United States Environmental Protection Agency

Context is everything: what controls nitrogen concentrations in U.S. streams

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8th GLOBAL NITROGEN CONFERENCE
30. MAY – 3. JUNE 2021 | BERLIN, GERMANY

1. Study goals and datasets

Understanding the controls on nutrient concentrations is important for managing aquatic ecosystems. Our work focuses on understanding the biologically important summer N concentrations of rivers and streams across the US.

Two national USEPA datasets are key to understanding the changes in stream water quality over time and how land management can affect stream total N concentration (TN) in the contiguous US:

- USEPA's national inventories of N inputs (2002-2012, watershed scale) for the contiguous US
- Stream N concentrations (TN, NO_3, NO_4, and TON) from the EPA National Rivers and Streams Assessment (NRSA, yrs. 2000-2004, 2008-2009, and 2013-2014). All samples were collected during summer.

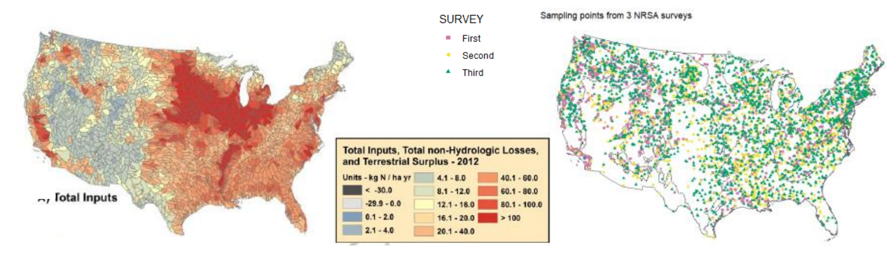

Figure 1. Left: Total N inputs in 2012 for HUC-8 subbasins of the CONUS (*Sabo et al., 2019*). N inventories used in this study are downscaled based on these results to NRSA watershed scale. Right: Sampling locations of three EPA National Rivers and Streams Assessment (NRSA) (*Lin et al., 2021*)

2. Relation between landscape TN input and stream N concentrations

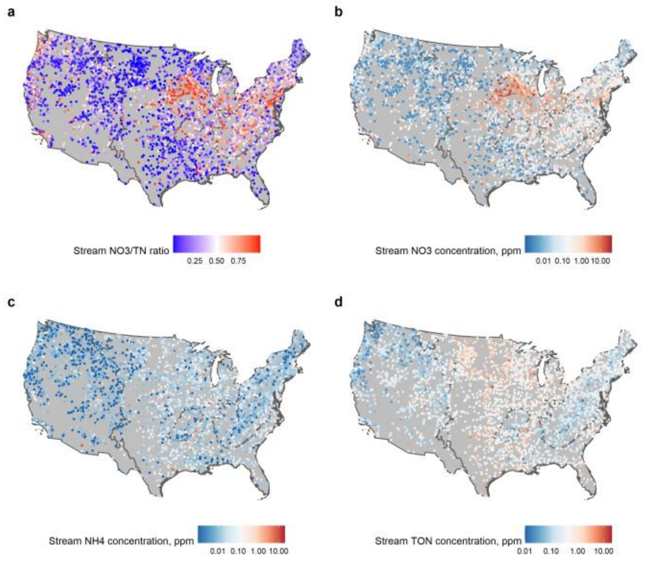

Figure 2. Spatial variations of stream NO_3/TN ration, and NO_3, NH_4, and TON concentrations from three NRSA surveys across the CONUS.

- Streams in the Central Plains had significantly greater N concentrations than streams in the West and Appalachians, reflecting the pattern in N inputs for those areas (agriculture vs. deposition).
- Nitrogen inputs alone explained 51% of the variation in stream TN concentrations across the US.

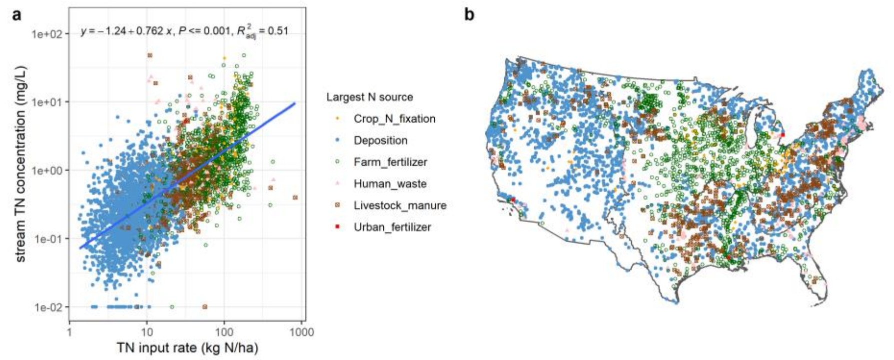

Figure 3. a. Stream TN concentrations and largest N sources across the CONUS; colors and shapes represent different largest landscape TN sources. b. Stream TN concentrations as a function of N inputs; colors and shapes represent different largest landscape TN sources. Lines are the three regions' boundaries (*Lin et al., 2021*)

3. Stream N forms and N saturation

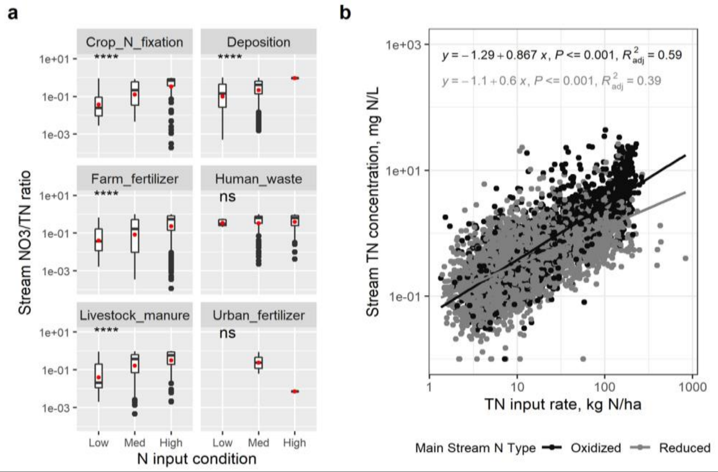

Figure 4. a. Comparing stream NO_3 contribution at three input levels and in watersheds with different larges N sources. Red points indicate group means. ****: p <= 0.0001; ns: not significant. b. Stream TN concentrations as a function of N inputs; colors represent the main N species ('oxidized'-black vs 'reduced'-grey).

- The elevated level and proportional contribution of in-stream NO_3 as N inputs increase supports N saturation theory.
- Streams where NO_3 was the largest N form, (the 'oxidized' type), exhibited a stronger and steeper relationship with N inputs as compared to the 'reduced' type of streams. The difference in regression slopes of the two types of watersheds was statistically significant.

4. Random forest modeling reveals context dependency

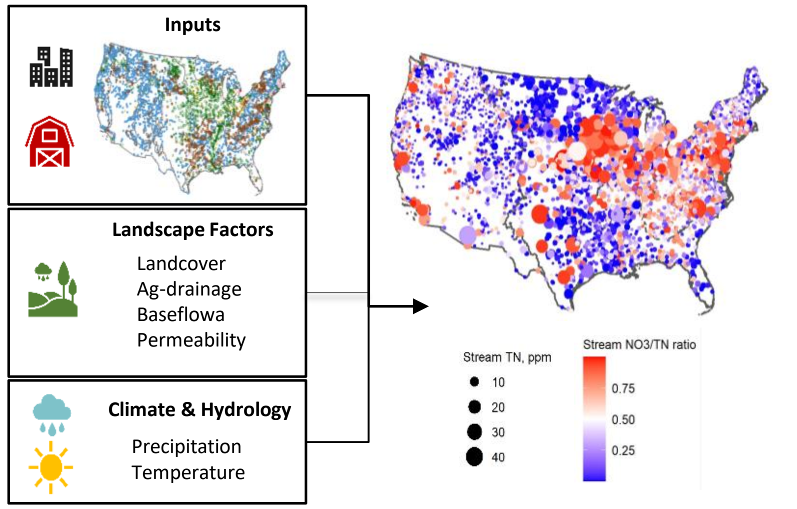

Fig 5. Random forest modeling is applied to explore relationships between stream N concentrations and watershed features, climate, and N inventories by combining data from the three surveys. The final set of predictor variables included variables from EPA StreamCat, PRISM and the Earth Observatory Network, and N input rate variables of six sources from the N inventories

- Watershed drivers ~ stream N concentration relationships are dependent on N input context.
- Wetlands play important but varying roles , especially in impacting stream TON
- Proportion of baseflow: an indicator of legacy groundwater contamination in high N input areas.

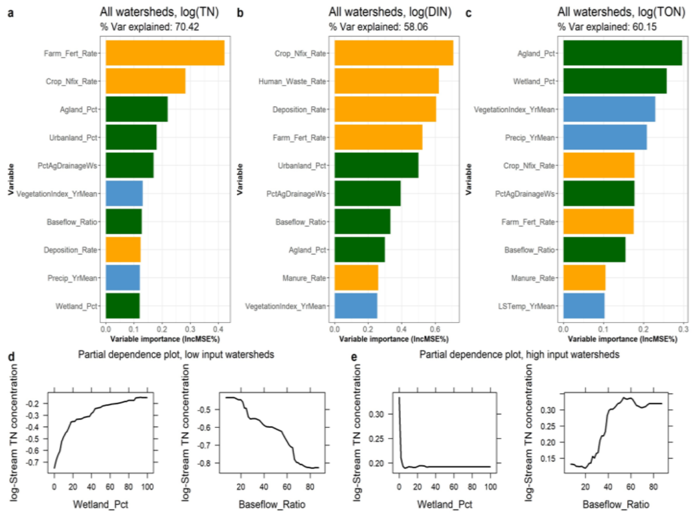

Figure 6. Variable importance plots of) random forest model results for a) stream TN concentration; b) DIN (NO_3+ NH_4 concentration, and c) TON concentration. Each model combined data from three surveys (n = 4997). Only the top 10 variables were plotted. Bar colors represent different predictor categories: Green—StreamCat landscape and land use (%) variables; Blue—climatic variables; Orange— N input rates of six sources. The partial dependence relationships of stream TN concentration vs. wetland coverage and baseflow contribution in low input watersheds (d) exhibited **opposite trends** with those in high input watersheds (e).

5. Summary

- Watershed N inputs explained 51% of the variation in log transformed stream total N (TN) concentrations.
- Both N source and input rates influenced stream NO_3/TN ratios and N concentrations.
- Streams dominated by oxidized N forms (NO_3/TN ratio > 0.50) were more strongly responsive to N input rate compared to streams dominated by other N forms. NO_3 proportional contribution increased with N inputs, supporting N saturation enhanced NO_3 export to aquatic ecosystems.
- By combining information about N inputs with climatic and landscape factors, random forest models of stream N concentrations explained 70%, 58%, and 60% of the spatial variation in stream concentrations of TN, dissolved inorganic N, and total organic N, respectively.
- **The strength and direction of relationships between watershed drivers and stream N concentrations and forms varied by N input intensity (context)**. Specifically, wetlands and baseflow index had a positive and negative effect on instream TN at low N input rates, respectively. However, these relationships changed directions at high N input rates.
- Model results for high N input watersheds indicated potential contributions from contaminated groundwater to high stream N concentrations, but also the mitigating role of wetlands.

References:

Lin, J., Compton, J.E., Hill, R.A., et al., 2021. Context is everything: Interacting inputs and landscape characteristics control stream nitrogen. Environmental Science & Technology, *in review*, ES&T.

Sabo, R.D., Clark, C.M., Bash, J., Sobota, D., Cooter, E., Dobrowolski, J.P., Houlton, B.Z., Rea, A., Schwede, D., Morford, S.L. and Compton, J.E., 2019. Decadal Shift in Nitrogen Inputs and Fluxes Across the Contiguous United States: 2002–2012. Journal of Geophysical Research: Biogeosciences, 124(10), pp.3104-3124.