Sanitary Sewer Exfiltration

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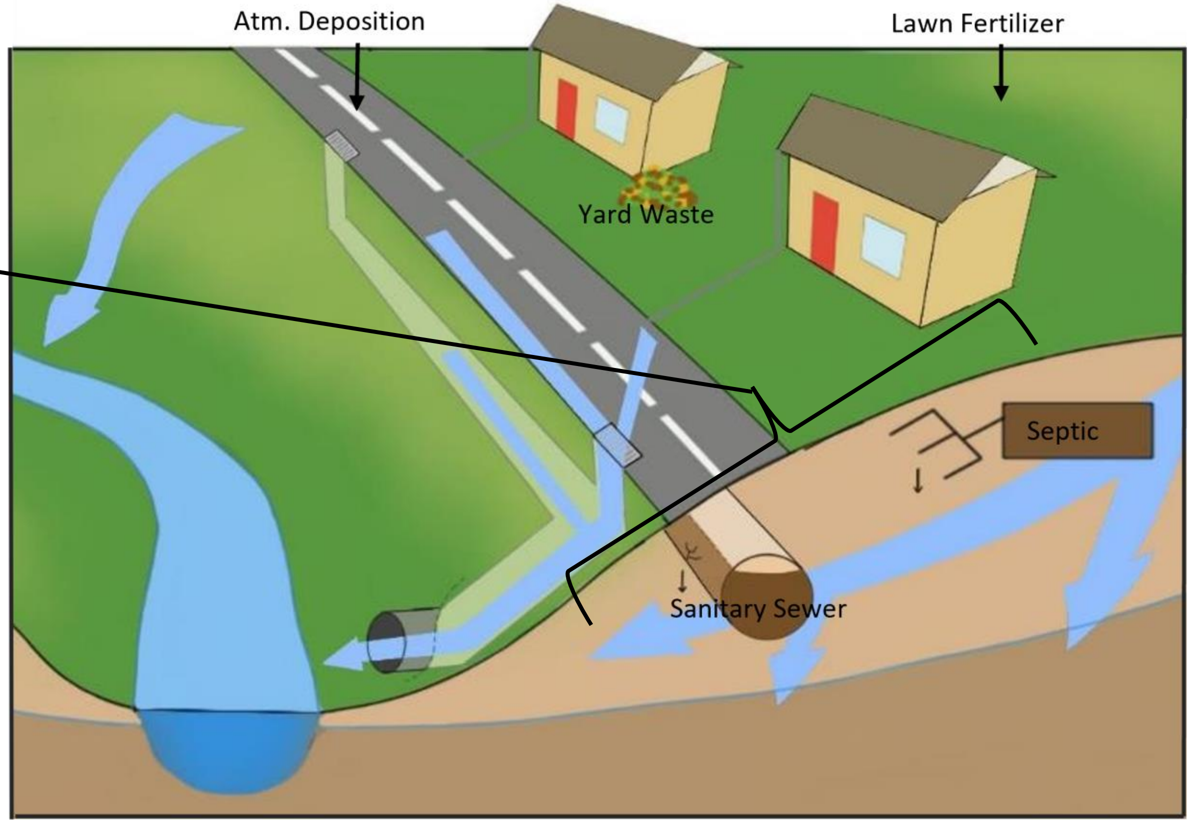
Agenda

- What is sanitary sewer exfiltration?
- Evidence from select research
  - Catchment-watershed scale, Delesantro et al., 2022
  - Pipe segment scale, Schiff et al., in prep.
  - Nationwide model (Germany), Nguyen and Venohr, 2021
- Compare studies
- Why does it matter for the model?
- Potential solutions (briefly)

- 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

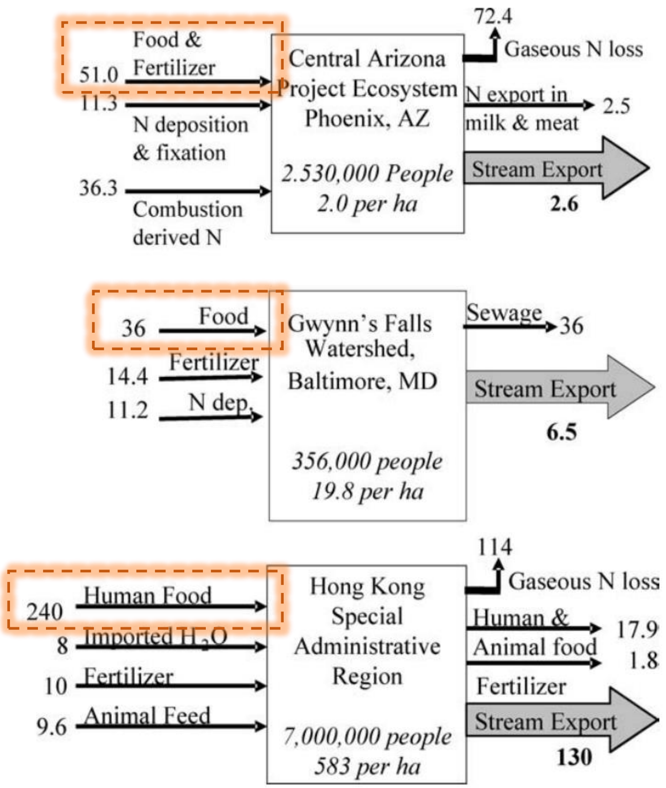


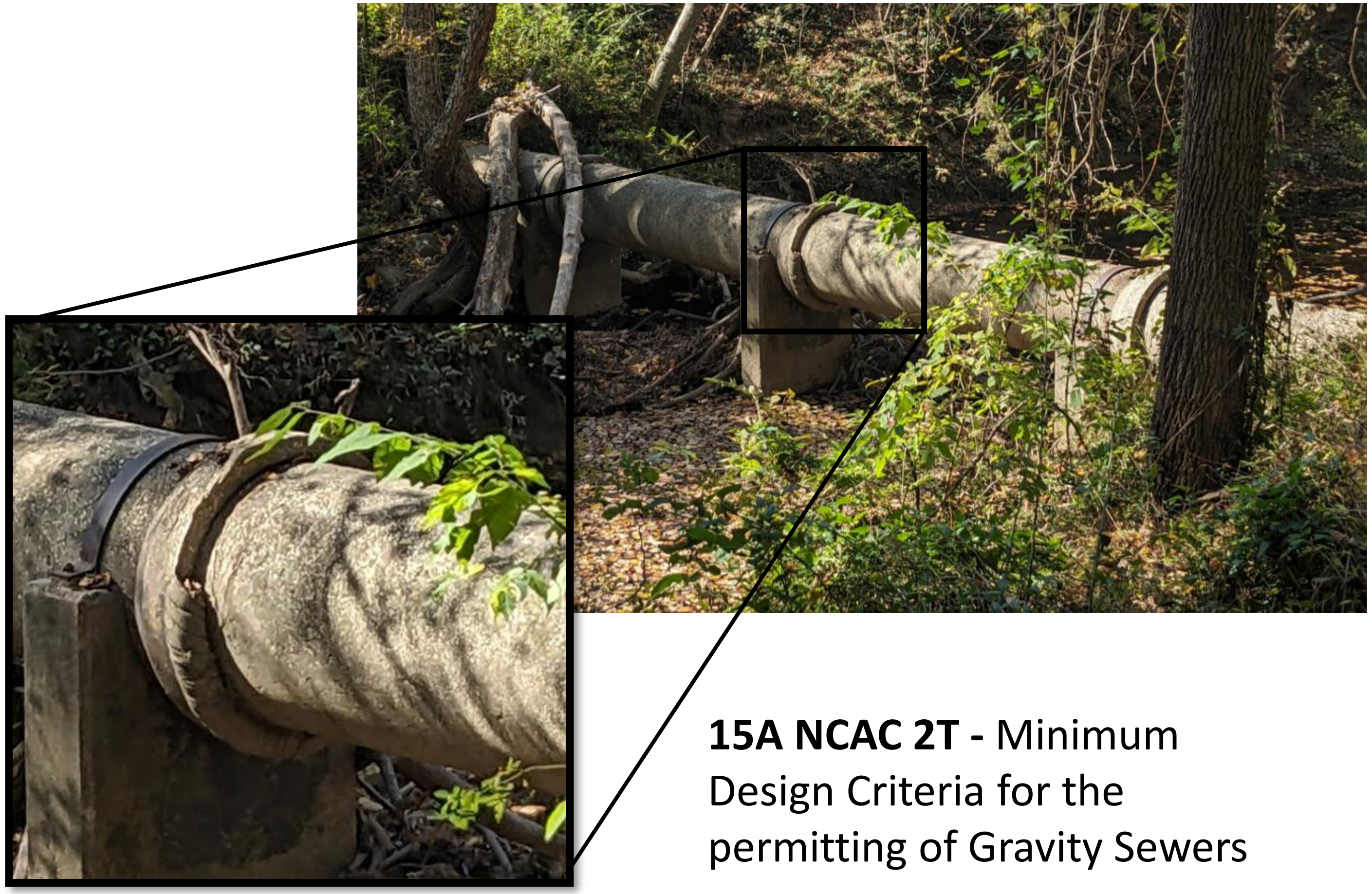
Figure 2. Compiled mass balance estimates for three cities (data in kg N ha^{-1} y^{-1}) arranged in order of increasing population density. Data for Phoenix from Baker *et al.* 2001, for Baltimore from Groffman *et al.* 2004, and for Hong-Kong from Warren-Rhodes and Koenig 2001. Note the discrepancies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

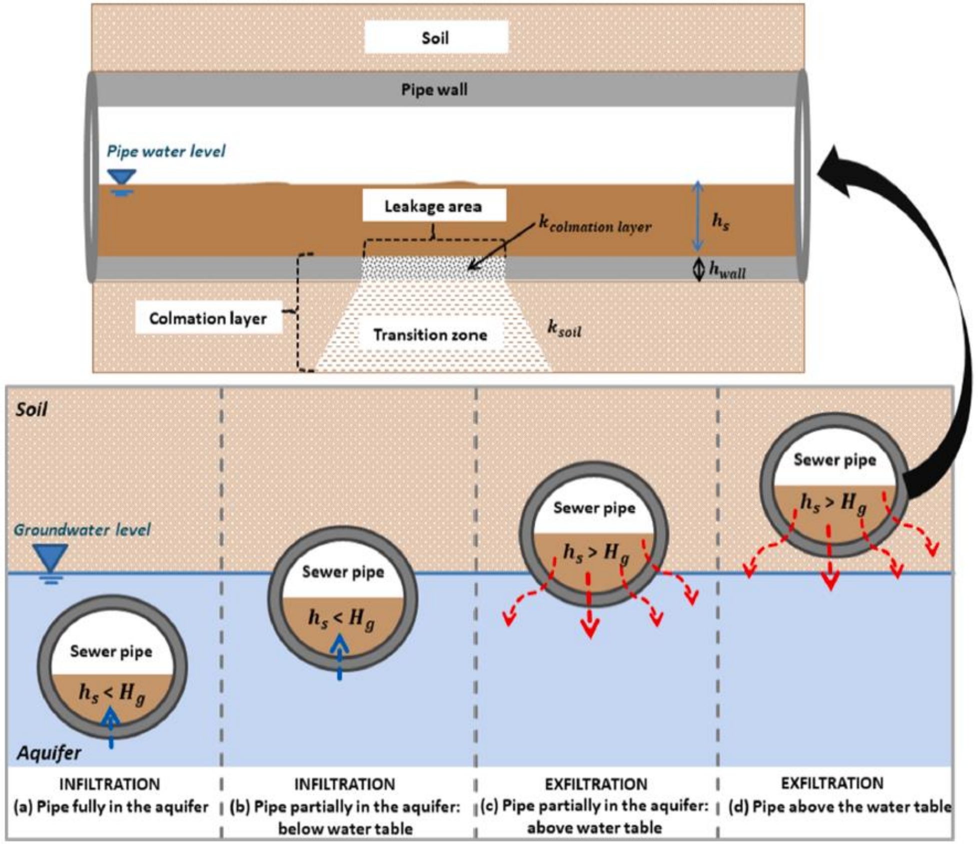


15A NCAC 2T - Minimum Design Criteria for the permitting of Gravity Sewers

“The leakage exfiltration or infiltration shall not exceed 100 gallons per inch of pipe diameter per mile per day for any section of the system.”

If it can infiltrate, it can exfiltrate.

- Net system infiltration does not exclude areas of exfiltration
- Segments may infiltrate in wet periods and exfiltrate in dry periods
- Because WW nutrient concentrations are 2-3 orders or magnitude greater than background, small amounts of exfiltration can represent large loads



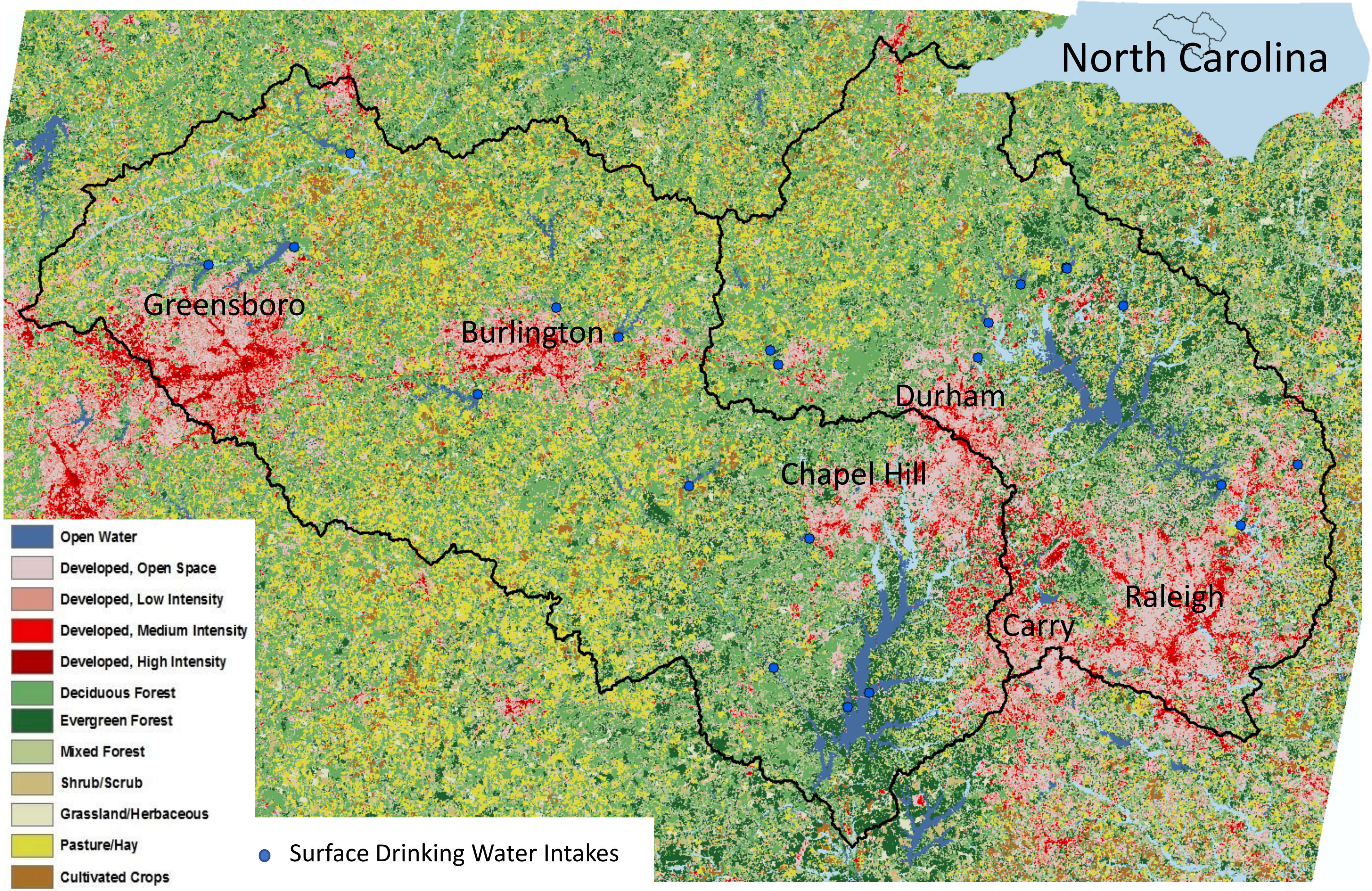
Nguyen, Hong Hanh, Aaron Peche, and Markus Venohr. "Modelling of sewer exfiltration to groundwater in urban wastewater systems: A critical review." *Journal of Hydrology* 596 (2021): 126130.

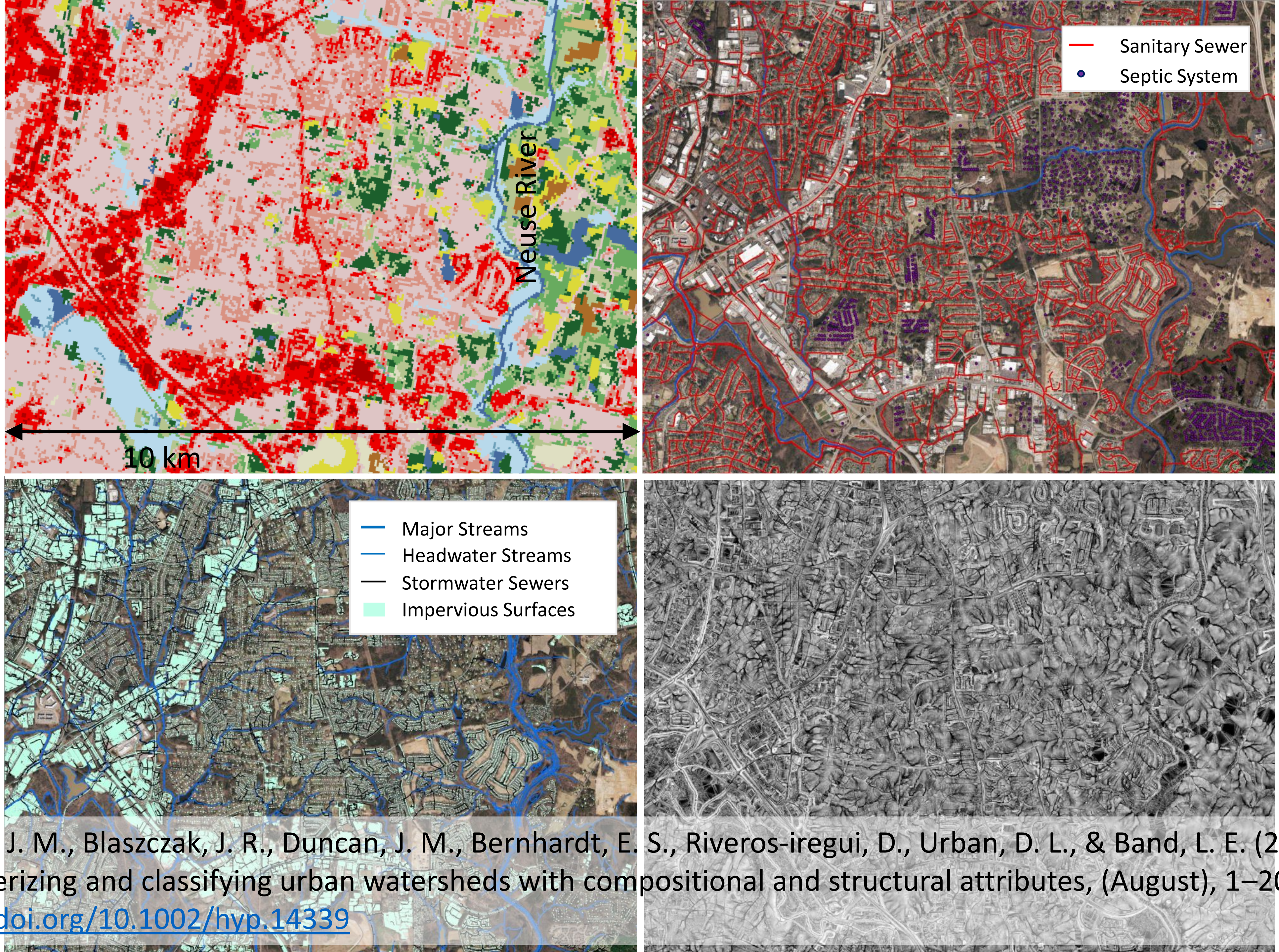
Select references on sanitary sewer exfiltration provided in meeting documents

Catchment to watershed scale

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

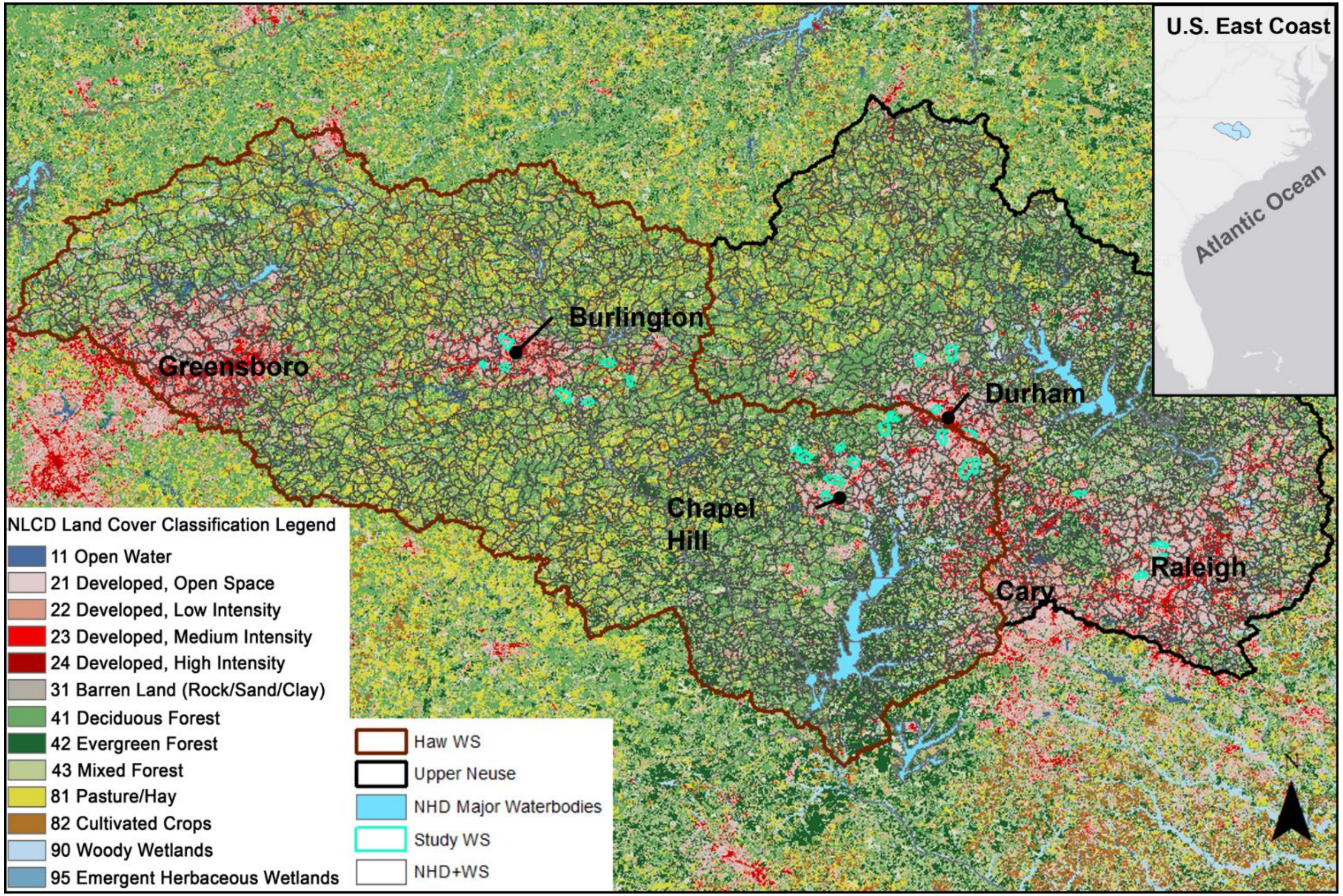
www.chesapeake.org/stac/events/using-local-monitoring-results-to-inform-the-chesapeake-bay-program-e2-80-99s-watershed-model/d
Model – STAC


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



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

To investigate nonpoint source baseflow nitrogen loading:

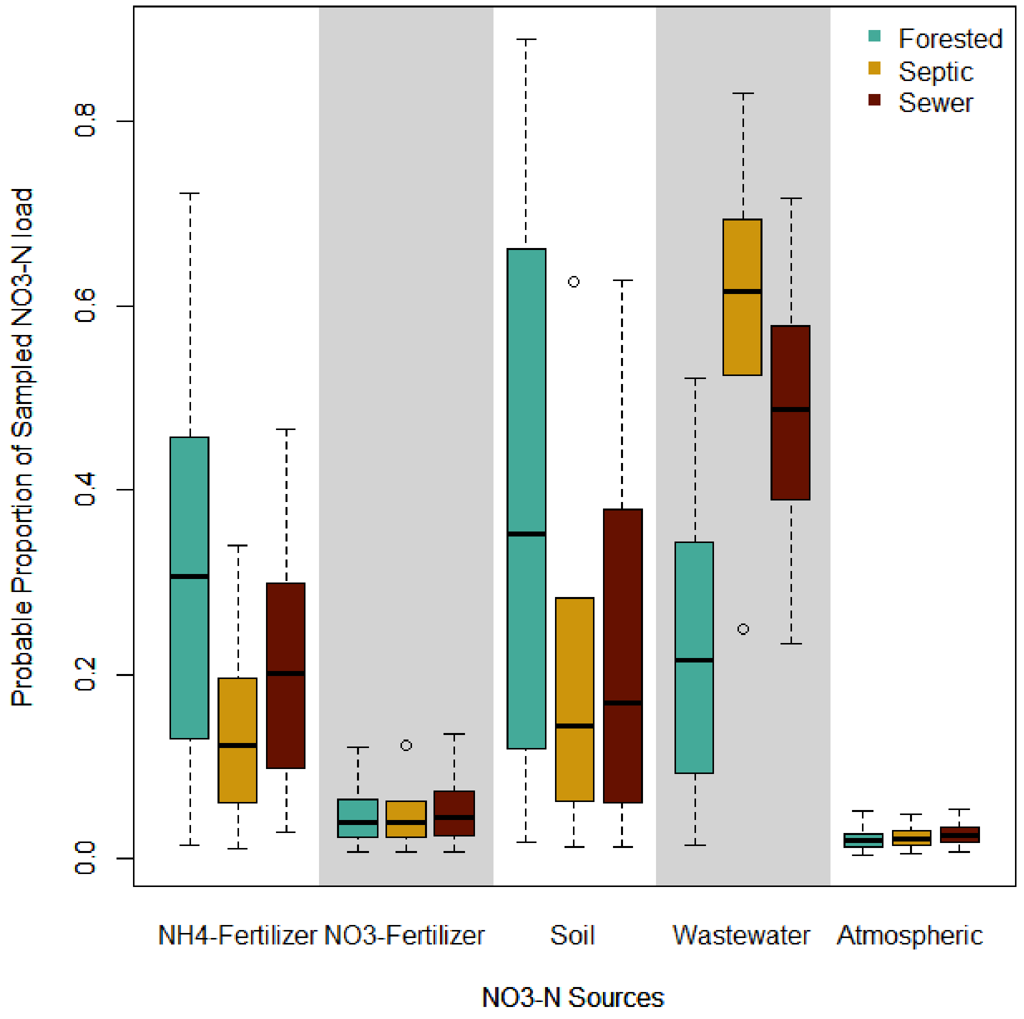


- Selected 27 NHD+ scale catchments which represent the regional distribution of metrics of landcover, infrastructure, and population
- 13 catchments were sampled for isotopic nitrate analysis, 1 primarily forested, 6 septic served, and 6 sewer served
- Catchments were sampled at baseflow every other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

Nitrate sources proportions by mass



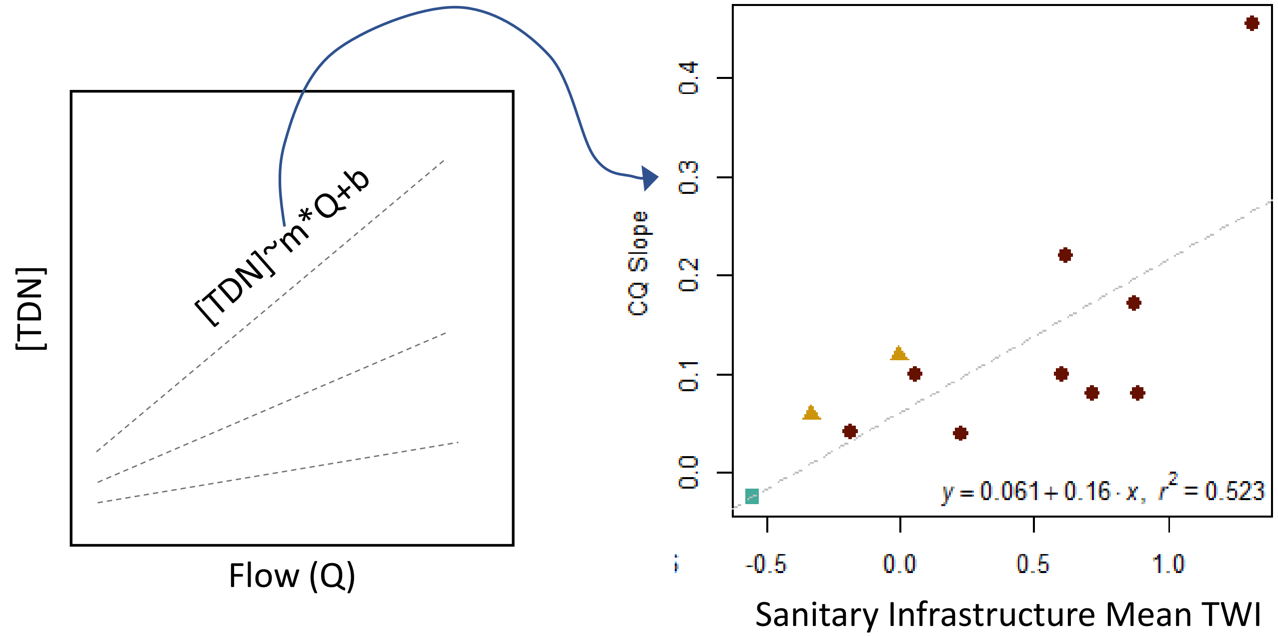
- Nitrate made up 73% of total dissolved nitrogen
- Different sources of nitrate have different isotopic signatures which can allow us to identify the likely sources of nitrate sampled from streams
- Wastewater was the probable primary source for both septic and sanitary sewer served catchments

Results are largely consistent with studies from urban and suburban Baltimore and Pittsburg

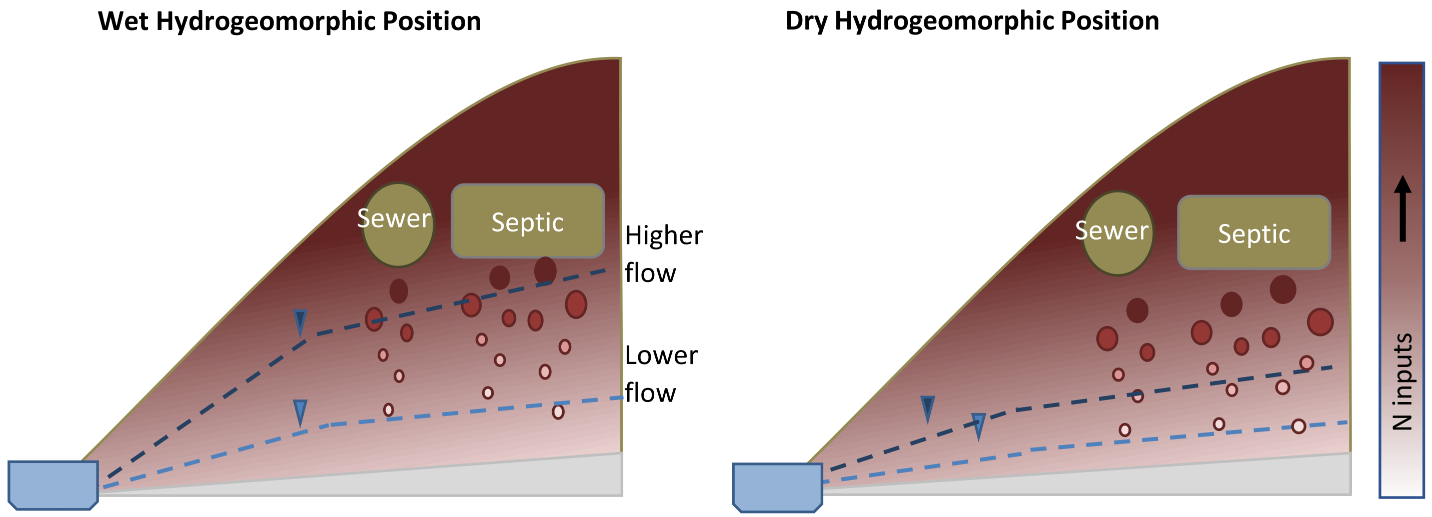
Kaushal, S. S., Groffman, P. M., Band, L. E., Elliott, E. M., Shields, C. A., & Kendall, C. (2011). Tracking nonpoint source nitrogen pollution in human-impacted watersheds. *Environmental Science and Technology*, **45**(19), 8225–8232.

Divers, M. T., Elliott, E. M., & Bain, D. J. (2014). Quantification of nitrate sources to an urban stream using dual nitrate isotopes. *Environmental Science and Technology*, **48**(18), 10580–10587.

How is baseflow nitrogen transported?



- The hydrogeomorphic position (wetness) of sanitary infrastructure was the best predictor of baseflow nitrogen loading dynamics (CQ slope).
- 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



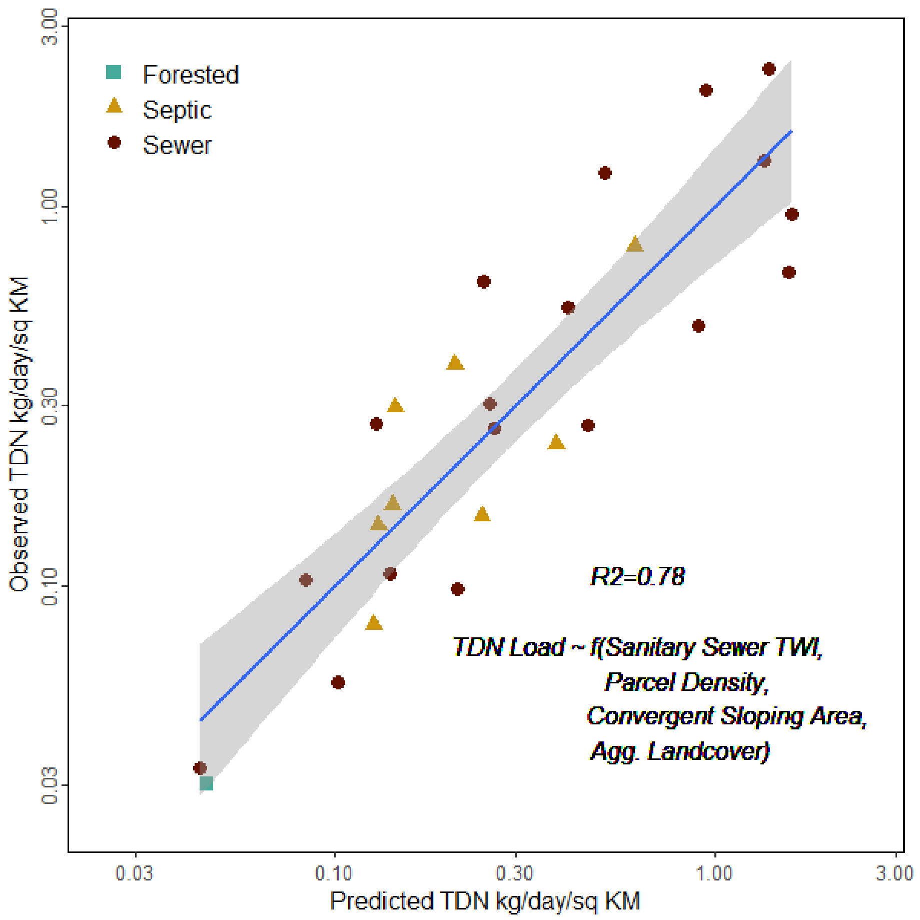
What landscape features control nitrogen loading?

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	+

- The topographic wetness of the location of sanitary infrastructure was the best predictor of baseflow nitrogen loading

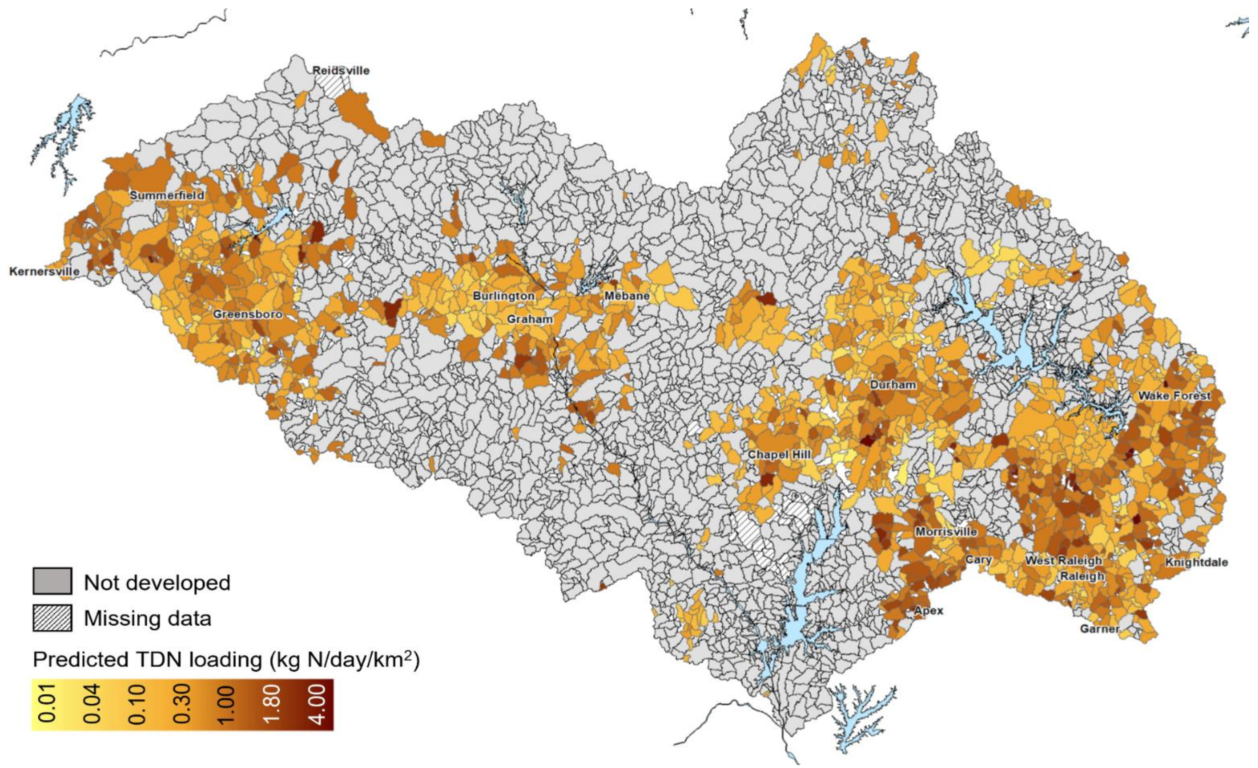
N loading ~ f(Population (supply),
Hydrogeomorphic position of N pools,
Geologic and topographic properties)

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

- We generate an empirical model which describes 78% of baseflow N loading



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

In Summary

- Nitrate isotopes indicated that wastewater was the single largest source of baseflow nonpoint source nitrate.
- The topographic wetness of the location of sanitary infrastructure was the best predictor of nitrogen export dynamics.
- The topographic wetness of the location of sanitary sewers was the best predictor of total nitrogen export.

Subsurface N, largely originating from nonpoint source wastewater, is abundant and the hydrologic connectivity of sanitary infrastructure largely governs loading.

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

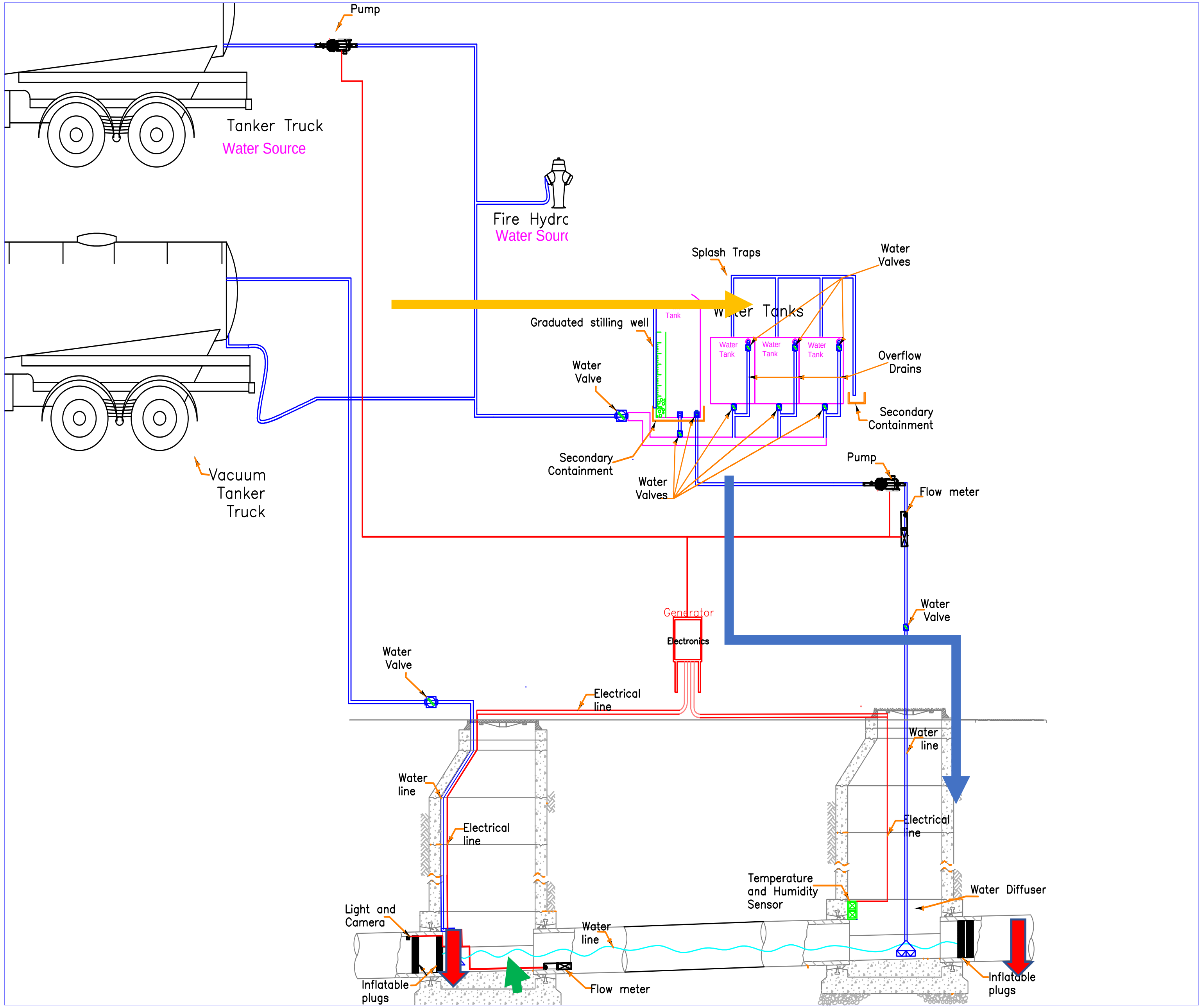
Sewer Segment Scale

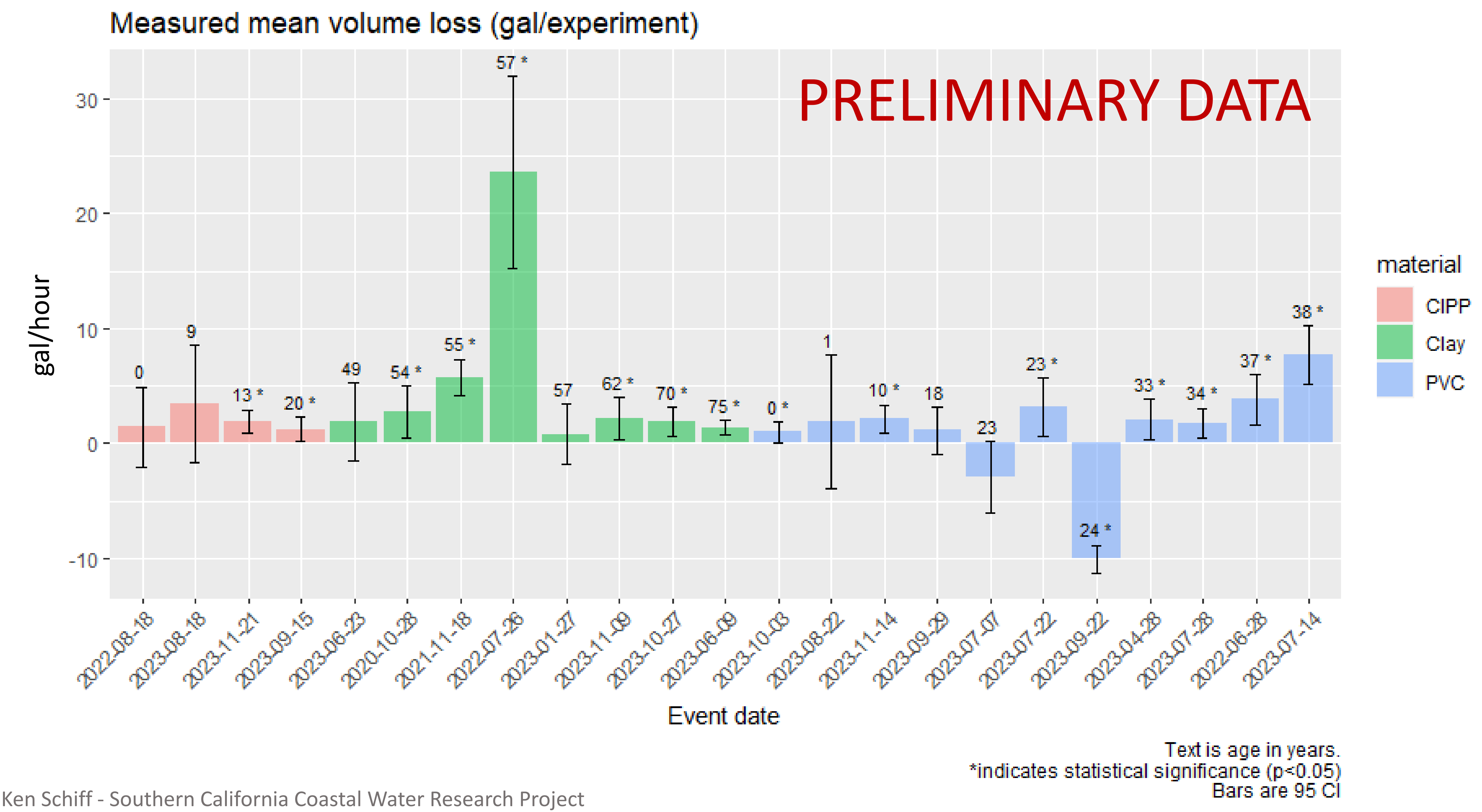
Ken Schiff - Southern California Coastal Water Research Project

www.SCCWRP.org

How It Works

- Mechanical bladders and sewage diversion
  - Add water to fill void spaces
- Large volume head tank pumps into pipe to re-create wet weather flows
  - Up to 1,200 gallons
- Recover volume at downstream end using high-capacity suction pump
  - No pipe surcharging
- Place recovered volume into head tank to measure losses

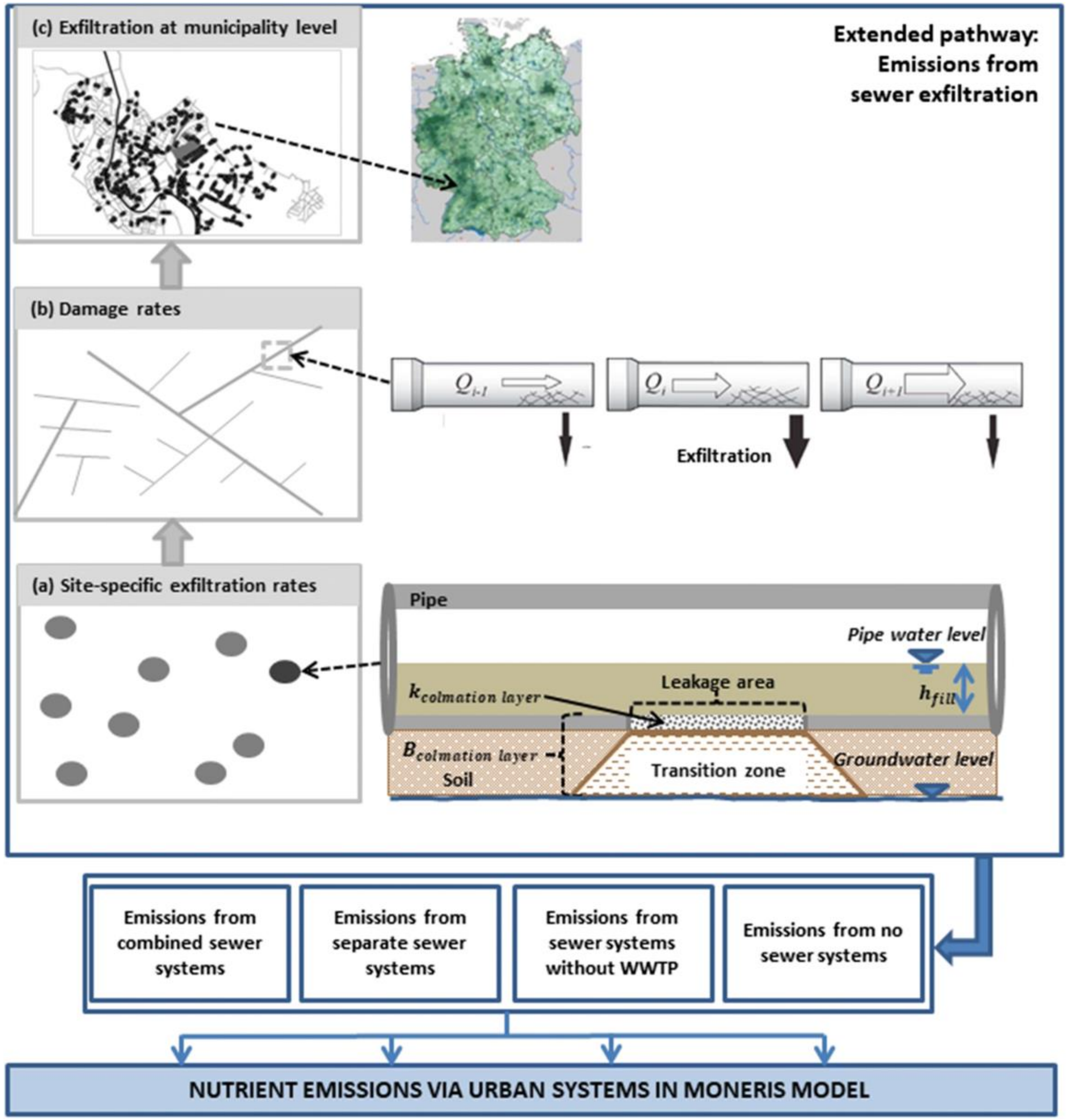




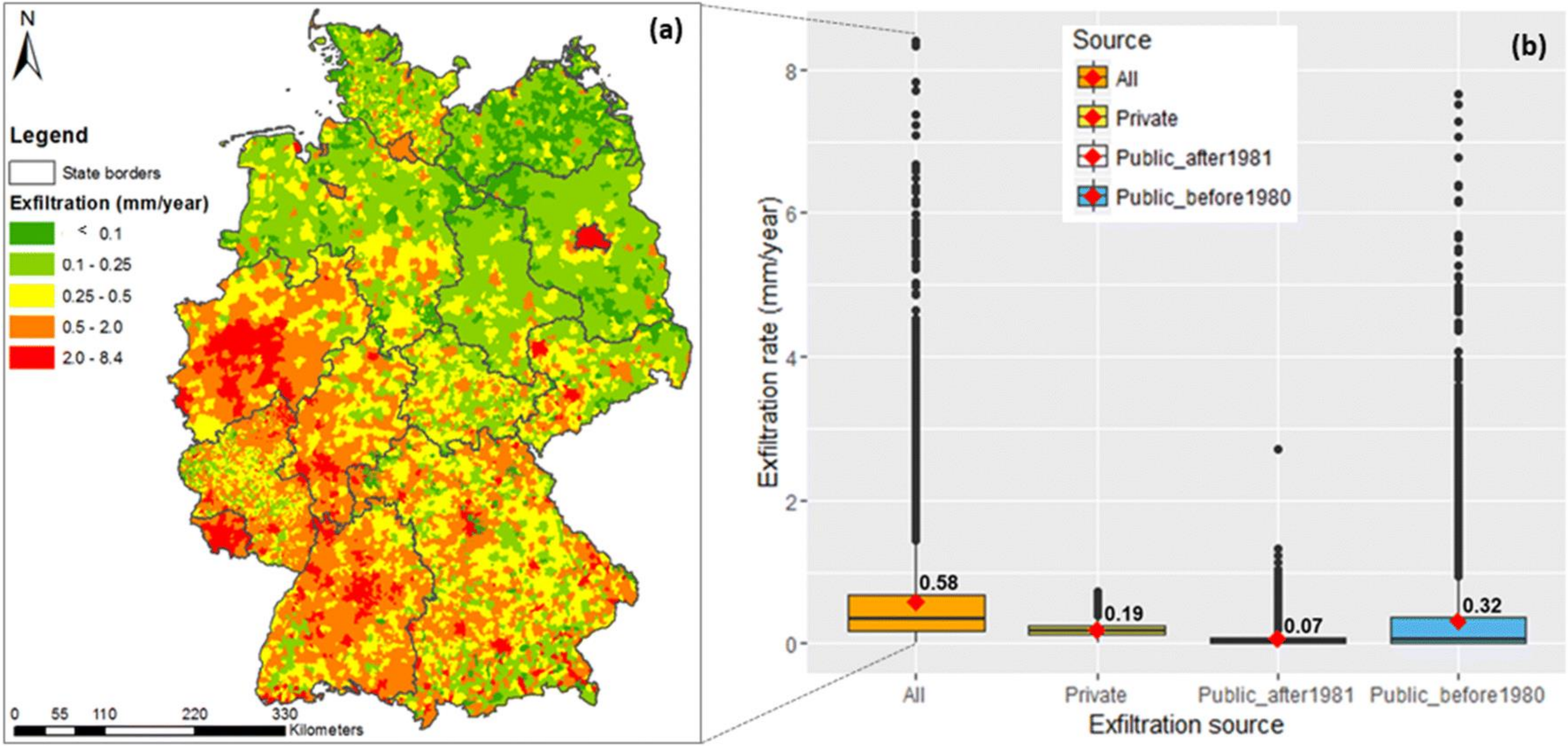
Measured mean volume loss (gal/experiment)
PRELIMINARY DATA
gal/hour
30
20
10
0
-10
0
9
13 *
20 *
49
54 *
55 *
57 *
57
62 *
70 *
75 *
0 *
1
10 *
18
23
23 *
24 *
33 *
34 *
37 *
38 *
2022-08-18
2023-08-18
2023-11-21
2023-09-15
2023-06-23
2020-10-28
2021-11-18
2022-07-26
2023-01-27
2023-11-09
2023-10-27
2023-06-09
2023-10-03
2023-08-22
2023-11-14
2023-09-29
2023-07-07
2023-07-22
2023-09-22
2023-04-28
2023-07-28
2022-06-28
2023-07-14
Event date
material
CIPP
Clay
PVC
Text is age in years.
*indicates statistical significance (p<0.05)
Bars are 95 CI

Nationwide - Germany

Nguyen, H.H., Venohr, M. Harmonized assessment of nutrient pollution from urban systems including losses from sewer exfiltration: a case study in Germany. Environ Sci Pollut Res 28, 63878–63893 (2021). https://doi.org/10.1007/s11356-021-12440-9



Nguyen, H.H., Venohr, M. Harmonized assessment of nutrient pollution from urban systems including losses from sewer exfiltration: a case study in Germany. *Environ Sci Pollut Res* **28**, 63878–63893 (2021). https://doi.org/10.1007/s11356-021-12440-9



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Comparing across studies

Good agreement despite very different methods and regions

Study	Study Area Pop. Dens.	Exfiltration Vol.	Exfiltrated N	
Nguyen and Venohr, 2021	239 per km2	228 gal/day/km	20.8 lb N/year/km	To groundwater
Delesantro et al., 2022	390 per km2	365 gal/day/km	33.2 lb N/year/km	Edge of stream
Schiff et al., in prep	1,887 per km2	630 gal/day/km	56.6 lb N/year/km	Exfiltration from pipe

Note: Values are the mean for each study or study region
Assuming 30mg/l N in raw WW,
Delesantro et al., 2022: Assuming NO_3^- proportion from WW ~ TN proportion from WW

0.15 – 1.76 lb N/acre/year

Why does this matter for the model?

- Proper appropriation of loads
- Improved targeting of BMPs
- Scenario analysis (E.g., remediation, pipe ageing, etc.)

This load is in the bay, the load is in the model, but it is currently misappropriated.

Solutions are available and can be targeted via existing research and modeling

- Inspection followed by:
  - chemical grouting
  - cement grouting
  - slip lining
  - cured-in-place pipe
  - fold and form pipe
  - digging and rehabilitation or replacement

Source: Greater Dublin Strategic Drainage Study., 2003

End