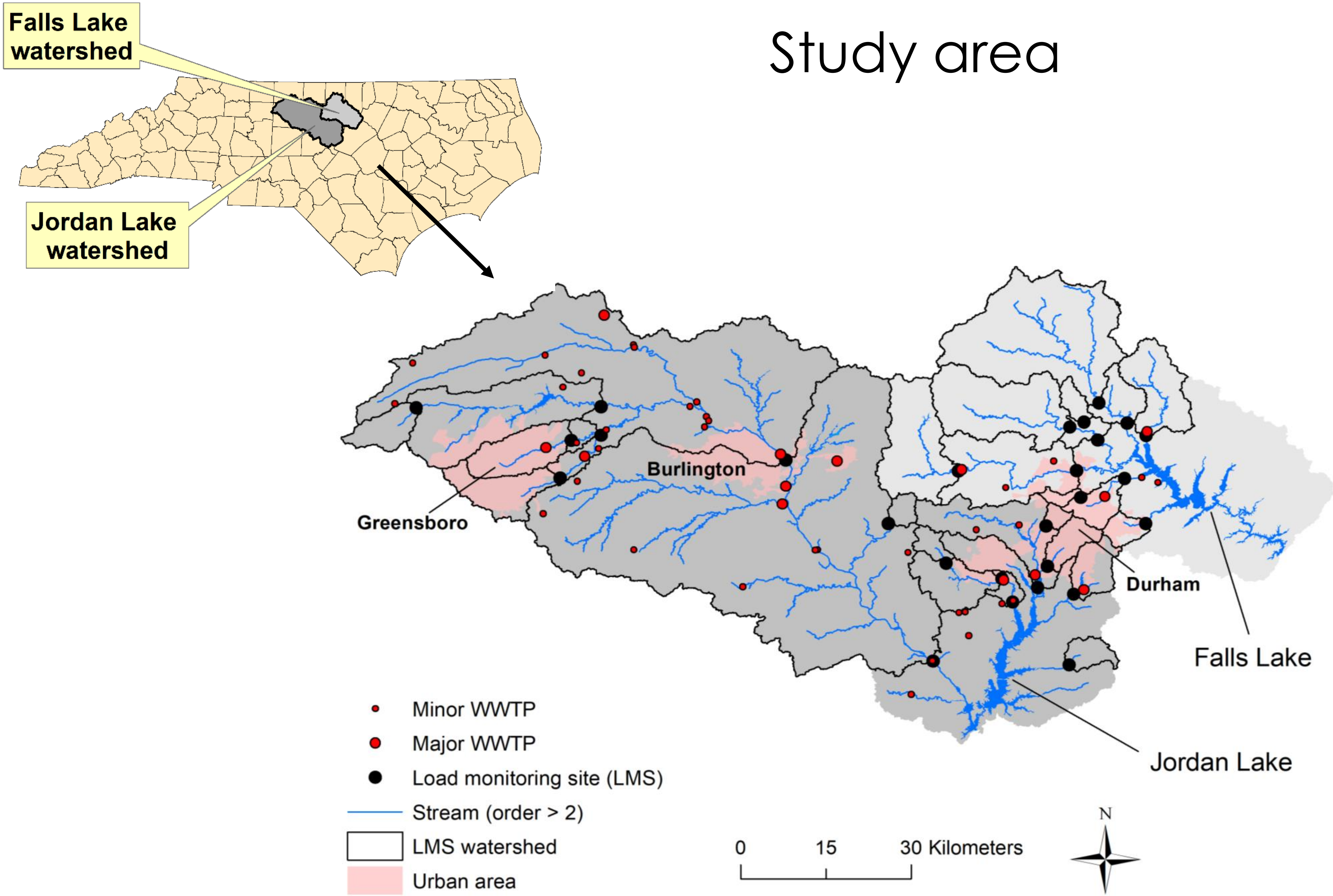
North Carolina
Triangle J Council of Governments
28 April 2020

Study area


Falls Lake watershed
Jordan Lake watershed
Burlington
Greensboro
Durham
Falls Lake
Jordan Lake
Minor WWTP
Major WWTP
Load monitoring site (LMS)
Stream (order > 2)
LMS watershed
Urban area
0
15
30 Kilometers
N

Research Questions

1) What are the **source allotments** of TN and TP in the watershed?

2) To what extent do **urban TN export** exceed natural and agricultural land covers?

3) Can we better **quantify intra-annual variation** due to differences in precipitation?

4) Are **better management practices** implemented by NC **helping to reduce** TN export?

5) What **% of TN and TP export** is reaching downstream reservoirs?

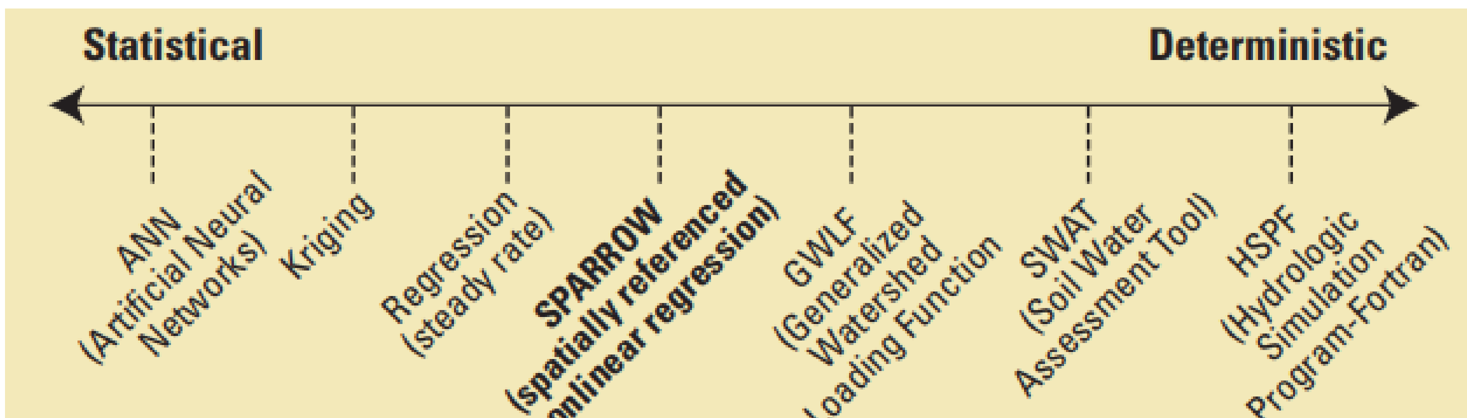
Water quality models

"This model" hybrid Bayesian watershed model

Temporal extent: yearly ⟷ sub-daily

Spatial extent: regional ⟷ site-specific

Model framework: general ⟷ detailed

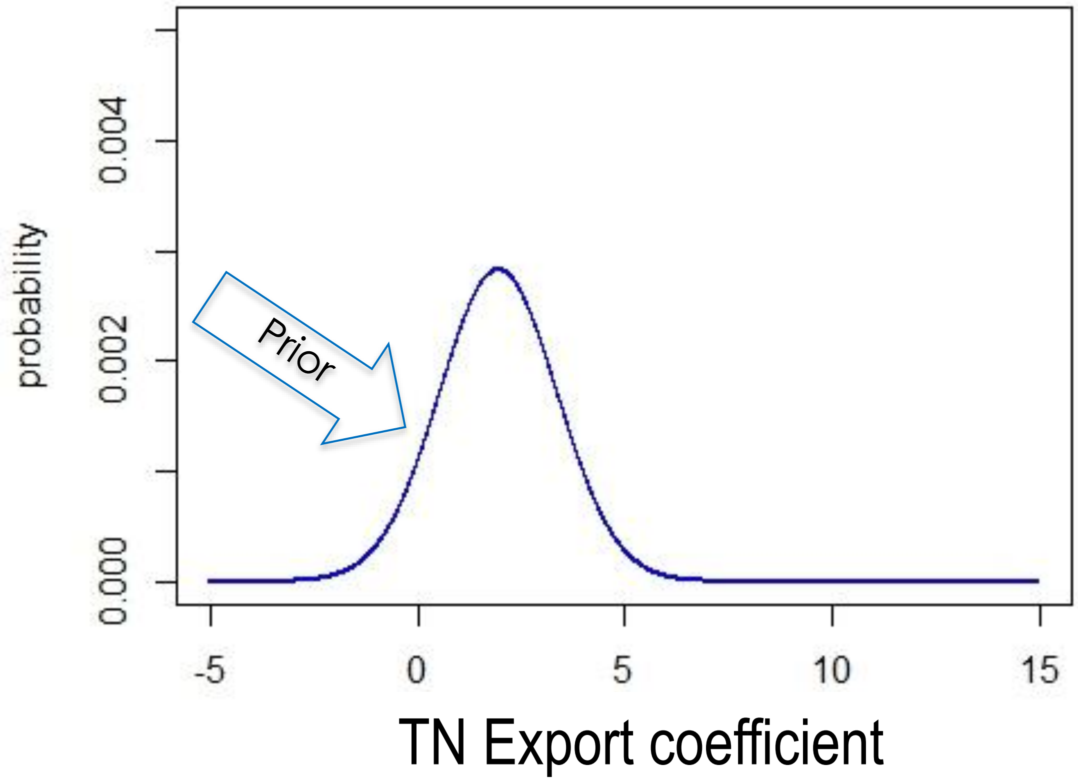


Preston et al. 2009; USGS

Mean loadings (SPARROW) vs. *yearly loadings*

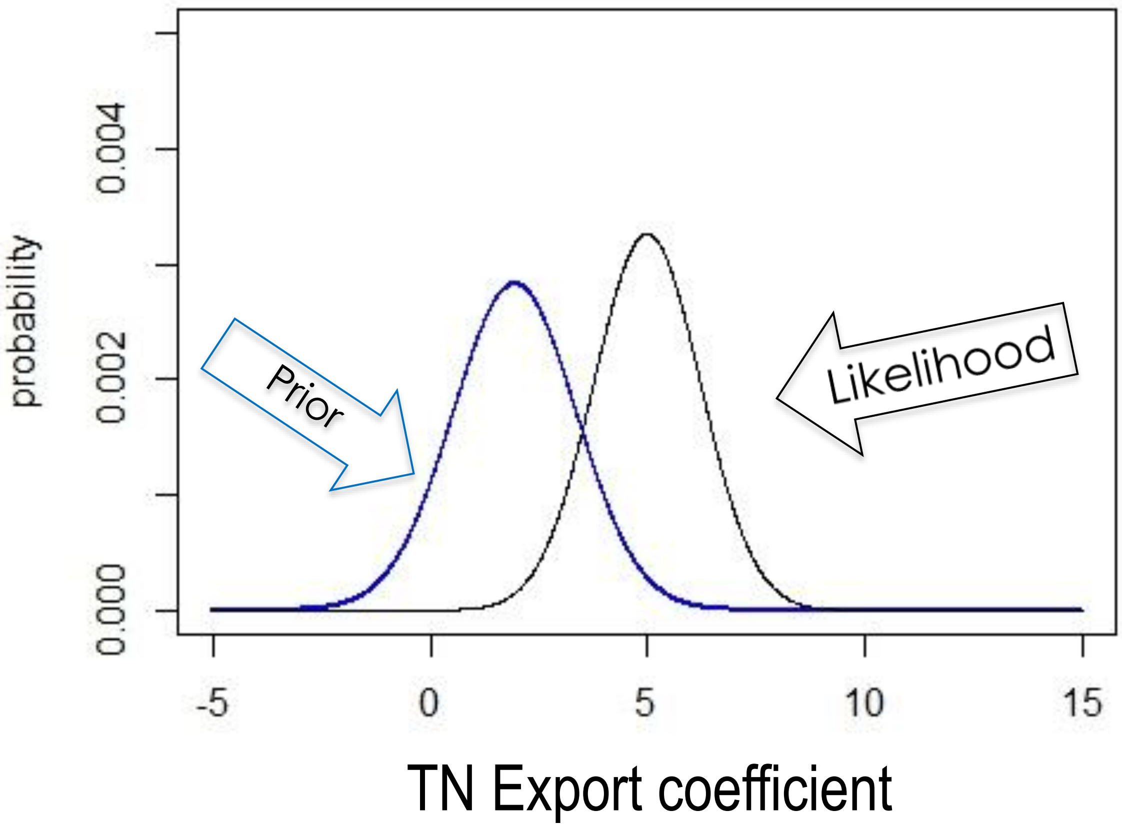
Bayesian modeling

Prior belief – distribution from prior research



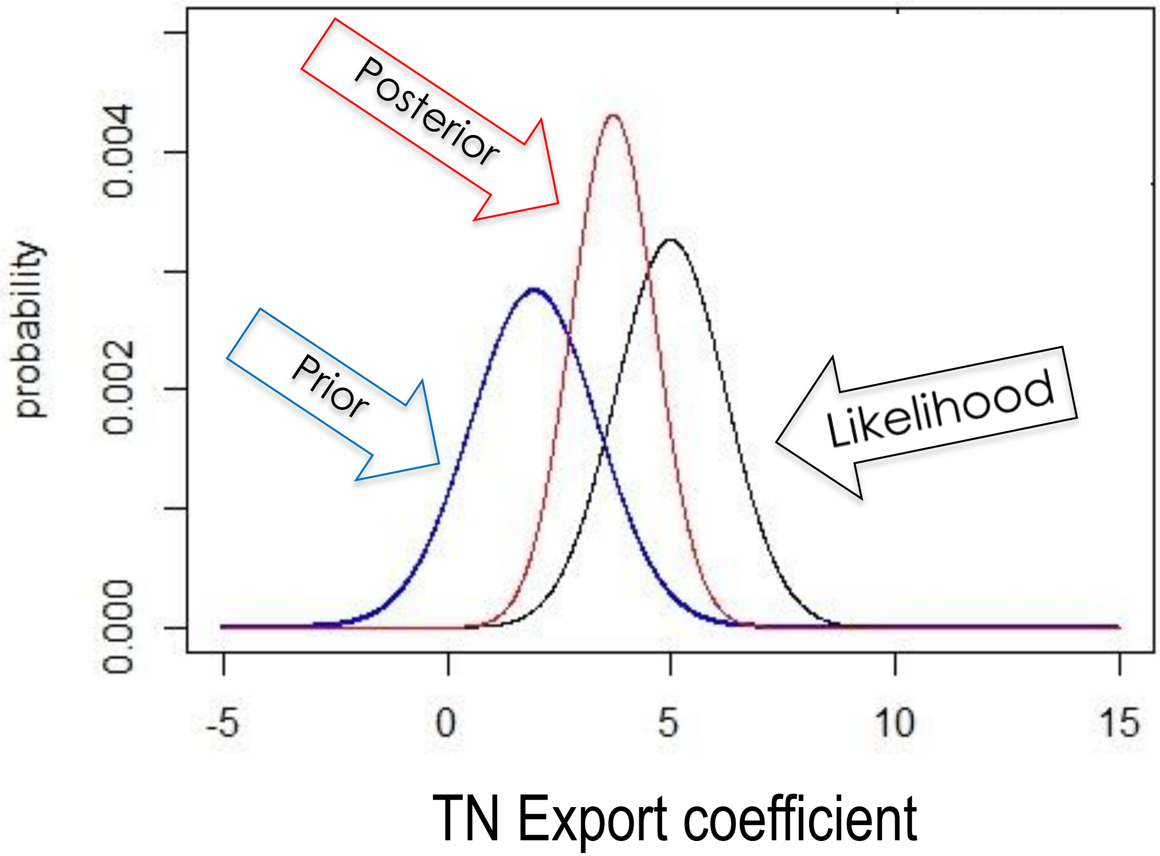
Bayesian modeling

Likelihood – distribution the data implies



Bayesian modeling

Prior belief – distribution from prior research
Likelihood – distribution the data implies
Posterior- final distribution for coefficients



Nutrient loading estimates

Yearly nutrient loading estimates

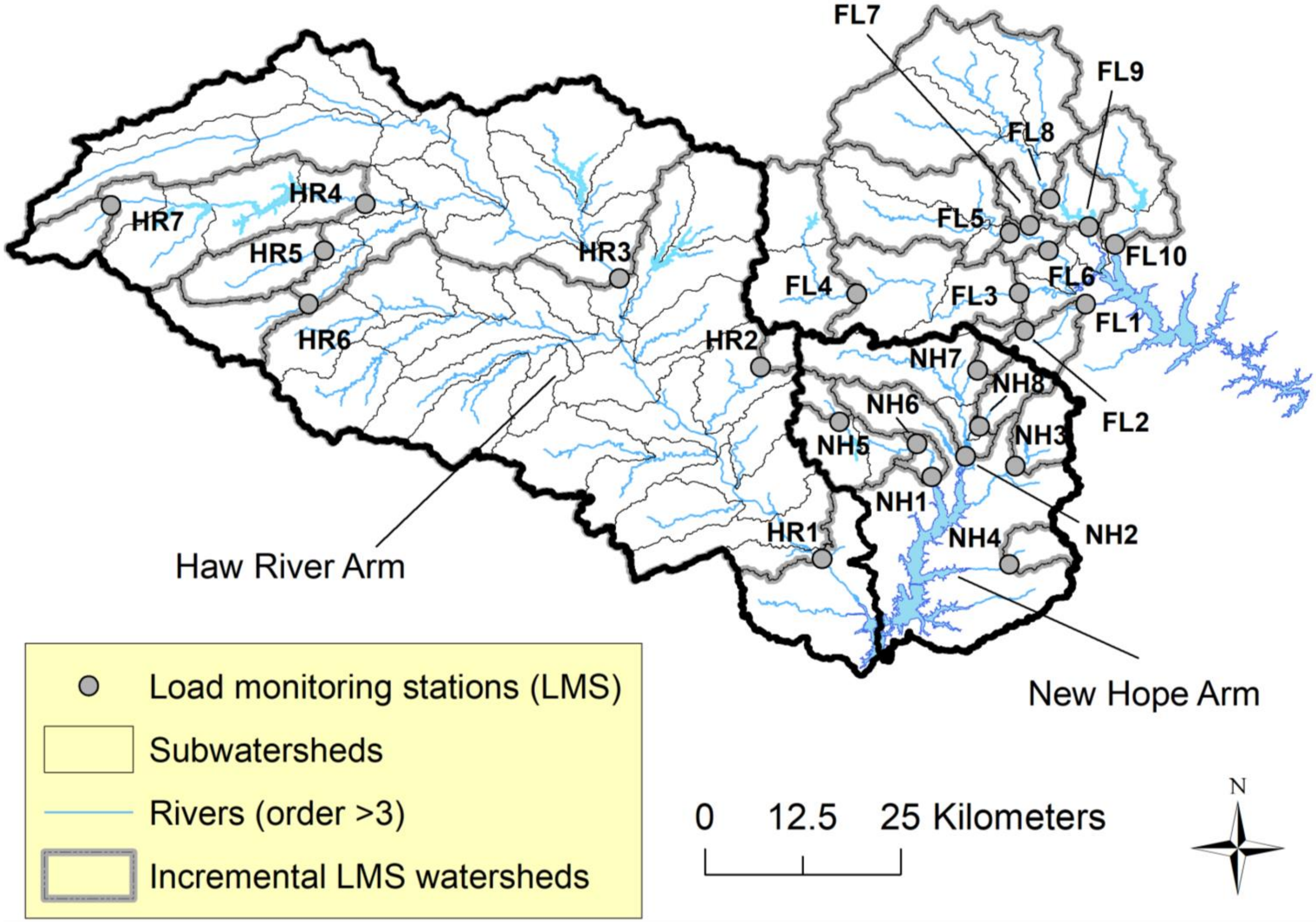
- Weighted Regression on Time, Discharge, and Season (WRTDS; *Hirsch et al. 2010)*

- Accounted for uncertainty in WRTDS estimates *(Strickling and Obenour 2018*)

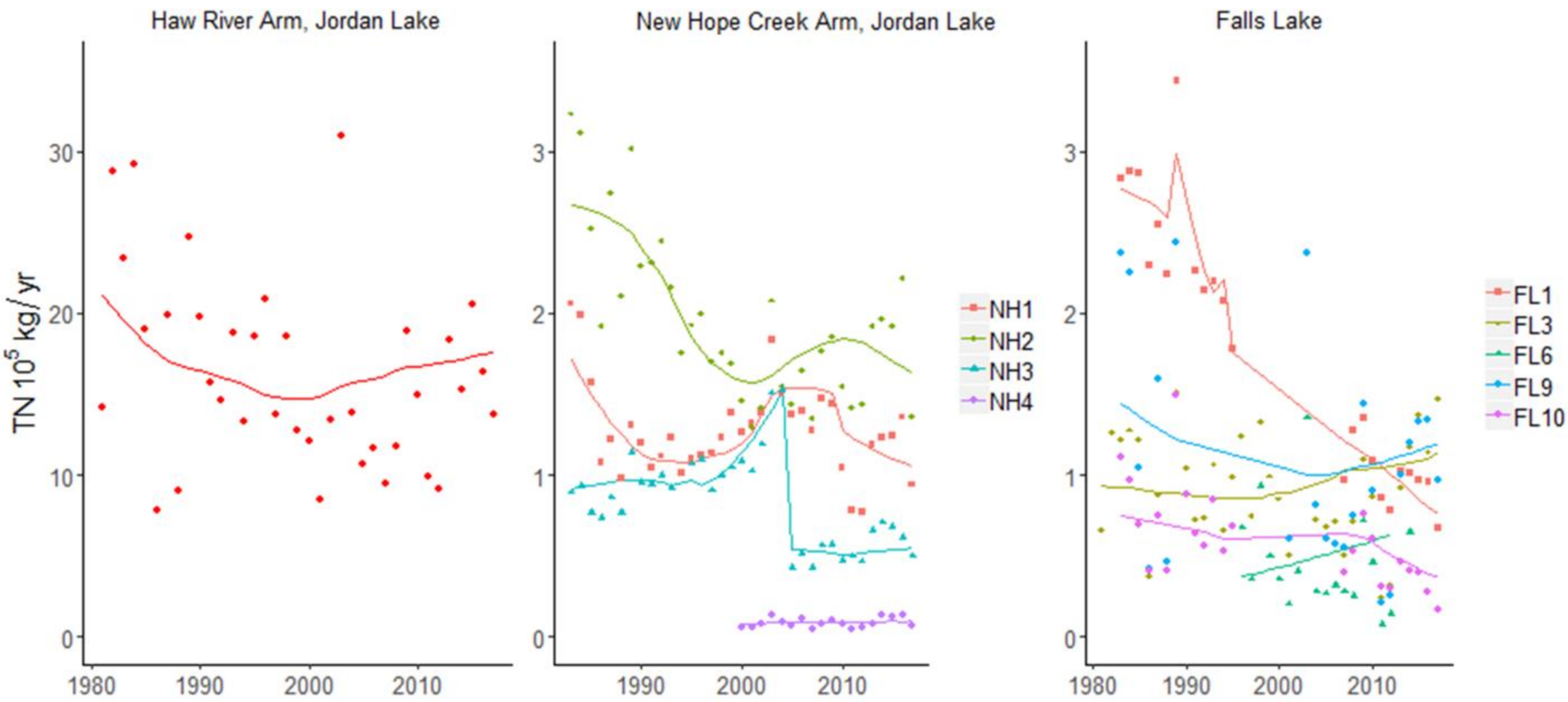
# of samples in a year↓ Uncertainty↑ (CV ~ 5 - 25%)

26 Load monitoring stations (1982-2017)

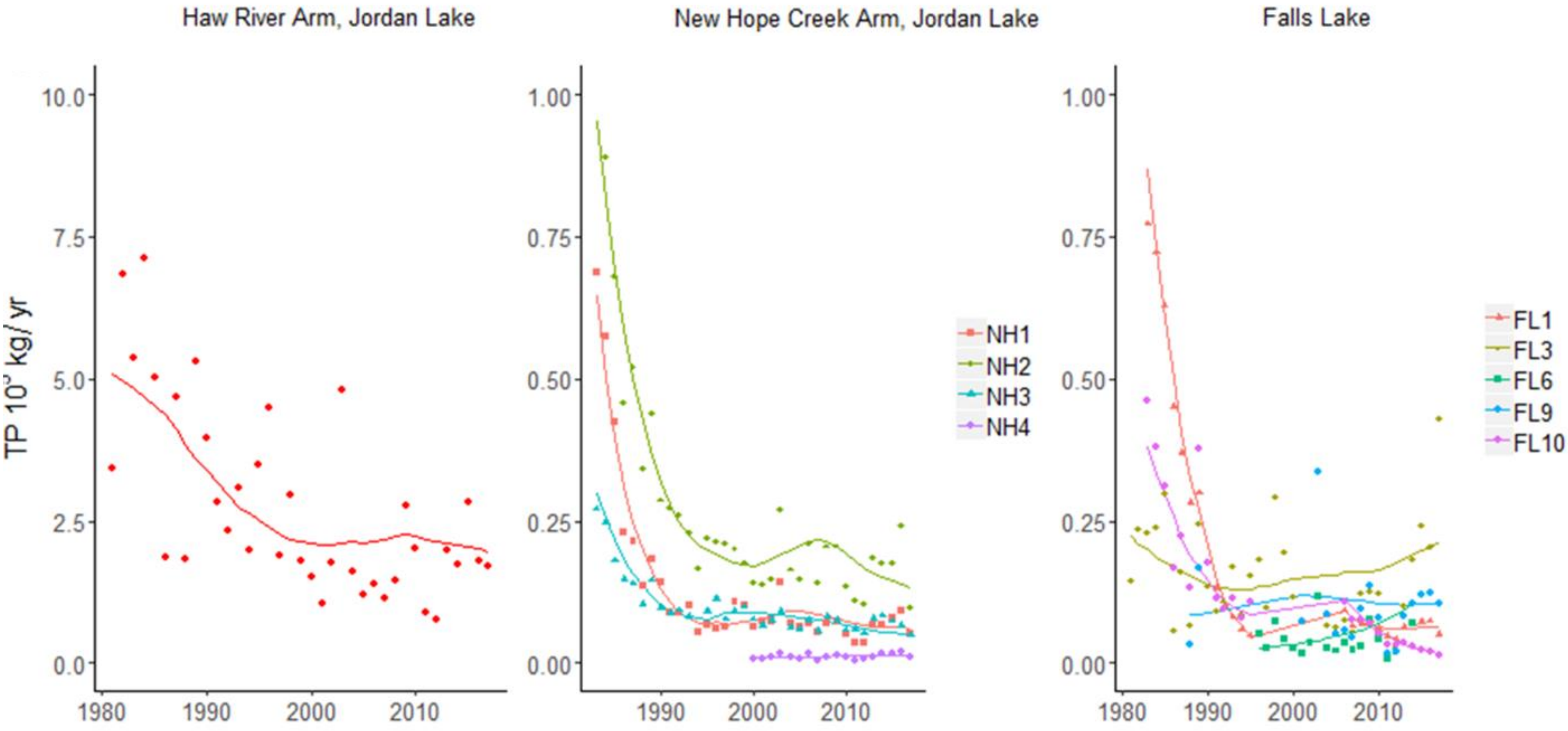
- > 5 years daily flow data
- > 50 TN/TP samples



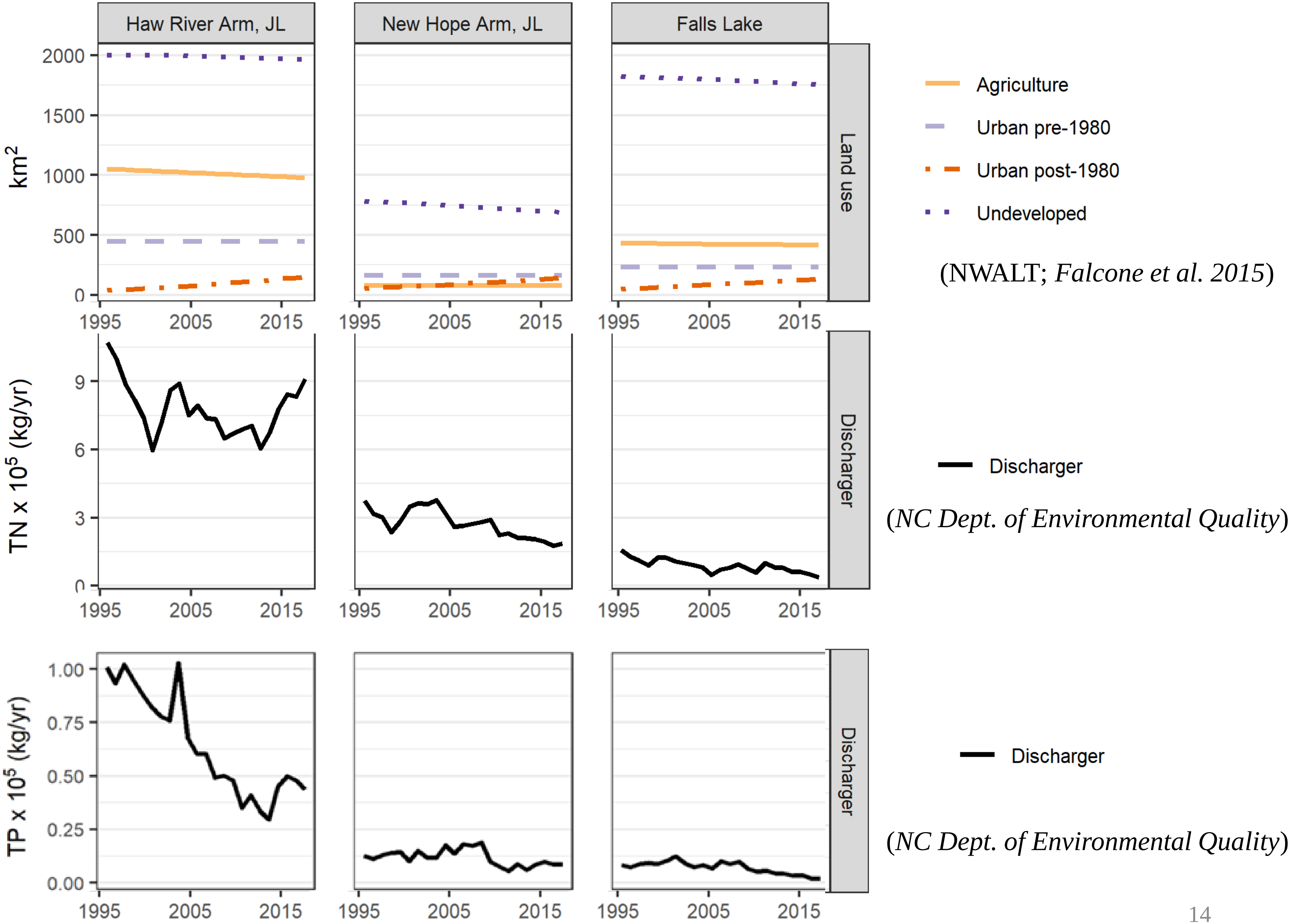
TN- Flow normalized loads

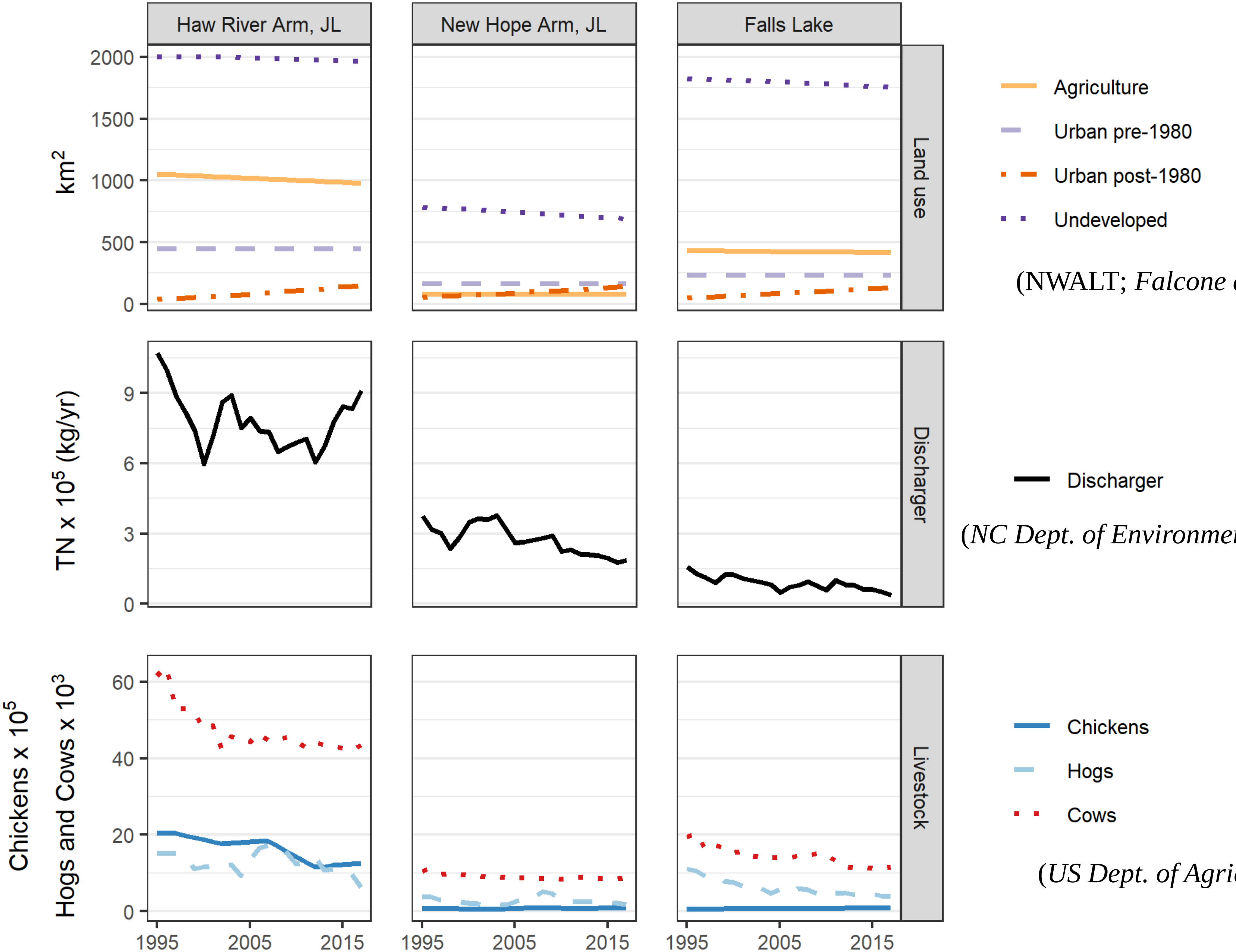


TP- Flow normalized loads



Model construction


Haw River Arm, JL
New Hope Arm, JL
Falls Lake
km2
2000
1500
1000
500
0
1995
2005
2015
Land use
Agriculture
Urban pre-1980
Urban post-1980
Undeveloped
(NWALT; Falcone et al. 2015)
TN x 105 (kg/yr)
9
6
3
0
Discharger
Discharger
(NC Dept. of Environmental Quality)
TP x 105 (kg/yr)
1.00
0.75
0.50
0.25
0.00
Discharger
Discharger
(NC Dept. of Environmental Quality)



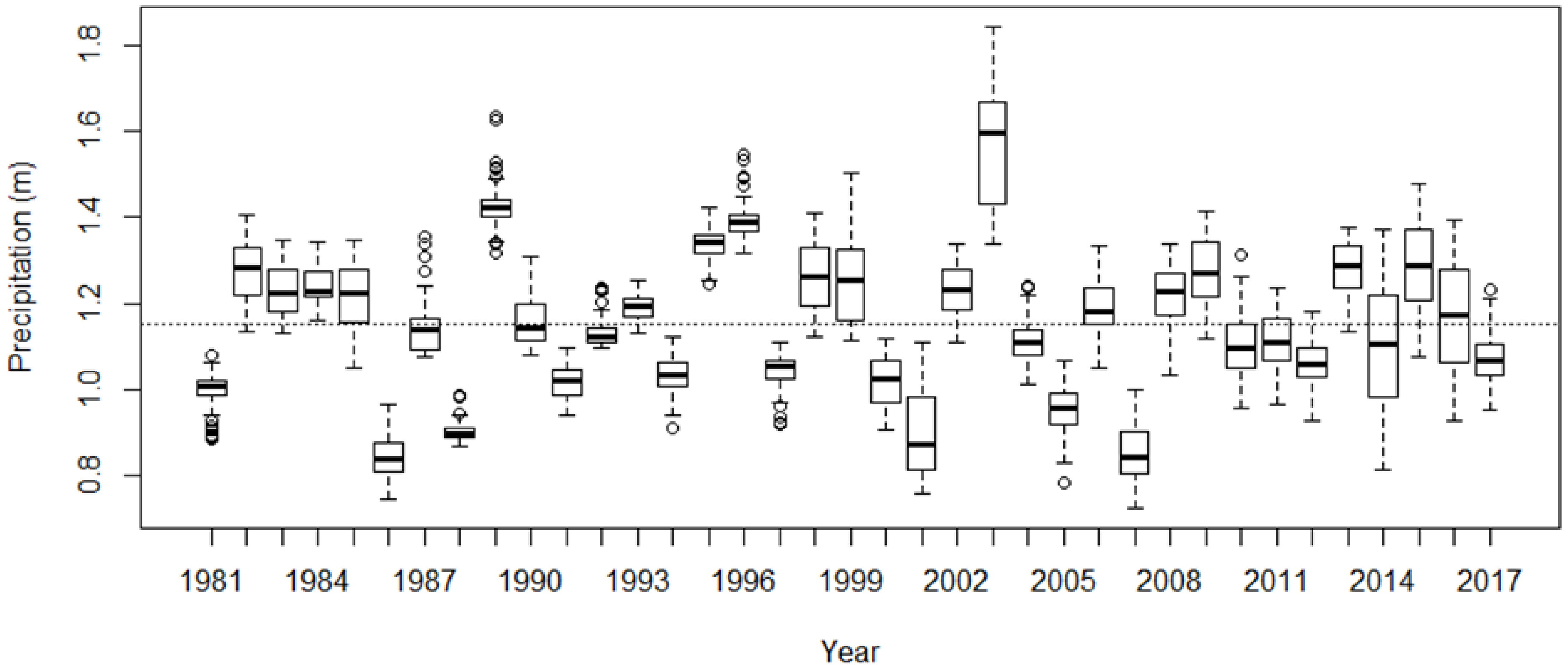
(NWALT; *Falcone et al. 2015*)

(*NC Dept. of Environmental Quality*)

(*US Dept. of Agriculture*)

Yearly precipitation

PRISM Climate Group (Oregon State)



Basic model construction

Inferred WRTDS estimates

Predicted incremental loads (from model)

$$\ln(y_{i,t}) \sim N(\ln(\hat{y}_{i,t} + \alpha_i), \sigma_\varepsilon)$$

$$\alpha_i \sim N(0, \sigma_{LMS})$$

Site random effect

Incremental loadings

(i = watershed t = year)

$$\hat{y}_{i,t} = L_{i,t,ur1} + L_{i,t,ur2} + L_{i,t,ag} + L_{i,t,und} + L_{i,t,ps} + L_{i,t,ch} + L_{i,t,h} + L_{i,t,cw} - U_{i,t} * r_{i,z} + \varepsilon_{i,t}$$

Land cover-
Pre-1980 Urban (ur1),
Post-1980 Urban (ur2).
Ag, Undeveloped

Dischargers-
Major and minor WWTPs

Livestock-
chickens, hogs, cows

Upstream load retention
(streams and lakes)

$$L_{i,t,x} = \beta_{ec}\left(p_{i,t}{}^{\gamma_{pic}}\right) * A_{i,t,x} * (1 - r_{i,t,x})$$

β_{ec} = **export** coefficients

Υ_{pic} = **precipitation impact** coefficients

$p_{i,t}$ = scaled precipitation

$A_{i,t,x}$ = **Area** of land cover (ha)

$r_{i,t,x}$ = Stream and lake **retention**

Results

TN/TP model

Table 3.2: Mean parameter estimates for the TN and TP models along with 95% credible intervals (CI). Units are kg/ha/yr and kg/count/yr (livestock)

		Export coefficients			
		TN		TP	
	Parameter	Mean	95% CI	Mean	95% CI
Agriculture	$\beta_{,ag}$	4.0	2.3-5.7	0.6	0.4-0.8
Pre-1980 Urban	$\beta_{,ur1}$	9.5	7.4-11.4	1.5	1.1-1.8
Post 1980 Urban	$\beta_{,ur2}$	3.9	0.7-7.3	0.6	0.03-1.4
Undeveloped	$\beta_{,und}$	0.7	0.1-1.5	0.05	0-0.13
	$\beta_{,ch}$	0.01	0-0.02	0.004	0-0.009
Livestock	$\beta_{,h}$	0.04	0.01-0.07	0.02	0-0.04
	$\beta_{,cw}$	0.5	0.1-1.0	0.16	0-0.55

Lands urbanized before 1980 are hot spots for diffuse nutrient export

Undeveloped lands export about an order of magnitude less (~10x)

TN/TP model

Table 3.2: Mean parameter estimates for the TN and TP models along with 95% credible intervals (CI).

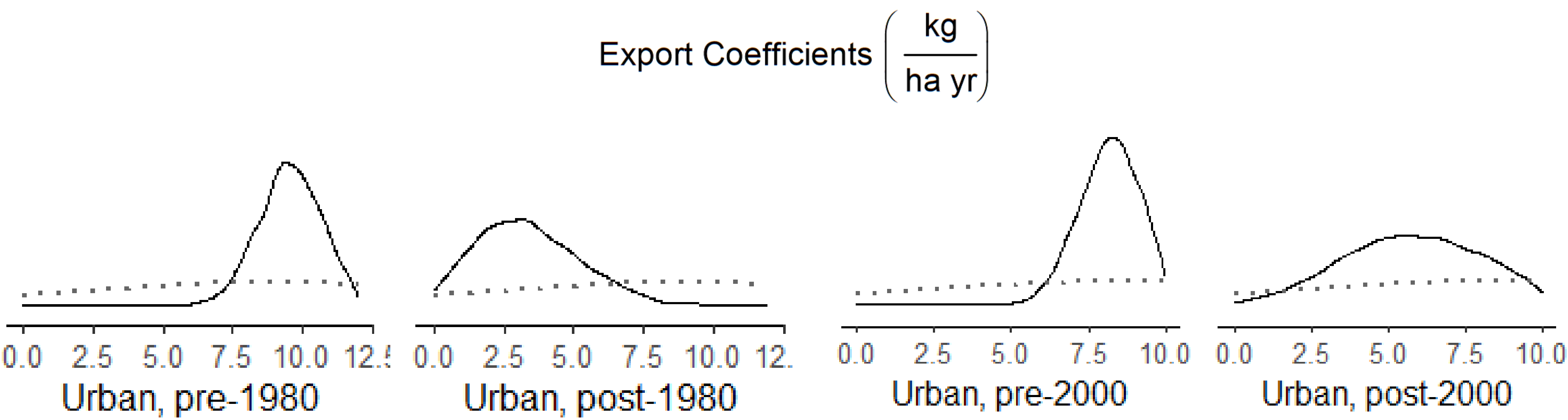
Precipitation Impact Coefficients

		TN		TP	
	Parameter	Mean	95% CI	Mean	95% CI
Agriculture	$\gamma_{,ag}$	4.1	2.9-5.0	4.0	2.9-5.1
Pre-1980 Urban	$\gamma_{,ur1}$	1.2	0.7-1.7	1.8	1.1-2.5
Post 1980 Urban	$\gamma_{,ur2}$	2.1	0.4-4.0	2.0	0.2-3.9
Undeveloped	$\gamma_{,und}$	2.8	0.6-5.2	2.4	0.5-4.5
	$\gamma_{,ch}$	1.9	0.3-3.8	2.4	0.5-4.8
Livestock	$\gamma_{,h}$	1.8	0.3-3.7	2.0	0.3-4.1
	$\gamma_{,cw}$	1.8	0.3-3.7	2.3	0.4-4.4

Agricultural lands vary the most due to precipitation.
Pre-1980 urban lands are the most constant source of nutrients

TN model- *pre-post models*

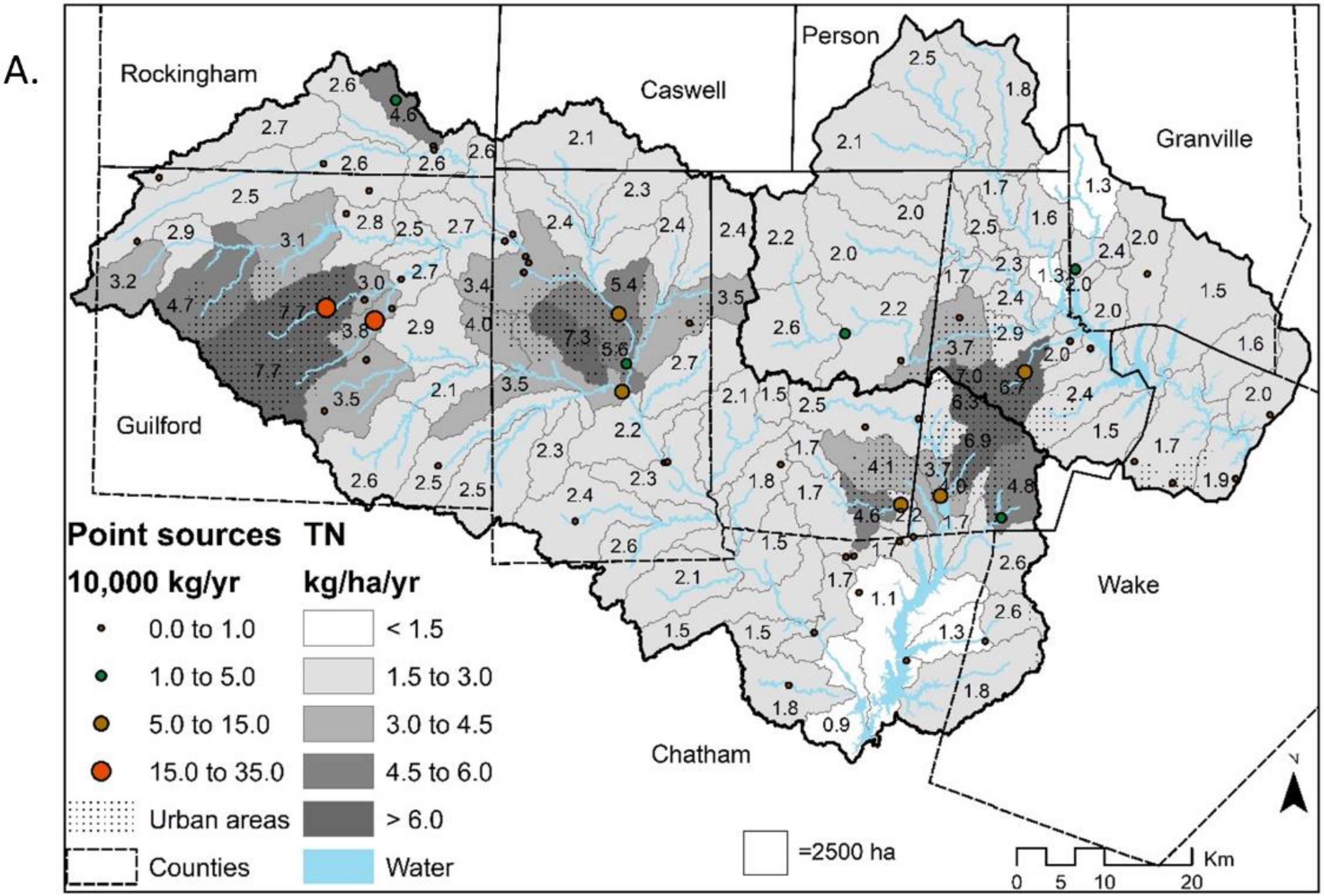
Pre/post 1980 **Pre/post 2000**



Pre > Post Export
> 99% certainty

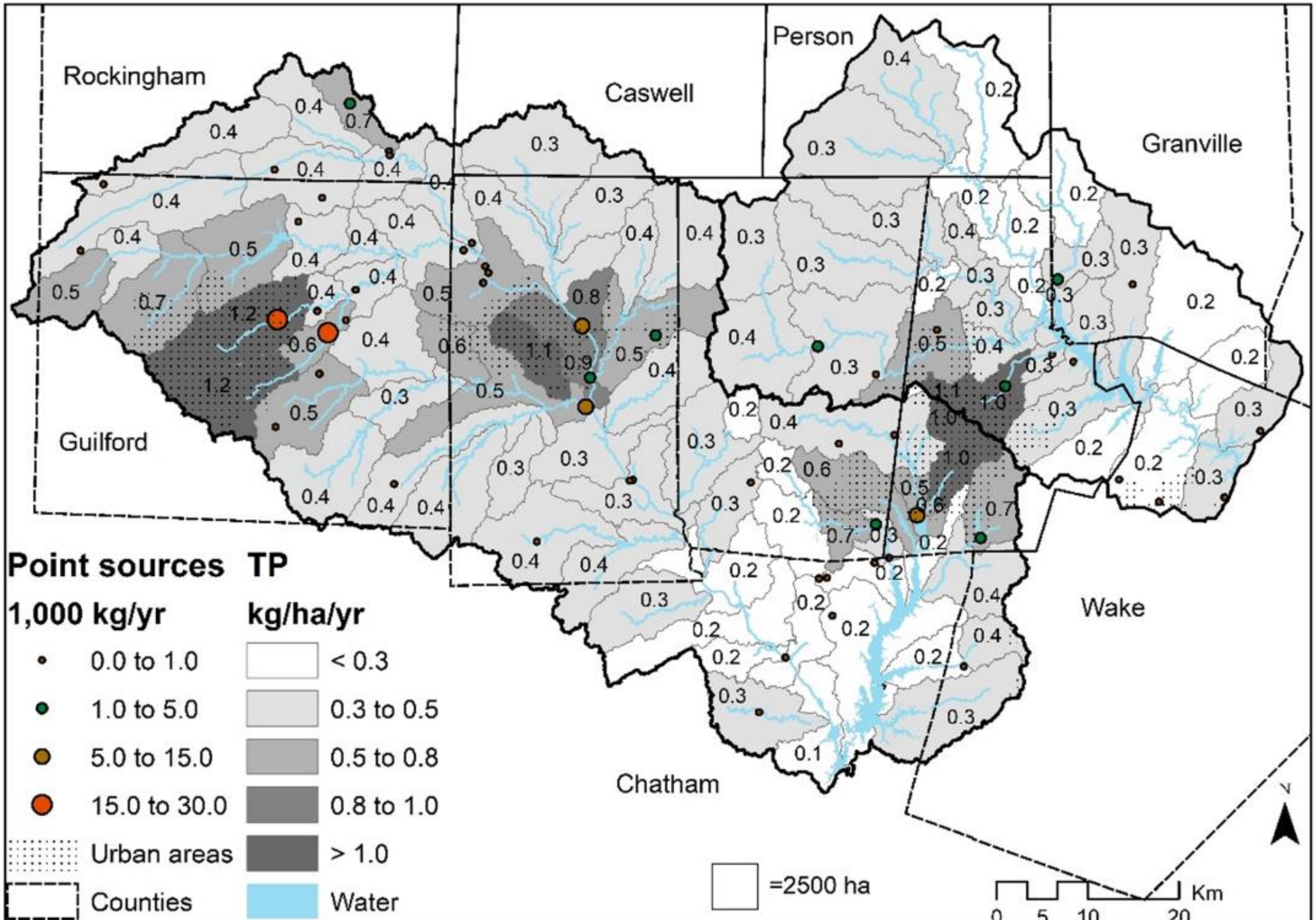
Pre > Post Export
81% certainty

TN export by subwatershed

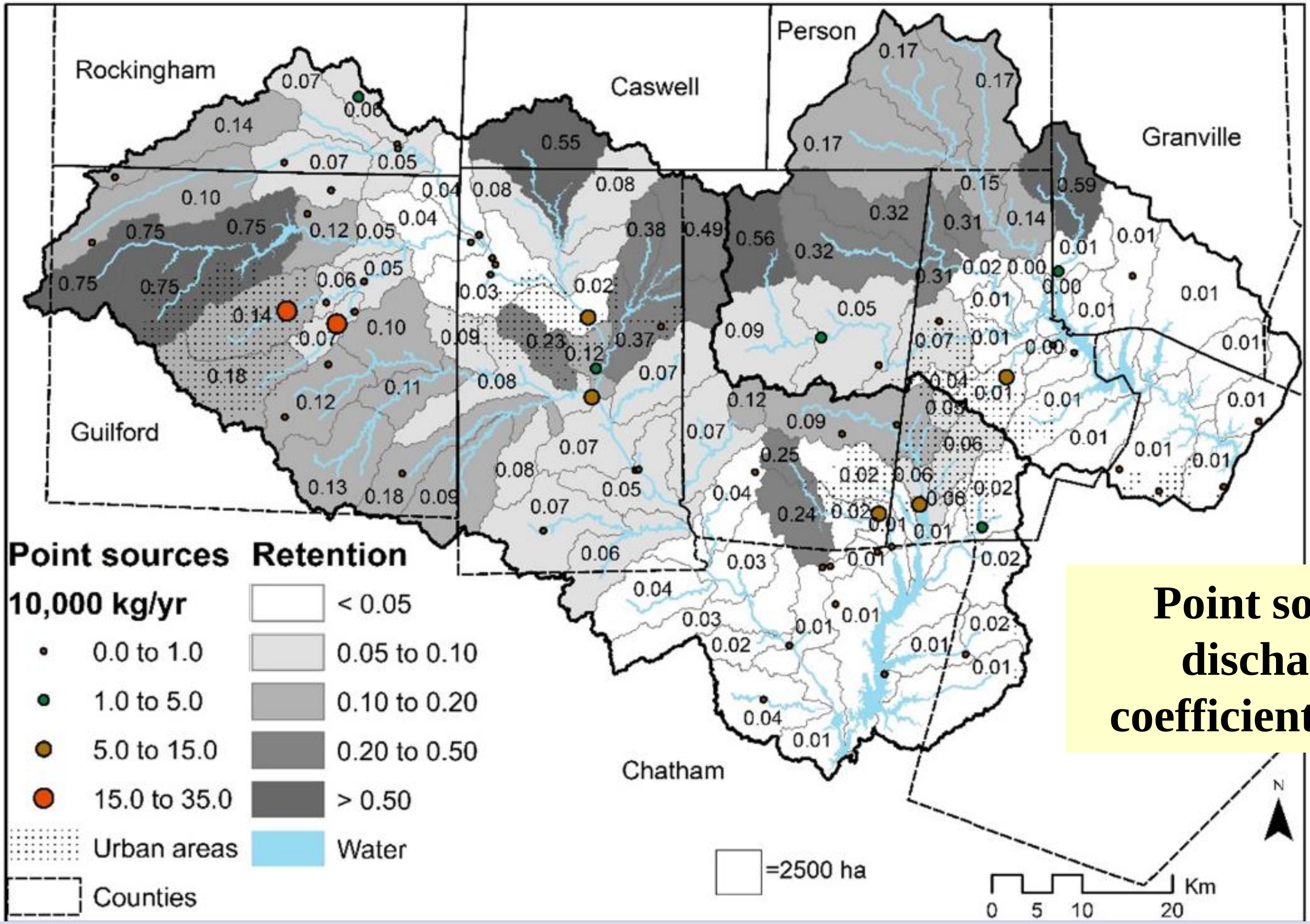


Lands urbanized before 1980 are hot spots for diffuse nutrient export

TP export by subwatershed



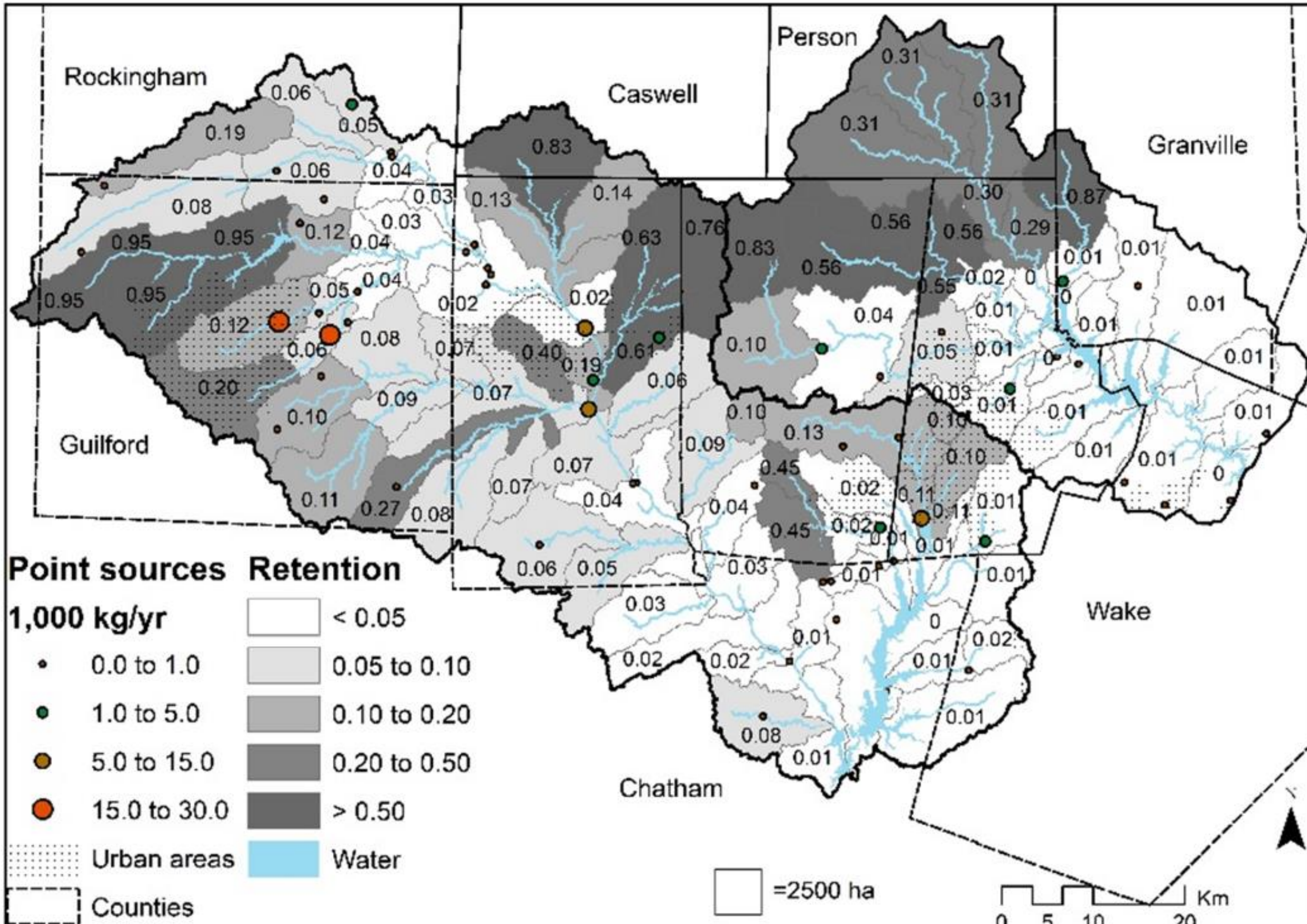
TN retention rates (*13% average*)



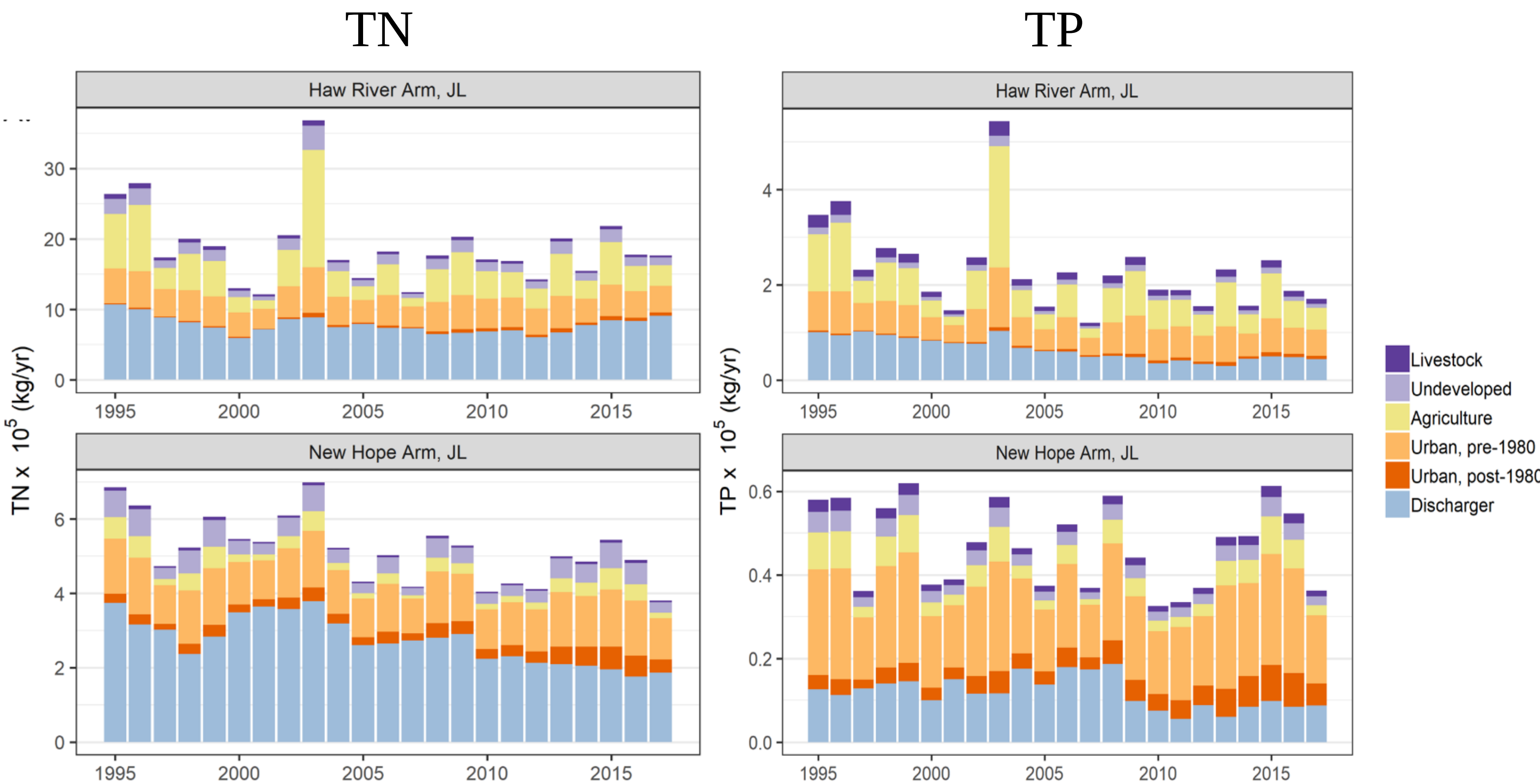
Point source discharge coefficient ~ 0.83

Majority of nutrients from northern Haw reach the reservoir (>70% for major dischargers near Greensboro)

TP retention rates (***17% average***)



Basin summary



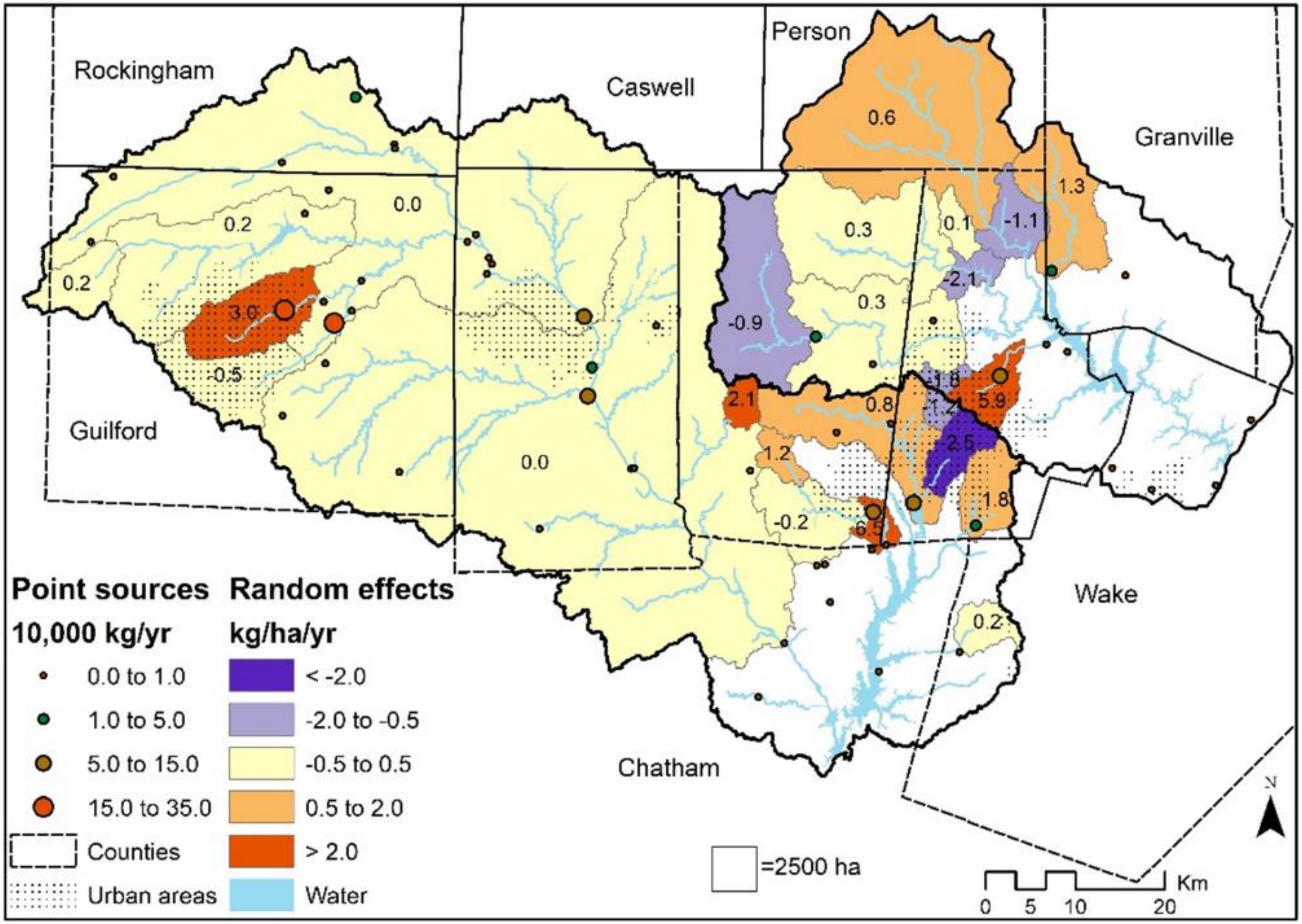
Basin summary

Table 3.4: Percent of nutrient sources that contributes to total Jordan Lake loadings from the Haw River (HR) and New Hope (NH) watersheds for normal flow years (33-67 percentile flow years). In parenthesis are the percent of each nutrient source during low flow years (lower 33%) and high flow years (upper 67%), respectively.

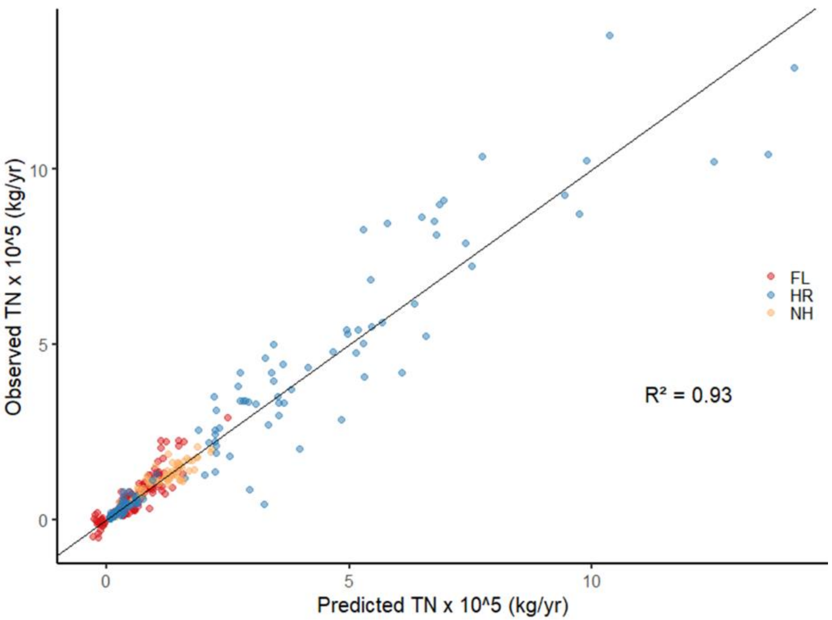
	% TN		% TP	
Nutrient source	HR	NH	HR	NH
Agriculture	17 (11,25)	1 (1,2)	24 (17,31)	2 (1,2)
Urban, pre-1980	18 (18,17)	6 (6,5)	25 (23,22)	8 (7,7)
Urban, post-1980	2 (1,1)	2 (1,1)	2 (2,2)	2 (2,1)
Undeveloped	6 (5,7)	2 (2,2)	4 (3,4)	1 (1,1)
Livestock	2 (2,2)	0 (0,0)	5 (5,6)	1 (1,1)
Discharger	33 (40,28)	11 (15,10)	21 (32,20)	5 (6,3)

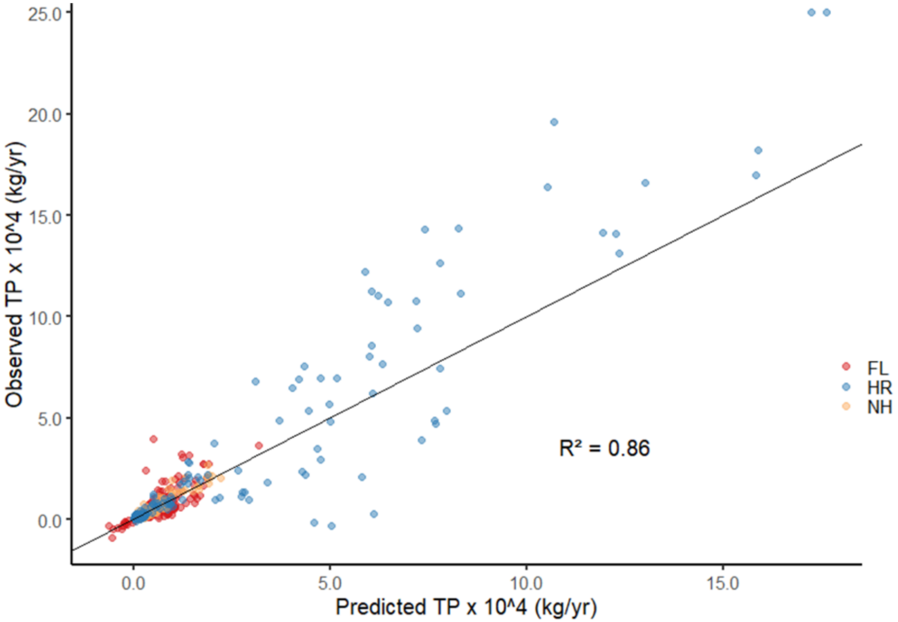
Point source dischargers make up between 38-55% of TN and 23-38% of TP loadings to Jordan Lake.

Watershed random effects



Predicted vs. Observed





Basin	TN (R^2)	TP (R^2)
Haw River	.95	.92
New Hope Creek	.92	.84
Falls Lake	.81	.62

Comparison to previous Tetra Tech model

Table 4.1: Summary of export coefficients for previous JL watershed model (Tetra Tech, 2014) and this study. Ranges for parameters represent export rates due to variations in precipitation, not the uncertainty of model parameters.

Model	Nutrient source	TN (kg/ha/yr)	TP (kg/ha/yr)
Tetra Tech (2014)	High-density residential/commercial	5.7-9.2	0.9-1.6
	Low/Medium-density residential	2.3-6.5	0.3-0.9
	Row crops	2.4-11.4	0.2-1.4
	Pasture/grassland	2.0-5.7	0.1-0.3
	Forest	1.1-3.4	0.05-0.2
Current model (2019)	Pre-1980 urban	7.4-11.6	1.0-2.0
	Post-1980 urban	2.5-5.5	0.4-0.8
	Agriculture	1.7-7.9	0.3-1.2
	Undeveloped	0.4-1.1	0.03-0.1

Summary- key points

- Point source dischargers make up nearly 50% of TN and 25% of TP loadings to Jordan Lake. Thus, loads from wastewater treatment plants remain substantial in comparison to diffuse (nonpoint) loads from the landscape.

- Lands urbanized before 1980 are hot spots for diffuse nutrient export. They release more than double the TN and TP of agricultural and post-1980 urban lands (per unit area).

- Undeveloped lands export about an order of magnitude (~10x) less TN and TP than agricultural and urban lands (per unit area). Thus, development of natural lands will substantially increase nutrient loading to Jordan Lake.

- Nutrient retention in watershed steams and waterbodies is less than 20% of total point and nonpoint loads, except where TP is intercepted by reservoirs with long residence times. As a result, most of the load from the upstream portions of the watershed (e.g., Triad area) reaches Jordan Lake.

Acknowledgements

NC Department of Environmental Quality (NC DEQ)

Members of Dan Obenour’s NCSU Lab Group
(Environmental Modeling to Support Management and Forecasting)

Alexey, Shiqi, and Dario