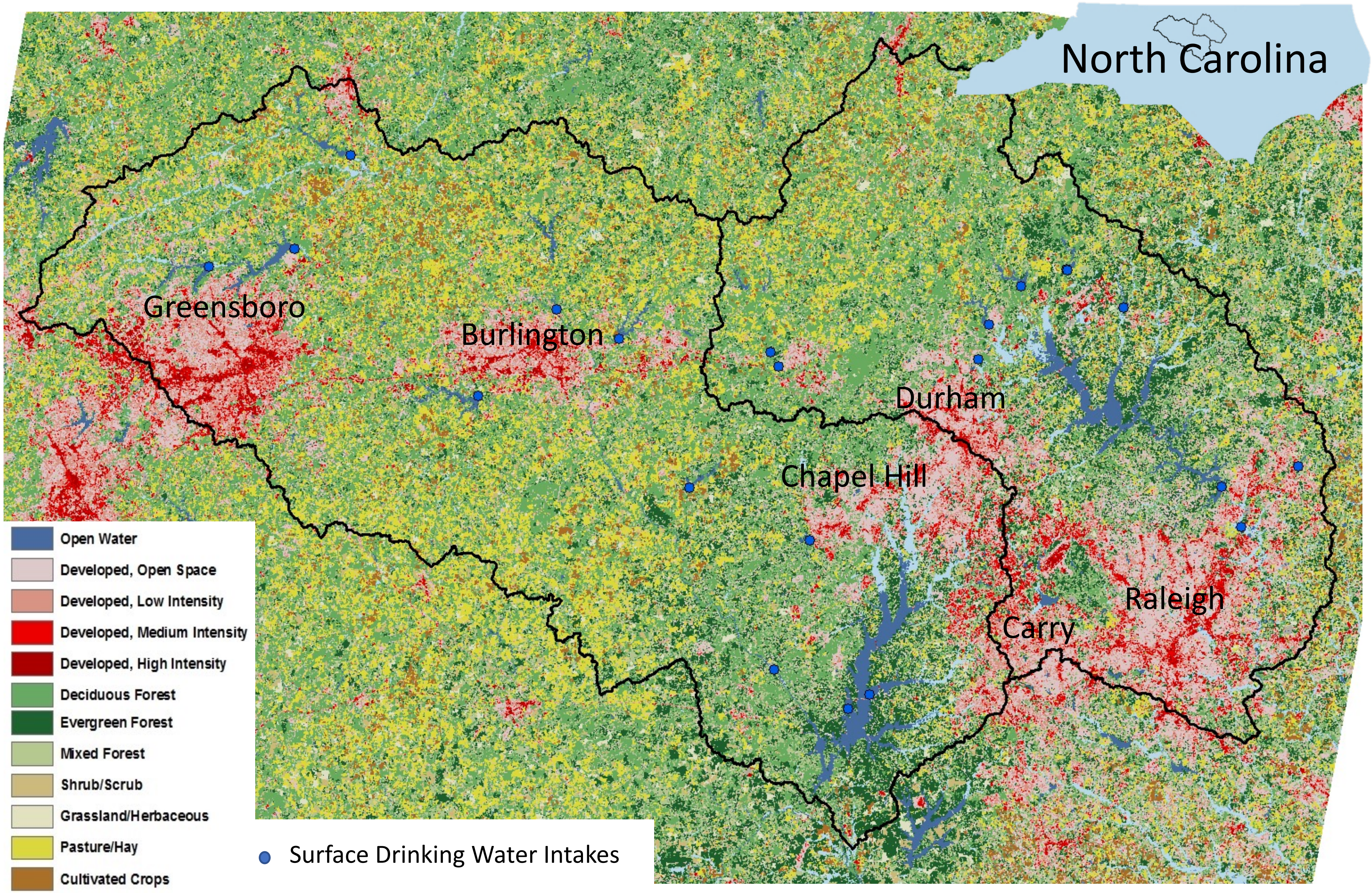
CONTROLS ON NITROGEN LOADING ALONG THE EXURBAN-URBAN GRADIENT OF THE NORTH CAROLINA PIEDMONT

Joseph Delesantro

Postdoctoral Scholar, Penn State University

jdelesantro@psu.edu

Jonathan M. Duncan, Diego Riveros-Iregui, Keridwen M. Whitmore, Joanna Blaszczak, Emily Bernhardt, Dean Urban, Lawrence E. Band


North Carolina
Greensboro
Burlington
Durham
Chapel Hill
Raleigh
Carry
Open Water
Developed, Open Space
Developed, Low Intensity
Developed, Medium Intensity
Developed, High Intensity
Deciduous Forest
Evergreen Forest
Mixed Forest
Shrub/Scrub
Grassland/Herbaceous
Pasture/Hay
Cultivated Crops
Surface Drinking Water Intakes

What are the dominant flow paths of nonpoint source nitrogen loading along the exurban-urban gradient?

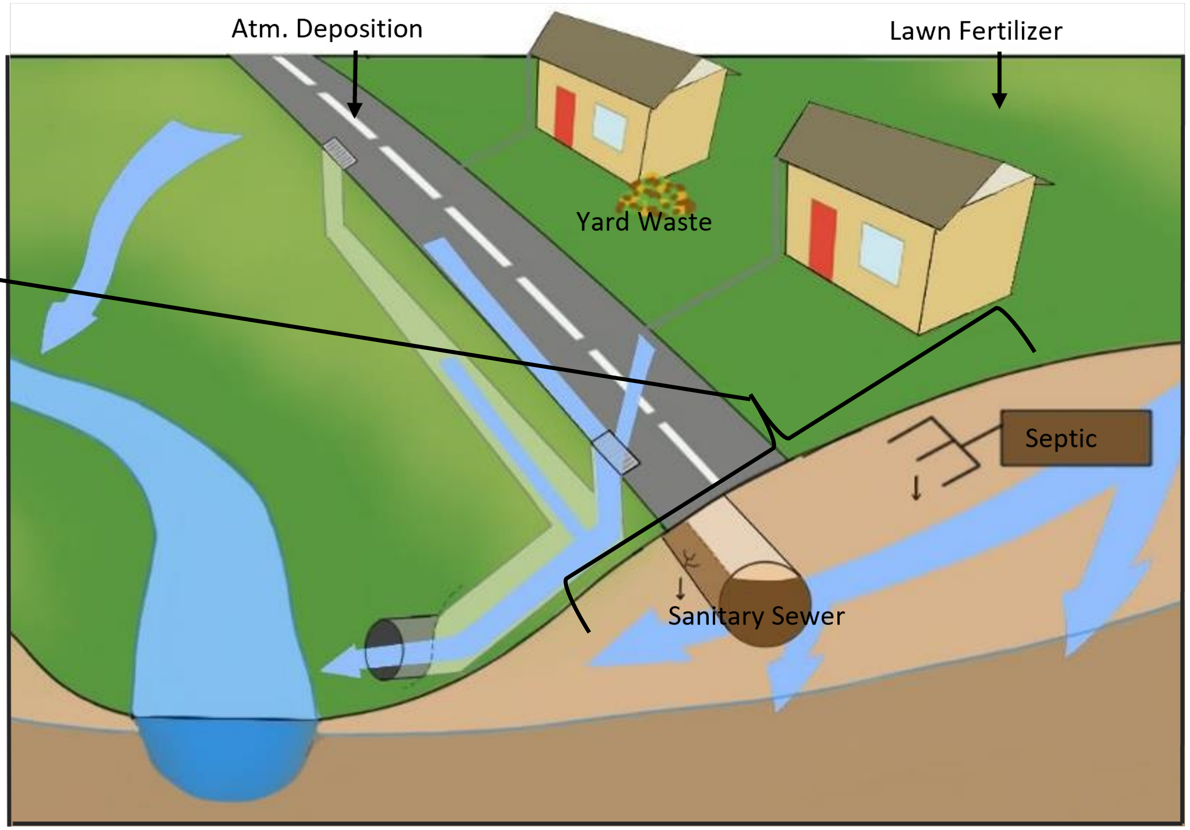
What are the primary sources of nonpoint source nitrogen loading to streams along the exurban-urban gradient?

What landscape features control nitrogen loading in developed watersheds?

Where is nitrogen coming from?

How is nitrogen transported to streams in developed watersheds?

- Humans convert food to wastewater
- And we depend on sanitary infrastructure to contain and treat this nitrogen source



Bernhardt et al.: Urban Impacts on Surface Water Nitrogen Loading

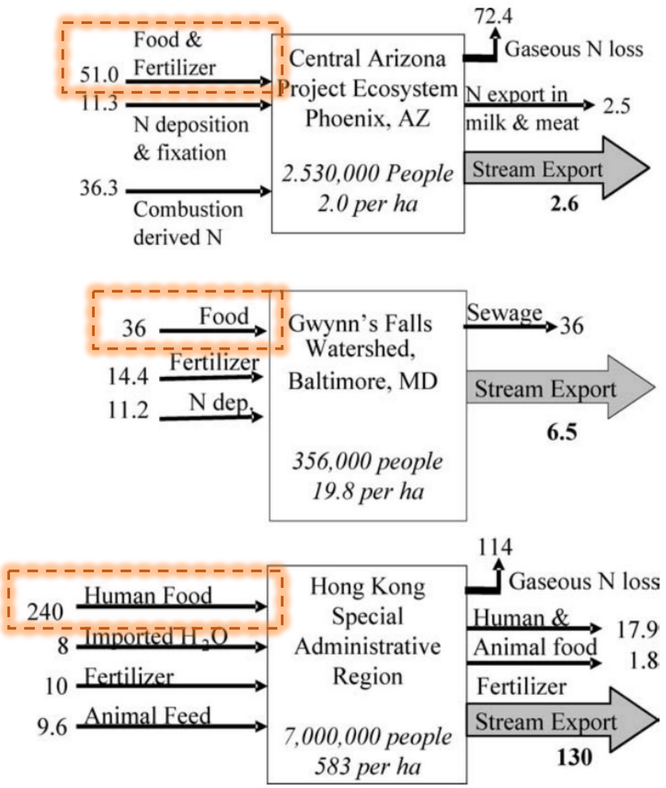


Figure 2. Compiled mass balance estimates for three cities (data in kg N ha^{-1} y^{-1}) arranged in order of increasing population density. Data for Phoenix from Baker *et al.* 2001, for Baltimore from Groffman *et al.* 2004, and for Hong-Kong from Warren-Rhodes and Koenig 2001. Note the discrepancies between the types of fluxes measured in each study.

Bernhardt, E. S., Band, L. E., Walsh, C. J., & Berke, P. E. (2008). Understanding, managing, and minimizing urban impacts on surface water nitrogen loading. *Annals of the New York Academy of Sciences*, *1134*, 61–96.

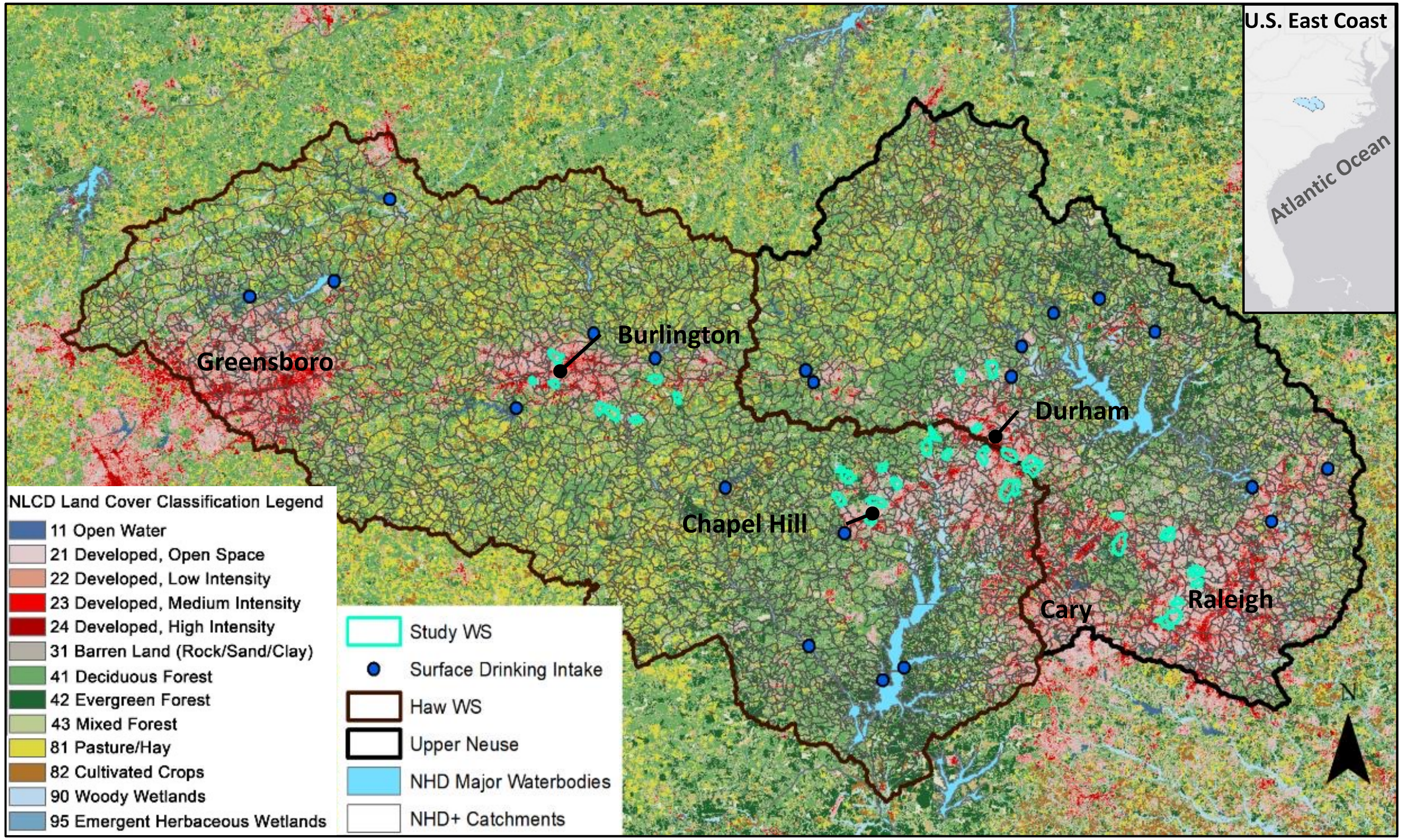
Baker, L. A., Hope, D., Xu, Y., Edmonds, J., & Lauver, L. (2001). Nitrogen balance for the Central Arizona-Phoenix (CAP) ecosystem. *Ecosystems*, *4*(6), 582–602.

Groffman, P. M., Law, N. L., Belt, K. T., Band, L. E., & Fisher, G. T. (2004). Nitrogen Fluxes and Retention in Urban Watershed Ecosystems. *Ecosystems*, *7*(4), 393–403.

Warren-Rhodes, K. & A. Koenig. (2001). Ecosystem ap- propriation by Hong Kong and its implications for sustainable development. Ecol. Econ. 39: 347–359.

Across the 6975 km^2 study area:

- Population density of developed sub catchments is low, with a median of 390 per/km^2
- There is a large overlap in the population density use of septic and sewers systems encompassing the median population density.
- 25% of the population is served by septic systems.
- Sanitary sewers are preferentially placed near streams, 91.1% of sanitary sewer volume was within 200ft of a stream

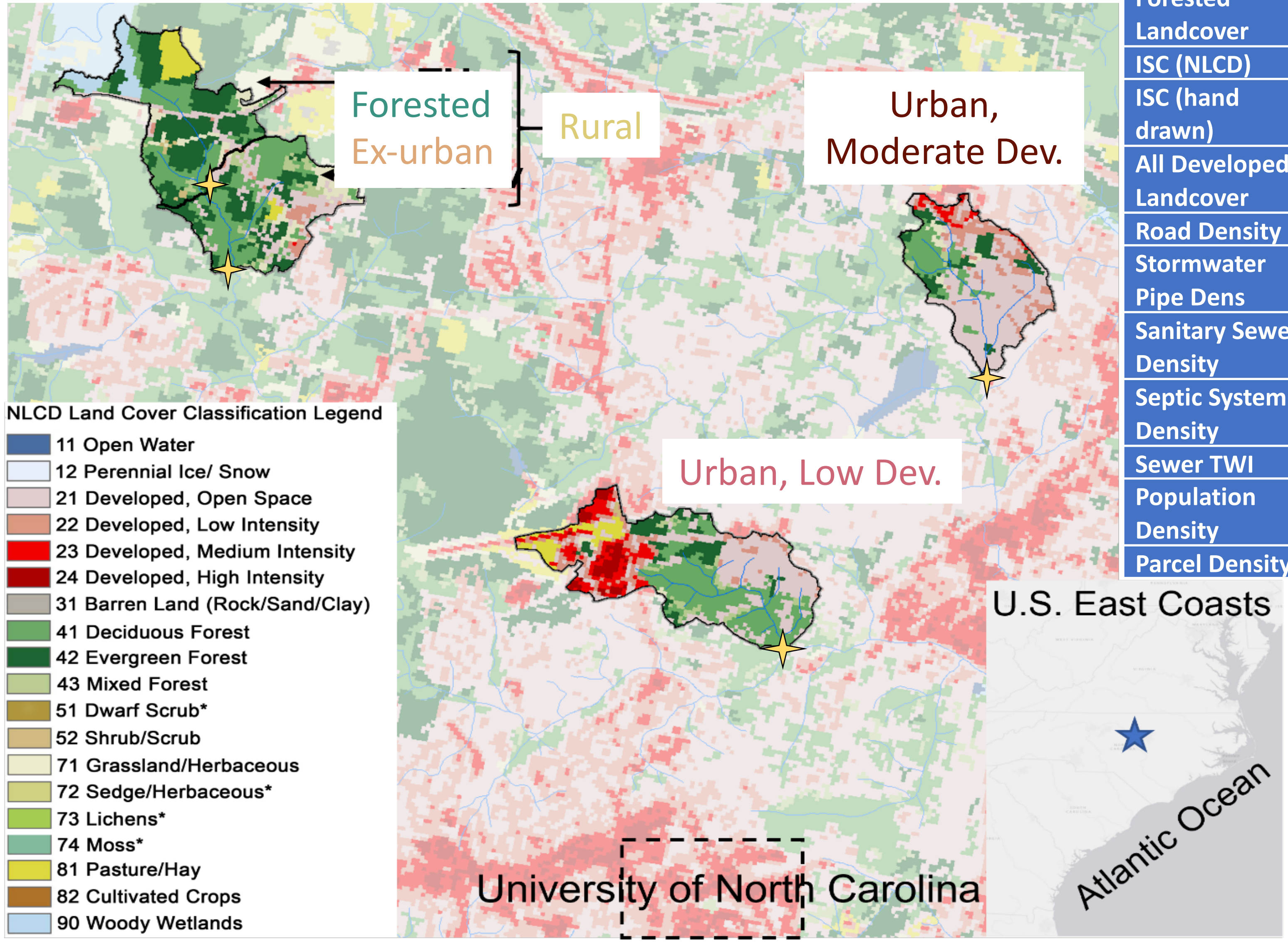


Read more about development patterns in the NC Piedmont:

Delesantro, J. M., Blaszczak, J. R., Duncan, J. M., Bernhardt, E. S., Riveros-iregui, D., Urban, D. L., & Band, L. E. (2021). Characterizing and classifying urban watersheds with compositional and structural attributes, (August), 1–20. https://doi.org/10.1002/hyp.14339

What are the dominant flow paths of nonpoint source nitrogen loading along the exurban-urban gradient?

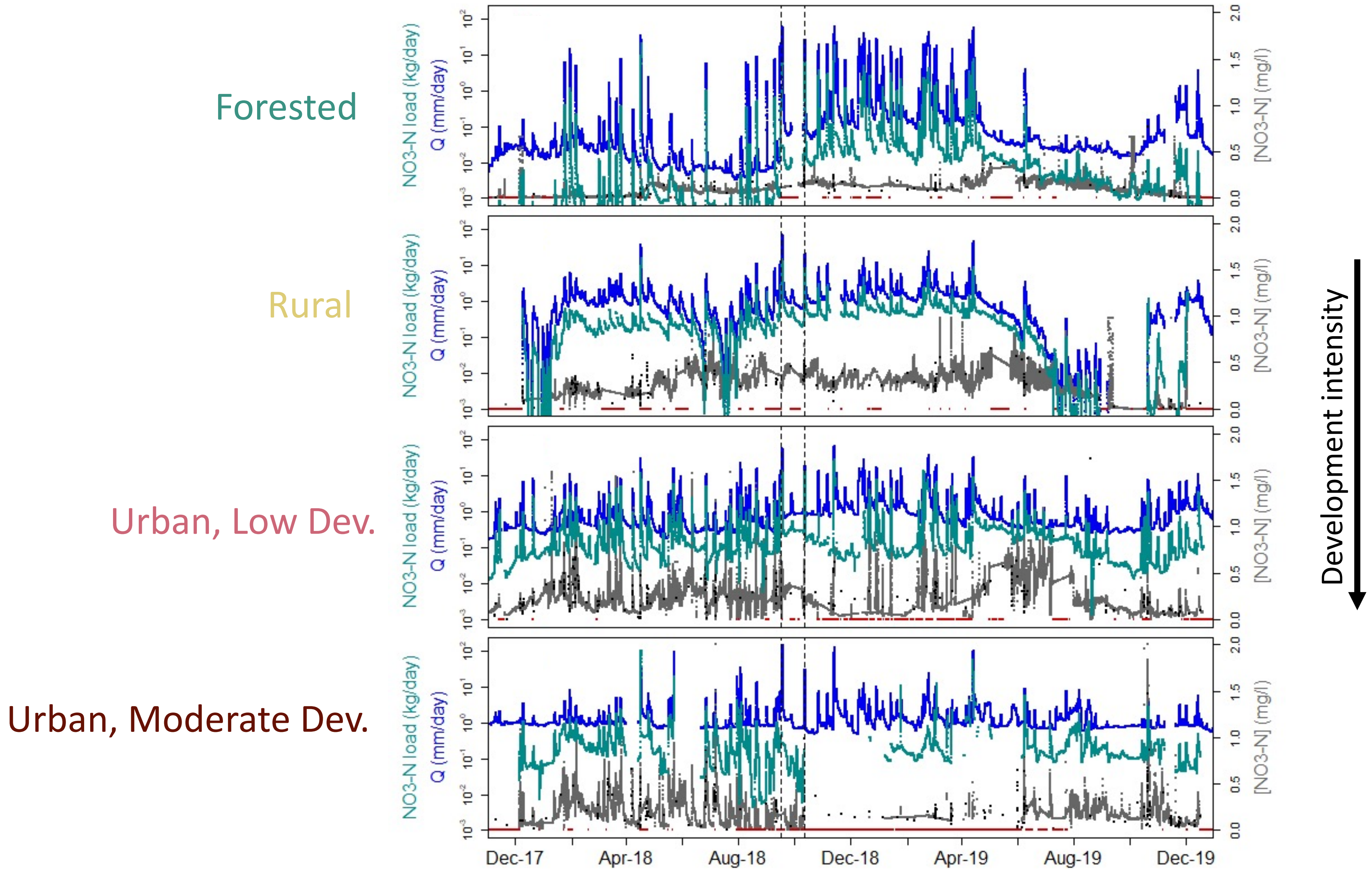
To investigate nitrogen loading across flows:

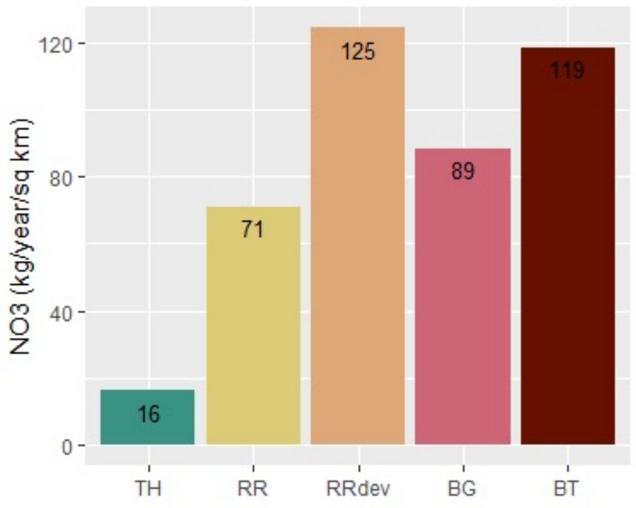


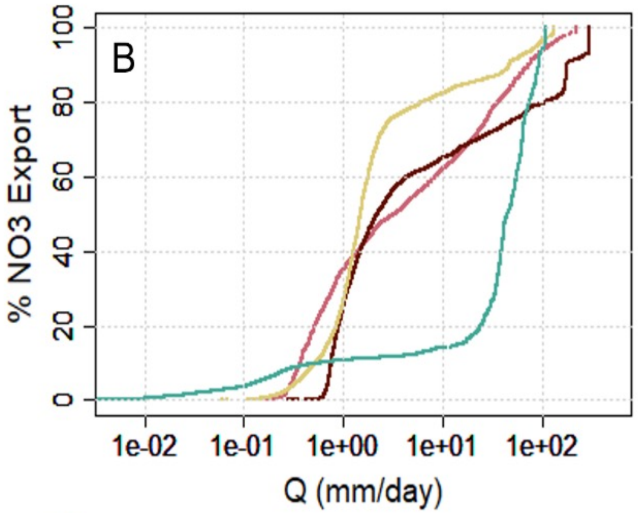
		Study WS ID				
Metric	Units	TH	RR	RRdev	BG	BT
Area	SqKM	0.99	1.94	0.95	1.51	0.95
Agg. Landcover	%	7.94	5.25	2.39	5.3	0.19
Forested Landcover	%	60.83	62.3	64.09	40.83	25.87
ISC (NLCD)	%	0.81	2.28	3.83	15.71	10.9
ISC (hand drawn)	%	1.57	3.77	6.9	20.03	23.22
All Developed Landcover	%	0.81	3.86	7.08	24.64	20.4
Road Density	km/km^2	2.59	3.64	4.75	5.6	7.43
Stormwater Pipe Dens	km/km^2	0.09	0.25	0.42	1.11	2.78
Sanitary Sewer Density	km/km^2	0	0.43	0.88	5.13	7.36
Septic System Density	per km^2	13	94	180	3	0
Sewer TWI		0	0.88	1.23	0.67	1.01
Population Density	per km^2	30	259	498	313	887
Parcel Density	per km^2	13	85	161	113	276

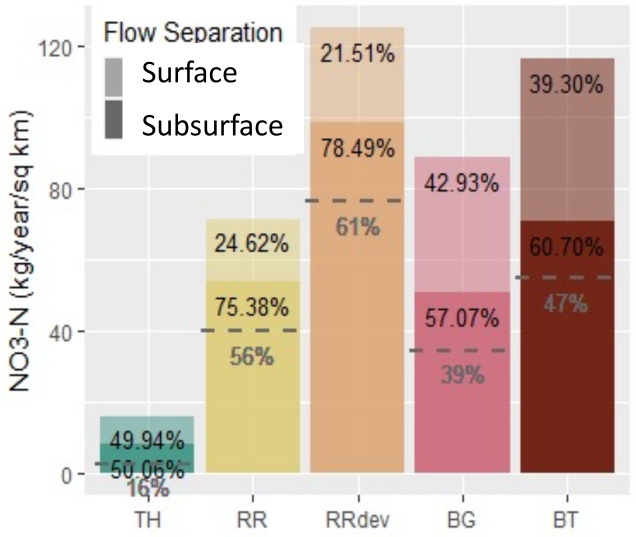

Solar Panels
Autosampler for storm samples
Datalogger
Batteries
Flow Sensor →
Spectrometer
Water Level

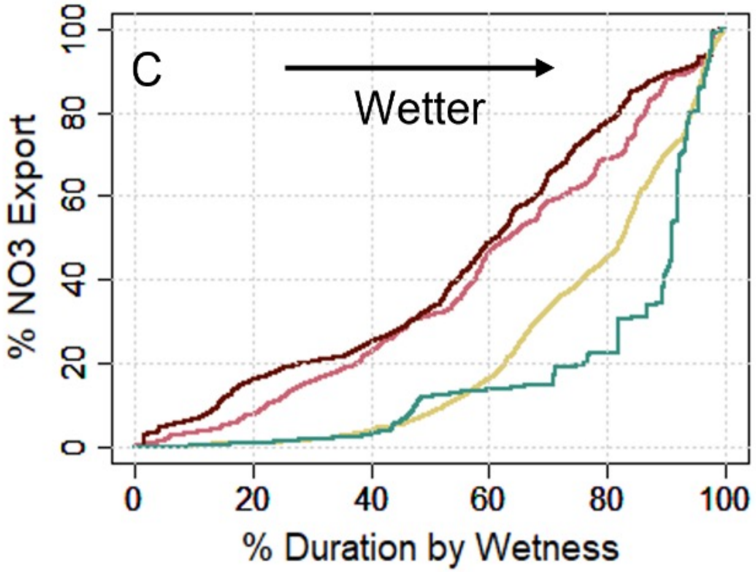
Nitrate concentration and loading timeseries



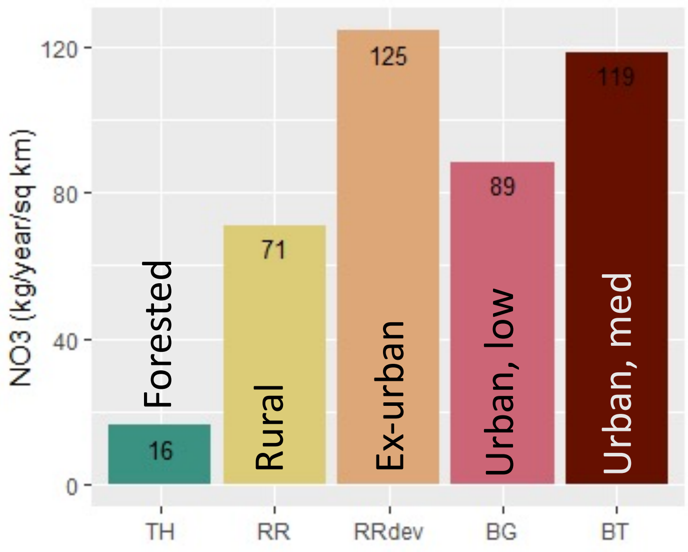

120
80
40
0
NO3 (kg/year/sq km)
16
71
125
89
119
TH
RR
RRdev
BG
BT

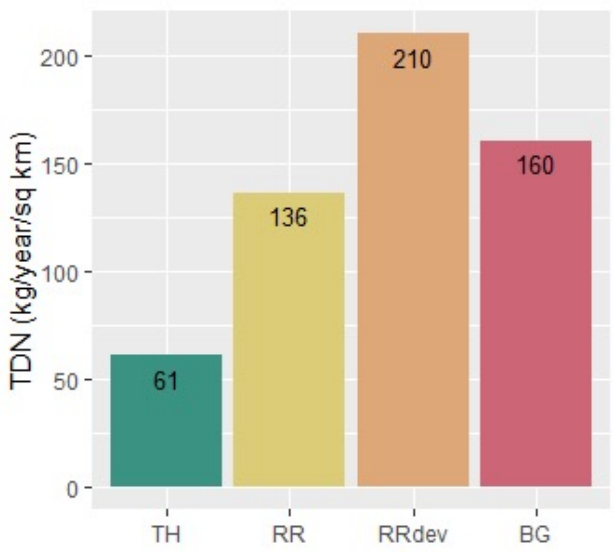

B
100
80
60
40
20
0
% NO3 Export
1e-02
1e-01
1e+00
1e+01
1e+02
Q (mm/day)

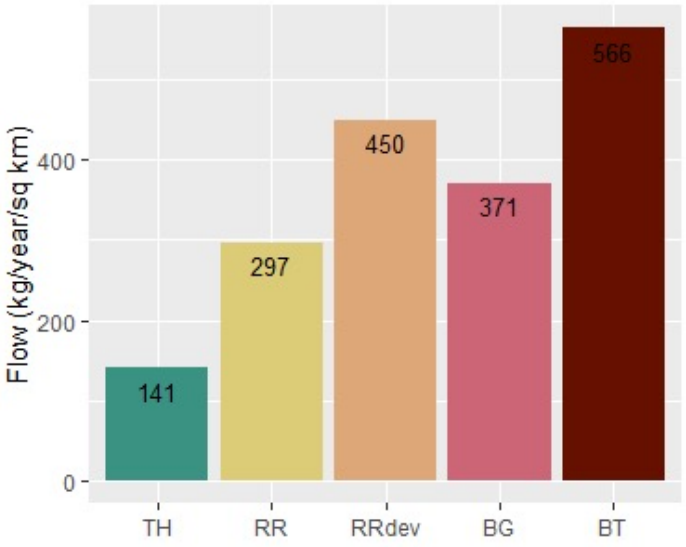

Flow Separation
Surface
Subsurface
120
80
40
0
NO3-N (kg/year/sq km)
49.94%
50.06%
16%
24.62%
75.38%
56%
21.51%
78.49%
61%
42.93%
57.07%
39%
39.30%
60.70%
47%
TH
RR
RRdev
BG
BT


C
Wetter
100
80
60
40
20
0
% NO3 Export
0
20
40
60
80
100
% Duration by Wetness

Total runoff and nitrogen loading







- Nitrogen loading was highest for the septic served ex-urban catchment, but otherwise increased with development intensity

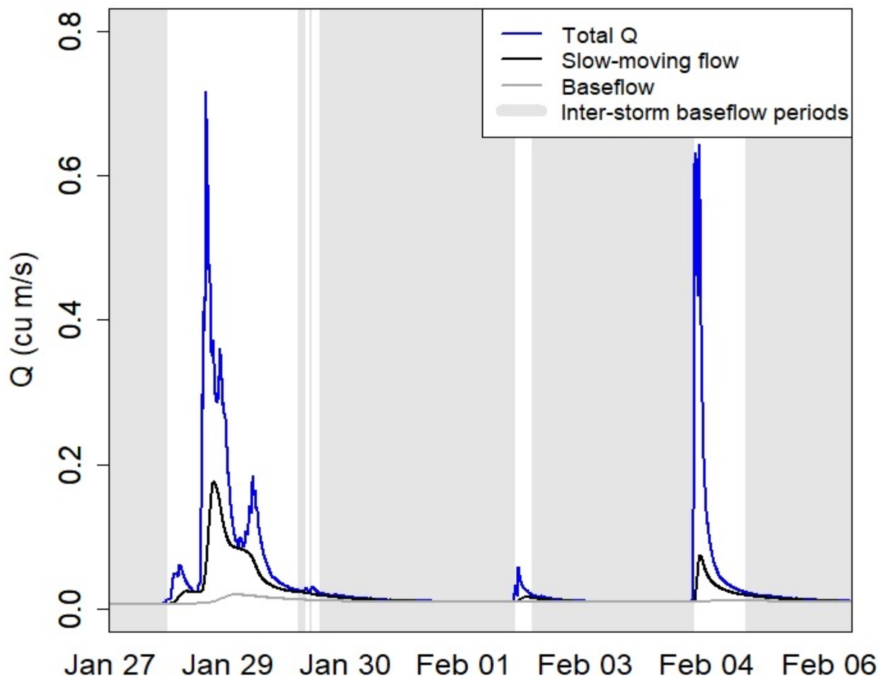
- Total TDN loads are consistent with the Baltimore region (Shields et al., 2008)

A note on hydrograph separation

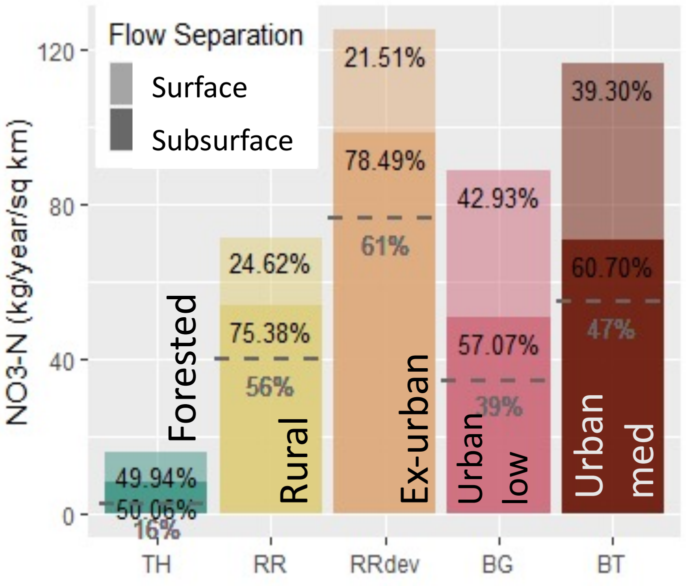
- The goal is to differentiate surface from subsurface flow

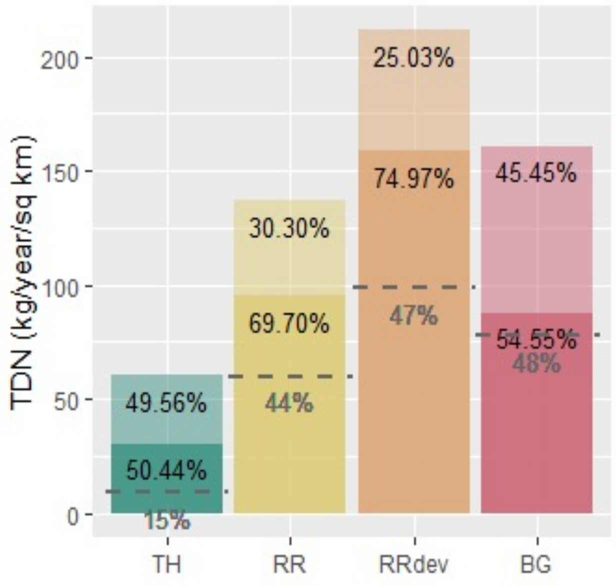
- Two graphical flow separation estimates
    - An estimate of baseflow and subsurface stormflow
    - A conservative baseflow estimate with little event scale variation

Example hydrograph separation

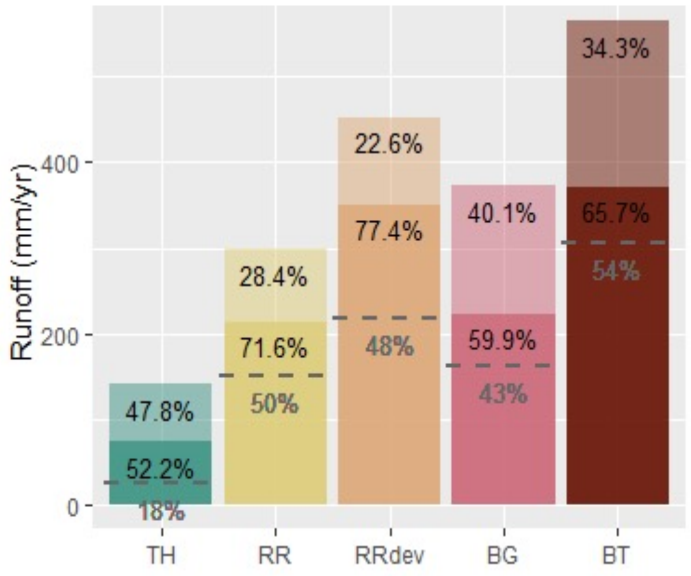


Total runoff and nitrogen loading split by estimated flow path





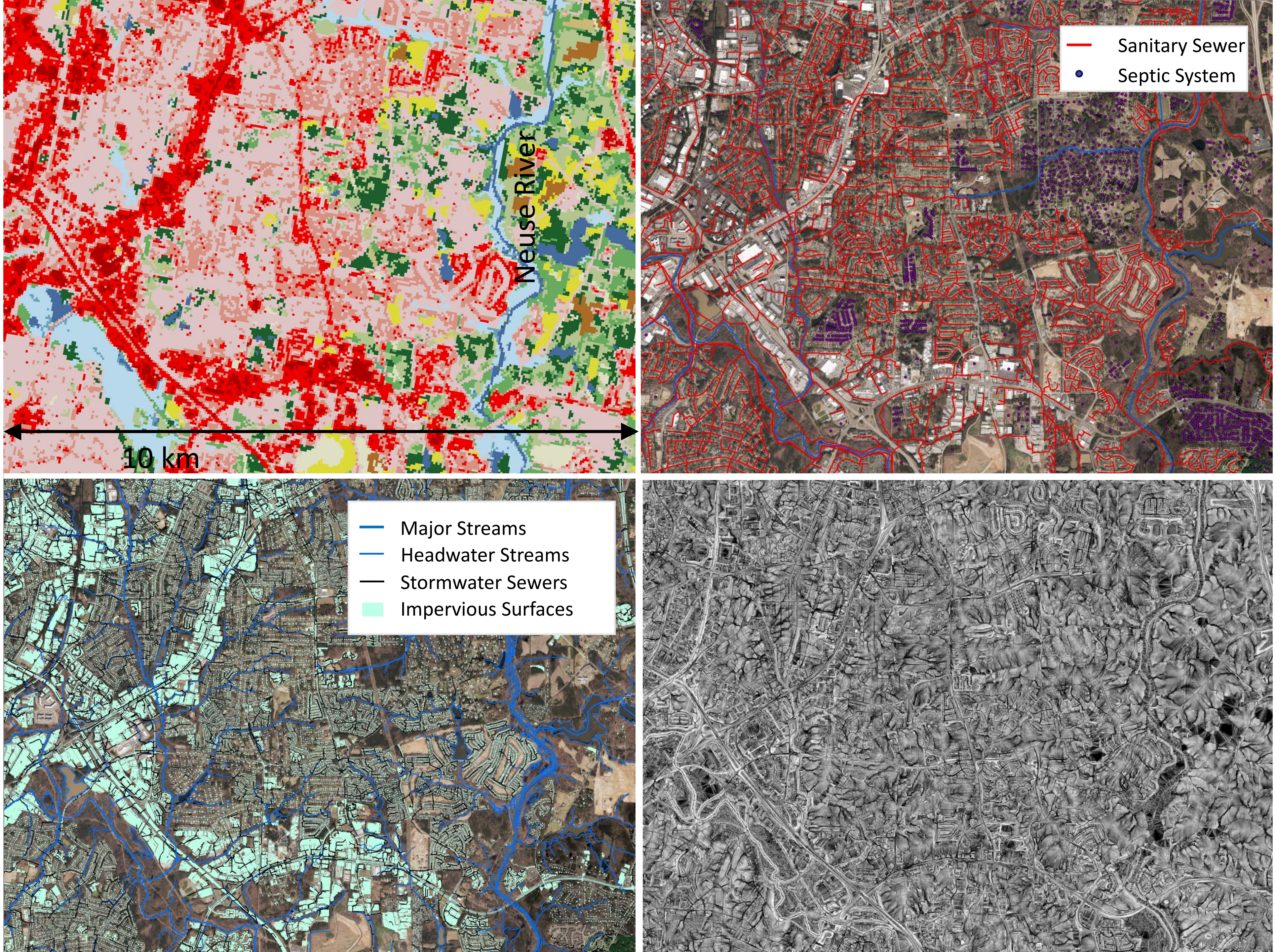
- Subsurface flow made up a large proportion of the total nitrogen loading, even for the most developed study catchment
- This is true using even the conservative estimate of baseflow



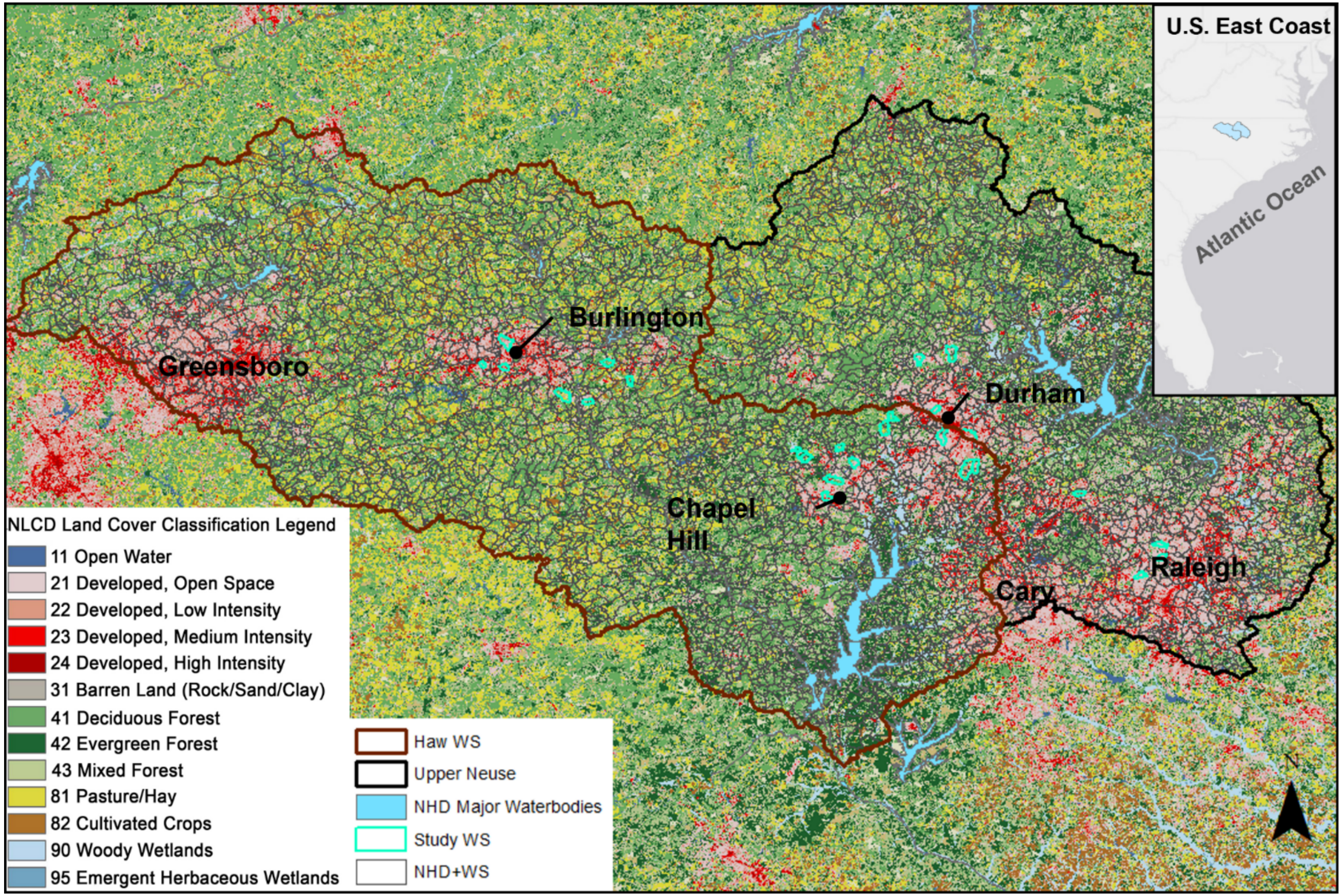
Baseflow nitrogen loading:

What are the primary sources of nonpoint source nitrogen loading to streams along the exurban-urban gradient?

What landscape features control nitrogen loading in developed watersheds? **Where is nitrogen coming from?**


Neuse River
10 km
Sanitary Sewer
Septic System
Major Streams
Headwater Streams
Stormwater Sewers
Impervious Surfaces

To investigate nonpoint source baseflow nitrogen loading:

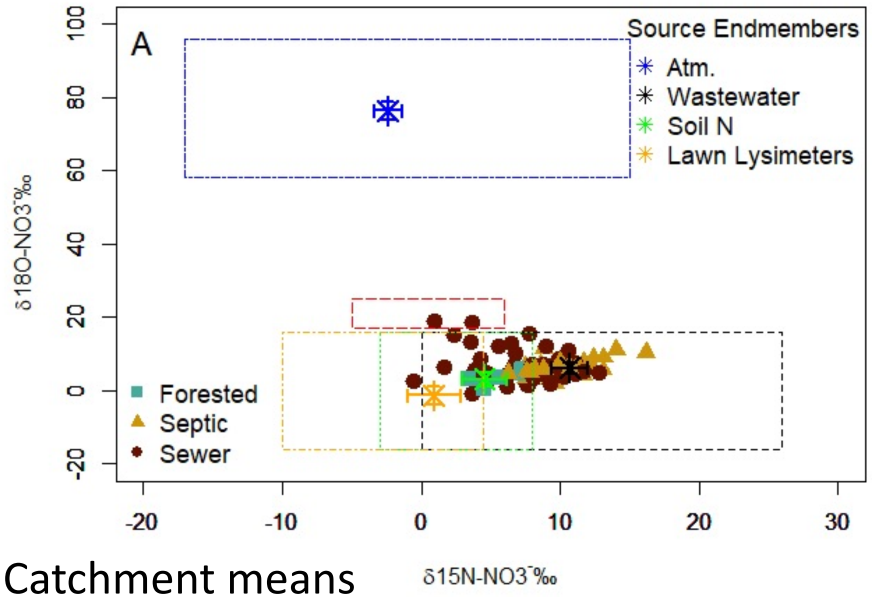


- Selected 27 NHD+ scale catchments which represent the regional distribution of metrics of landcover, infrastructure, and population
- 13 catchments were sampled for isotopic nitrate analysis, 1 primarily forested, 6 septic served, and 6 sewer served
- Catchments were sampled at baseflow every other week with between 1 and 5 years of data

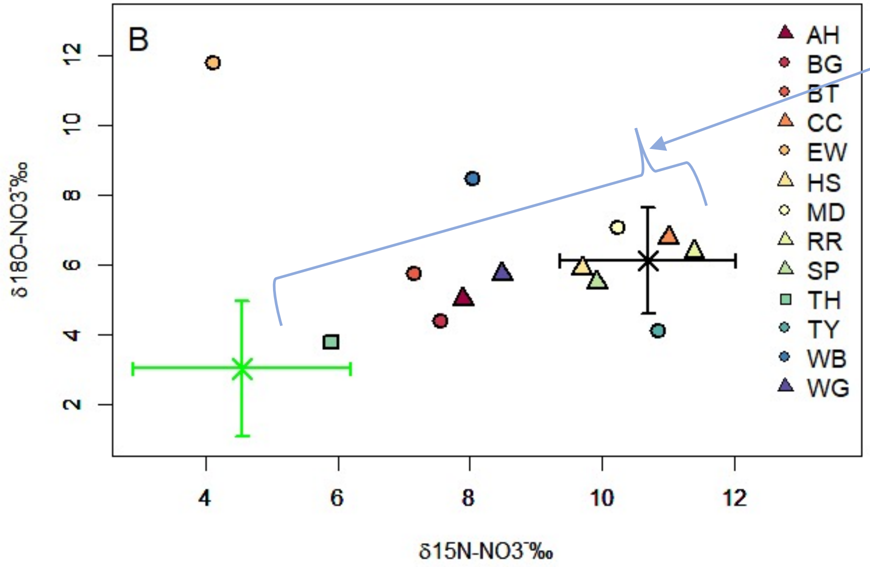
Delesantro, J. M., Duncan, J. M., Riveros-Iregui, D., Blaszczak, J. R., Bernhardt, E. S., Urban, D. L., & Band, L. E. (2022). The Nonpoint Sources and Transport of Baseflow Nitrogen Loading Across a Developed Rural-Urban Gradient. *Water Resources Research*, *58*(7), 1–25. https://doi.org/10.1029/2021WR031533

What are the primary baseflow sources?

All sampling



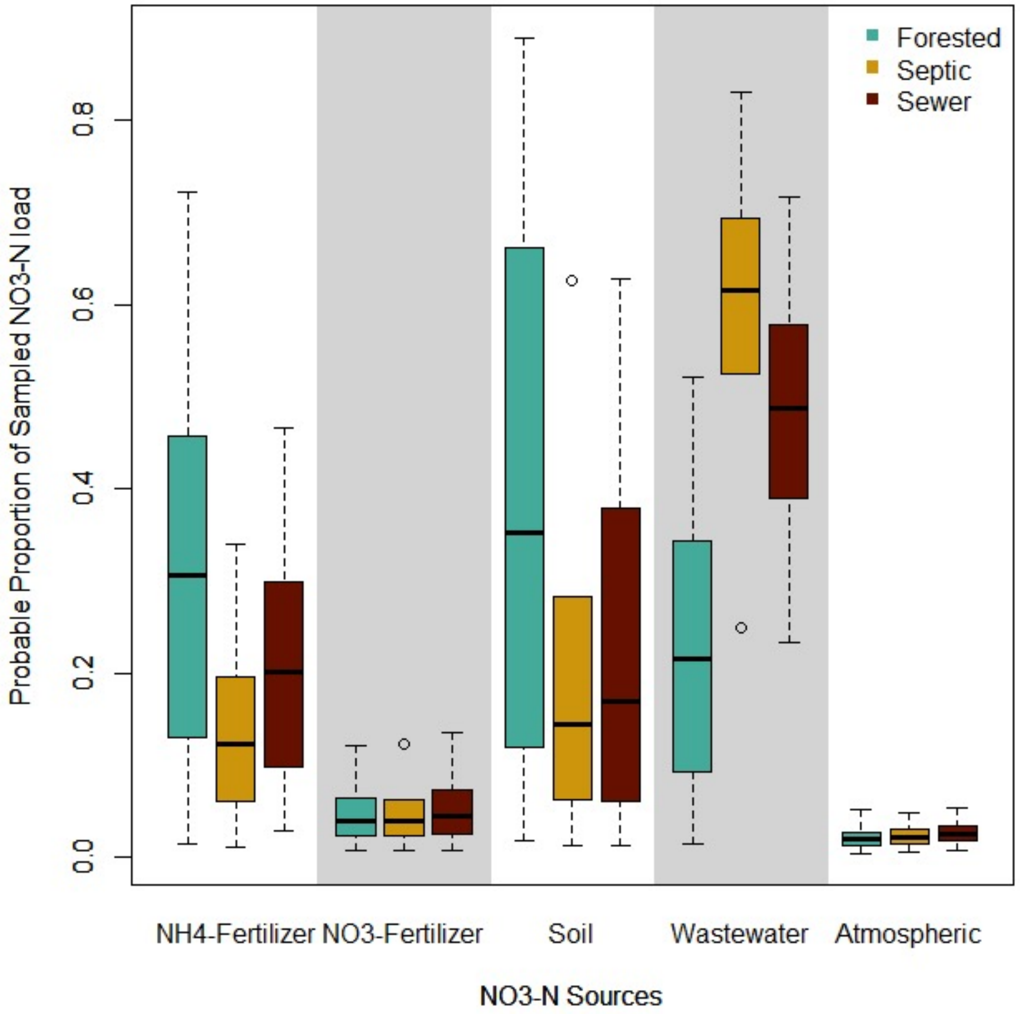
Catchment means



- Nitrate made up 73% of total dissolved nitrogen
- Most of the sampled isotopic nitrate values were within the literature range for wastewater and clustered around our wastewater endmember sampling
- Mean catchment values generally clustered around the wastewater endmember or along the wastewater-soil N mixing line

The source regions (A) are from: Kendall, C., Elliott, E. M., & Wankel, S. D. (2008). Tracing Anthropogenic Inputs of Nitrogen to Ecosystems. *Stable Isotopes in Ecology and Environmental Science: Second Edition*, 375–449.

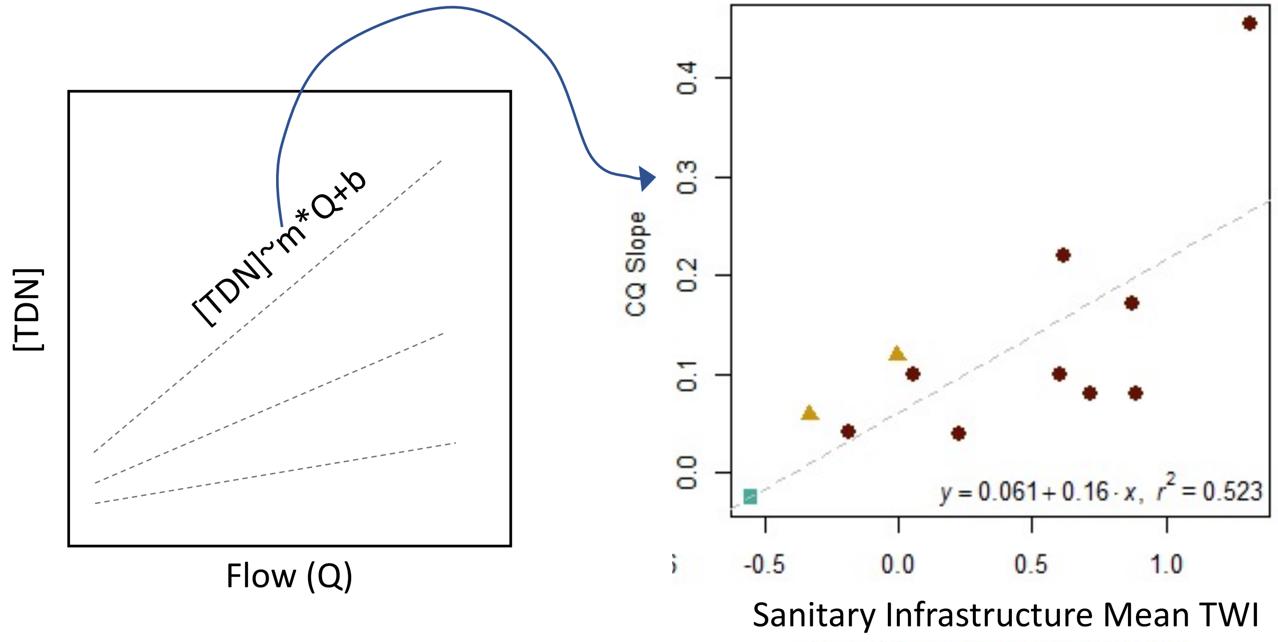
What are the primary sources?

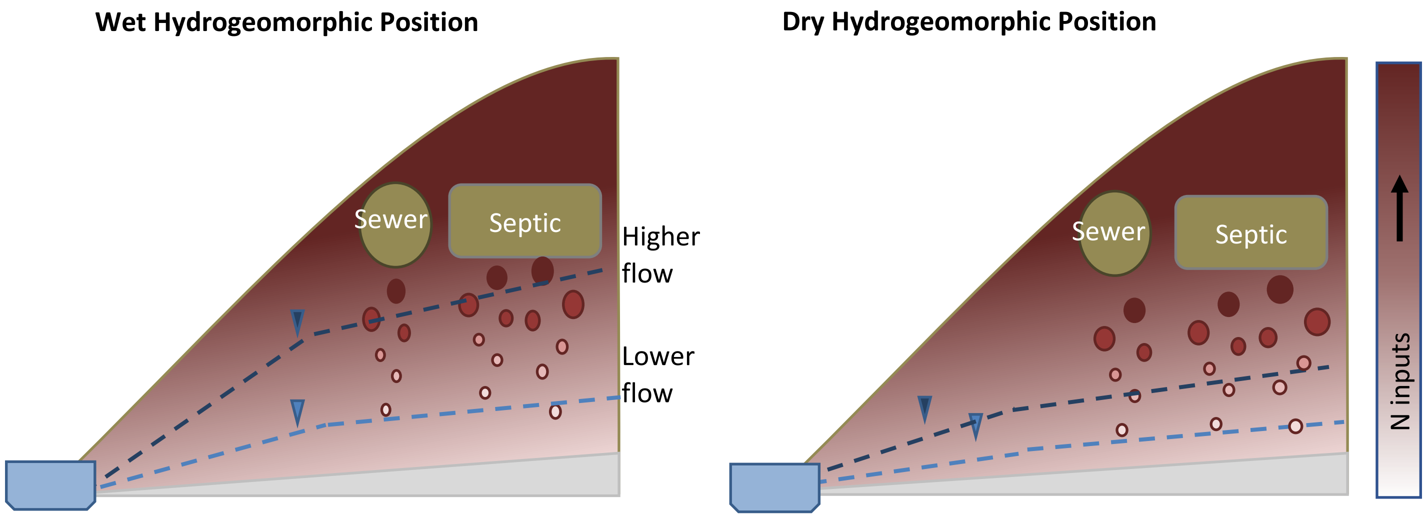


Probability distribution estimates of NO_3^- sources proportions by mass

- Uses a Bayesian approach to solve mixing equations and reflect uncertainty
- Wastewater was the probable primary source for both septic and sanitary sewer served catchments

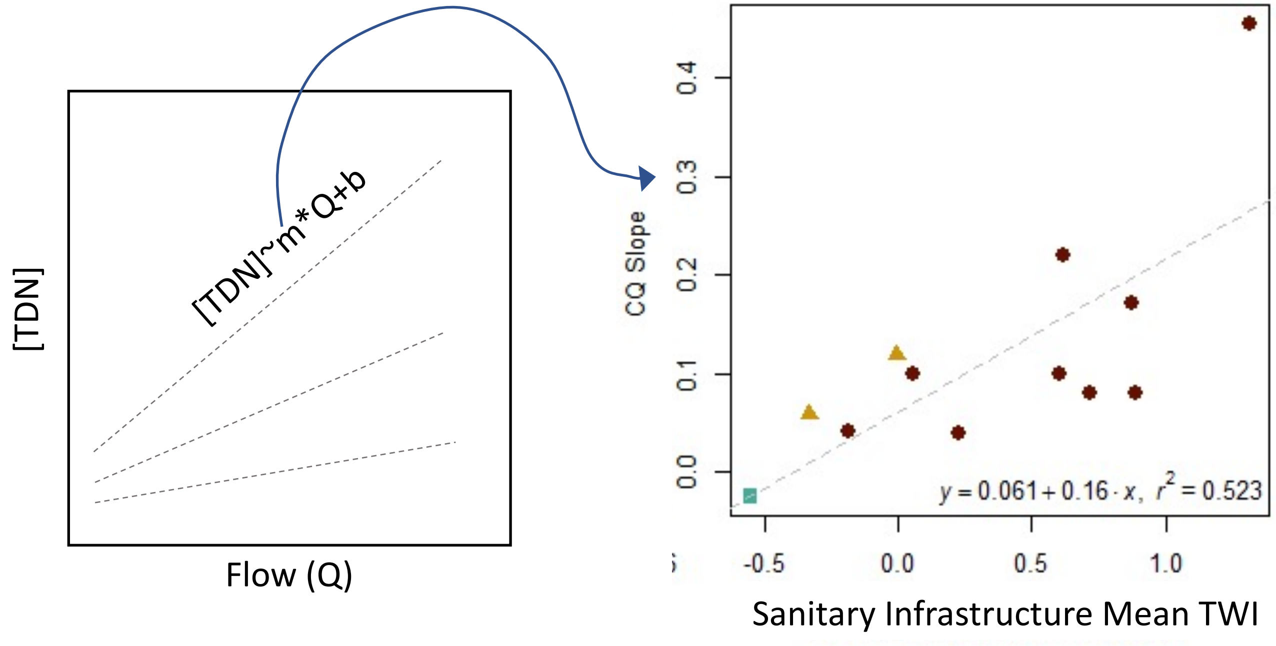
How is baseflow nitrogen transported?



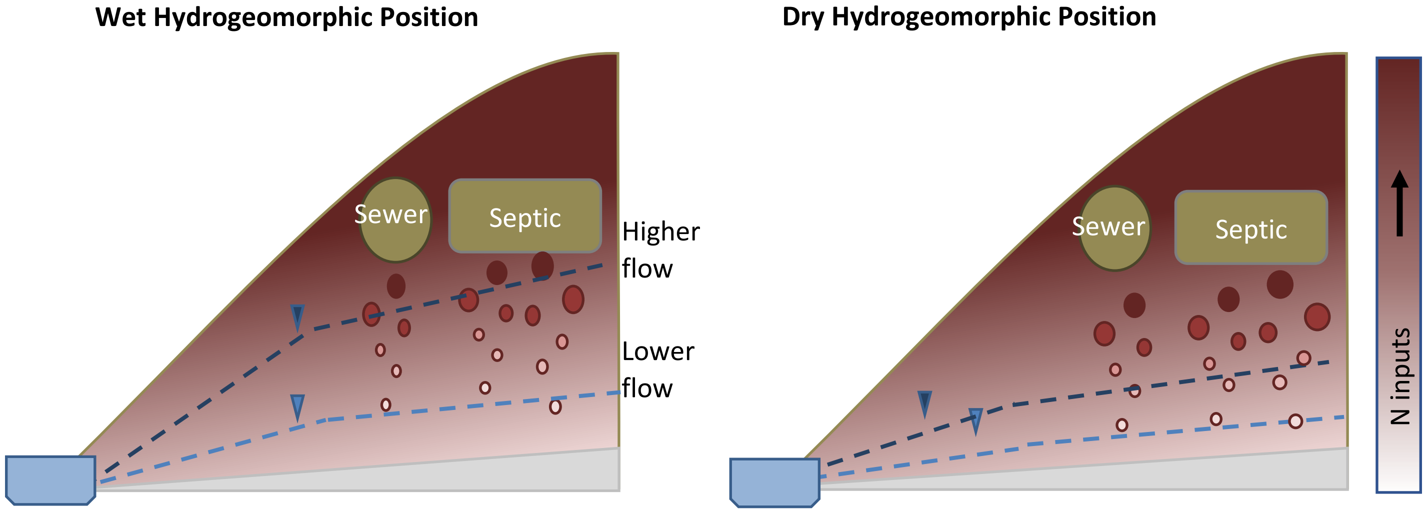


- All significant linear concentration-discharge (CQ) relationships were positive for developed catchments
- The catchment CQ slope was well predicted by the hydrogeomorphic position of sanitary infrastructure
- This suggests that nitrogen from sanitary infrastructure in wet locations, was more ready transported by increases in water tables, than nitrogen from sanitary infrastructure in dry locations

How is baseflow nitrogen transported?

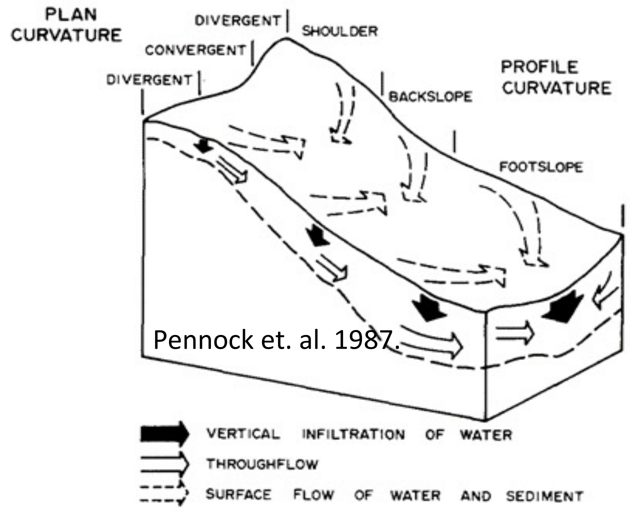


- Wastewater was the primary source of baseflow nitrogen across developed catchments
- Subsurface N was abundant, and export was transport limited
- The position of sanitary infrastructure within the terrestrial flow field largely governed loading



What landscape features control nitrogen loading?

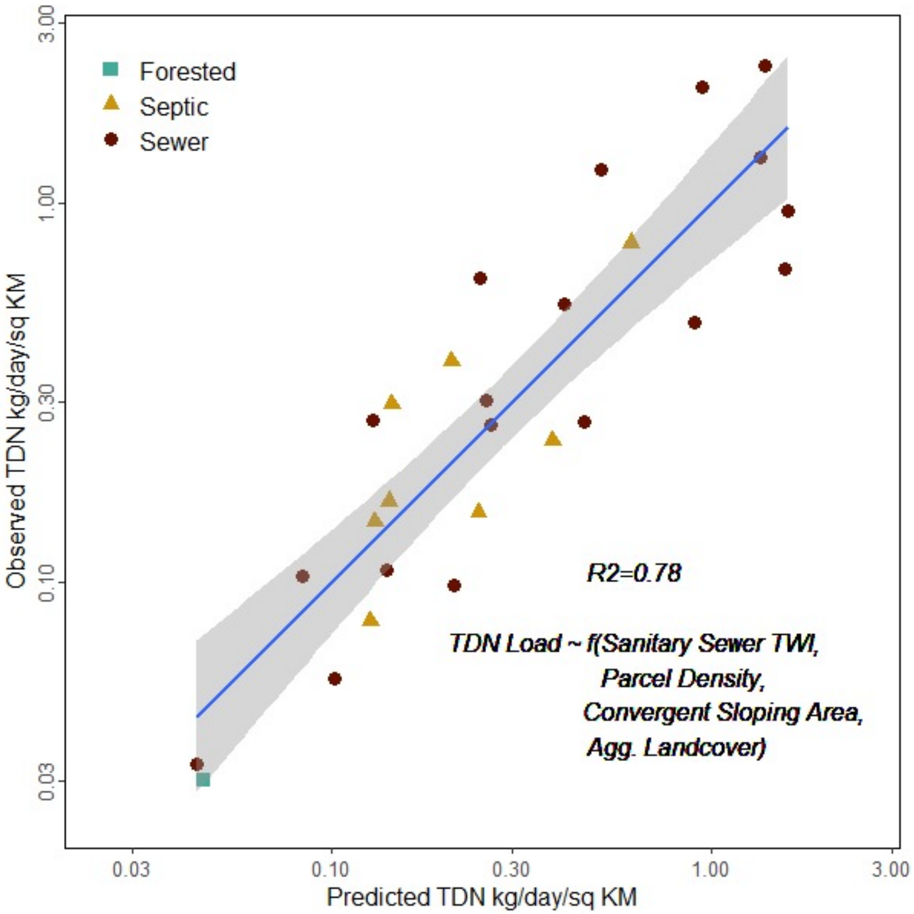
Best landscape predictors of baseflow TDN loading		
	TDN (kg/sq km)	
	R^2	effect
Hydrogeomorphic position		
Sewer TWI (median)	0.41	+
Sanitary TWI	0.39	+
Topography		
Convergent area	0.27	+
Footslope area	0.26	+
Population		
Parcel Density	0.25	+



N loading ~ f(Population (supply),
Hydrogeomorphic position of N pools,
Geologic and topographic properties)

- Wastewater was the primary source of baseflow nitrogen across developed catchments
- Subsurface N was abundant, and export was transport limited
- The position of sanitary infrastructure within the terrestrial flow field largely governed loading
- The topographic wetness of the location of sanitary infrastructure was the best predictor of baseflow nitrogen loading

Conceptually informed, parsimonious empirical model



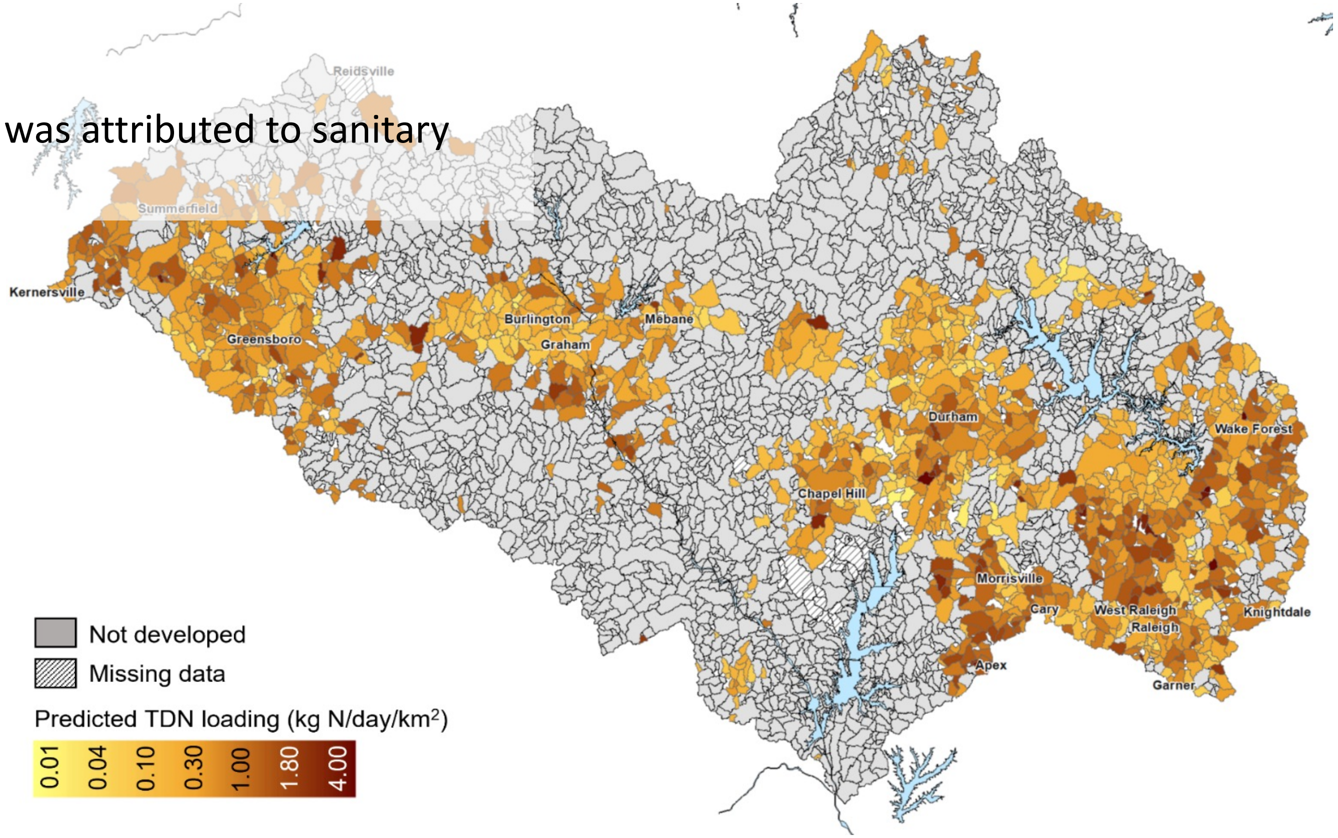
Parameter	Estimate	Std Error	p
Convergent landform	0.0772	0.0179	0.0002
Parcel Dens	0.0029	0.0006	0.0001
Sewer TWI	1.0353	0.3316	0.0049
NLCD Agg	0.0816	0.0197	0.0004
Intercept	-5.137	0.5511	4.27E-09

- Wastewater was the primary source of baseflow nitrogen across developed catchments
- Subsurface N was abundant, and export was transport limited
- The position of sanitary infrastructure within the terrestrial flow field largely governed loading
- The topographic wetness of the location of sanitary infrastructure was the best predictor of baseflow N loading
- We generate an empirical model which describes 78% of baseflow N loading

- In and around the lowest population density cities agricultural land-use and convergent sloping land area were large drivers of spatial variation in baseflow loading

- While across most sub catchments, population density and sanitary infrastructure placement drove spatial variation

- We estimate that 39% of baseflow loading regionally was attributed to sanitary infrastructure in wet areas of the landscape



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How is nitrogen transported to streams in developed watersheds?

- Baseflow and subsurface flows contributes most N loading across the most common low and moderate development intensity landscapes.

- Subsurface N, originating from wastewater, is abundant and the position of sanitary infrastructure within the terrestrial flow field largely governs loading.

Management implications

- The current paradigm of focusing urban watershed management on surface sources and surface flow paths may only be valid for the most heavily developed catchments.
- To manage the most common exurban, low, and moderate development intensity catchments we will need to focus on subsurface sources by considering the hydrogeomorphology of development and sanitary infrastructure.
- And we can make better use of the longer residence times of subsurface and baseflow transport. This provides strong support for restoration, but we'll to curb peak flows to support restoration and reduce erosion and entrenchment.

I would like to thank Aleah Walsh, and Brooke Hassett for their work in the field, lab, and office and all the dedicated and curious undergraduates who have assisted: Natalie Gauger, Rhyan Stone, Will Hamilton, Lauren Whitenack, Helen Drotor, Tianzhen Nie, Maribel Herrera, Grace Allen, and Meredith Emery.

Questions?