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Application of SPARROW Modeling to Understanding Water-Quality Trends in the Chesapeake Bay Watershed

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Silvia Terziotti, Greg Schwarz, Doug Moyer, Joel Blomquist, Jeff Chanat, Andy Sekellick

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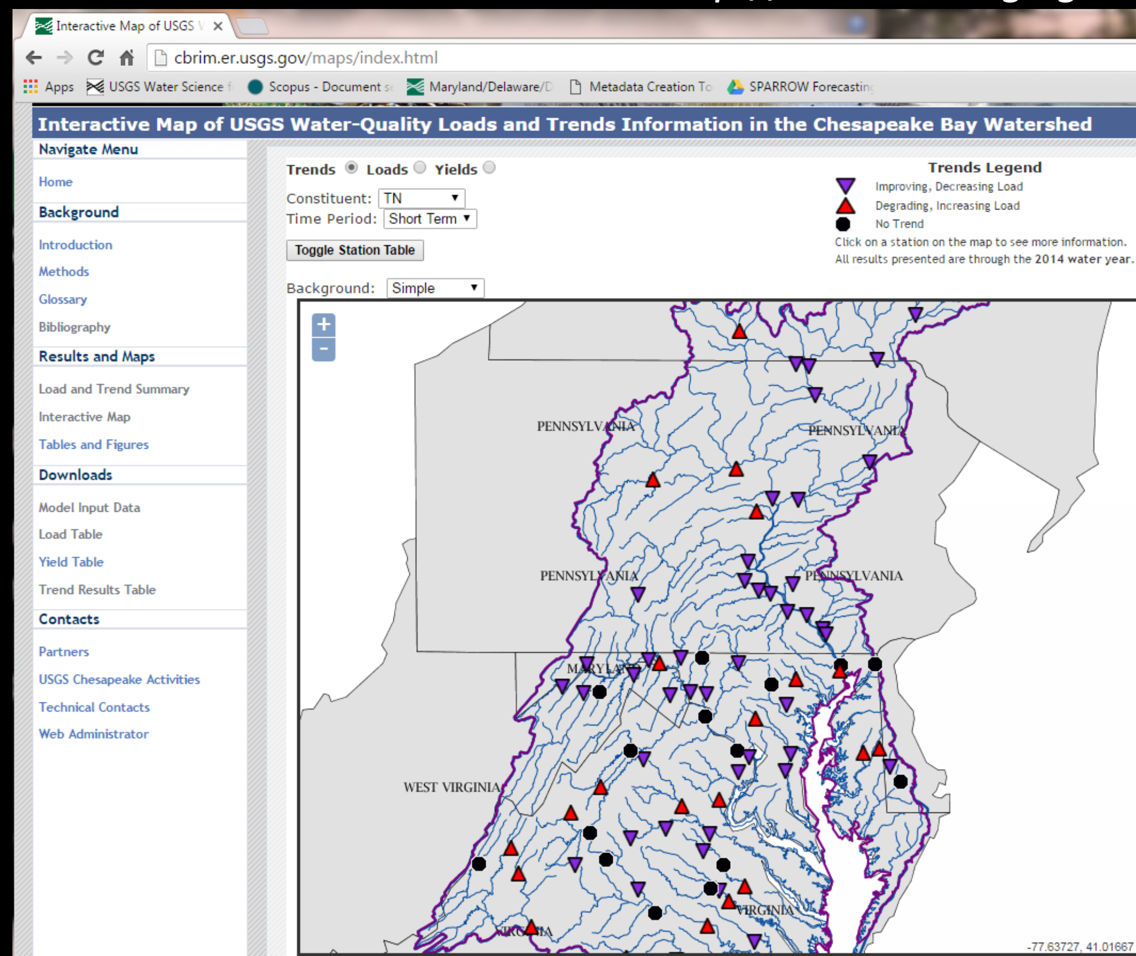
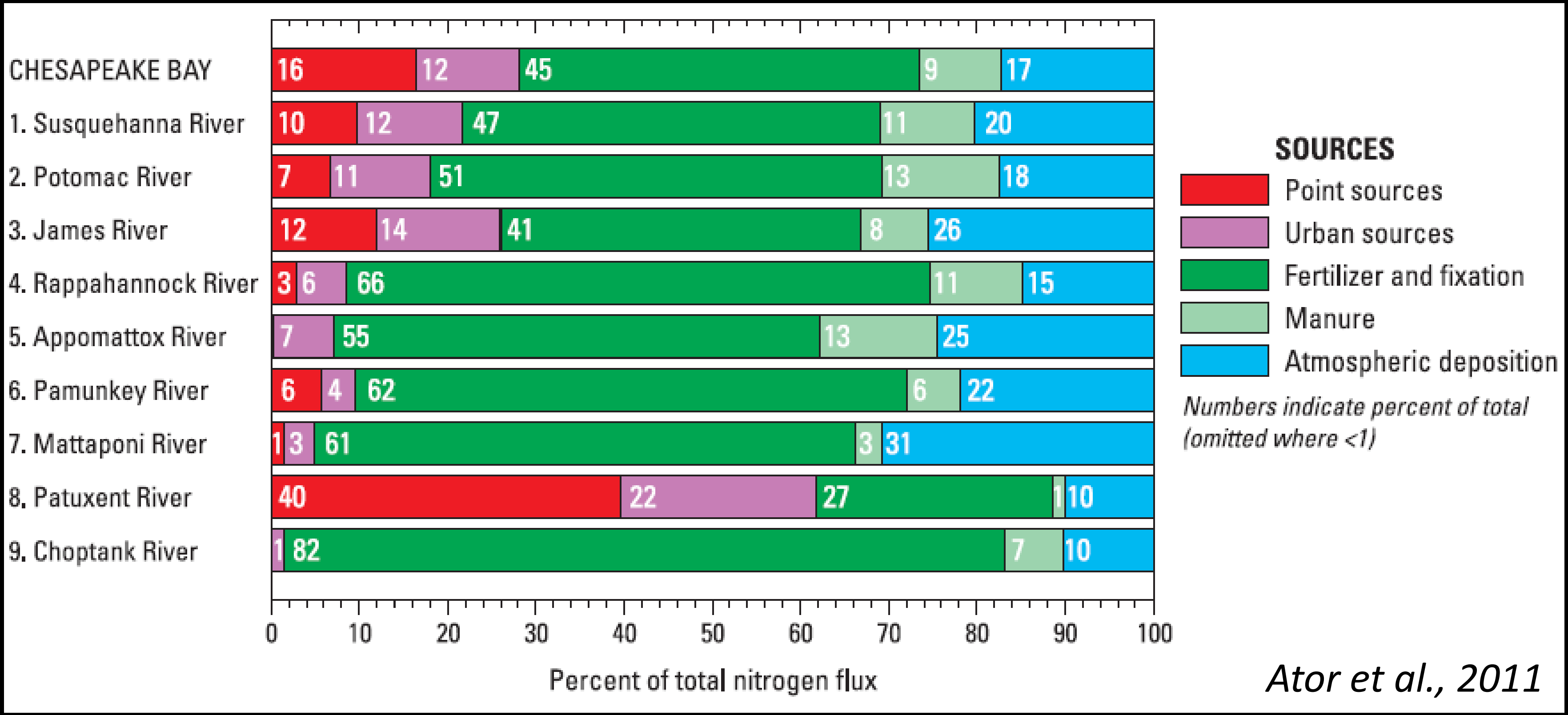
Nitrogen and Phosphorus in Chesapeake Bay

http://cbrim.er.usgs.gov

- Sources and transport of N and P to Chesapeake Bay have been studied at multiple scales.
- Water-quality trends in selected tributaries are well documented.
- Less clear are the **causes** of different trends in different areas.



Sources of Nitrogen



- Agriculture provides the majority of nitrogen inputs to Chesapeake Bay and most major tributaries.

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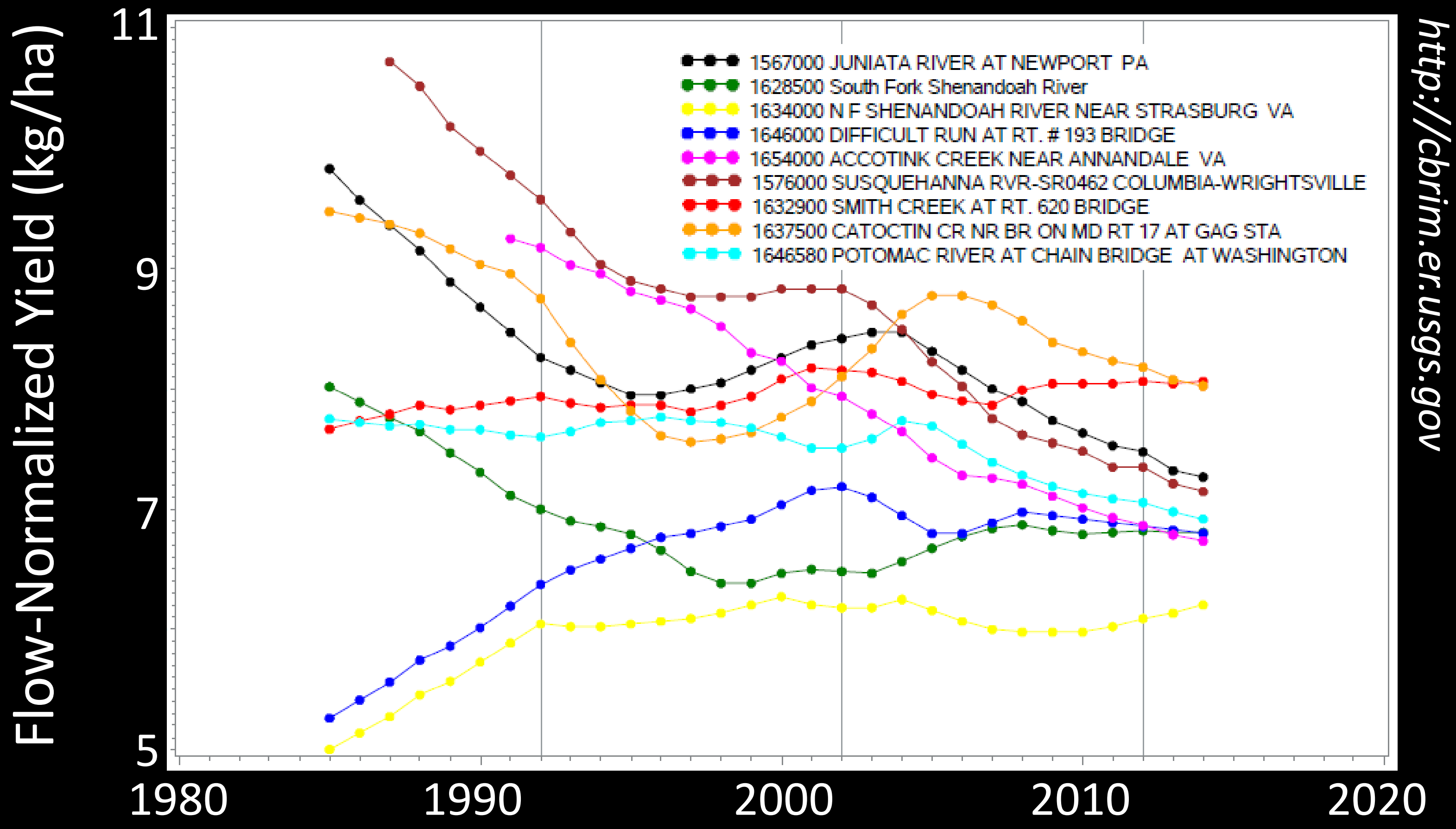
Nitrogen in Streams

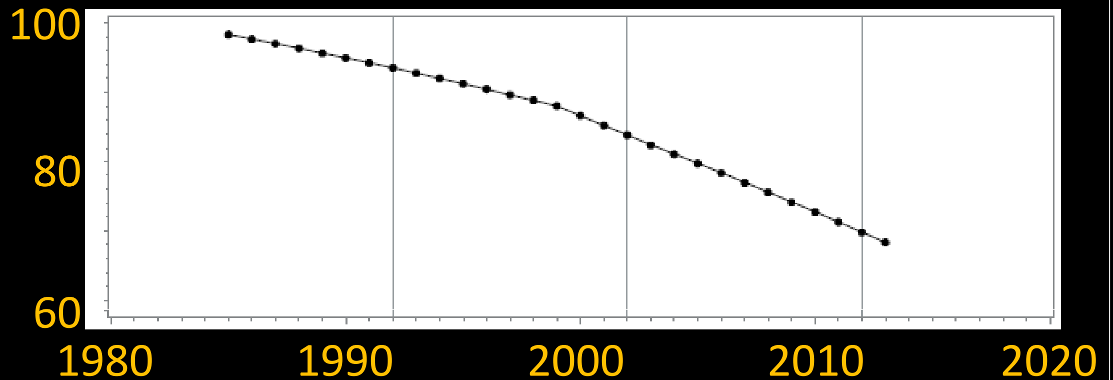


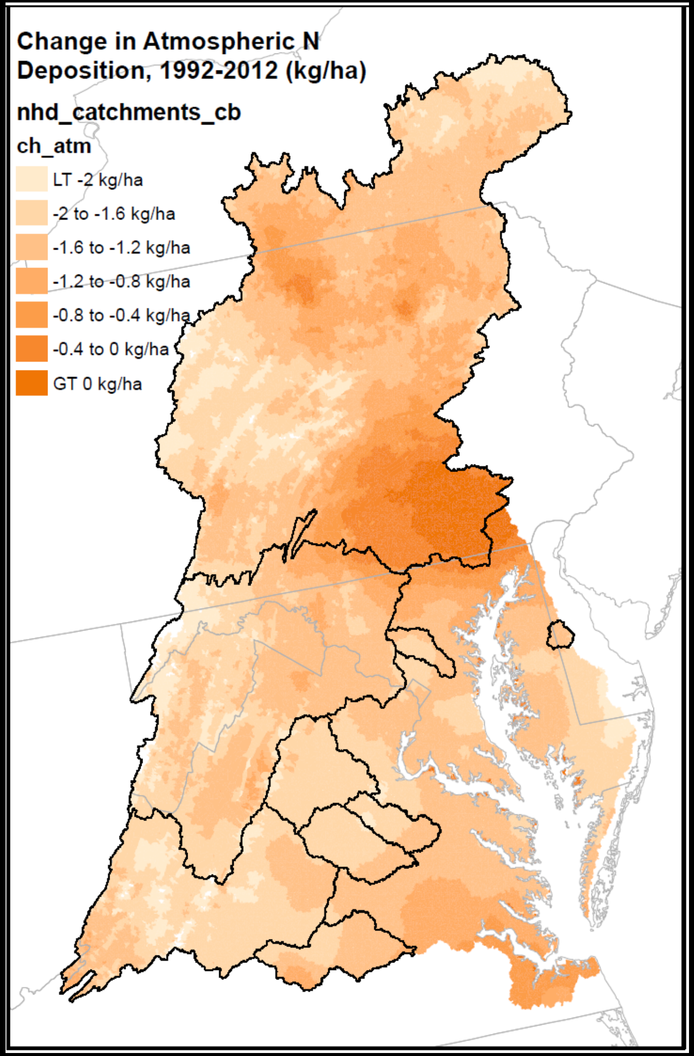
- Nitrogen concentrations have generally decreased in recent years in many tributaries, but increased in others.

Nitrogen Sources

- Atmospheric deposition has generally decreased over time, but varies spatially.

Atmospheric Nitrogen Deposition
in 1000's of Metric Tons (LOESS smooth).

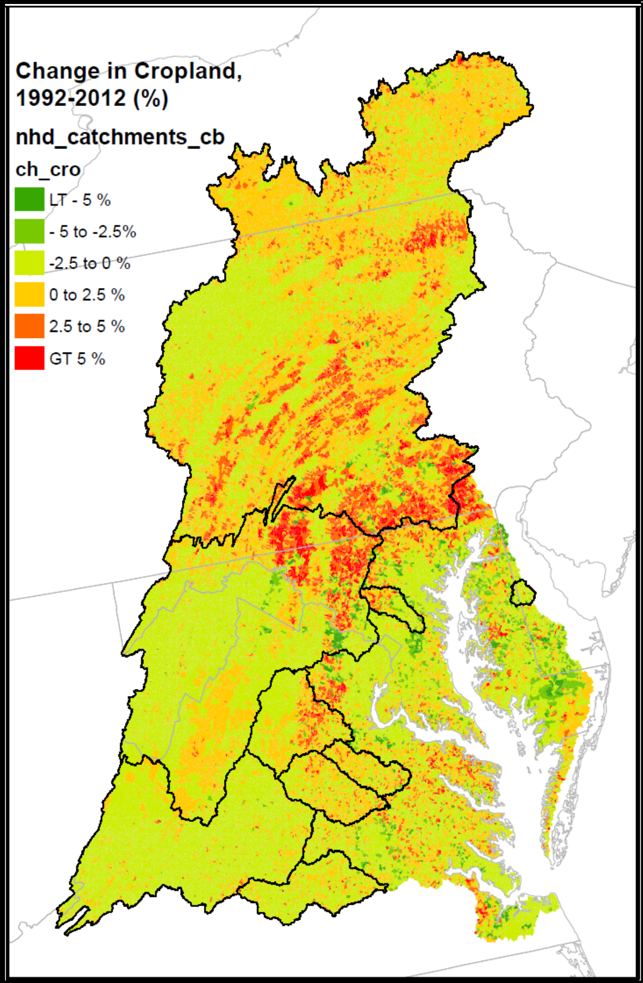


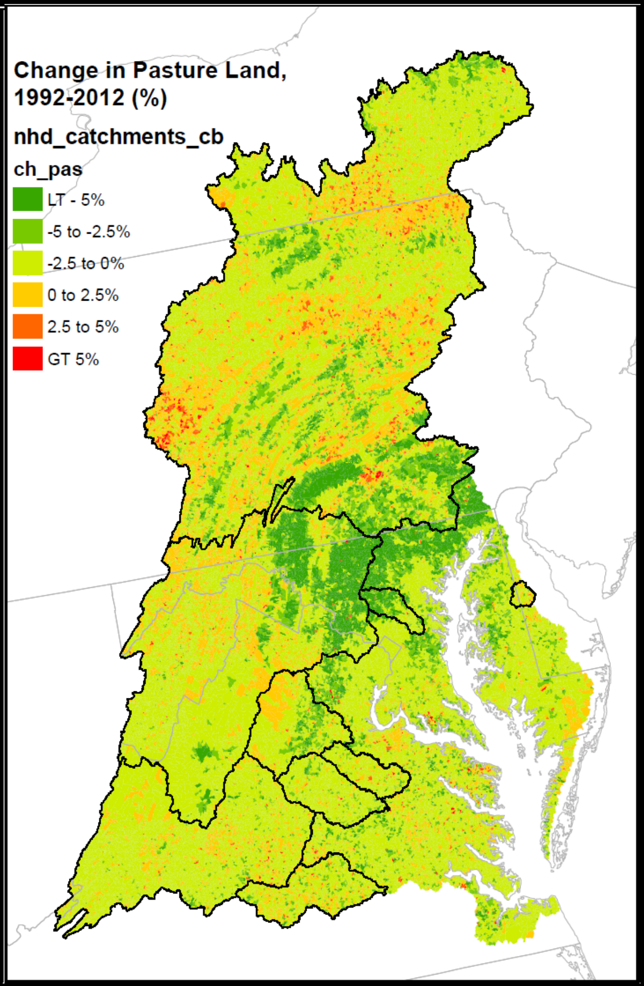


Data from Chesapeake Bay Program

Nitrogen Sources

- Land-use change, 1992 – 2012.





Falcone, 2015

Research Questions

- How do changes in stream chemistry relate to:
  - changing land use patterns?
  - changing practices within certain land-use settings?
  - changing atmospheric deposition or point sources?
- How can multiple steady-state SPARROW models calibrated for decadal time steps help to improve our understanding of landscape factors driving changes in stream chemistry?

Outline

- Background: What is SPARROW?
- Approach: How might SPARROW models be developed to understand water-quality changes over time?
- Preliminary Results
- Next Steps

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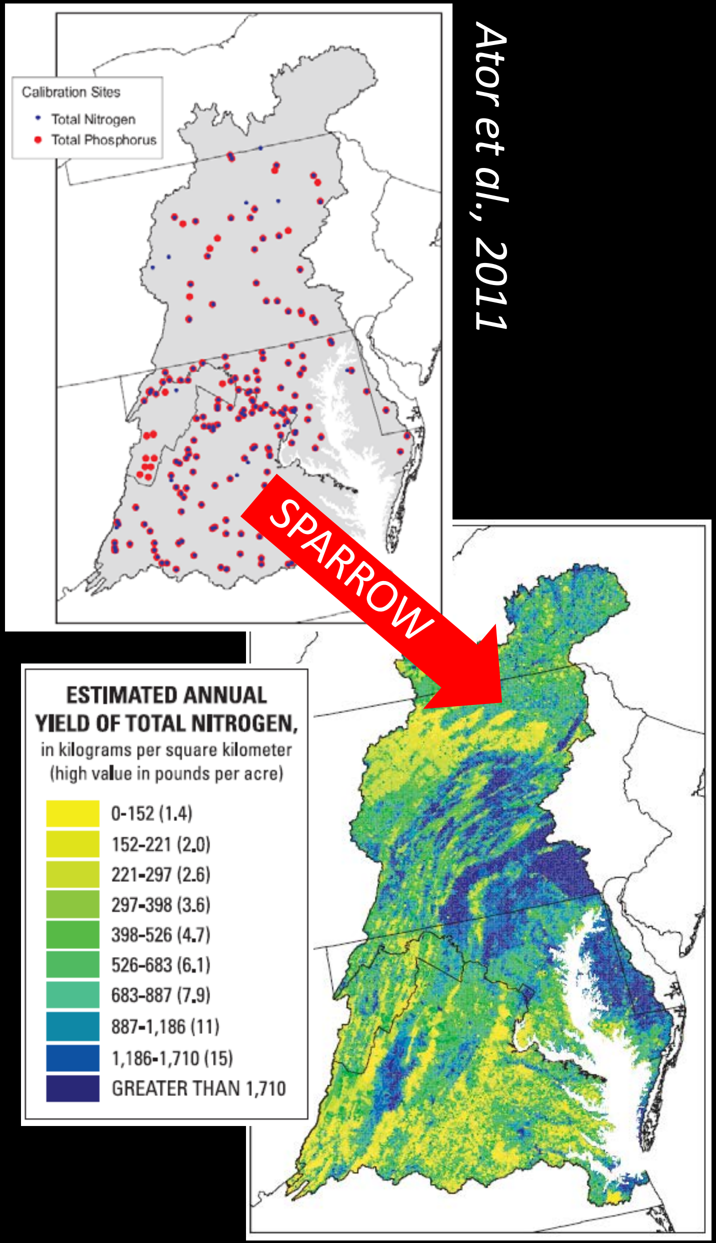
The SPARROW Model

- SPAtially-Referenced Regression On Watershed attributes
- Developed in the 1990s by USGS (Smith et al., 1997)
- Regression (NLLS) approach to extrapolate estimated mean-annual flux (load) at monitored streams to unmonitored streams on the basis of watershed attributes
- Includes mass-balance and flow-routing
- Steady-state model of mean-annual conditions*



Ator et al., 2011

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The SPARROW Model

- Regression approach
  - Dependent variable: mean annual flux of contaminant in a stream
  - Explanatory variables: watershed or stream attributes representing:
    - upland or in-stream sources
    - overland transport
    - in-stream transport

Flux_i = Flux delivered from upstream + Flux generated in local catchment

$$F_i^{*} = \left(\sum_{j \in J(i)} F_j' \right) \delta_i A\left(\mathbf{Z}_i^S, \mathbf{Z}_i^R; \theta_S, \theta_R\right) + \left(\sum_{n=1}^{N_S} S_{n,i} \alpha_n D_n\left(\mathbf{Z}_i^D; \theta_D\right) \right) A'\left(\mathbf{Z}_i^S, \mathbf{Z}_i^R; \theta_S, \theta_R\right).$$

Schwarz et al., 2006

i = stream reach
j = upstream reach(es)
n= sources

D = overland delivery function (DVF_i)
A = fluvial delivery function
α, θ = estimated coefficients

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The SPARROW Model

- Source Specification:

Input Variable	Interpretation of Model-Estimated Coefficient
Mass from a particular source	Mean proportion of that mass reaching local streams
Area of a particular landscape setting	Mean yield of contaminant from that setting to local streams

Flux_i = Flux delivered from upstream + Flux generated in local catchment

$$F_i^* = \left(\sum_{j \in J(i)} F_j' \right) \delta_i A\left(\mathbf{Z}_i^S, \mathbf{Z}_i^R; \boldsymbol{\theta}_S, \boldsymbol{\theta}_R\right) + \left(\sum_{n=1}^{N_S} S_{n,i} \alpha_n D_n\left(\mathbf{Z}_i^D; \boldsymbol{\theta}_D\right) \right) A'\left(\mathbf{Z}_i^S, \mathbf{Z}_i^R; \boldsymbol{\theta}_S, \boldsymbol{\theta}_R\right).$$

Schwarz et al., 2006

i = stream reach
j = upstream reach(es)
n= sources (S)

D = overland delivery function (DVF_i)
A = fluvial delivery function
α, θ = estimated coefficients

Approach

- Calibrate individual SPARROW models for 1992, 2002, and 2012 using:
  - A common stream network, land-to-water specification, and aquatic decay specification
  - Flow-normalized annual loads for 1992, 2002, and 2012 at the same group of sites (for calibration)
  - Consistent and comparable land-use and atmospheric and point sources (as source terms)
- Evaluate estimated source coefficients (α_n) to understand trends

$Flux_i$ = Flux delivered from upstream + Flux generated in local catchment

$$F_i^* = \left(\sum_{j \in J(i)} F_j' \right) \delta_i A\left(\mathbf{Z}_i^S, \mathbf{Z}_i^R; \boldsymbol{\theta}_S, \boldsymbol{\theta}_R\right) + \left(\sum_{n=1}^{N_S} S_{n,i} \alpha_n D_n\left(\mathbf{Z}_i^D; \boldsymbol{\theta}_D\right) \right) A'\left(\mathbf{Z}_i^S, \mathbf{Z}_i^R; \boldsymbol{\theta}_S, \boldsymbol{\theta}_R\right).$$

Schwarz et al., 2006

i = stream reach
j = upstream reach(es)
n= sources

D = overland delivery function (DVF_i)
A = fluvial delivery function
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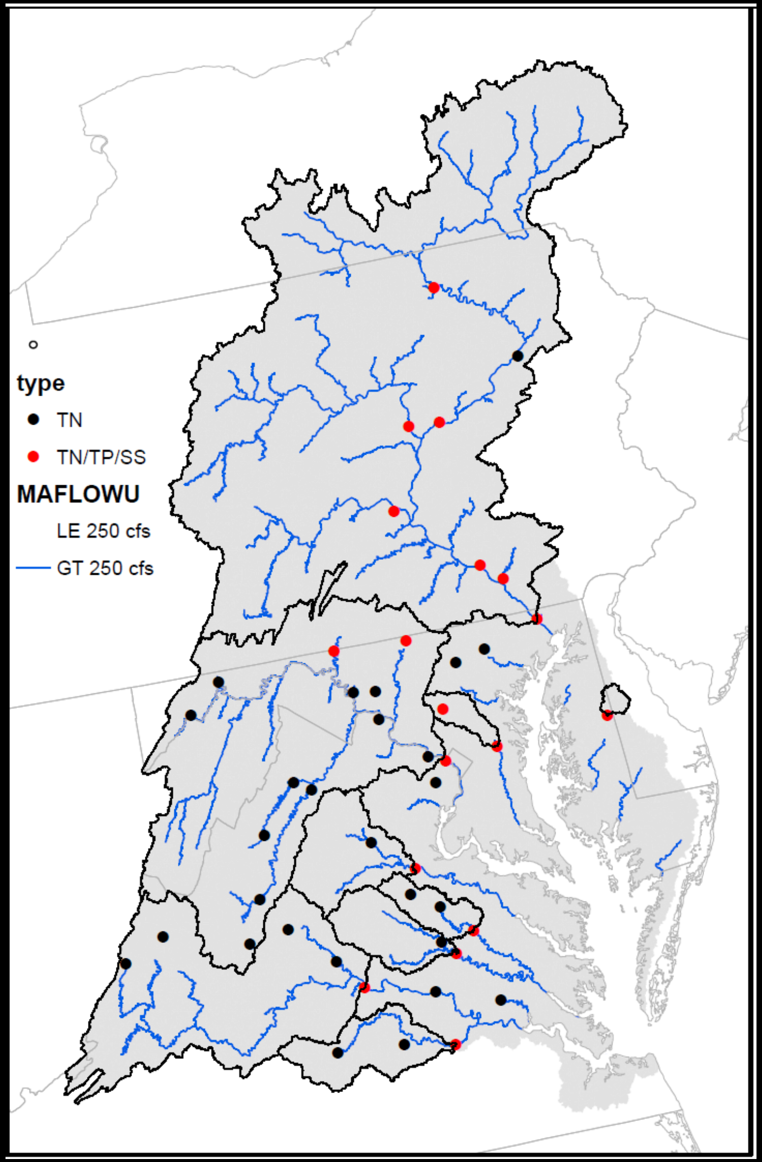
Inputs: Calibration Data

- Flow-normalized annual loads are estimated and published for sites in the Chesapeake non-tidal monitoring network (NTN)
- With loads for 1992, 2002, and 2012:
  - TN (n=45 sites)
  - TP and SS (n=18 sites)



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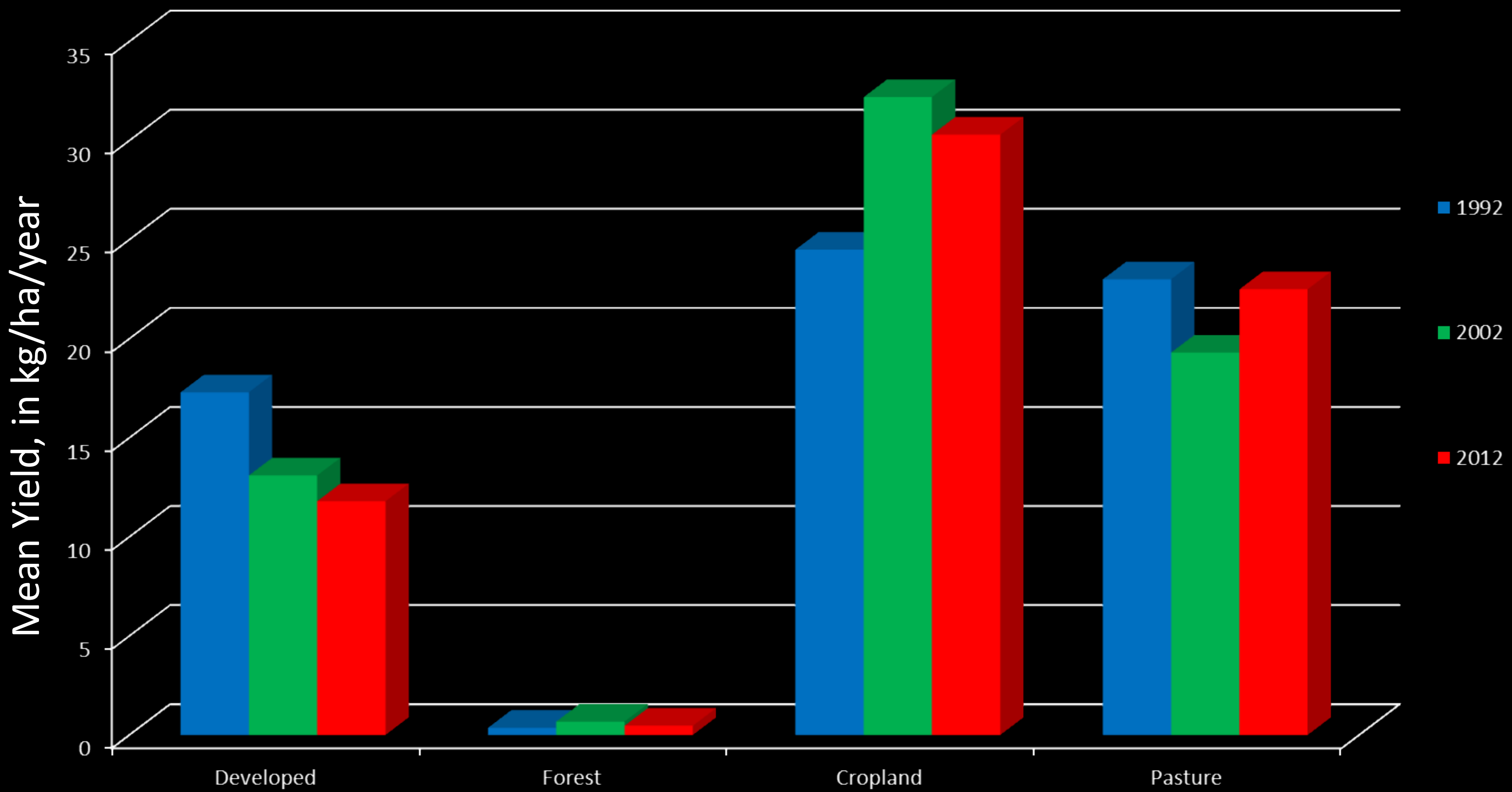
Preliminary Nitrogen Models

	Explanatory Variable	1992		2002		2012	
		Coef	p	Coef	p	Ceof	p
Sources	Point sources (kg)	1.78	0.0213	1.38	0.0533	0.687	0.1416
	Developed (ha)	17.3	0.0003	13.1	0.0018	11.8	0.0016
	Forest (ha)	0.37	0.3170	0.68	0.2166	0.47	0.3006
	Cropland (ha)	24.5	0.0070	32.2	0.0055	30.3	0.0047
	Pasture (ha)	23.0	0.0001	19.3	0.0008	22.5	0.0004
L2W	GW recharge	0.924	0.0226	0.631	0.1671	0.783	0.0516
	Soil AWC	-1.43	0.0326	-1.15	0.1106	-1.22	0.0401
	Pied. carbonate	0.247	0.0505	0.279	0.0257	0.232	0.0483
Aquatic	Res Decay (d)	0.004	0.0526	0.004	0.0760	0.006	0.0543
	Small Str Decay (d)	0.539	0.0102	0.574	0.0165	0.559	0.0177
	Large Str Decay (d)	0.085	0.0999	0.067	0.1708	0.069	0.1738

Preliminary Nitrogen Models



Next Steps

- Post-processor to:
  - Test H_0: source coefficients are not significantly different among time steps
  - Evaluate relative importance of changing sources (ie. land-uses) vs. changing average yield from each source (ie. model coefficients) to observed changes in stream chemistry.
- Look at change in average yields for different hydrogeologic settings

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For More Information….

- Ator, S.W., Brakebill, J.W., and Blomquist, J.D., 2011, Sources, fate, and transport of nitrogen and phosphorus in the Chesapeake Bay Watershed-An empirical model: U.S. Geological Survey Scientific Investigations Report 2011-5167. http://pubs.er.usgs.gov/publication/sir20115167
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