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National Water Quality Program
National Water Quality Assessment Project

Chesapeake Bay Science Team

Assessing the Causes of Changes in Nutrient Loading from Major Tributaries of Chesapeake Bay

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10th National Monitoring Conference

Motivation for Focus on Causes

The attribution of the causes of trends in nutrient loading is often limited to

correlation,
qualitative reasoning, or
simply references to the work of others.

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Causal Attribution Examples from a Variety of USGS Studies

Trends **may** have been related to live s.

Results suggest that soils or agricultural practices contributed to high phosphorus … & that effluent from … wastewa plants lik to high p

Upgrades at this [wastewater treatment facility] and other point sources … may have resulted in substantial changes to inputs with a combined ially t flux of

Decreases in row-crop agricultural activities & improved wastewater treatment were **suggested** as **possible** causes for nitrate decline.

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Motivation for Choosing the Chesapeake Bay

Provides an ideal regional test case

because of the availability of nutrient data from a large network of fairly long-term sites

&

well-developed geospatial data describing changes in potential causal factors over time.

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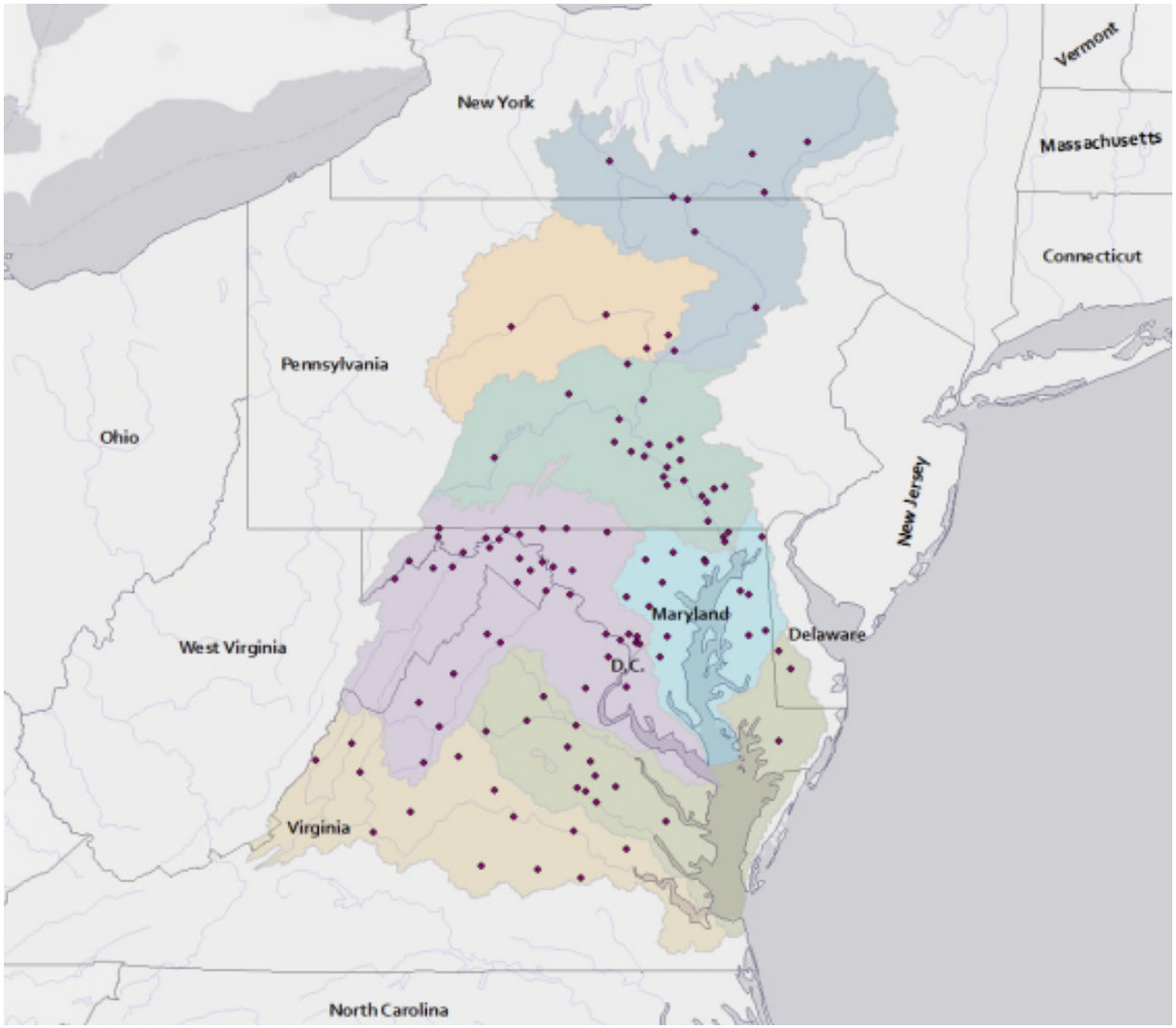
Non-tidal Network Sites

Long-term total phosphorus and nitrogen loads are available at a subset of these sites, as well as extensive ancillary data at each site.



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Structural Equation Modeling

SEM

Supports the testing of causal hypotheses.

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Loads and Causal Hypotheses

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Loads Calculated Using WRTDS

Weighted Regressions on

- Time,
- Discharge (streamflow),
- and Season.

Smoothing model that computes estimates of concentration and load, or flux, for every day in the study period.

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Hirsch, R.M, Moyer, D.L., and Archfield, S.A., 2010, Weighted Regressions on Time, Discharge, and Season (WRTDS), with an Application to Chesapeake Bay River Inputs, Journal of the American Water Resources Association p. 857-880.

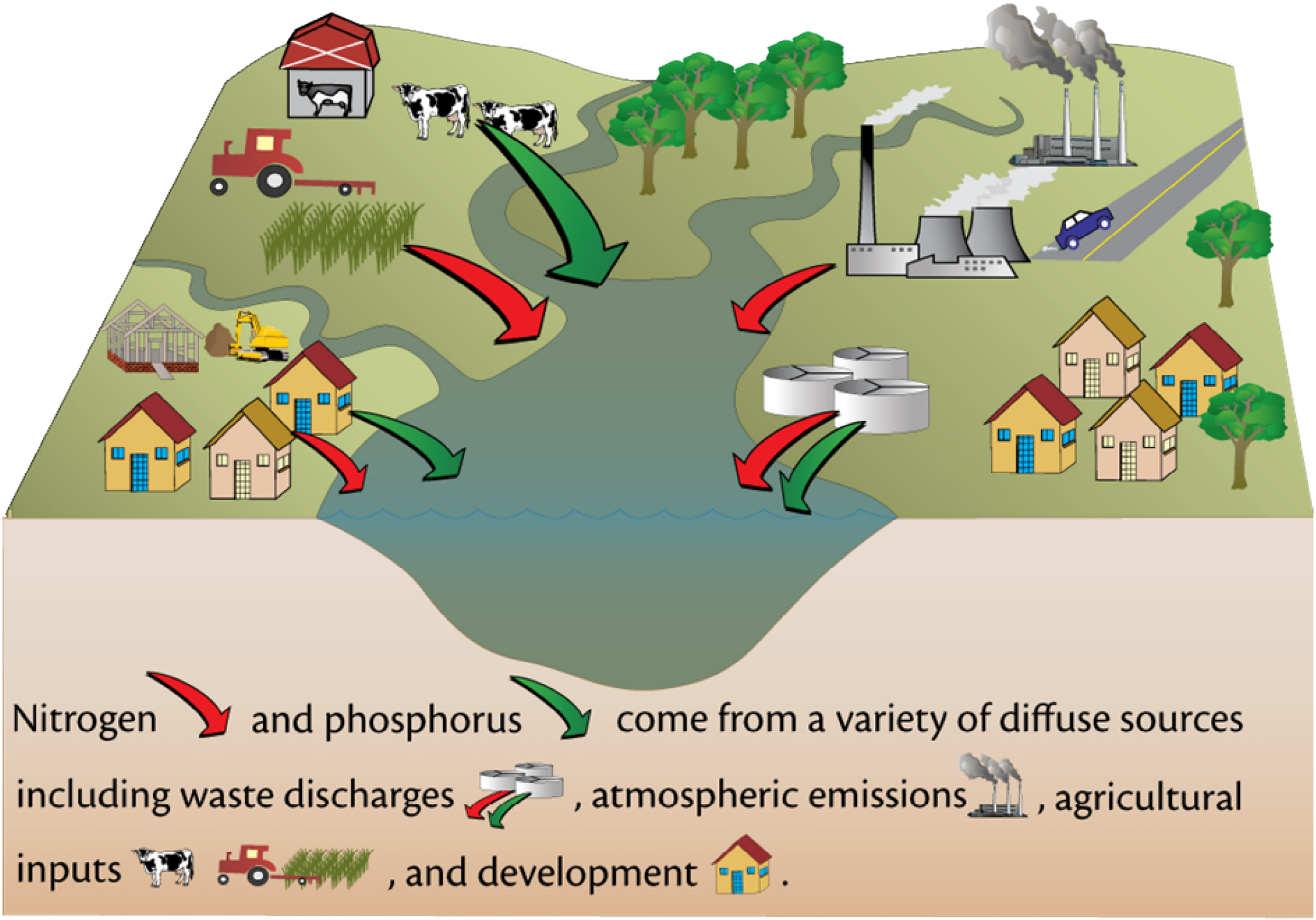

Diagram courtesy of the Integration and Application Network (ian.umces.edu), University of Maryland Center for Environmental Science. Source: Lane, H., J.L. Woerner, W.C. Dennison, C. Neill, C. Wilson, M. Elliott, M. Shively, J. Graine, and R. Jeavons. 2007. Defending our National Treasure: Department of Defense Chesapeake Bay Restoration Partnership 1998-2004. Integration and Application Network, University of Maryland Center for Environmental Science, Cambridge: MD.

Subset of Multiple Working Hypotheses for Nitrogen Loads

Causal factors	Potential influence	Data	Decision
		Agriculture	
Fertilizer	Fertilizer makes its way to the stream in crop residue or is adsorbed to sediments that may make their way to the stream.	Annual fertilizer data are available for the sites for the period 1950-2012 for ag census years. Data also available from National Water-Quality Assessment (NAWQA) project	Use Chesapeake Bay Team data
Animal waste	Animal waste, particularly in the form of manure used as fertilizer contributes N to streams. Some BMPs are designed to encourage volatilization. Waste could be mobilized directly by overland flow or be part of soils eroded to streams.	Annual manure data are available for the sites for the period 1950-2012 for ag census years. An interpolated dataset and non interpolated, may use multivariate imputation of missing values with principal components analysis to estimate missing years. Data also available from NAWQA	Use Chesapeake Bay Team data
CRP (as surrogate for management practices)	Biggest effect is that it is no longer in production - no fertilizer being applied. May impact soil erosion. CRP related to other economic and climatic factors.	Data compiled by USGS NAWQA	Use NAWQA data

Data for Potential Causal Factors

The BIGGEST Challenge

Will be published in a USGS Data Release

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Examples of Data Determined Feasible to Attempt Use in the Chesapeake Bay

- Annual precipitation
  - Including measures of annual seasonal precipitation
- Land use
  - Percent land developed and in agricultural production
- Crop types
  - Percent of ag land harvested corn and soybeans
- Palmer Hydrologic Drought Index
- Atmospheric deposition
- Wastewater treatment plant effluent

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The Challenge

Widely varying periods of record

Some annual series, some every 5 years, every 4 years, or varying measurement intervals

Annual estimates needed

At right is an example of the missing data problem for select years during the study period.

✕ No data available
✓ Data available
NA not applicable to that time period

Year	Land Use	CRP	Crops	WWTP Load
1972	✕	NA	✕	✕
1986	✕	✓	✓	✓
1987	✕	✓	✕	✕
1988	✕	✓	✕	✓
1989	✕	✓	✕	✕
1990	✕	✓	✕	✓
1991	✕	✓	✕	✕
1992	✓	✓	✓	✓
2012	✓	✓	✓	✓

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Missing Years Estimated

- In some cases, there was little change over multi-year periods, so missing years were filled in with linear interpolation.

- Many other variables have much more year-to-year variability. They can be estimated using multivariate imputation of missing values with principal components analysis.

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Structural Equation Modeling

Preliminary

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Structural Equation Modeling

"Unlike the more traditional multivariate linear model, … the response variable in one regression equation in an SEM may appear as a predictor in another equation; indeed, variables in an SEM may influence one-another reciprocally, either directly or through other variables as intermediaries.

These structural equations are meant to represent causal relationships among the variables in the model" (Fox, 2002).

Fox, John, 2002, Structural Equation Models: Appendix to an R and S-PLUS companion to applied regression, http://cran.r-project.org/doc/contrib/Fox-Companion/appendix-sems.pdf

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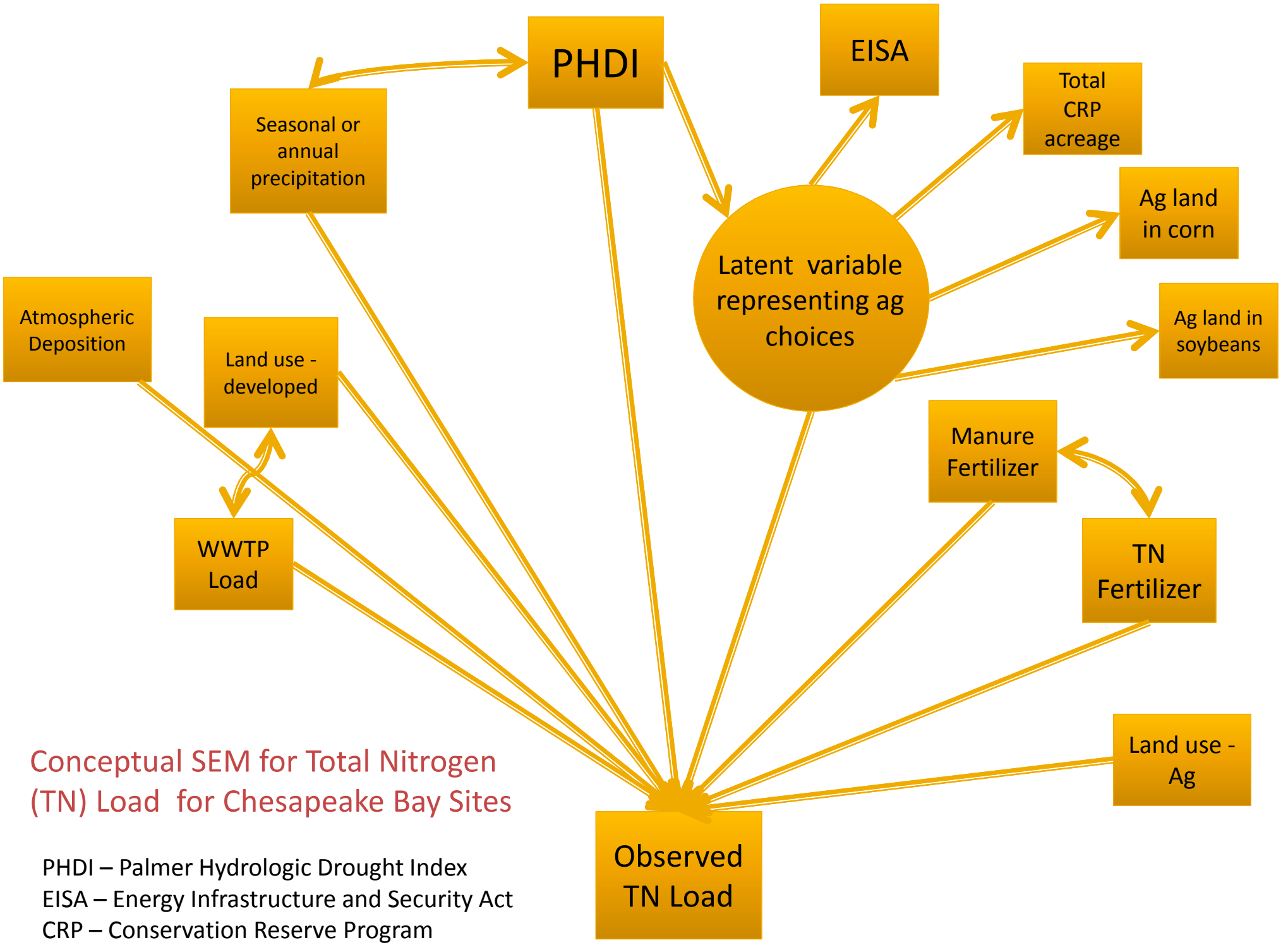

Conceptual SEM for Total Nitrogen (TN) Load for Chesapeake Bay Sites

PHDI – Palmer Hydrologic Drought Index
EISA – Energy Infrastructure and Security Act
CRP – Conservation Reserve Program

Structural Equation Modeling

In pursuit of knowledge, every day something is acquired;
in pursuit of wisdom, every day something is dropped.

- Lau Tzu

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Actual Working Model

Explains about 70% of the variability in total nitrogen load at four sites on the Susquehanna/ West Branch of Susquehanna.

Measured variable

Latent variable

Directional effect

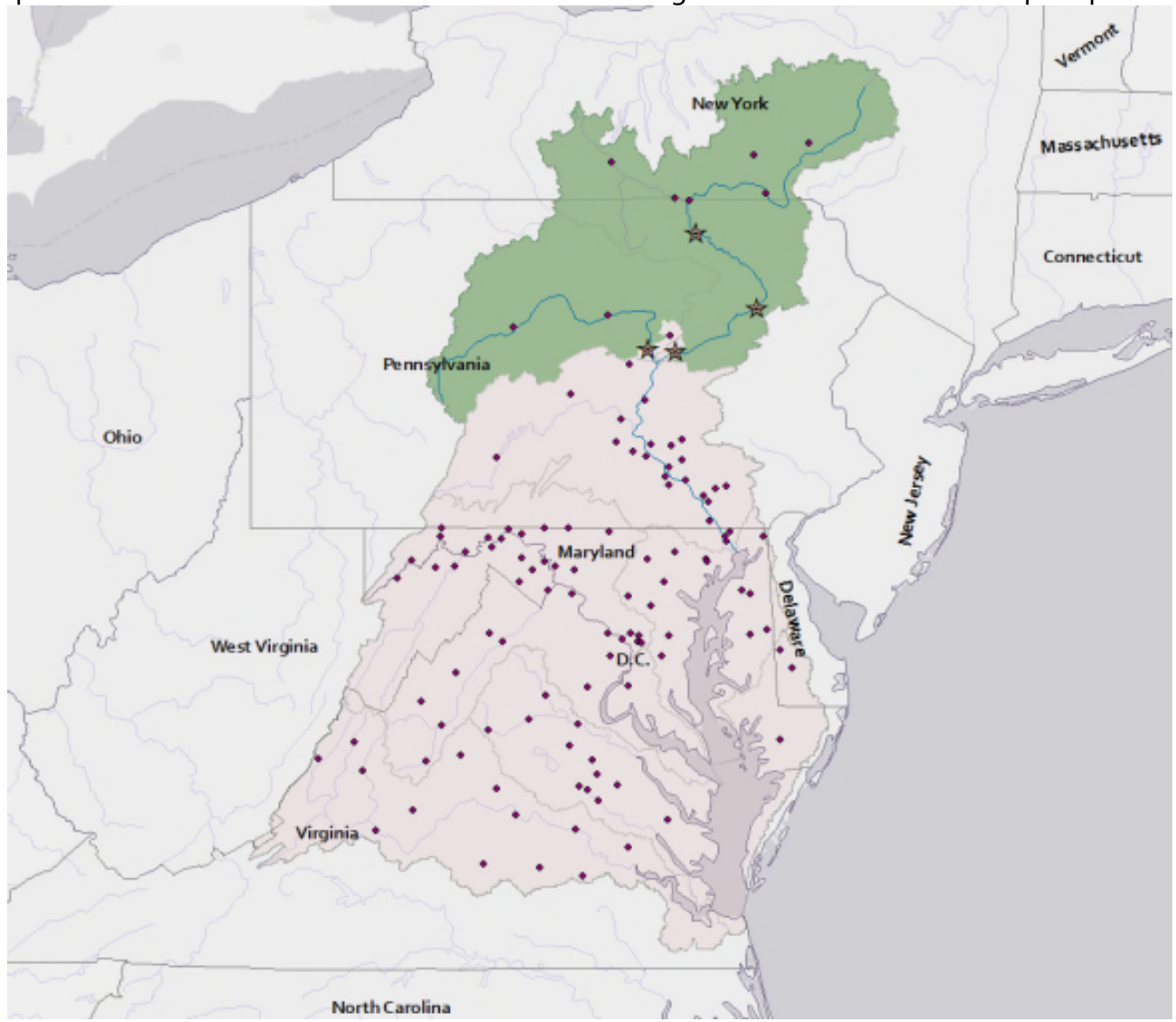
Correlation

% land in ag production

% ag land harvested corn

Annual amount of nitrogen-based fertilizer

Calendar year precipitation



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More to Come….

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Thanks to other members of our respective teams for their input and assistance.

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