United States Environmental Protection Agency

Advances in Nutrient Mass Balance Analyses

1. The release of USEPA's National Nutrient Inventory
2. Leveraging AI and the Chesapeake Bay Nutrient Inventory to identify long-term drivers of nitrogen export in the Bay watershed

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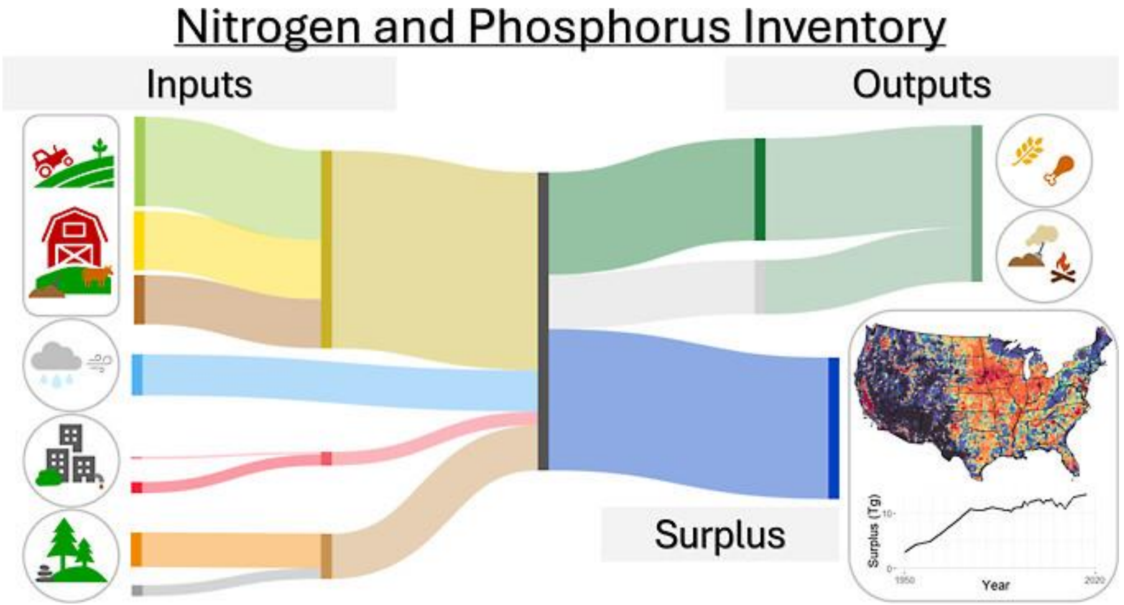
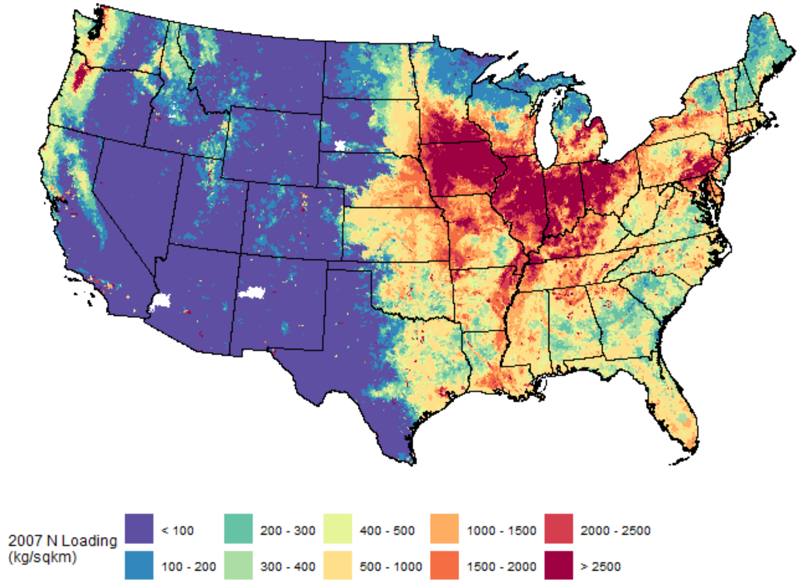
Presentation Objectives

1. Announce the release of the next generation of the National Nutrient Inventory (NNI).
2. Provide a summary of the overall research portfolio and emphasize NNI's big data and AI/Machine learning transition.
3. Dive into how AI and the *Chesapeake Bay Nutrient Inventory* are being leveraged to identify long-term drivers of nitrogen export.





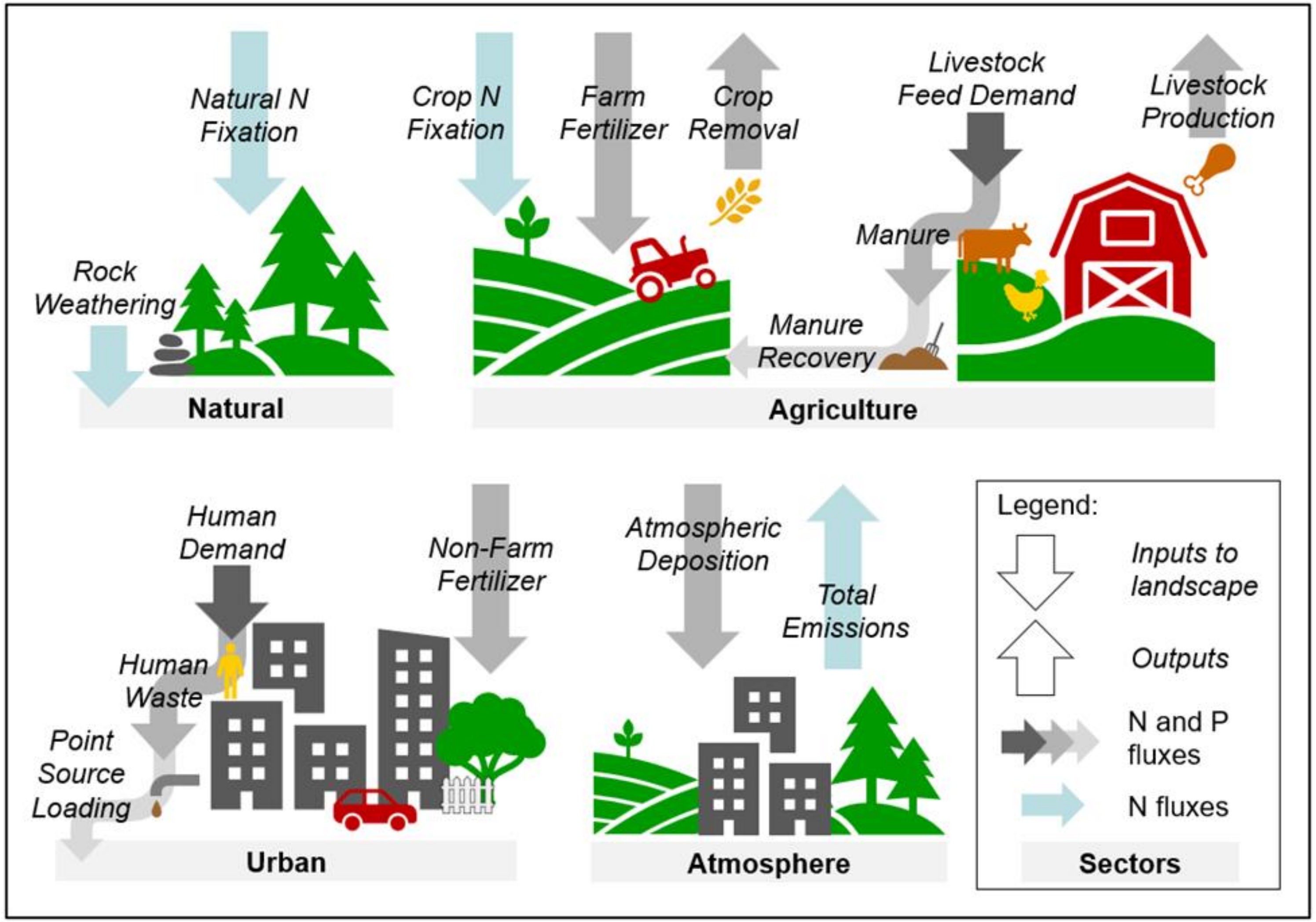
National Nutrient Inventory to inform water quality management

How can NNI support state CWA program implementation?

- Integrated mass balance with management relevant metrics to track nutrient sources
- Empirical, interpretable, and predictive models of water quality
- Web-based tools, prioritization schemes, and tailored products
- Robust stakeholder engagement
- Operational flexibility to meet evolving information needs

USEPA's National Nutrient Inventory Released

- Multi-sector mass balance data for N and P
  - County and subbasin scale (HUC12)
  - 1987-2017 (some ag variables back to 1950)
- Tractable input and output estimates
  - Management relevant metrics to track progress
  - Power predictive water quality models
- Inform nutrient reduction strategies



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Key Findings: USEPA National Nutrient Inventory

- Innovative technologies and management have stemmed or even decreased major sources of nutrient pollution.
  - Large increases in crop harvest and animal production with little change in agricultural surplus.*
    - Since 1950, an estimated 655 Tg of N and 127 Tg of P have been left on US lands due to agricultural activities.
  - Total N emissions down 22% and atmospheric deposition down 15% since the late 1980s.
  - Stable municipal wastewater loads despite population growth, likely due to treatment upgrades and detergent phaseouts.

* Agricultural Surplus: N and P left on the landscape due to agricultural activities, after the balance of inputs and outputs

Agricultural Surplus = Total Agricultural Inputs (*Manure, Farm Fertilizer, Crop N Fixation*) – Non-Hydrologic Agricultural Outputs (*Crop Removal*)

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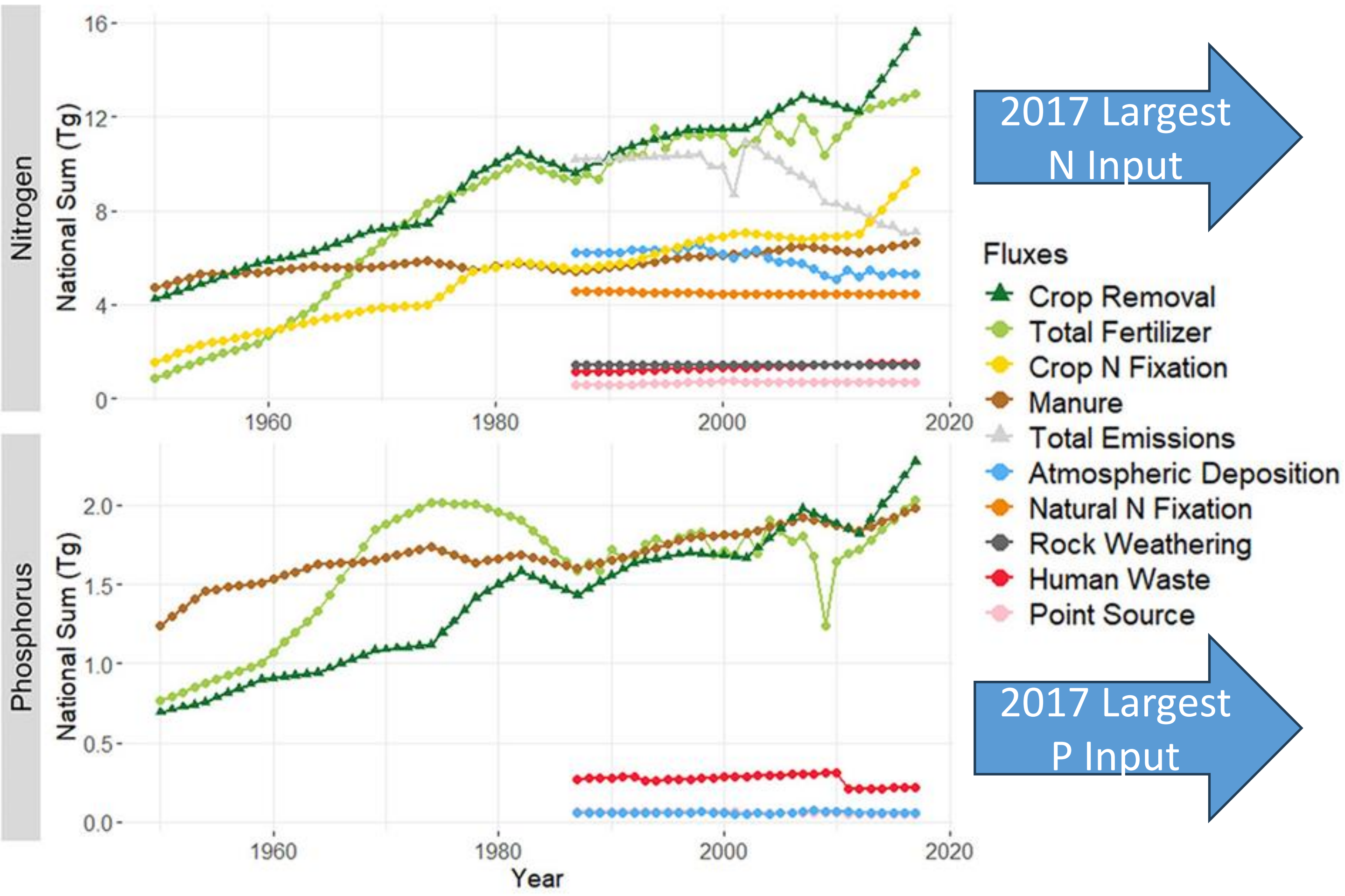
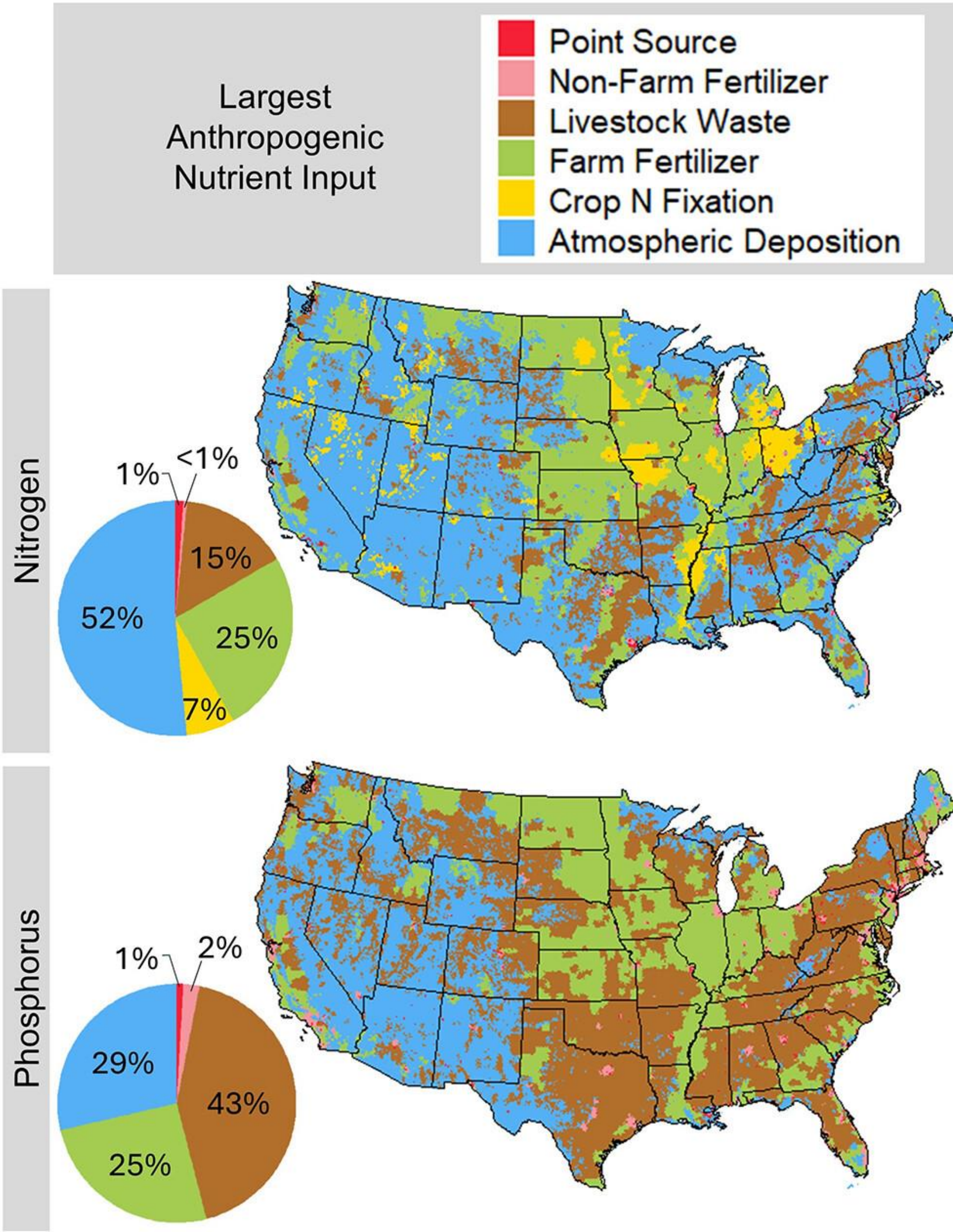
National outlook for N and P sources continues to evolve

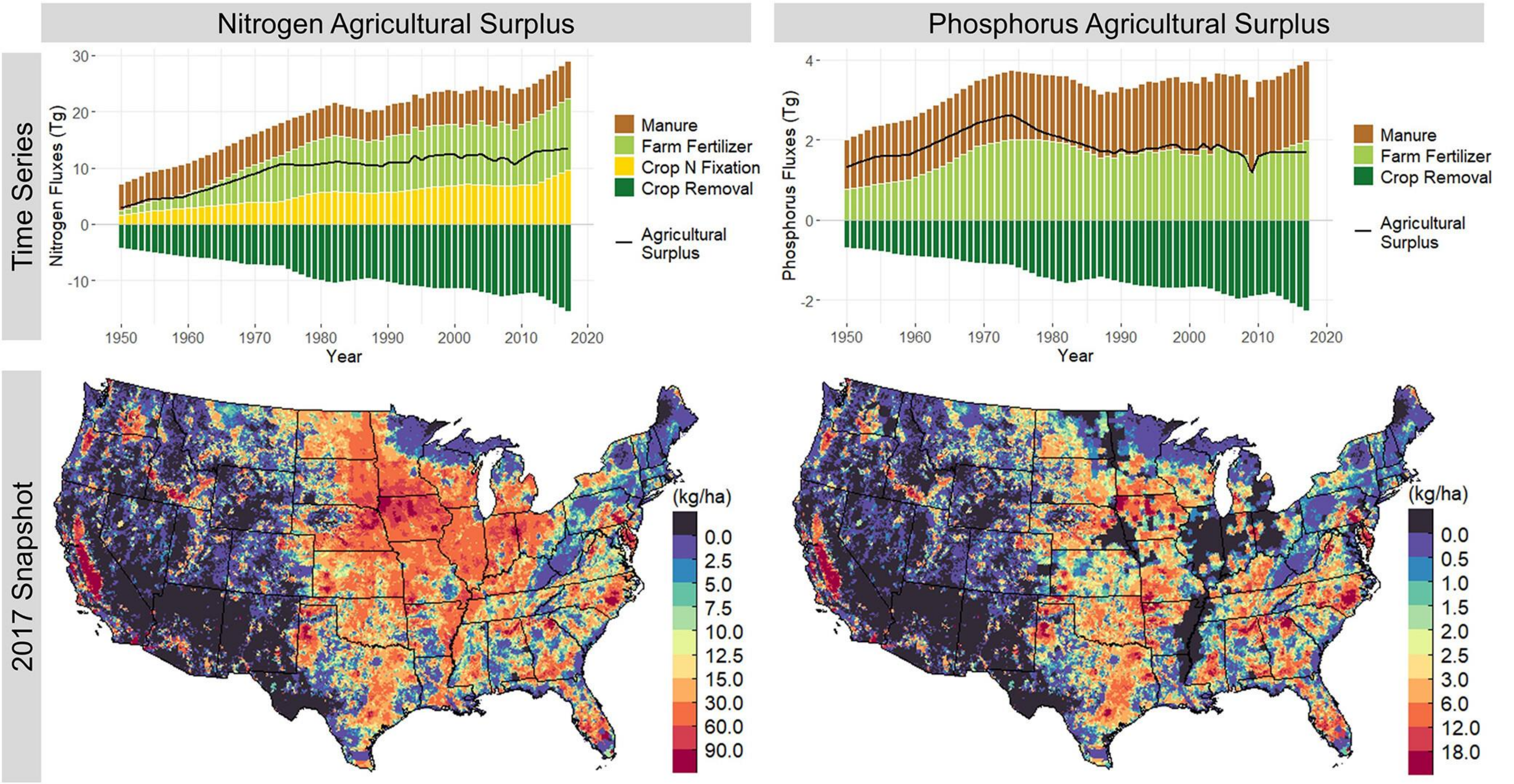


2017 Largest N Input

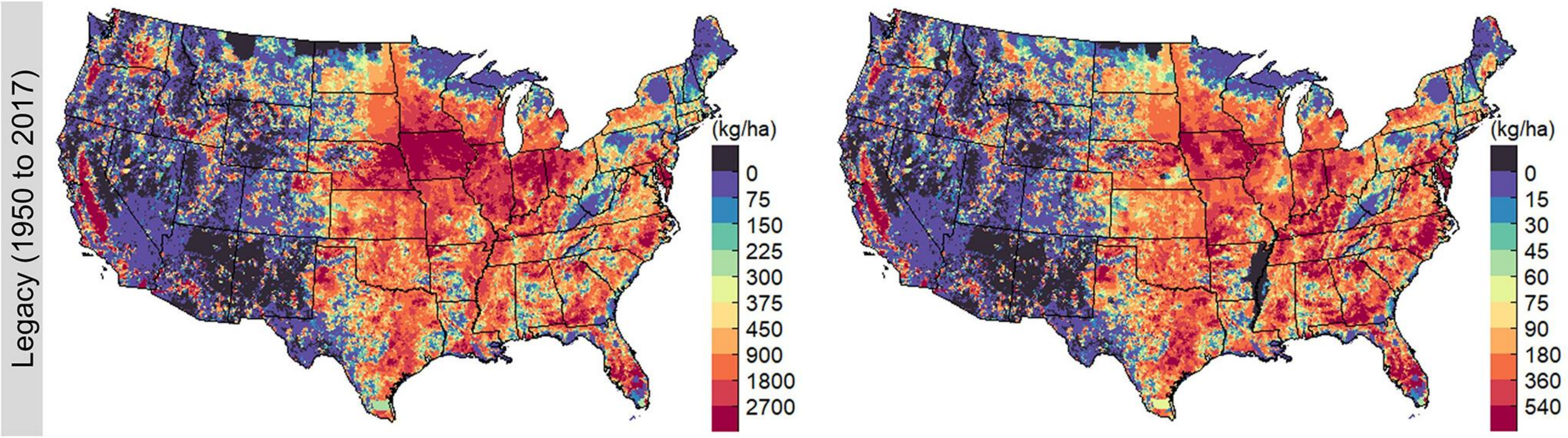
2017 Largest P Input



Nationwide agricultural surplus has stabilized, while production continues to increase.



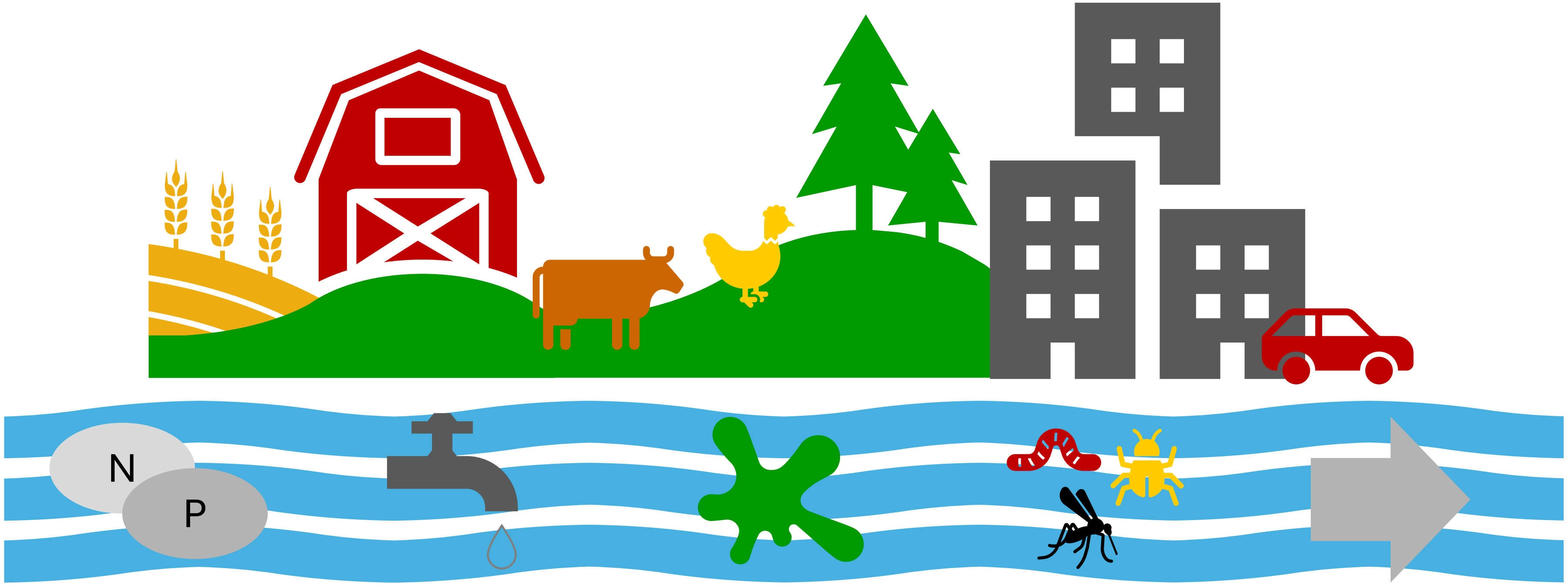
Large amounts of agricultural N and P have been left on agricultural lands across many areas.



Using the NNI to develop predictive models

NNI's big data and AI/Machine learning transition

SET
(Source, Extent, Trends)



Predictive Models and Technical Analyses

Data-driven modeling projects

- Growing Season Nutrient Concentrations
- Drinking Water Conditions (NO_3 and HABs Risk)
- Harmful Algal Blooms (Chl-a and Toxins)
- Biotic Assemblages (Macroinvertebrates)
- Nutrient Export and Concentration

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

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

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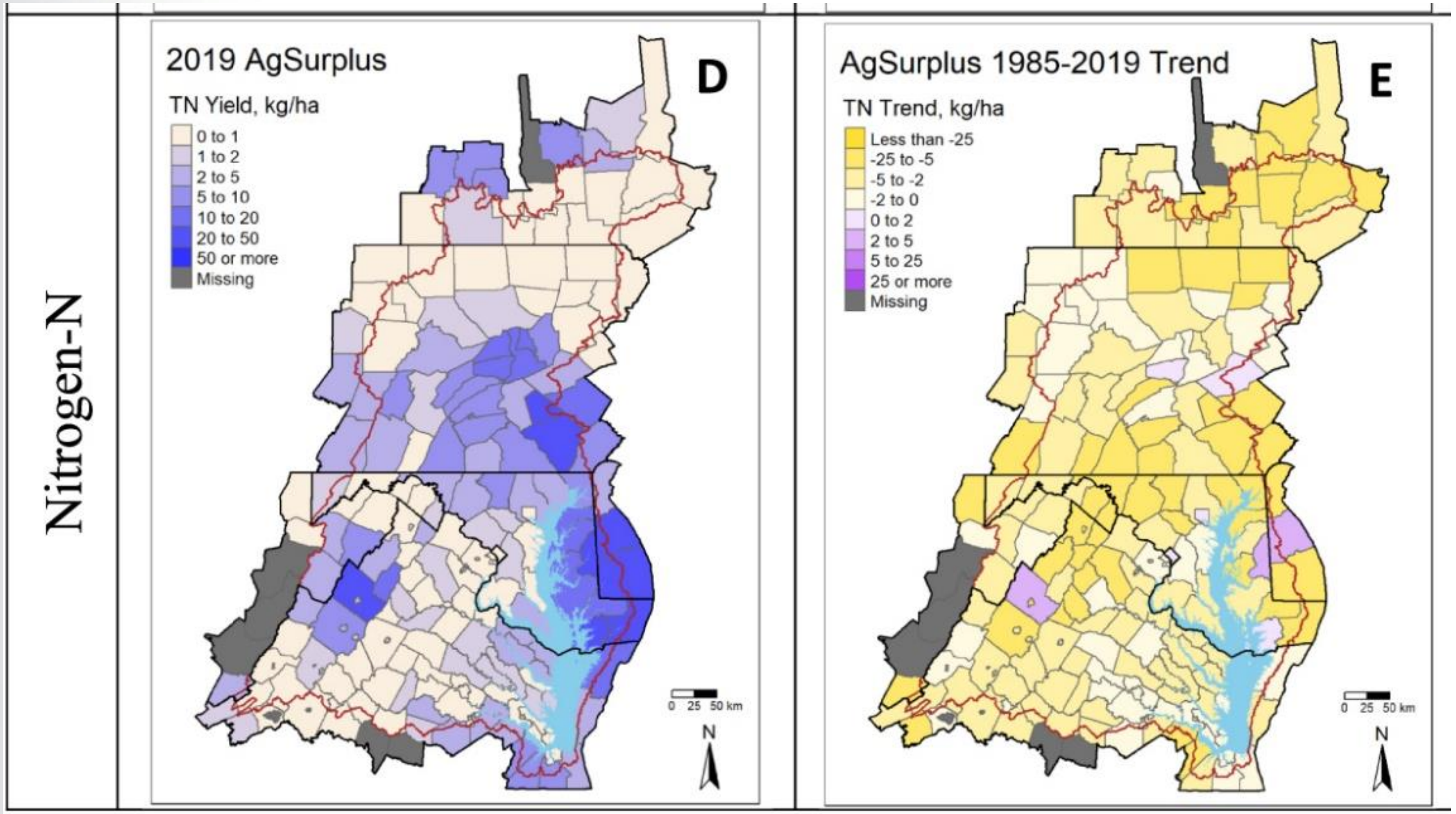
CAST-BASED, Chesapeake Bay Nutrient Inventory

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

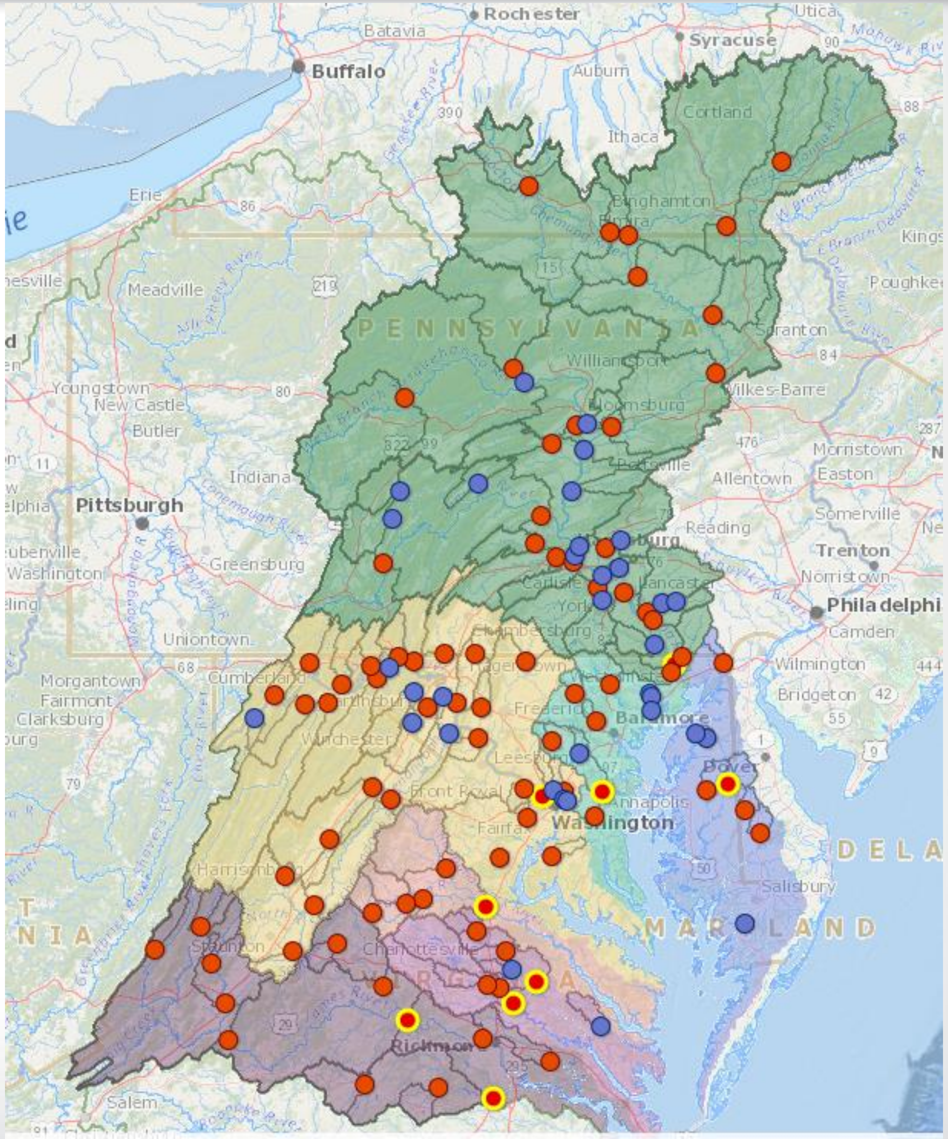


- Farmers are leaving less nitrogen on fields, reducing potential losses to waterways.
  - Not integrated into previous empirical modeling work
- Atmospheric deposition has declined throughout the Bay watershed.
- Point source loads have declined in major urban areas and smaller industrial towns/cities,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

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

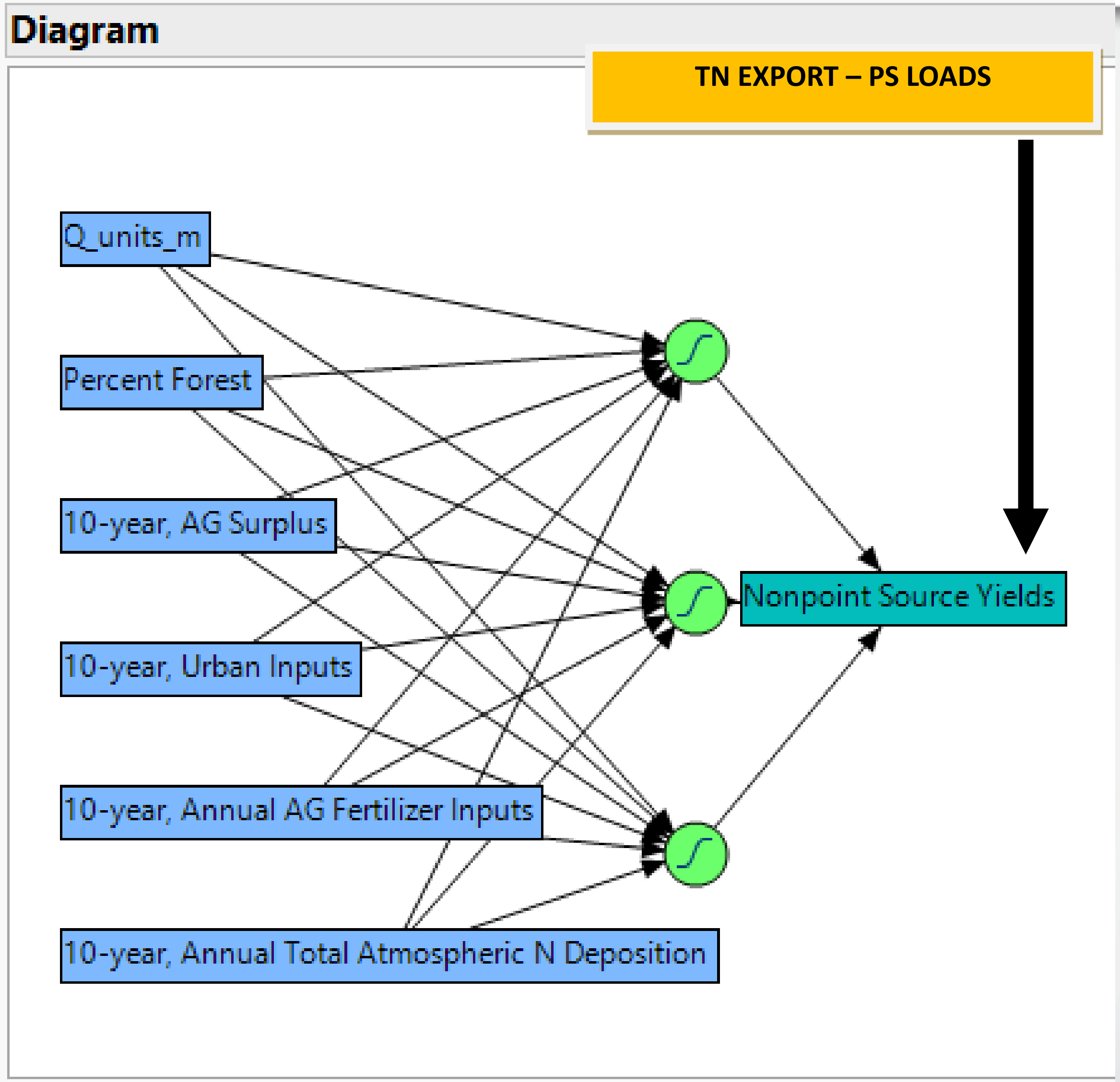
- Leverage the Chesapeake Bay Nutrient Inventory and down-scaled USGS product*:
  - Agricultural surplus,
  - Urban inputs (septic + fertilizer)
  - Point source loads
  - Total atmospheric N deposition
- Pair the nutrient inventory mass balance terms with estimated total nitrogen loads across 121 monitoring stations in the Chesapeake Bay
  - Station time series vary but range from 1985 to 2020
- Develop 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

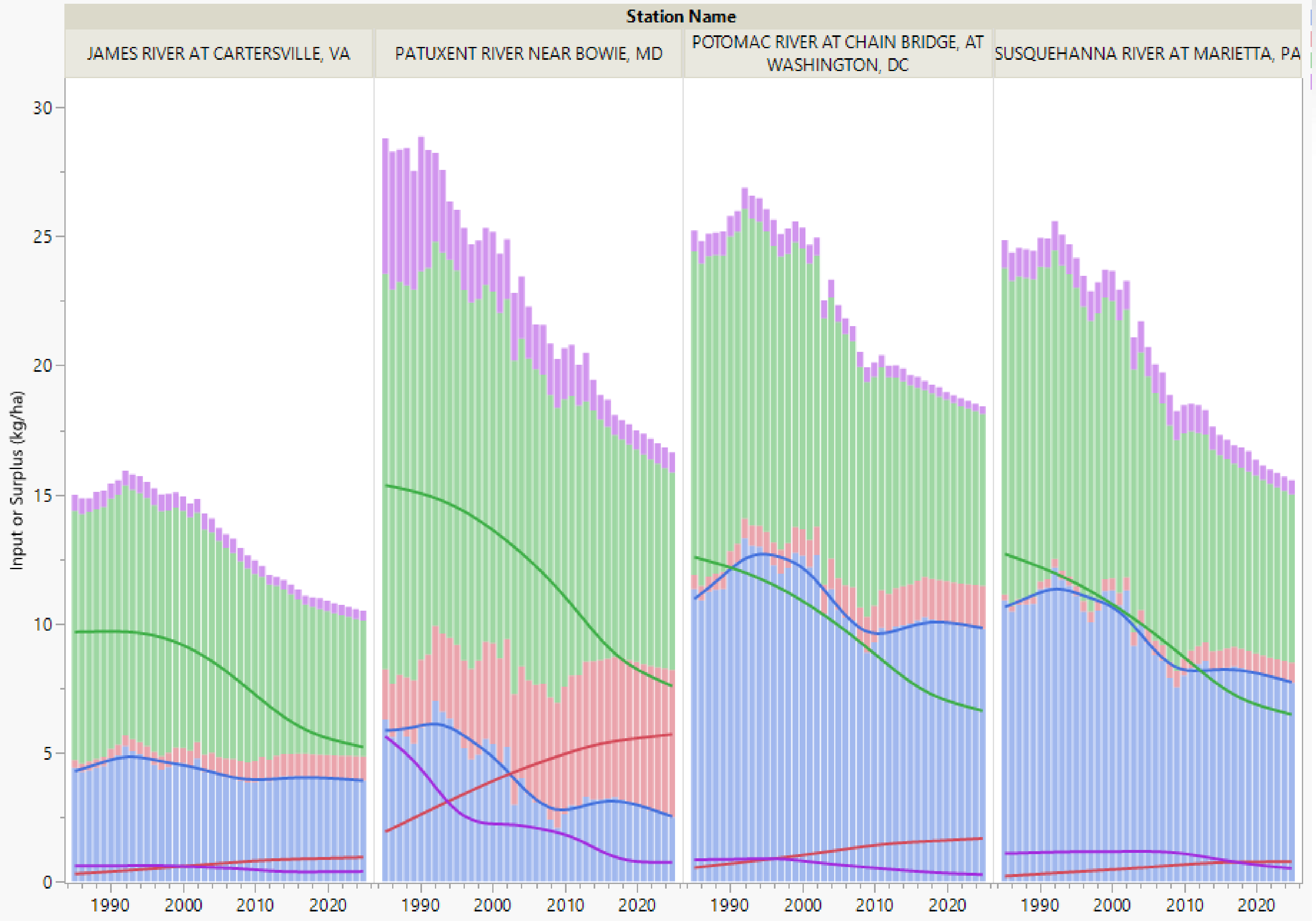
*Courtesy of James Weber and Jeff Chanat, USGS



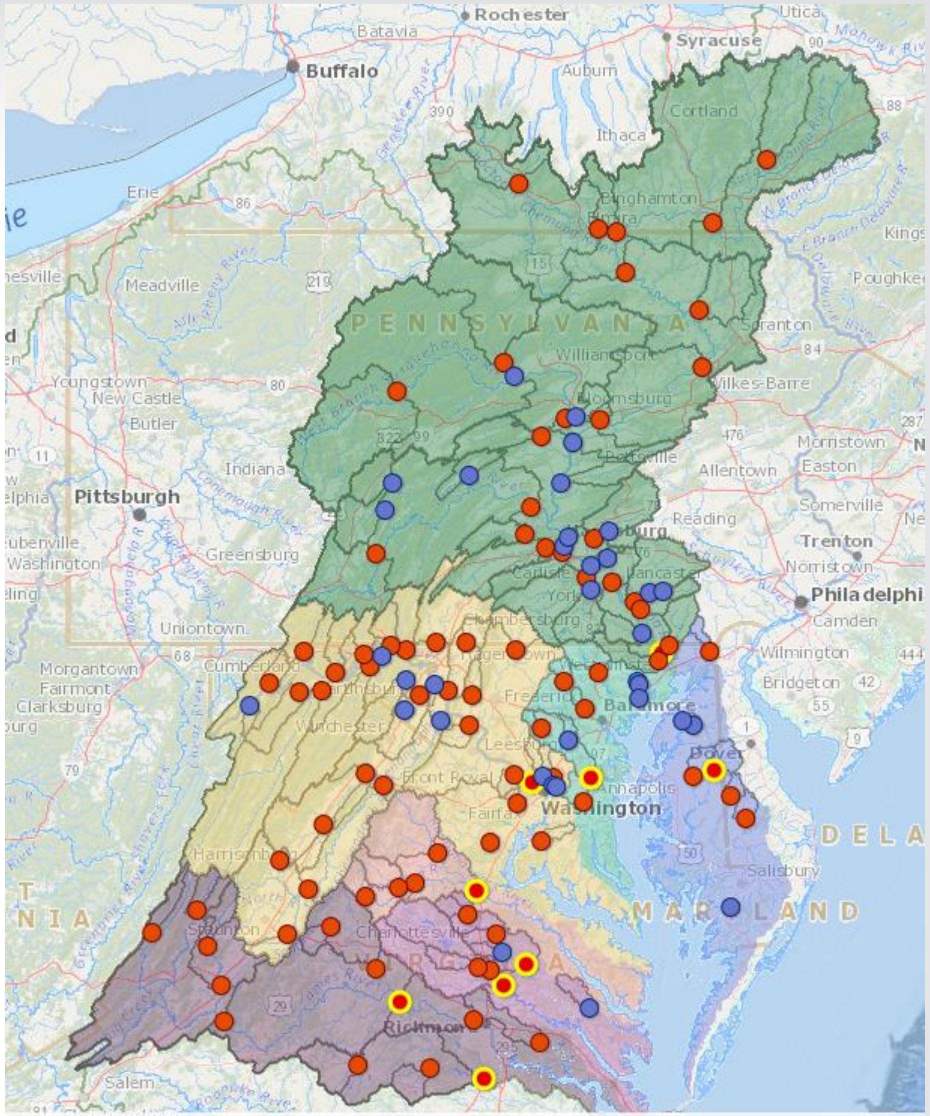
What is a neural net?

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





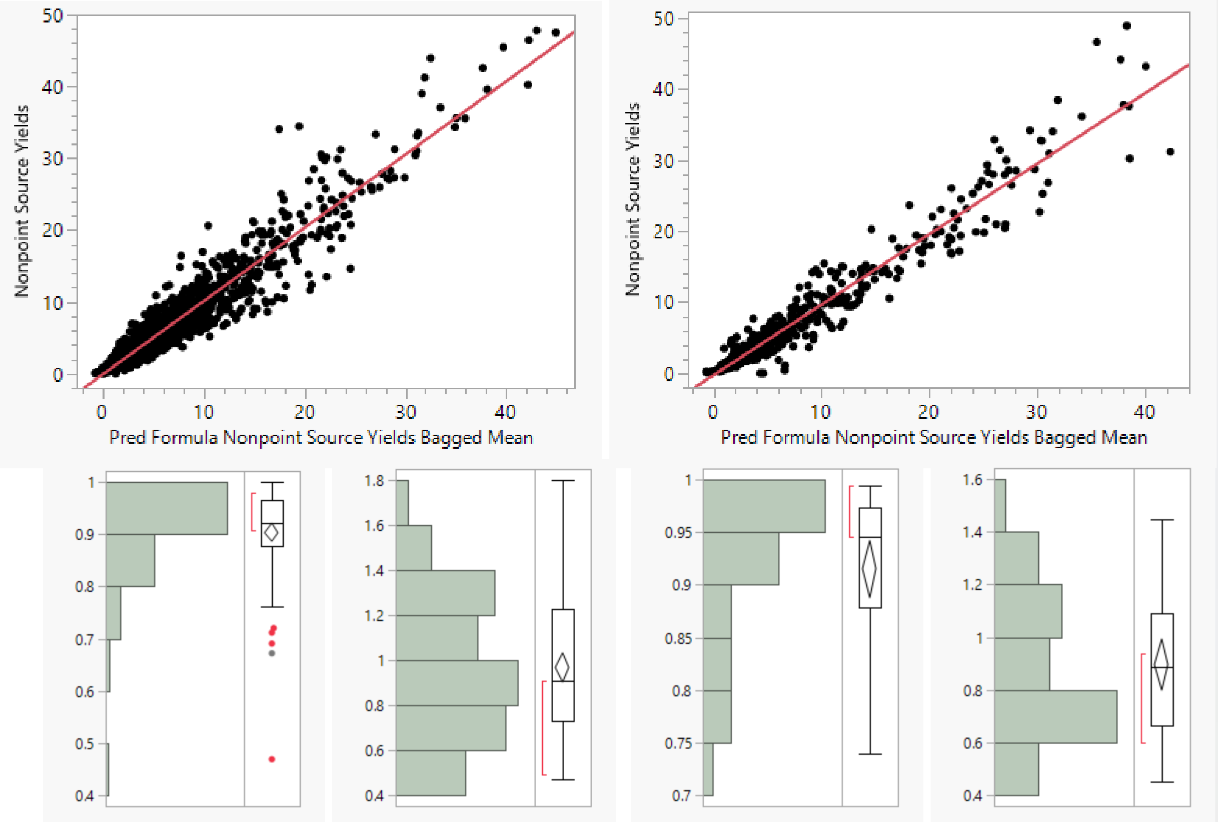
Annual Ag Surplus
Annual Urban Inputs
Annual Total Atmospheric N Deposition
Annual Wastewater Loads



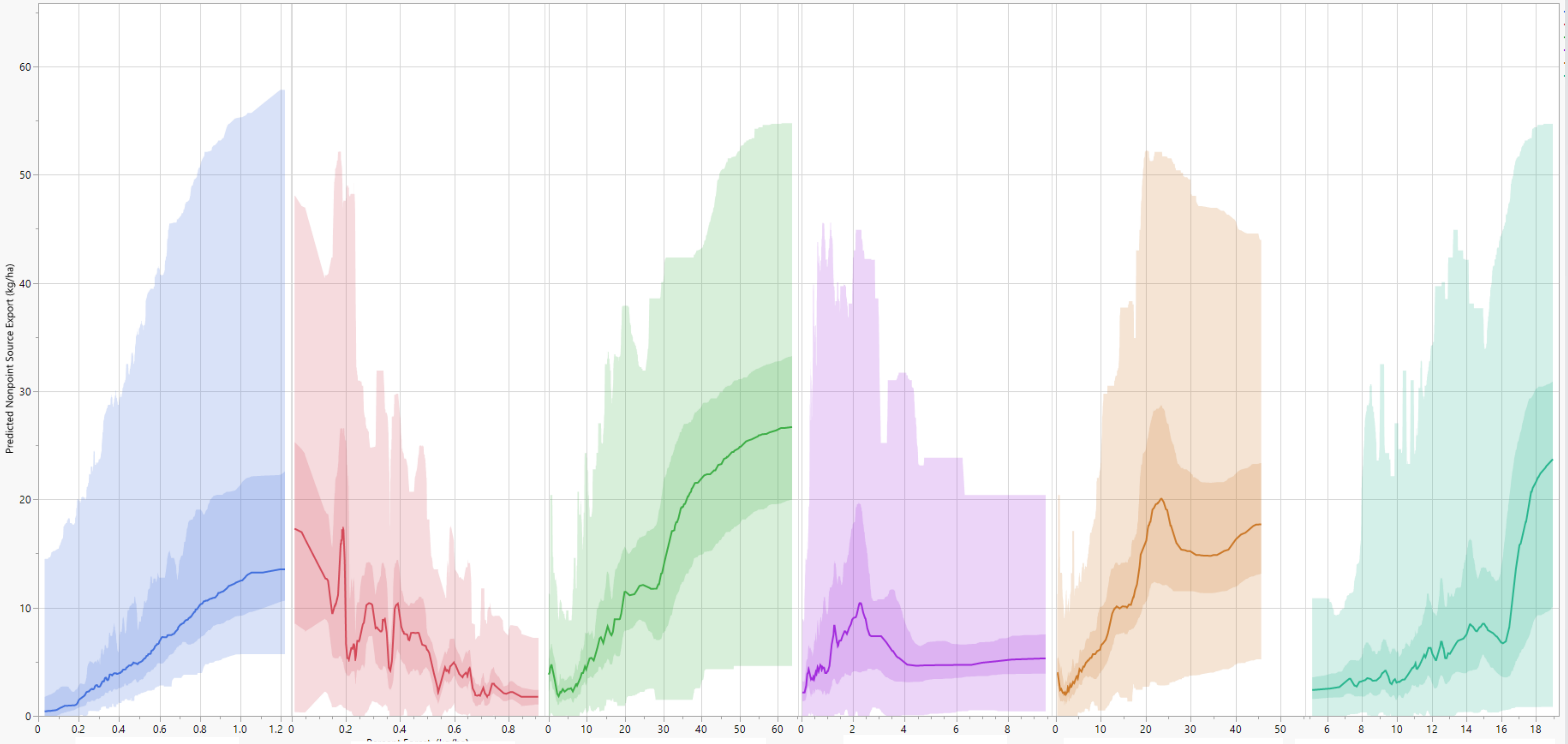
Please note these graphics are available for all monitoring sites.

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

- Calibrated ensemble of 100 models had R2 >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)

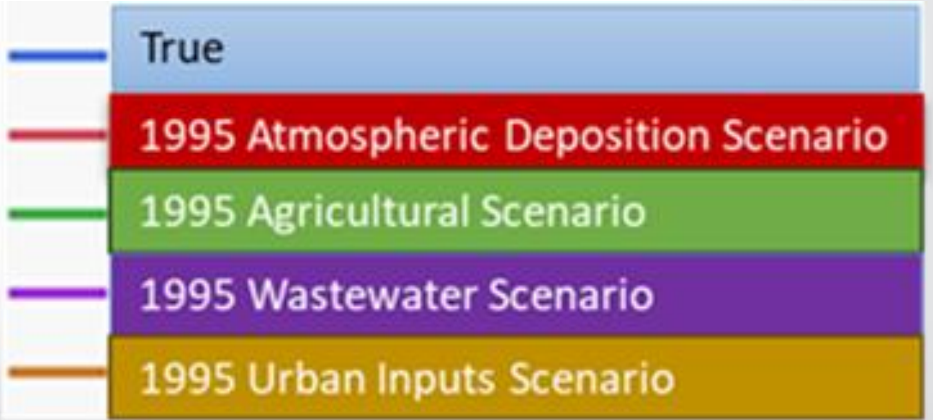
Urban Inputs (kg/ha)

Agricultural Fertilizer (kg/ha)

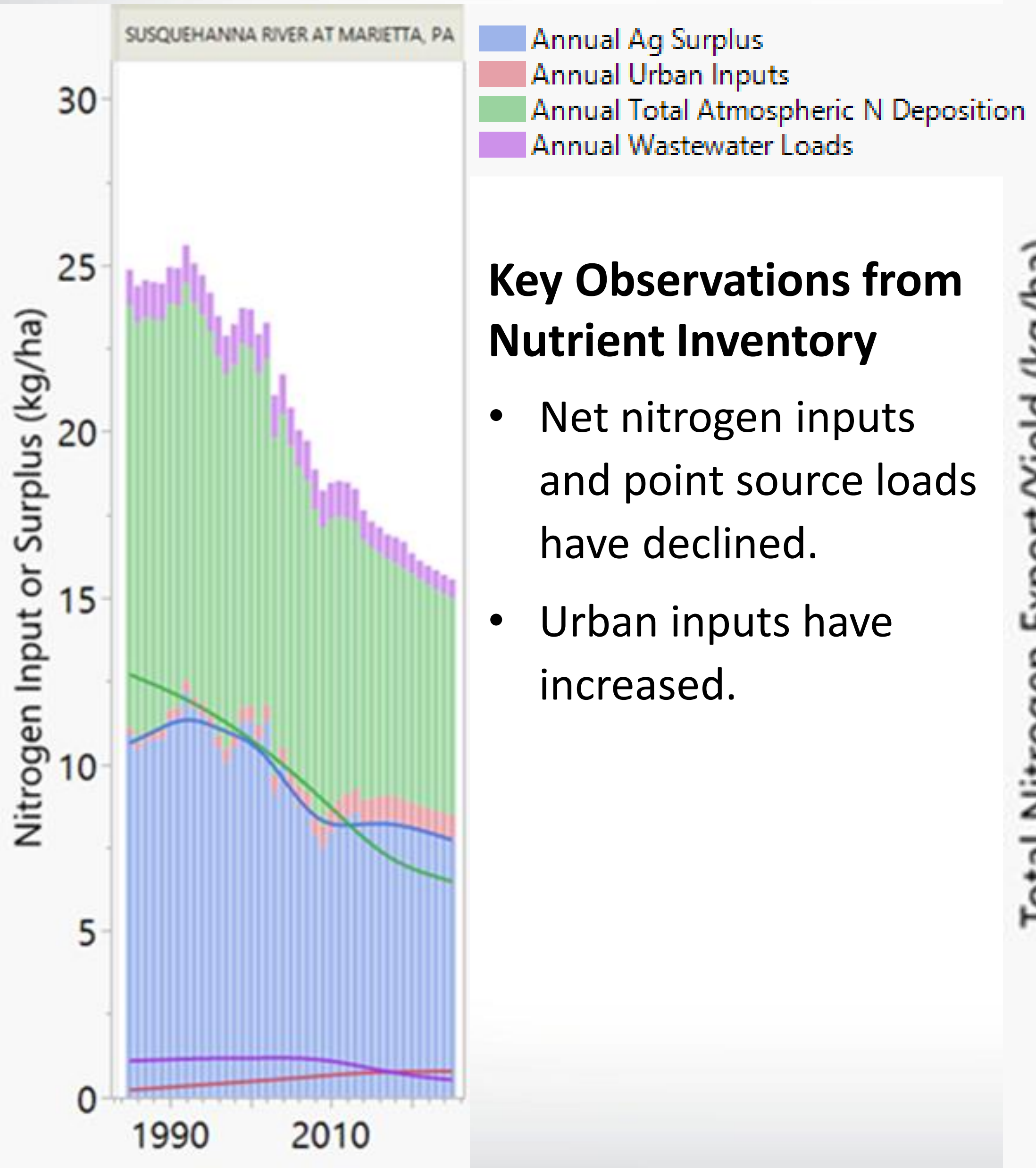
Atmospheric Deposition (kg/ha)

“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

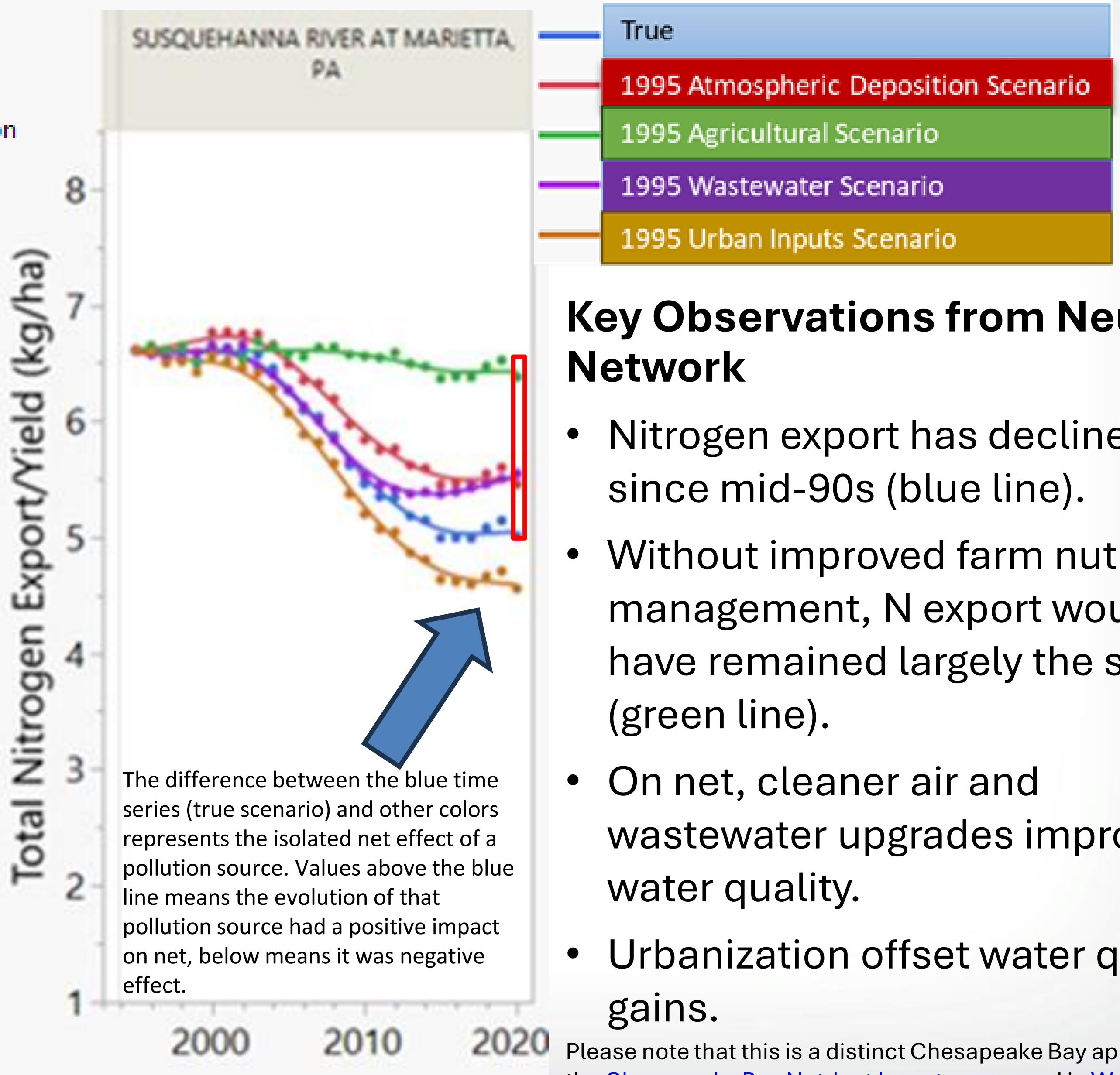


Zoom into jurisdictions or watersheds



Key Observations from Nutrient Inventory

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

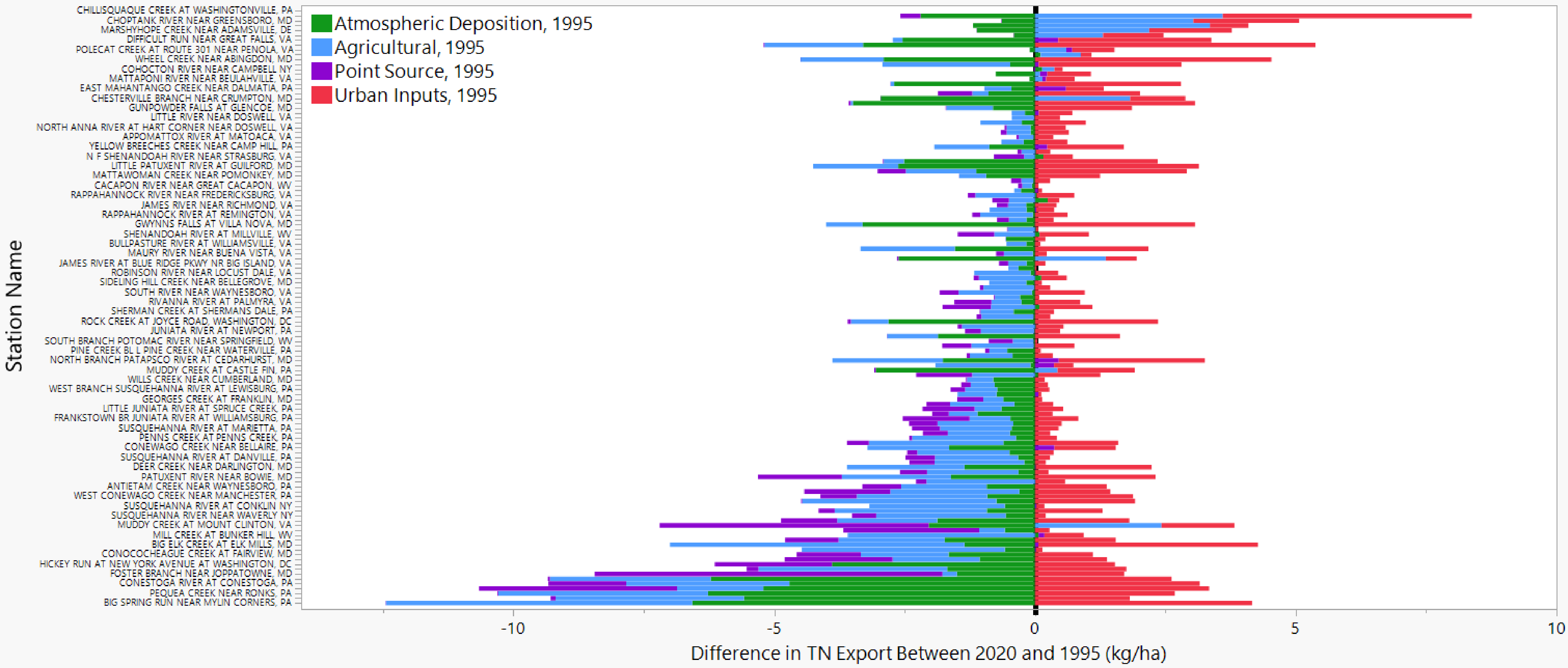


Key Observations from Neural Network

- 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.

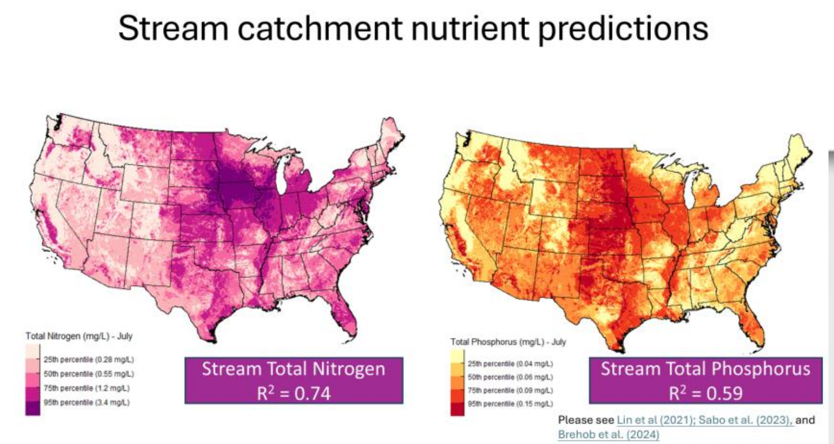
Please note that this is a distinct Chesapeake Bay application using the Chesapeake Bay Nutrient Inventory as used in Weber et al. (2024), CESER Report, Zhang et al (2022), and Zhang et al (2023).

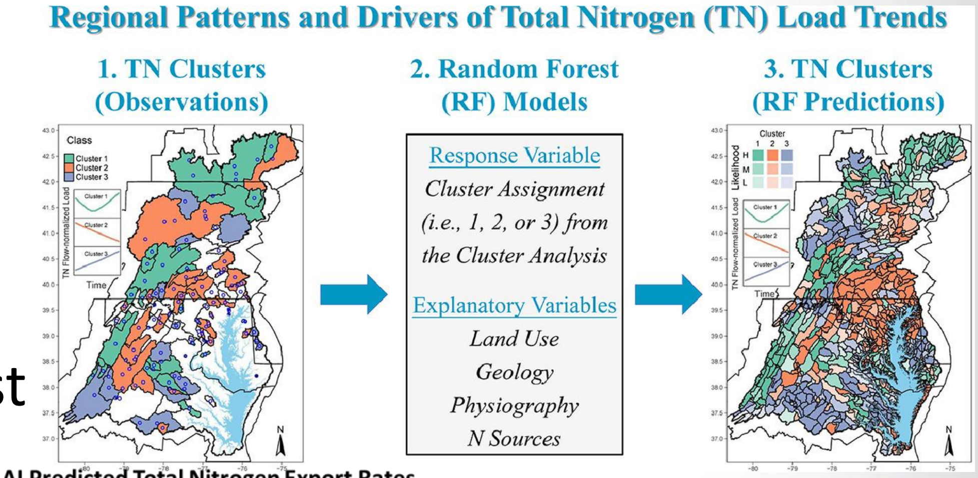
Cleaner air, improved agricultural nutrient management, and declines in wastewater loads decreased N export in most watersheds.

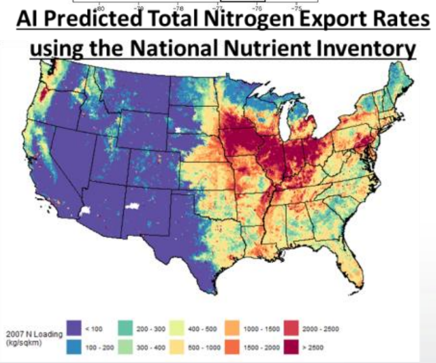


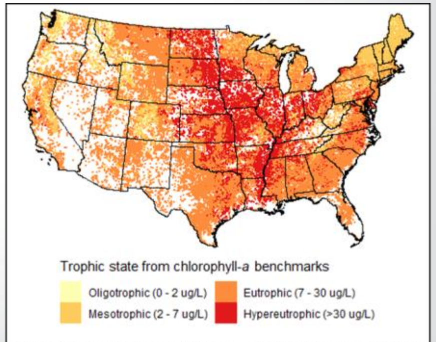
Value of nutrient inventories

- The USEPA National Nutrient Inventory and customized regional Nutrient Inventories (e.g., CB Nutrient Inventory) continue to be developed and updated.
  - Track progress
  - Engage stakeholders thru a simple quantitative framework
  - Inform nutrient reduction strategies
- Nutrient Inventories and other environmental factors are being paired with water quality endpoints of interest (e.g., nutrient concentrations/loads, export trends, HABs) to power predictive statistical and AI models.
- Novel decision support tools and datasets are being developed to support state and regional partners.









Map of lake chlorophyll-a predictions for July 2007

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Please reach out with questions/ideas

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