EPA United States Environmental Protection Agency

Net declines in nonpoint source pollution into one of the world's largest estuaries

AI and the CAST-based *Chesapeake Bay Nutrient Inventory* are being leveraged to identify long-term drivers of nitrogen export

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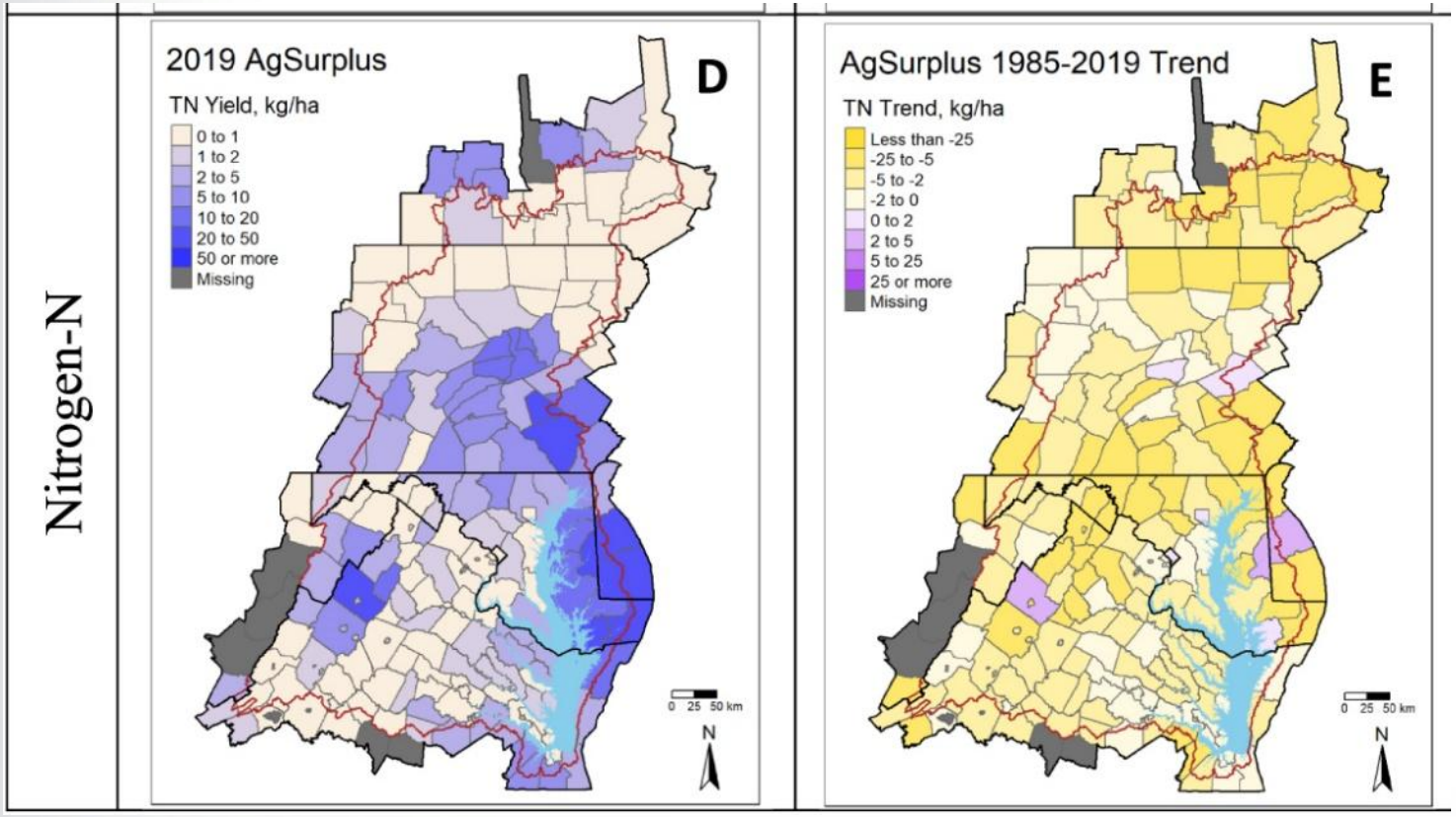
NOTE: Results included on the following slides have not yet been peer-reviewed or published, so are considered preliminary; please do not cite.

Key Points

- Identify drivers of long-term total nitrogen loading trends
- Leveraged neural networks and Chesapeake Bay Nutrient Inventory data to holistically link nutrient source and riverine discharge information to watershed nitrogen loads for 121 stations
- Farm-level nutrient management, as well as reductions in air pollution and wastewater loads, have likely improved water quality in most watersheds
  - Urbanization partially offset gains

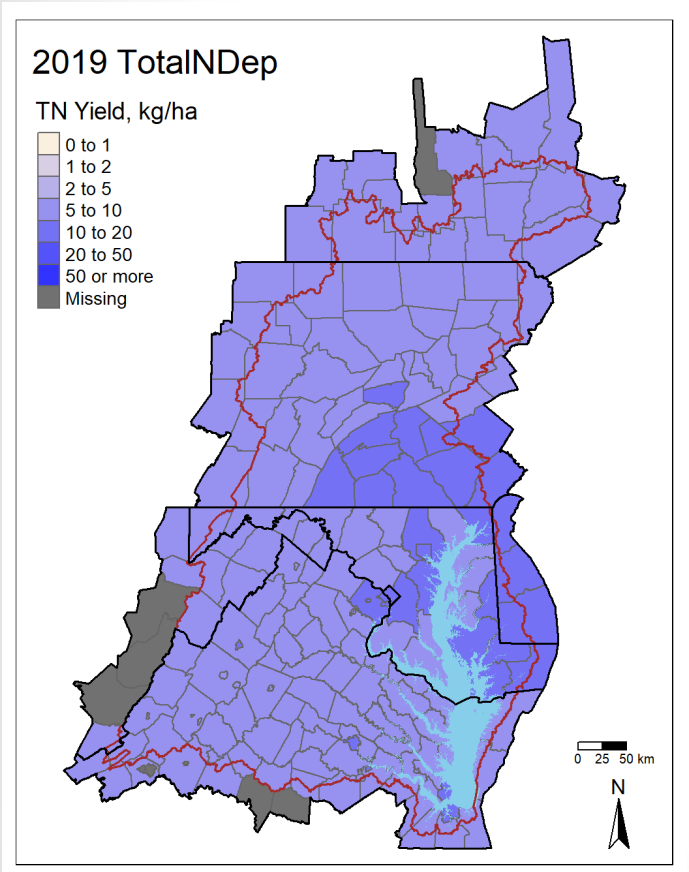
Chesapeake Bay Nutrient Inventory insights into major nutrient sources—Agriculture Surplus

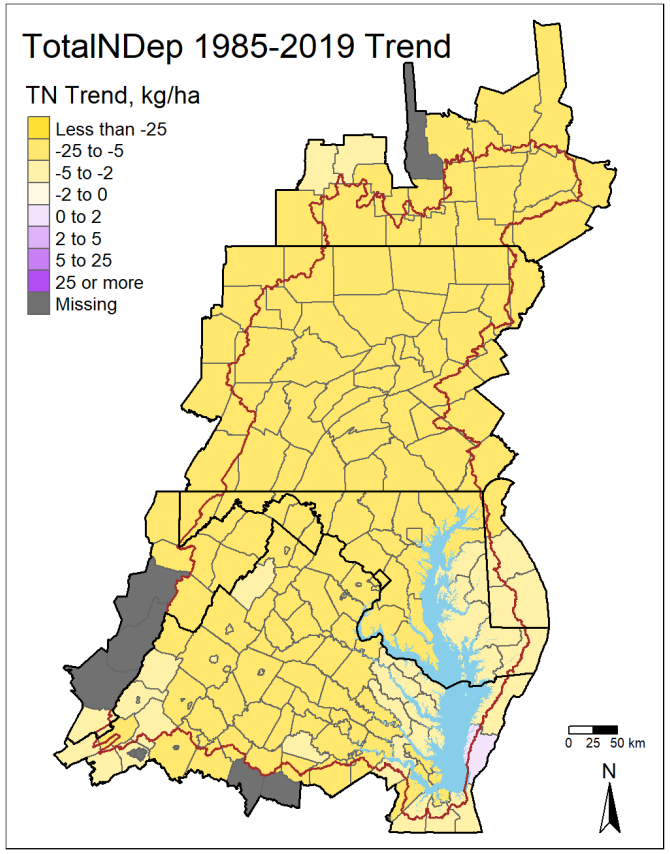
Agricultural N Surplus = Farm Fertilizer + Manure Application + Crop/Pasture N Fixation – Crop Removal



- **Farmers are leaving less nitrogen on fields, reducing potential losses to waterways.**
  - **Not integrated into previous empirical modeling work**
- Atmospheric deposition has declined throughout the Bay watershed.
- Point source loads have declined in major urban areas and smaller industrial towns/cities, primarily in tidally influenced areas.

Chesapeake Bay Nutrient Inventory insights into major nutrient sources—Atmospheric Deposition





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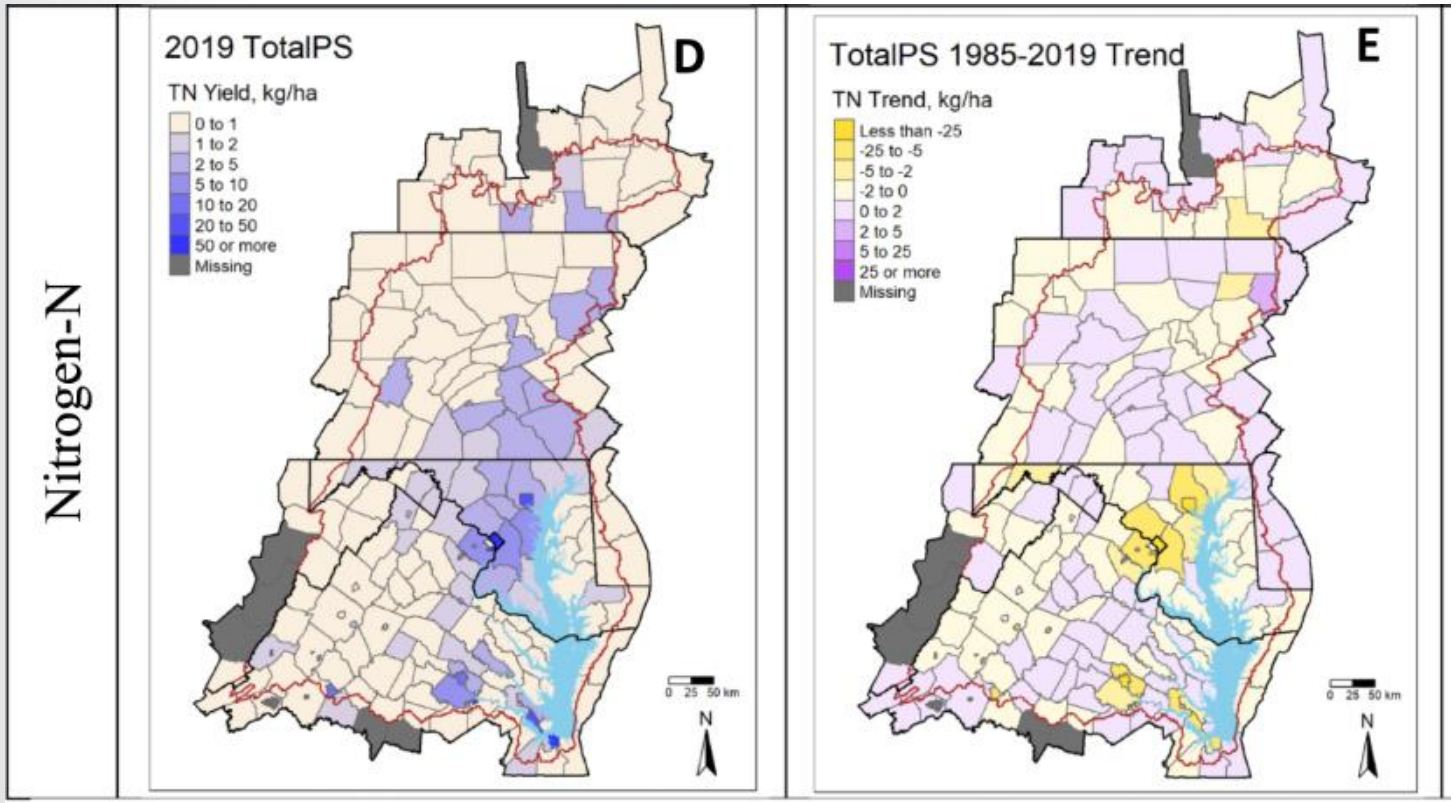
Chesapeake Bay Nutrient Inventory insights into major nutrient sources—Point Source Loads



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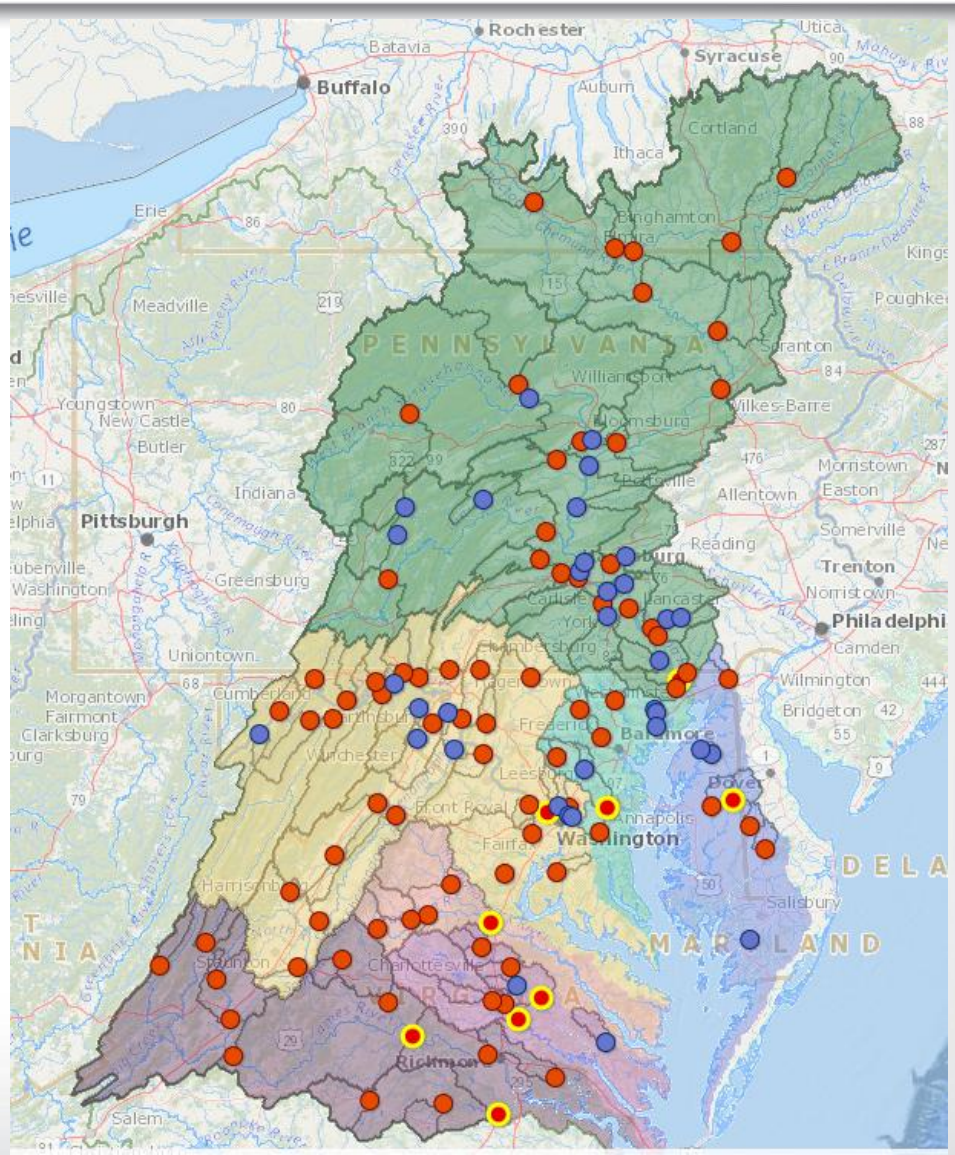
To what extent can long-term trends in watershed nitrogen export be attributed to shifts in agricultural surplus, urban nutrient inputs, atmospheric deposition, and point-source loads?

Develop an empirical modeling/accounting framework to simultaneously account for point and nonpoint nitrogen pollution sources

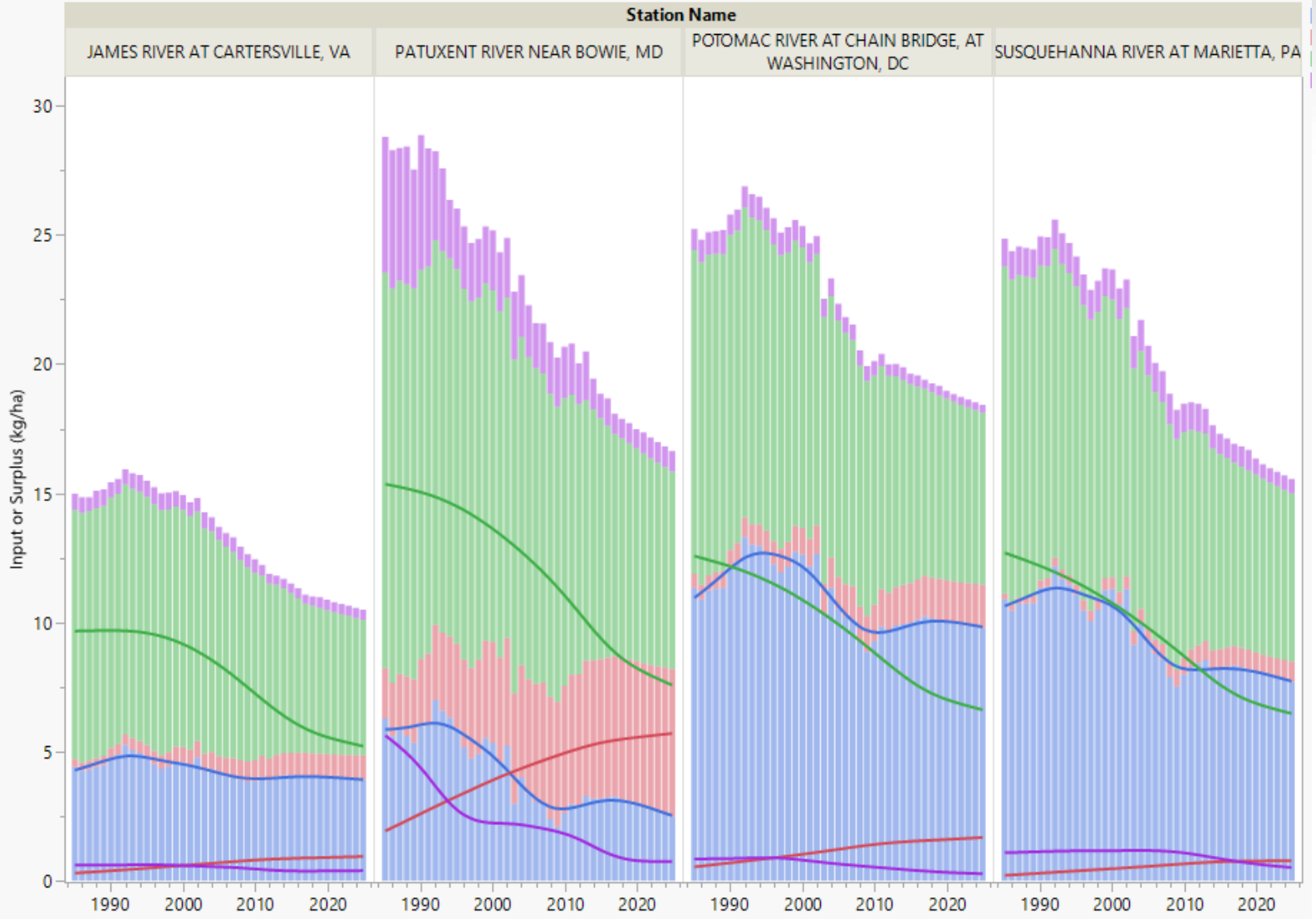
- Leverage the Chesapeake Bay Nutrient Inventory and down-scaled USGS product*:
  - Agricultural surplus
  - Urban inputs (septic + fertilizer)
  - Point source loads
  - Total atmospheric N deposition
- Pair the nutrient inventory mass balance terms with estimated total nitrogen loads across 121 monitoring stations in the Chesapeake Bay
  - Station time series vary, but range from 1985 to 2020
- Develop a simple and interpretative predictive model that can account for predictors that may partly covary across space and time
  - AI → Neural Network
- Run counterfactuals to explore impacts of shifting pollution source

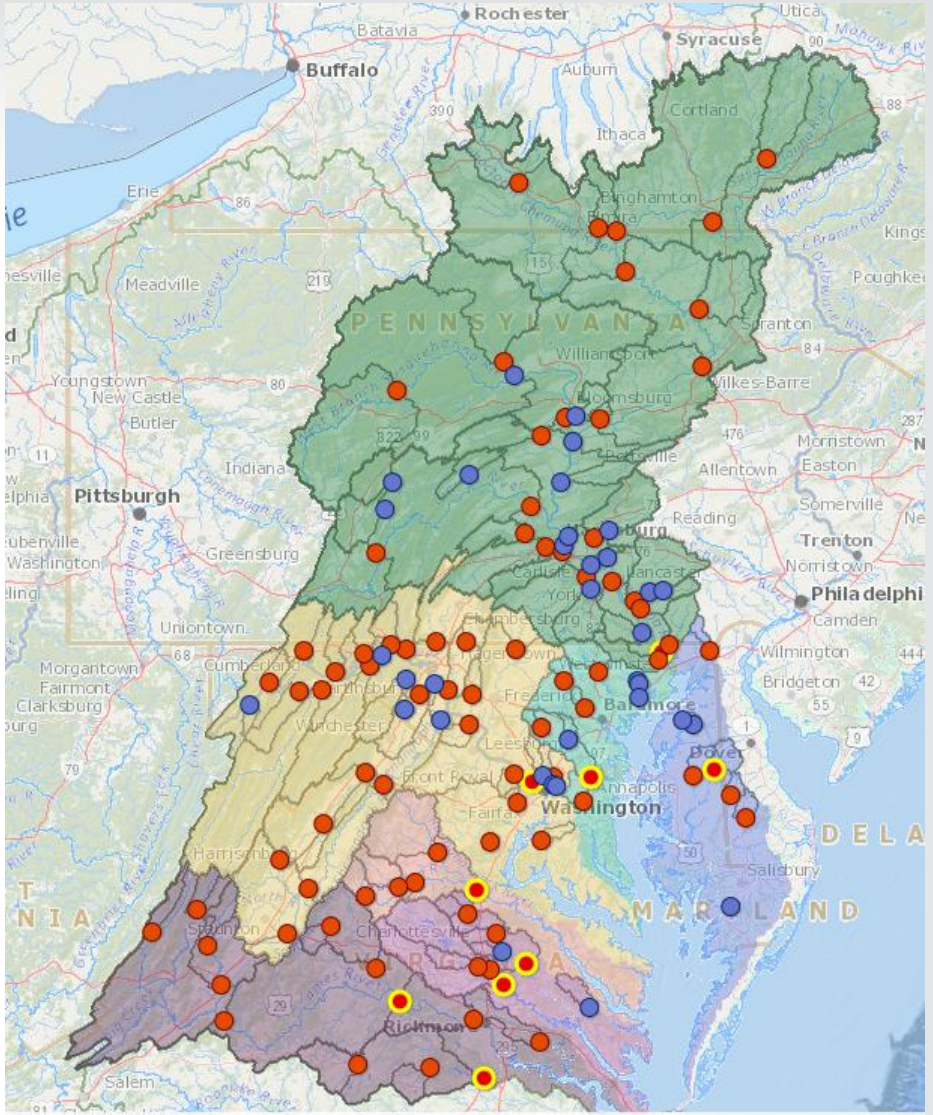


*Courtesy of James Weber and Jeff Chanat, USGS

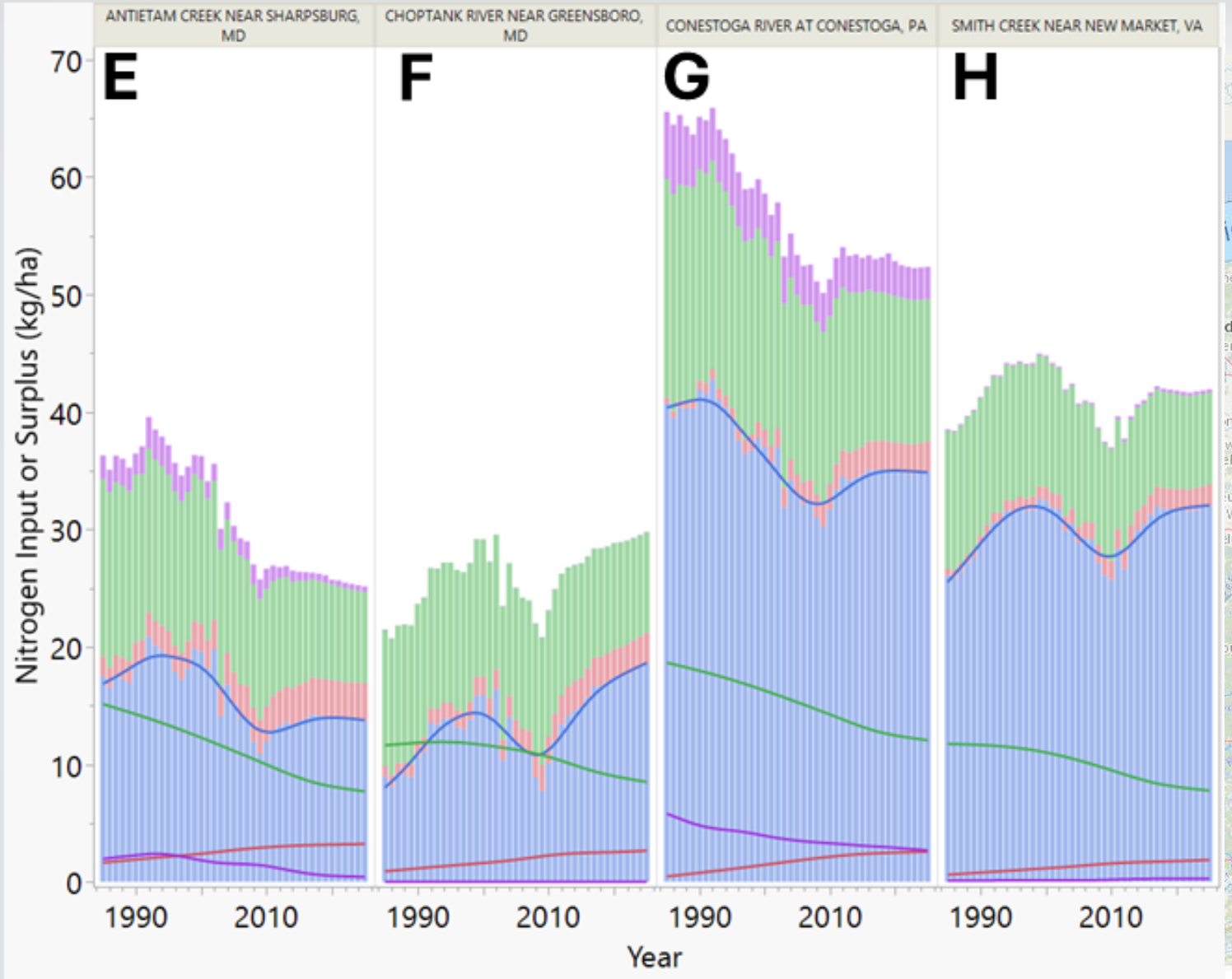
CAST-Based, Chesapeake Bay Nutrient Inventory Insights*

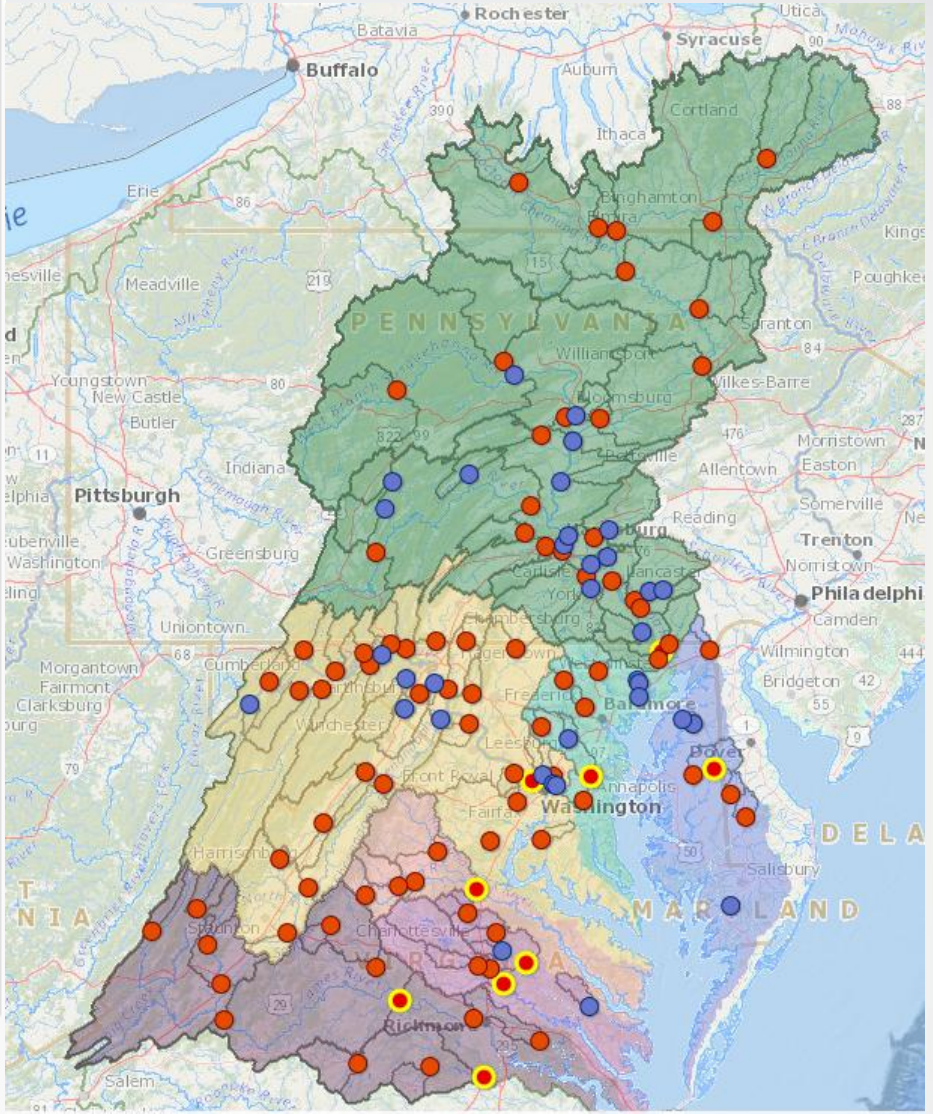
*Chesapeake Bay Nutrient Inventory and down-scaled USGS product





These graphics are available for all monitoring sites.

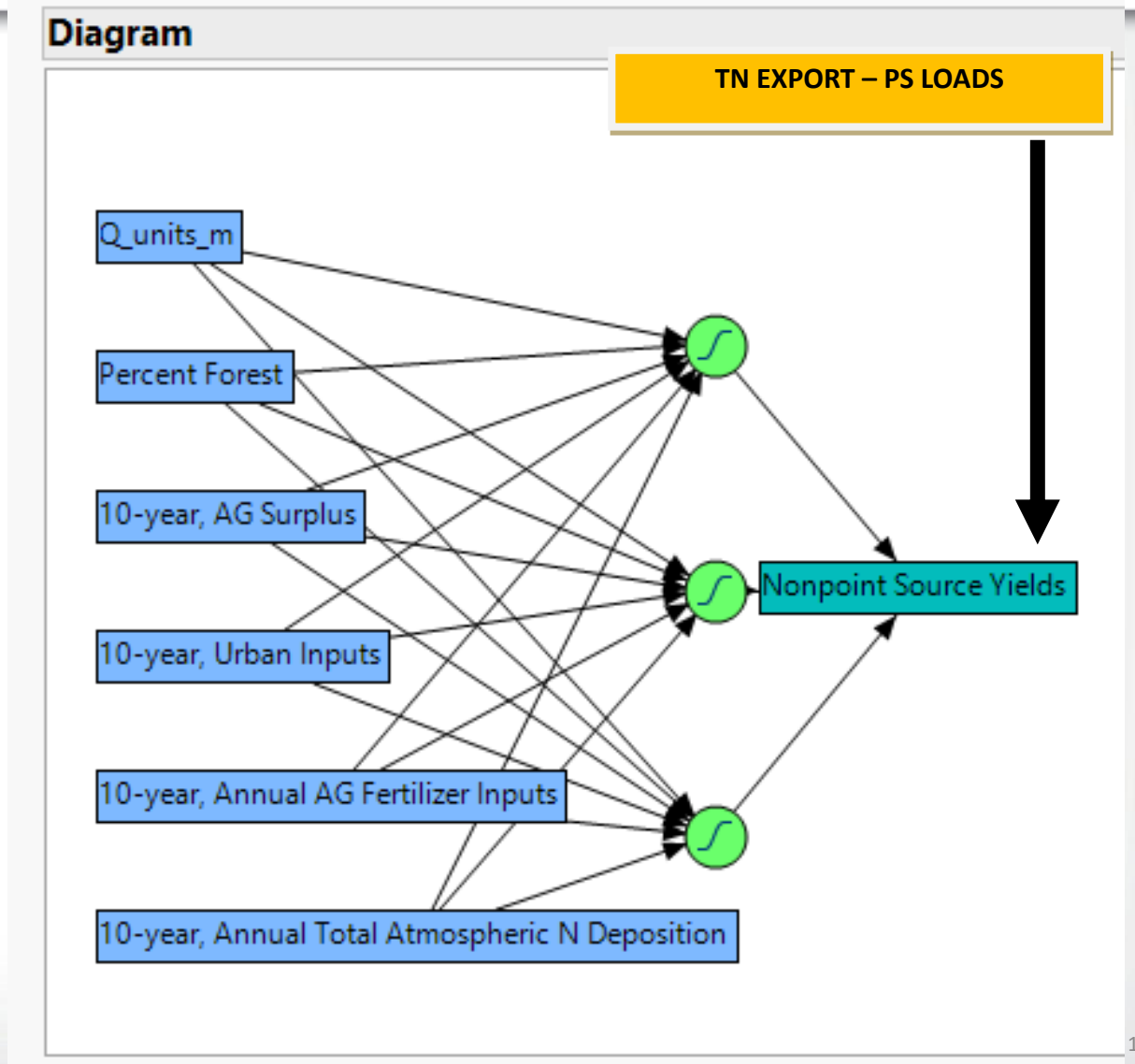

ANTIETAM CREEK NEAR SHARPSBURG, MD
CHOPTANK RIVER NEAR GREENSBORO, MD
CONESTOGA RIVER AT CONESTOGA, PA
SMITH CREEK NEAR NEW MARKET, VA
E
F
G
H
Nitrogen Input or Surplus (kg/ha)
0
10
20
30
40
50
60
70
1990
2010
Year
Annual Ag Surplus
Annual Urban Inputs
Annual Total Atmospheric N Deposition
Annual Wastewater Loads


Rochester
Buffalo
Syracuse
Batavia
Auburn
Cortland
Ithaca
Erie
Binghamton
Meadville
PENNSYLVANIA
Williamsport
Youngstown
New Castle
Butler
Bloomsburg
Wilkes-Barre
Scranton
Allentown
Morristown
Easton
Indiana
Pittsburgh
Reading
Somerville
Trenton
Greensburg
Lancaster
Norristown
Phila delphi
Uniontown
Camden
Wilmington
Morgantown
Fairmont
Clarksburg
Cumberland
Bridgeton
Baltimore
Annapolis
Washington
Salisbury
MARYLAND
Harrisonburg
Staunton
Charlottesville
Richmond
Salem

Neural Network Model

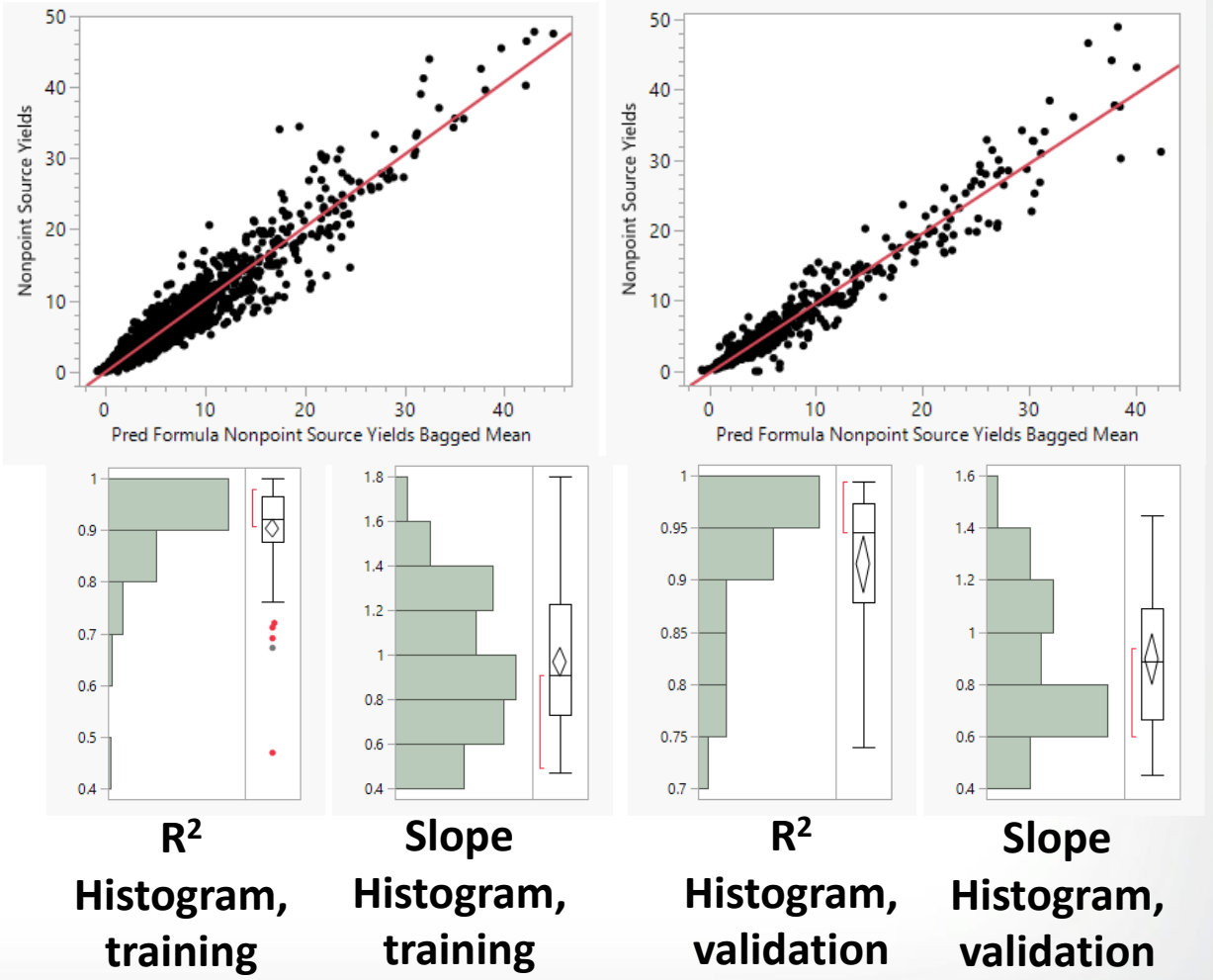
What is a neural network?

- Function of a set of derived inputs, called hidden nodes.
  - Hidden nodes are nonlinear functions of the original inputs
  - Predicted Y variable is a function of the nodes
- Efficiently models different response surfaces
- Results are sometimes not easily interpretable
  - Layers obfuscate the direct relationship between X and Y variables

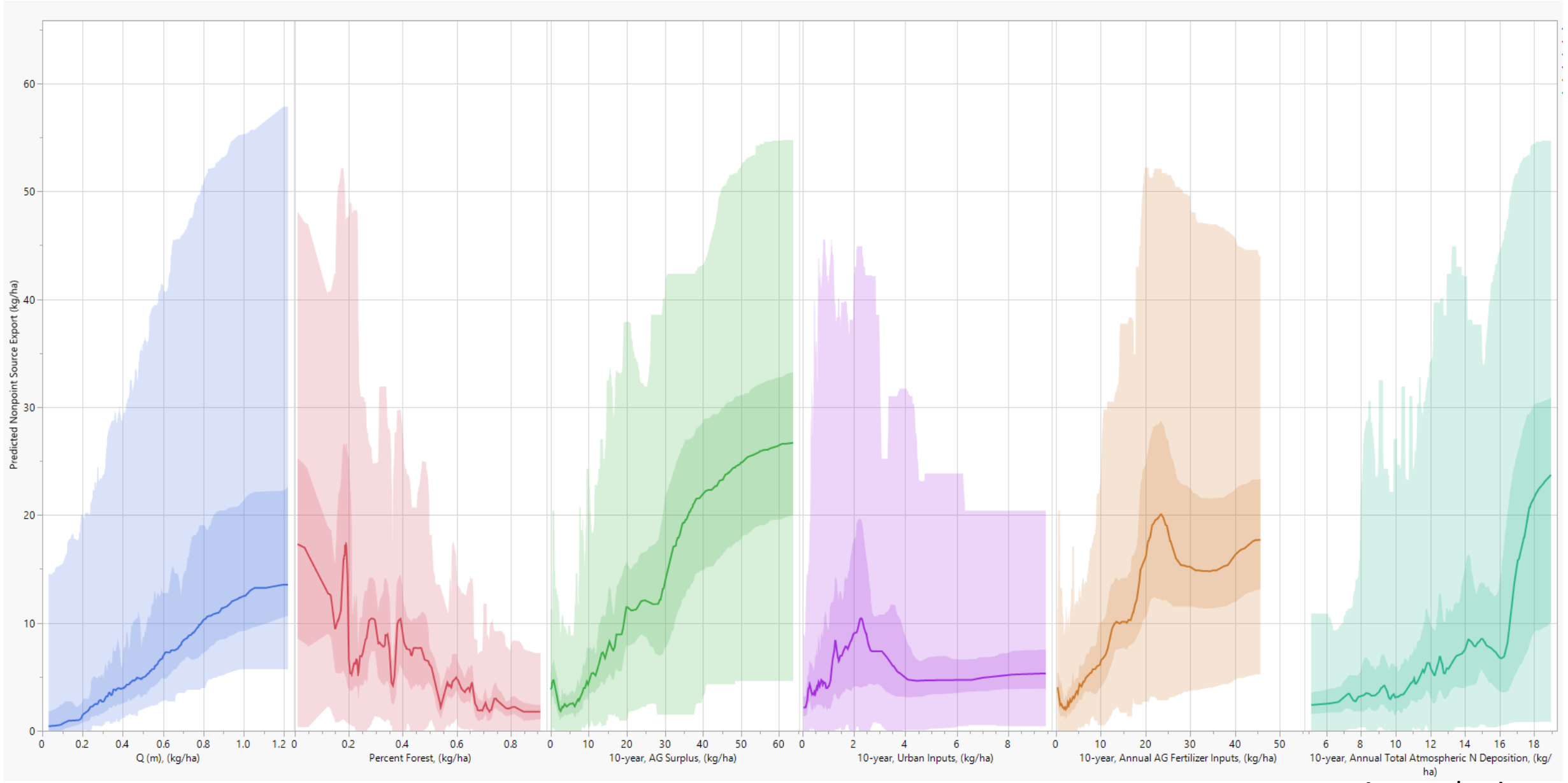


Neural network is generally predictive of the spatial and temporal variation in nitrogen export.

- Calibrated ensemble of 100 models had R^2 >0.9 for both the training and validation watersheds.
- Individual watershed performance was similarly robust.
- No indication of large bias after evaluating the slope distributions for individual watersheds.



R^2 Histogram, training | Slope Histogram, training | R^2 Histogram, validation | Slope Histogram, validation



Discharge

Percent Forest Cover (%)

Agricultural Surplus (kg/ha)

Urban Inputs (kg/ha)

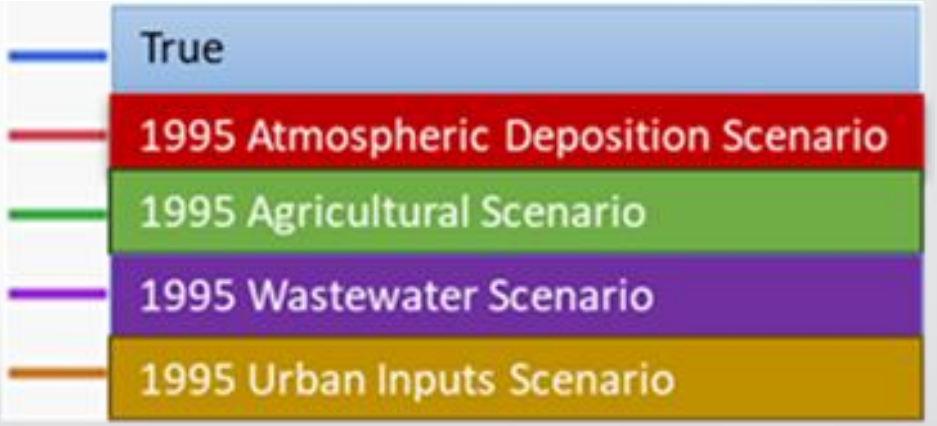
Agricultural Fertilizer (kg/ha)

Atmospheric Deposition (kg/ha)

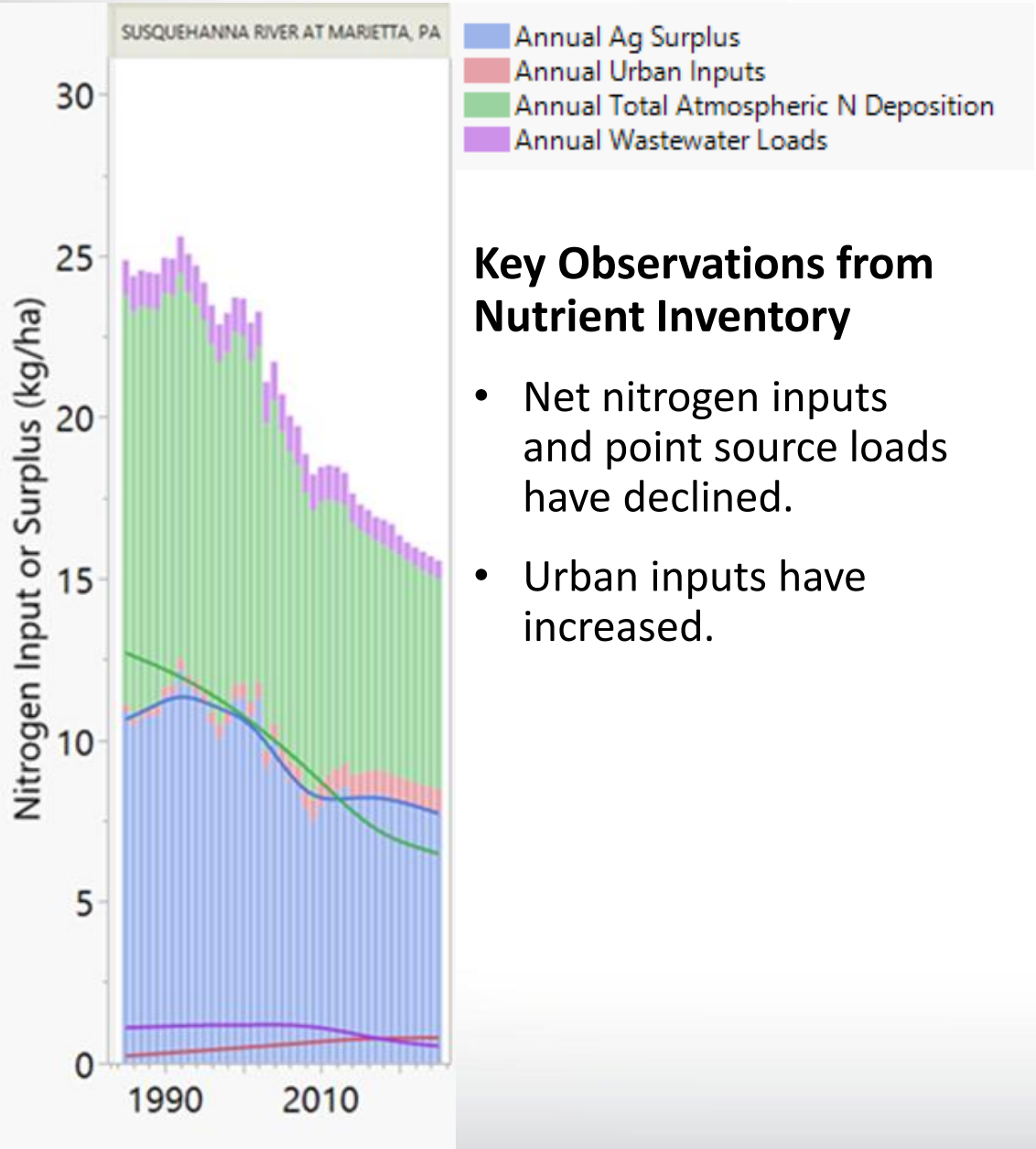
"What if?" questions can be answered via counterfactual experiments.

Hold individual factors at 1995 levels at observed median discharge level to assess the impacts of:

- Point source loading reductions
- Shifts in agricultural nutrient management
- Reductions in atmospheric N deposition
- Increases in urban inputs

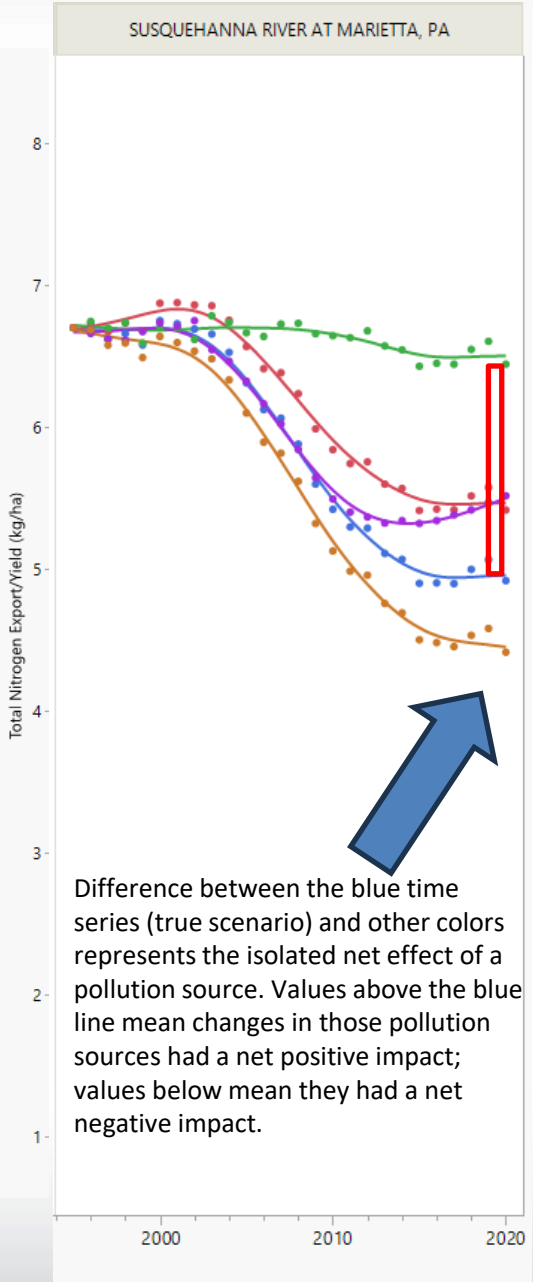


Example: Susquehanna River at Marietta, PA

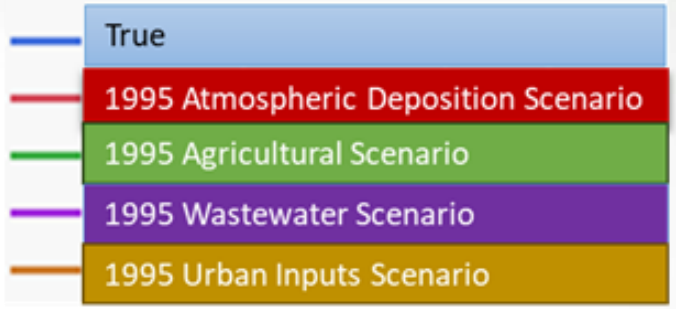


Key Observations from Nutrient Inventory

- Net nitrogen inputs and point source loads have declined.
- Urban inputs have increased.



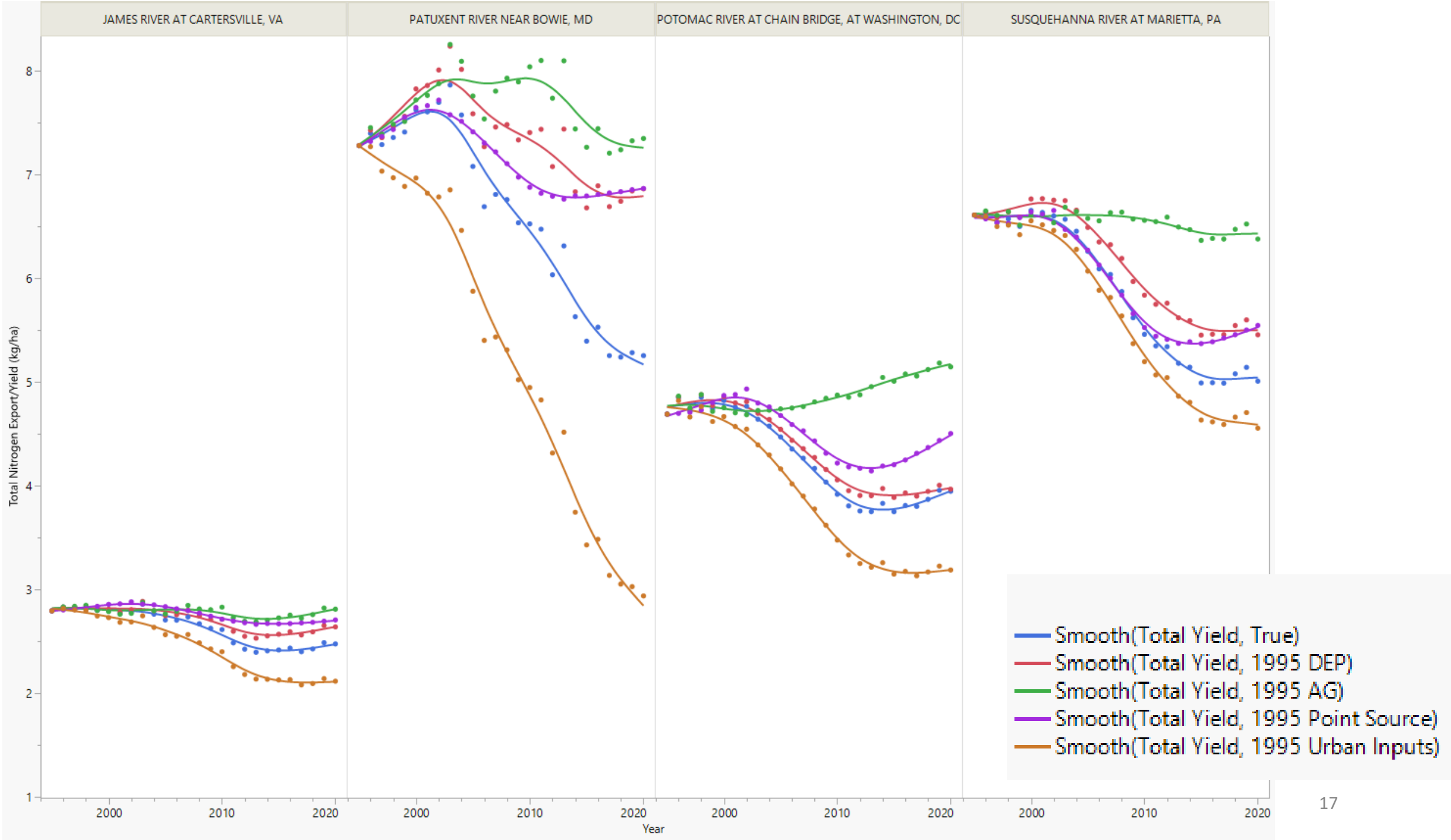
Difference between the blue time series (true scenario) and other colors represents the isolated net effect of a pollution source. Values above the blue line mean changes in those pollution sources had a net positive impact; values below mean they had a net negative impact.



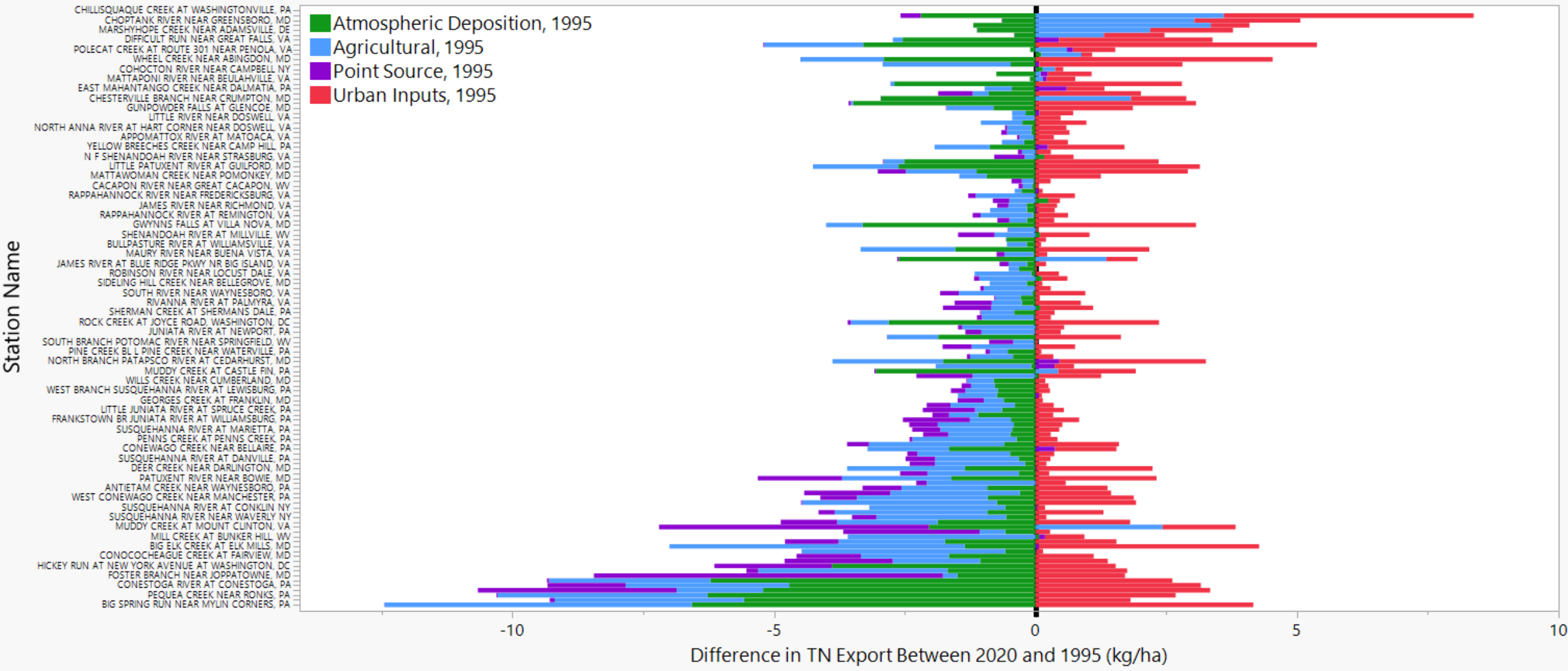
Key Observations from Neural Network

- Nitrogen export has declined since mid-90s (blue line).
- Without improved farm nutrient management, N export would have remained largely the same (green line).
- On net, cleaner air and wastewater upgrades improved water quality.
- Urbanization offset water quality gains.

Note that this is a distinct Chesapeake Bay application using the Chesapeake Bay Nutrient Inventory as used in Weber et al. (2024), CESER Report, Zhang et al. (2022), and Zhang et al. (2023).


JAMES RIVER AT CARTERSVILLE, VA
PATUXENT RIVER NEAR BOWIE, MD
POTOMAC RIVER AT CHAIN BRIDGE, AT WASHINGTON, DC
SUSQUEHANNA RIVER AT MARIETTA, PA
Total Nitrogen Export/Yield (kg/ha)
1
2
3
4
5
6
7
8
2000
2010
2020
Year
Smooth(Total Yield, True)
Smooth(Total Yield, 1995 DEP)
Smooth(Total Yield, 1995 AG)
Smooth(Total Yield, 1995 Point Source)
Smooth(Total Yield, 1995 Urban Inputs)

Cleaner air, improved agricultural nutrient management, and declines in wastewater loads decreased N export in most watersheds



Conclusions

- Modeled declines in agricultural surplus and atmospheric deposition were the primary drivers of long-term reductions in nitrogen export.
- Increasing urban nutrient inputs offset gains from agricultural management, cleaner air, and wastewater upgrades in many watersheds.
- Wastewater load reductions improved water quality, but played a smaller role than nonpoint source changes in many monitored basins.
- Further reductions in agricultural surplus and mitigation of urbanization effects will likely help drive nutrient improvements.

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Please reach out with questions/ideas!

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