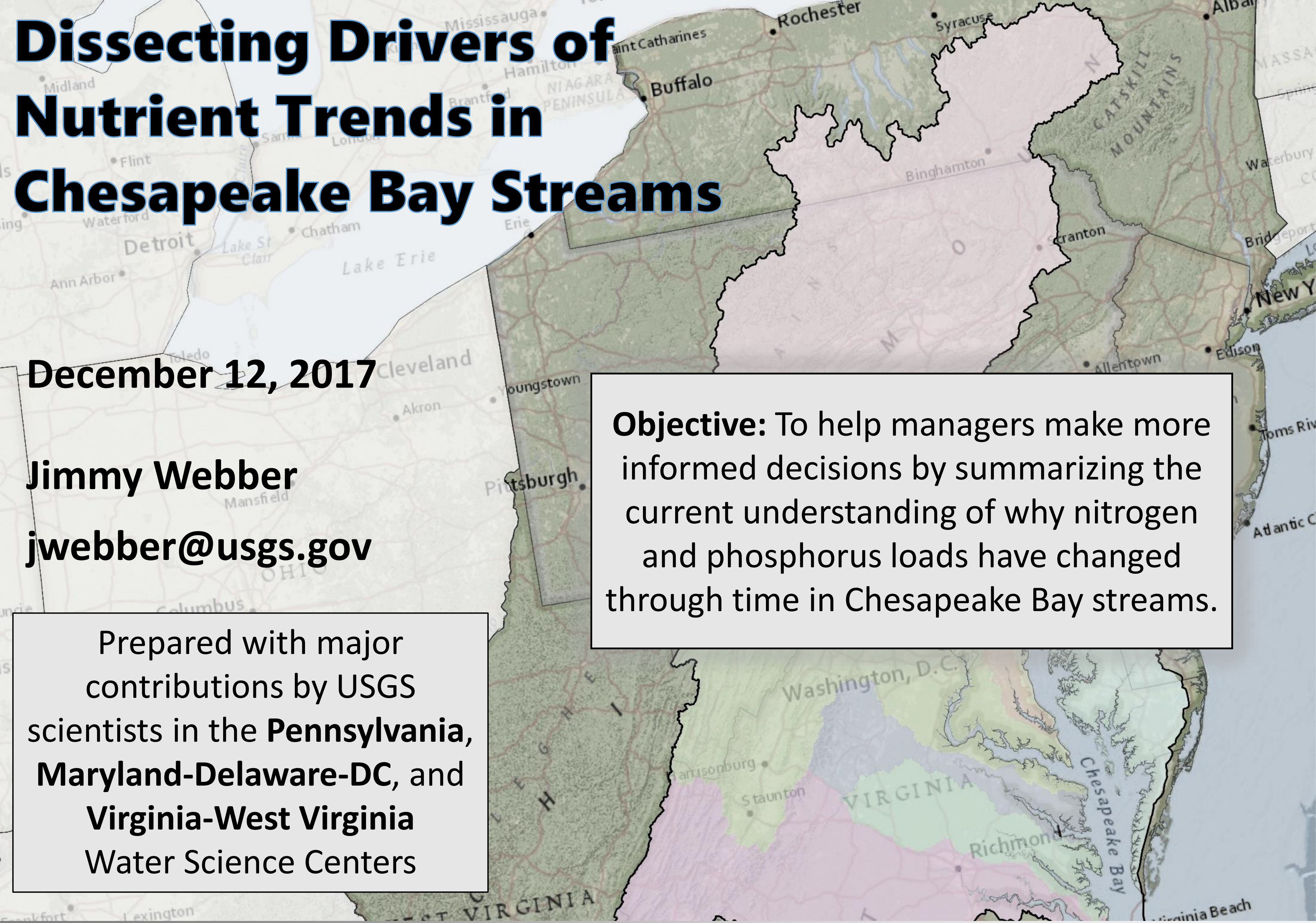


Dissecting Drivers of Nutrient Trends in Chesapeake Bay Streams

December 12, 2017

Jimmy Webber

jwebber@usgs.gov

Objective: To help managers make more informed decisions by summarizing the current understanding of why nitrogen and phosphorus loads have changed through time in Chesapeake Bay streams.

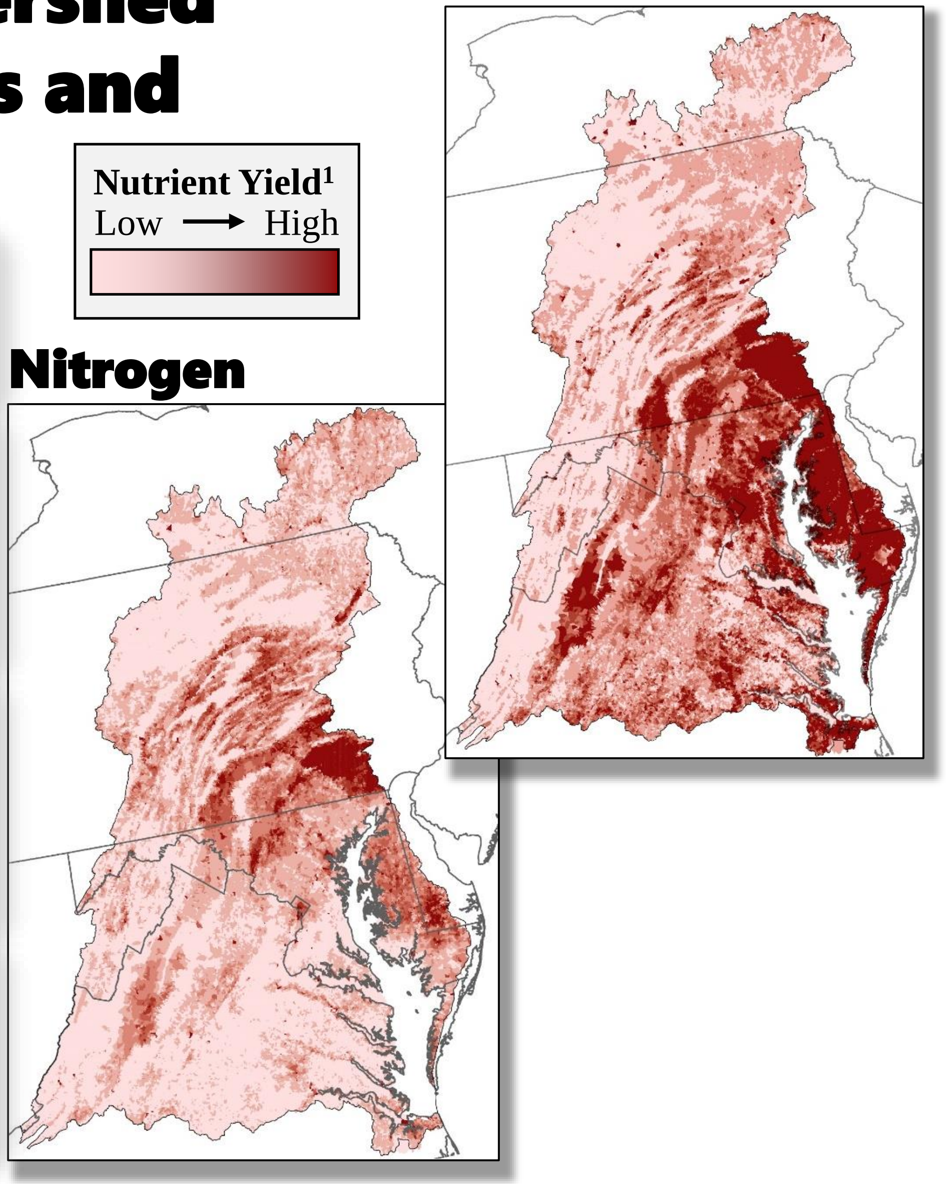
Prepared with major contributions by USGS scientists in the **Pennsylvania**, **Maryland-Delaware-DC**, and **Virginia-West Virginia** Water Science Centers

Nitrogen and phosphorus loads vary throughout the watershed based on human activities and environmental settings

Nutrient loads measured in streams throughout the watershed are highly variable as a result of:

1. The amount of nutrients applied to the landscape or added directly to streams (“*nutrient inputs*”), which reflects the intensity of human activities.
2. The movement of nutrients from the landscape to streams (*“nutrient transport”*), which is primarily a function of geologic setting and climatic conditions.

Nutrient loads may change over time as a result of changing nutrient inputs or changing nutrient transport



Nutrient Yield[1]

Low → High

Nitrogen

Phosphorus

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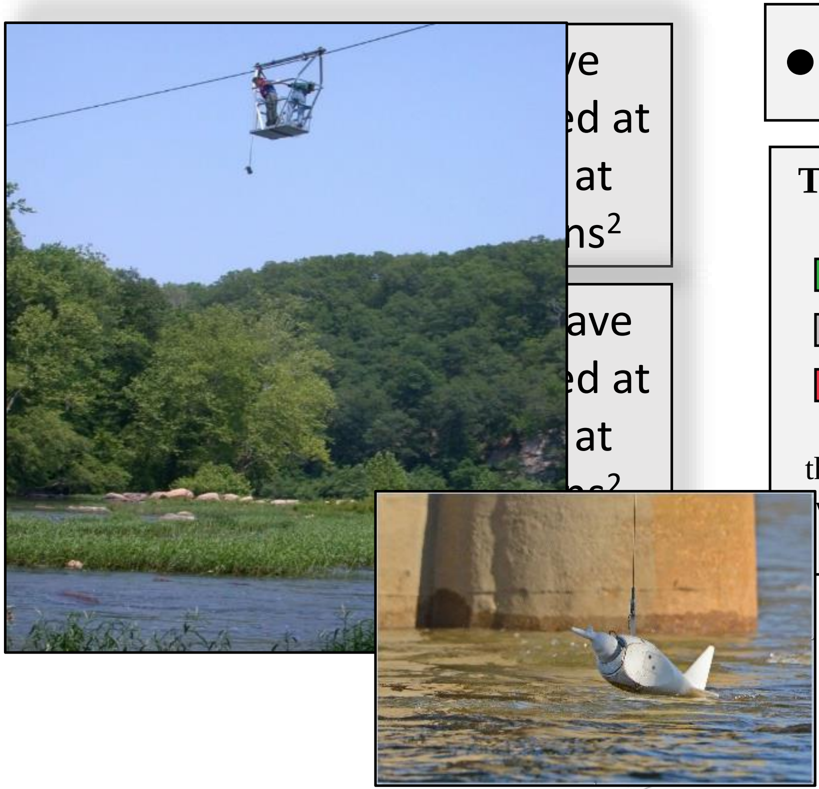
[1] Ator and others, 2011.

Reductions in nitrogen and phosphorus loads have been observed in some streams in recent years



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● Nontidal Network Monitoring Station

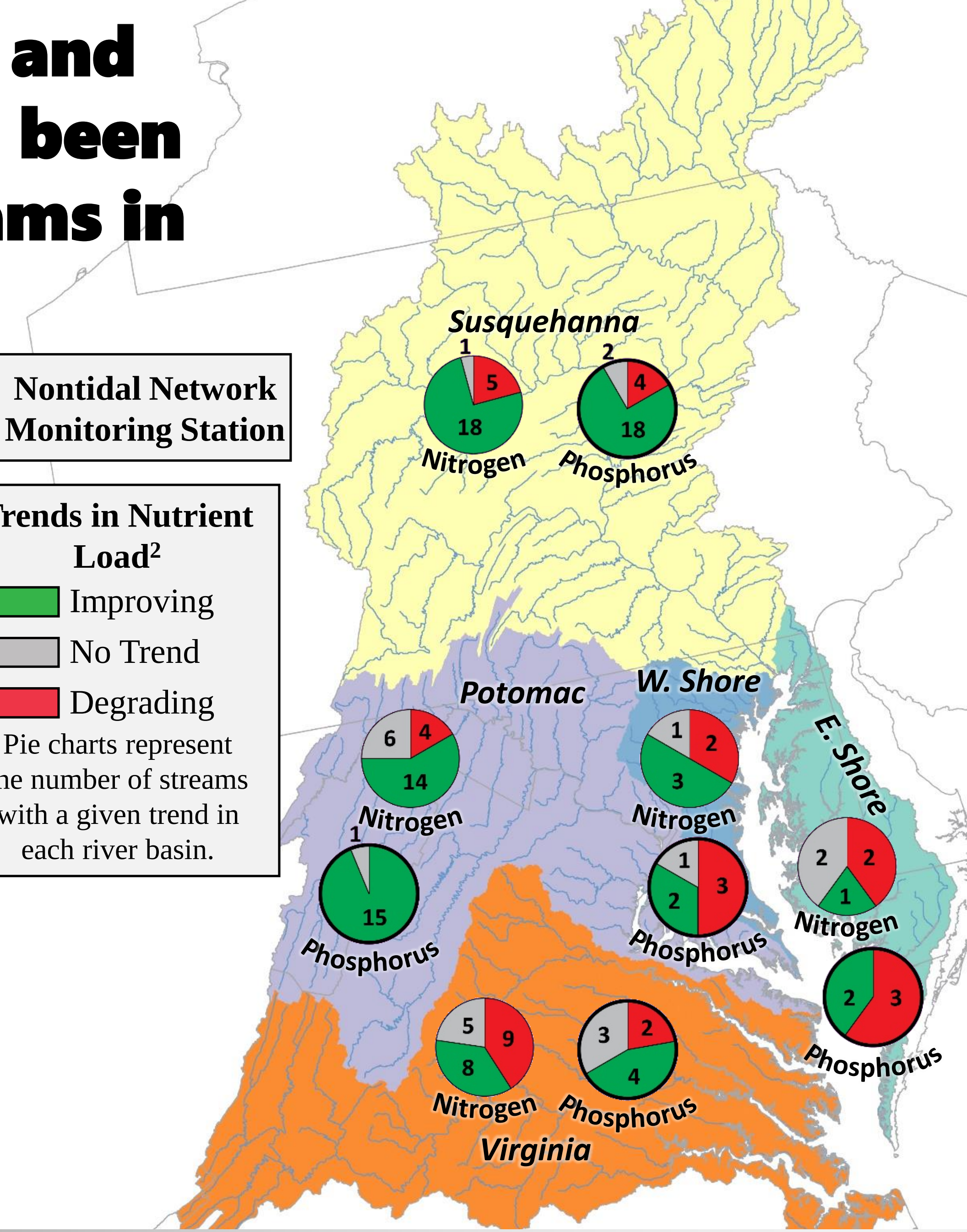
Trends in Nutrient Load[2]

🟩 Improving

▨ No Trend

🟥 Degrading

Pie charts represent the number of streams with a given trend in each river basin.



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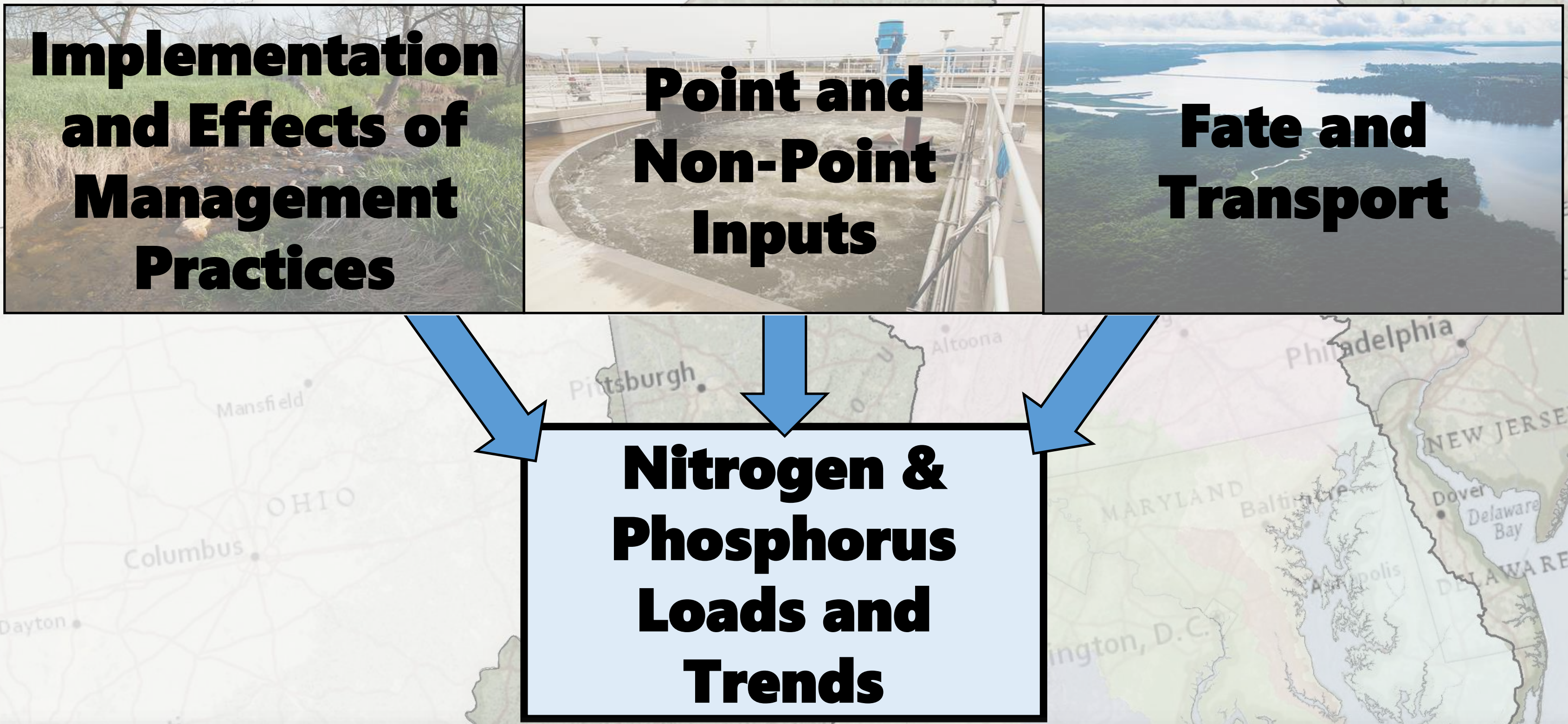
[2] Between 2005 or 2006 and 2014, as reported by the Weighted Regression on Time, Discharge, and Season (WRTDS) model; Moyer and others, 2017; https://www.sciencebase.gov/catalog/item/59403814e4b0764e6c63121b

What are the primary drivers of nutrient trends?



Implementation and Effects of Management Practices

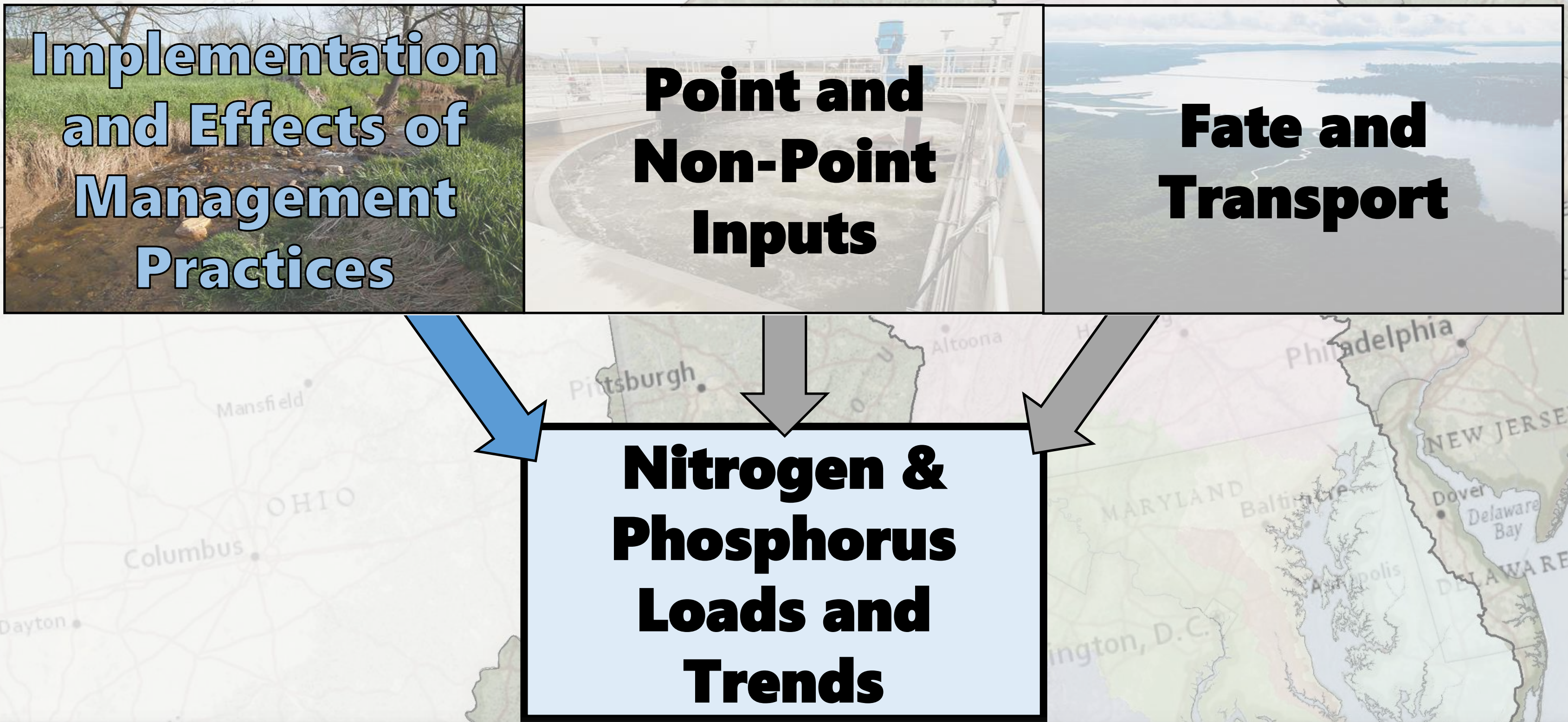
Point and Non-Point Inputs

Fate and Transport

Nitrogen & Phosphorus Loads and Trends

Nutrient loads and trends are a function of highly variable land use, inputs, and environmental settings. Integrative tools have been developed that account for many of these interactions.

What are the primary drivers of nutrient trends?



Implementation and Effects of Management Practices

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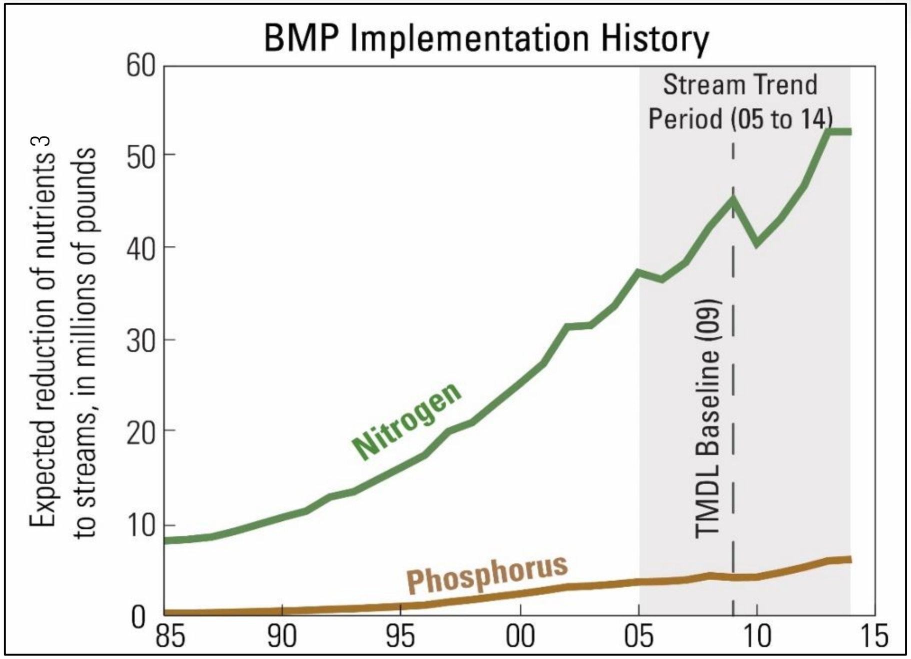
Nitrogen & Phosphorus Loads and Trends

Nutrient loads and trends are a function of highly variable land use, inputs, and environmental settings. Integrative tools have been developed that account for many of these interactions.

The implementation of management practices intended to reduced nutrient transport has increased through time, but expected reductions have not occurred in all streams.

In 2014, management practices are estimated to have reduced **11%** of the nitrogen and **19%** the phosphorus load in Chesapeake Bay streams[3].



Field scale studies have highlighted the benefits of various management practices, but it remains a challenge to identify management practice effects at an integrated watershed scale[4,5].

[3]Sekellick and others, in review

[4]Staver and Brinsfield, 1998

[5]Liu and others, 2017

Why are nutrient loads not responding to management practice effects in all streams?

The expected reductions from management practices may be overly optimistic.

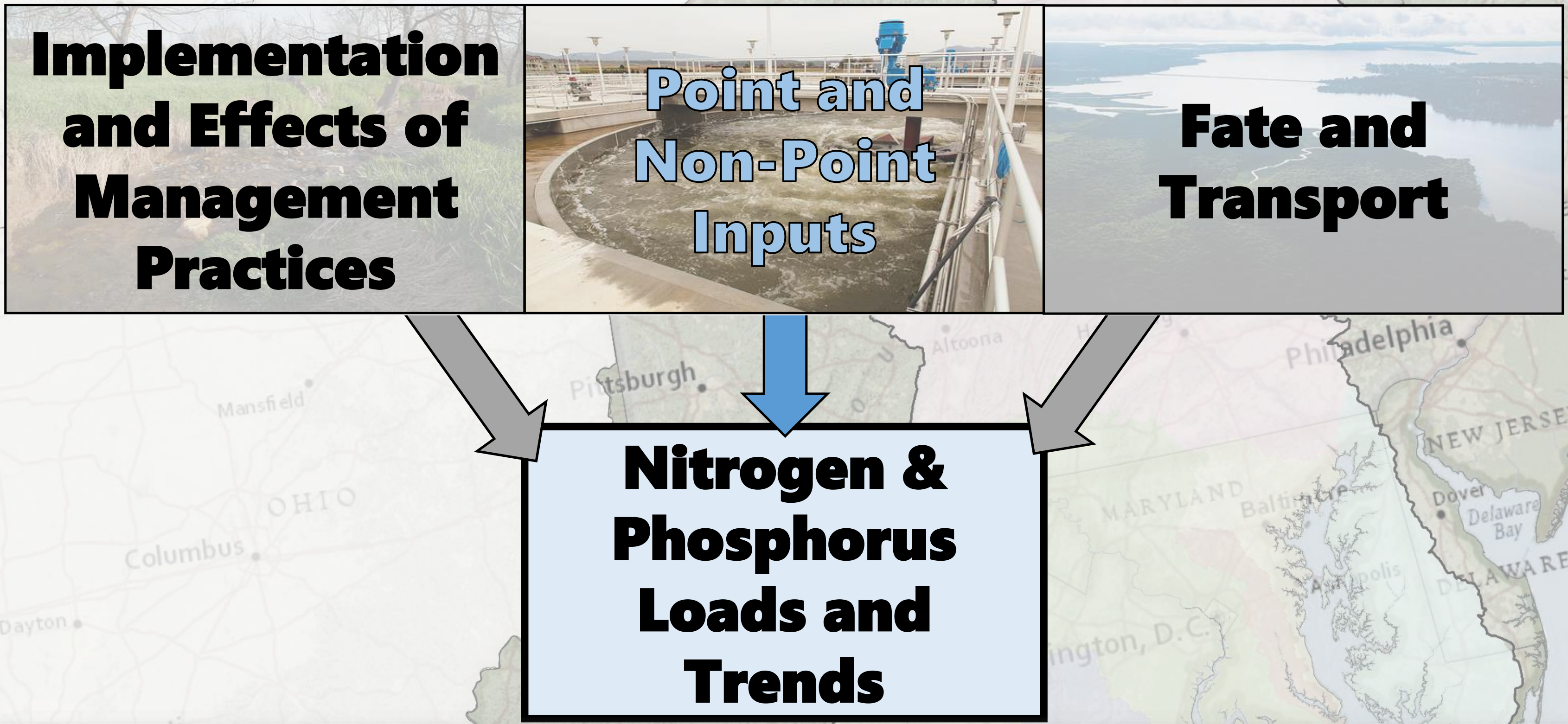
Management practice effects may be outweighed by new nutrient applications.

Our monitoring networks may not be sensitive enough to detect the level of change that has occurred.

Management practices may not target the dominant nutrient sources or transport pathways within a watershed.

Time lags between implementation and monitoring may have not aligned.

What are the primary drivers of nutrient trends?



Implementation and Effects of Management Practices

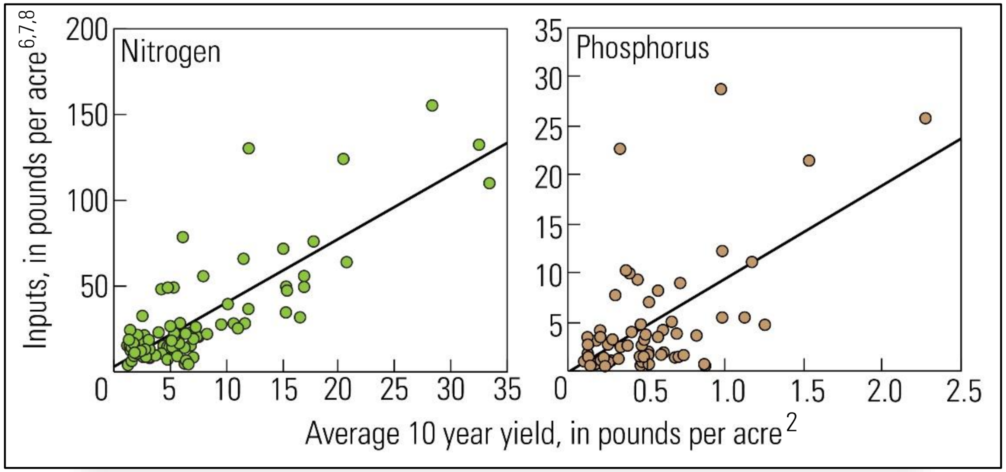
Point and Non-Point Inputs

Fate and Transport

Nitrogen & Phosphorus Loads and Trends

Nutrient loads and trends are a function of highly variable land use, inputs, and environmental settings. Integrative tools have been developed that account for many of these interactions.

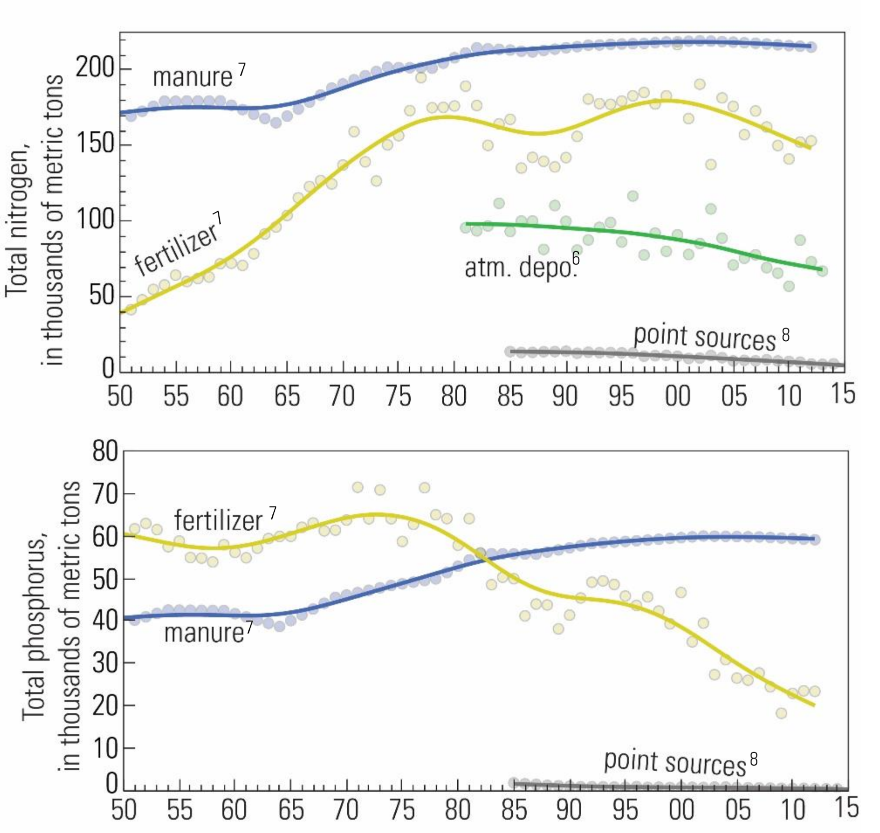
The load of nutrients delivered to streams is primarily determined by the mass of nutrients applied in the watershed



Changes in nutrient inputs do not fully explain nutrient trends because of highly variable interactions between landuse, inputs, and environmental setting.

But…

A significant, long-term reduction in nutrient inputs is the most effective way to reduce nutrient loads.



Additional nutrient sources include inputs from urban areas and naturally occurring phosphorus in sedimentary rocks.

[2] Moyer and others, 2017

[6] National Atmospheric Deposition Monitoring Program (NADP)

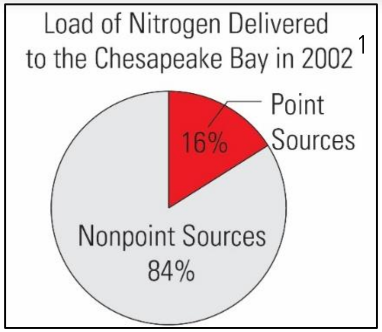
[7] Sekellick, 2017

[8] Chesapeake Bay Program (CBP) nutrient point source database

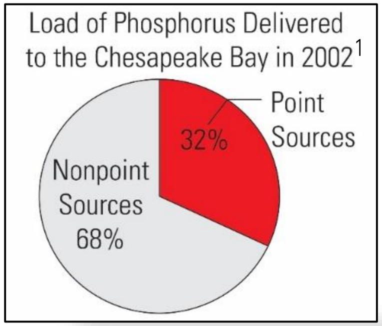
Reduced point source inputs have improved nutrient loads in some streams

Point source inputs include industrial and municipal wastewater discharges and combined sewer overflows.

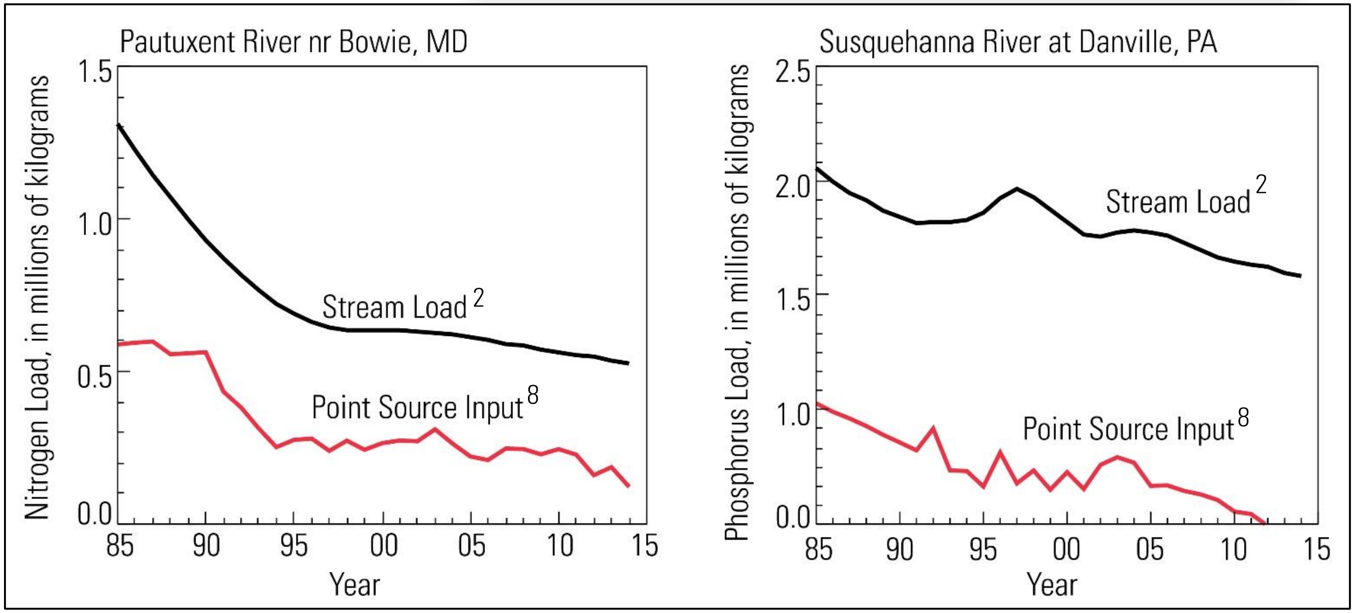
Water-quality responses to point source reductions can be observed relatively quickly because inputs are delivered directly to streams.



Load of Nitrogen Delivered to the Chesapeake Bay in 2002[1]



Load of Phosphorus Delivered to the Chesapeake Bay in 2002[1]



Continued improvements in wastewater treatment may be limited by available technology. Declines in non-point source inputs will be necessary to achieve continued nutrient reductions.

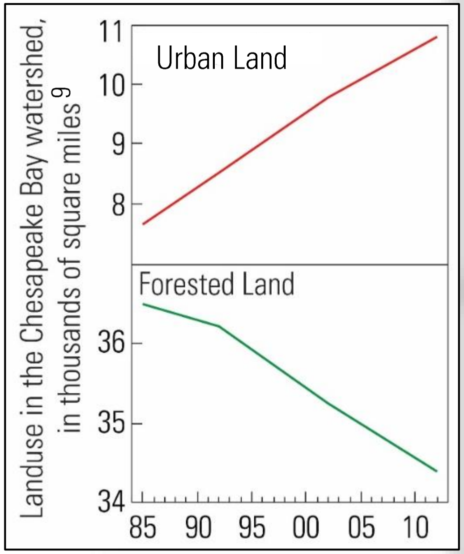
[1] Ator and others, 2011.

[2] Moyer and others, 2017

[8] CBP nutrient point source database

Urbanization typically adds nutrient inputs to a watershed

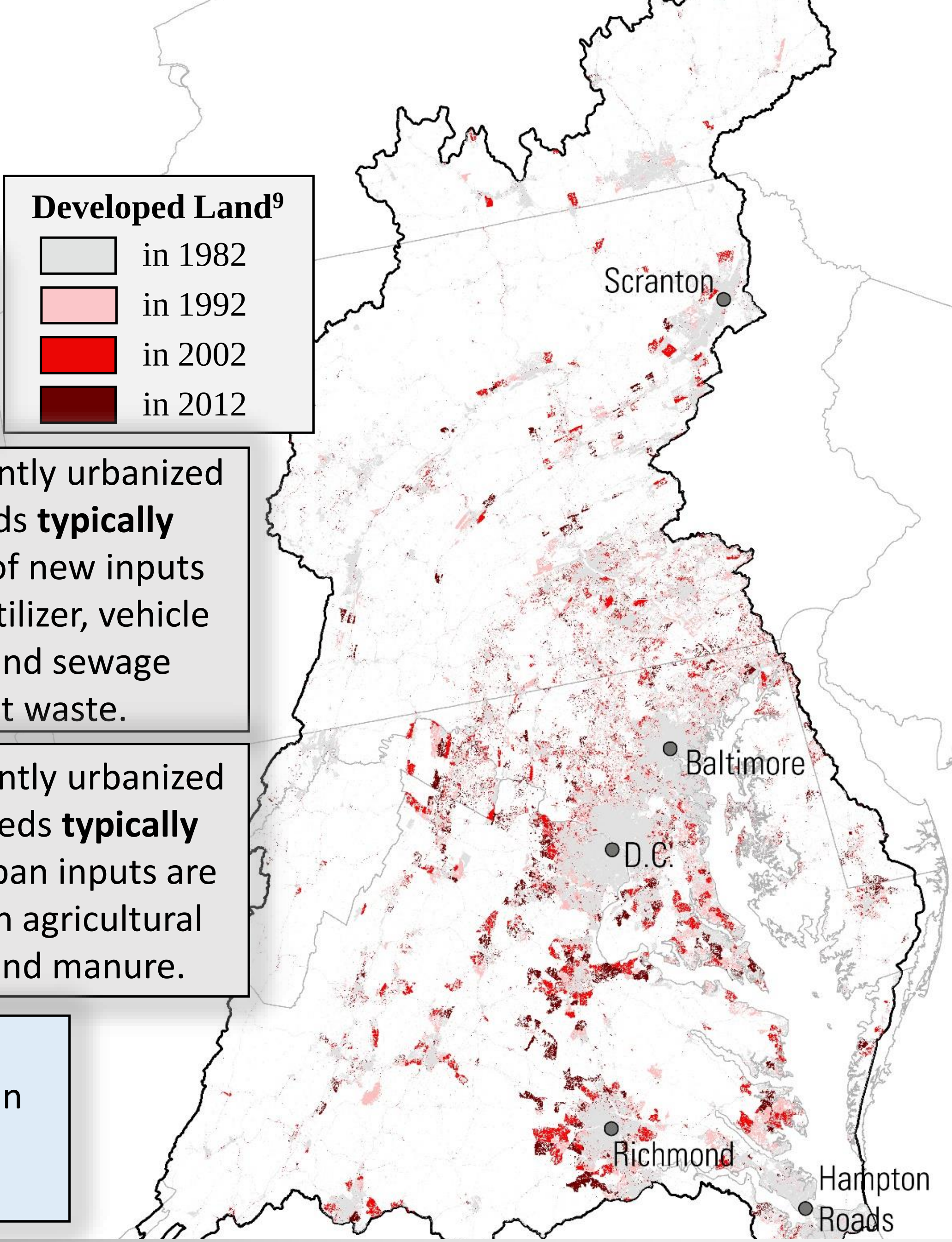
About 3,000 square miles of urban land were added to the watershed over the past 30 years, typically at the expense of forested land[9].



Nutrient loads in recently urbanized forested watersheds **typically increase** as a result of new inputs that include lawn fertilizer, vehicle emissions, septic and sewage effluent, and pet waste.

Nutrient loads in recently urbanized agricultural watersheds **typically decrease** because urban inputs are typically smaller than agricultural inputs of fertilizer and manure.

As population continues to grow in the watershed, effective management of urban nutrient loads will be needed to achieve mandated load reductions.



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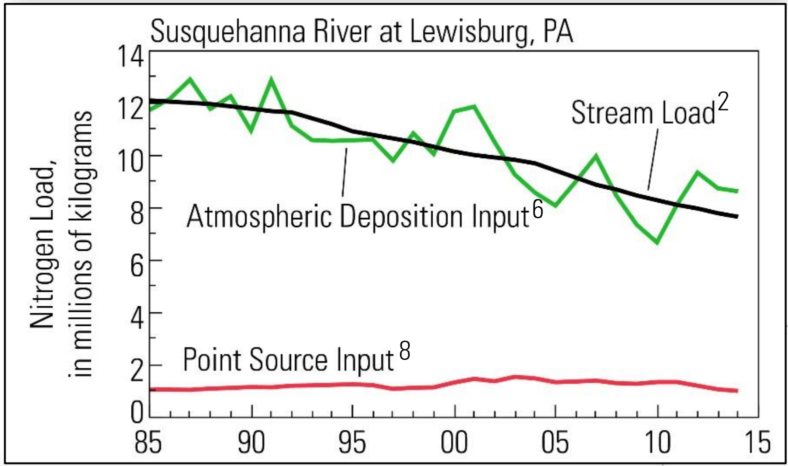
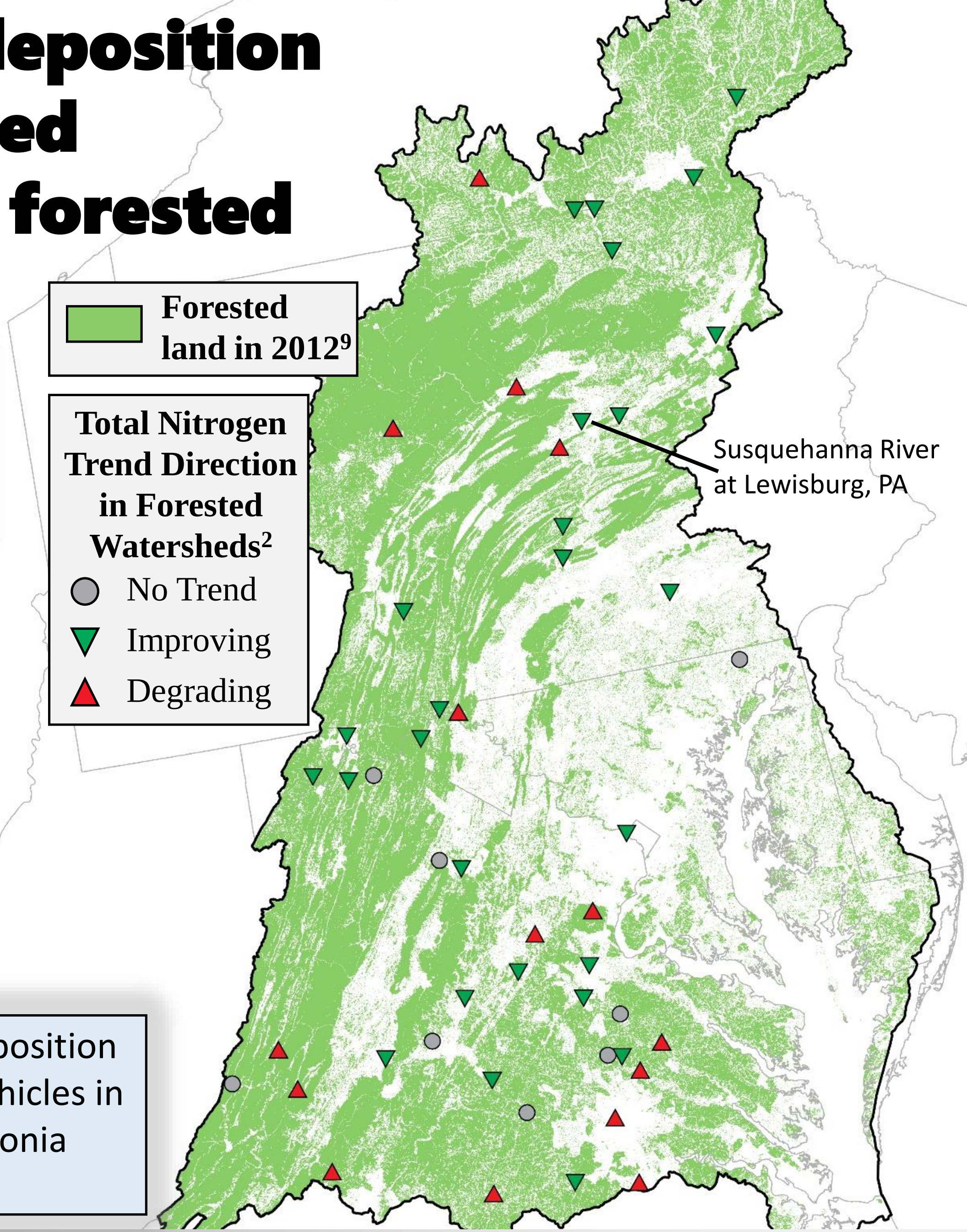
[9] Falcone, 2015.

Reduced atmospheric deposition of nitrogen has improved nitrogen loads in some forested watersheds[10]

Atmospheric deposition is a relatively minor source of nitrogen to the bay, but is the only source in heavily forested areas where other inputs are limited.



Larger reductions of atmospheric nitrogen deposition have been offset by the growing number of vehicles in the watershed and increased rates of ammonia volatilization from poultry houses[11].



🟩 **Forested land in 2012**[9]

Total Nitrogen Trend Direction in Forested Watersheds[2]

- ● No Trend
- ▼ Improving
- ▲ Degrading

---

[2] Moyer and others, 2017

[6] NADP

[8] CBP nutrient point source database

[9] Falcone, 2015.

[10] Eshelman and others, 2013

[11] Lyerly and others, 2014.

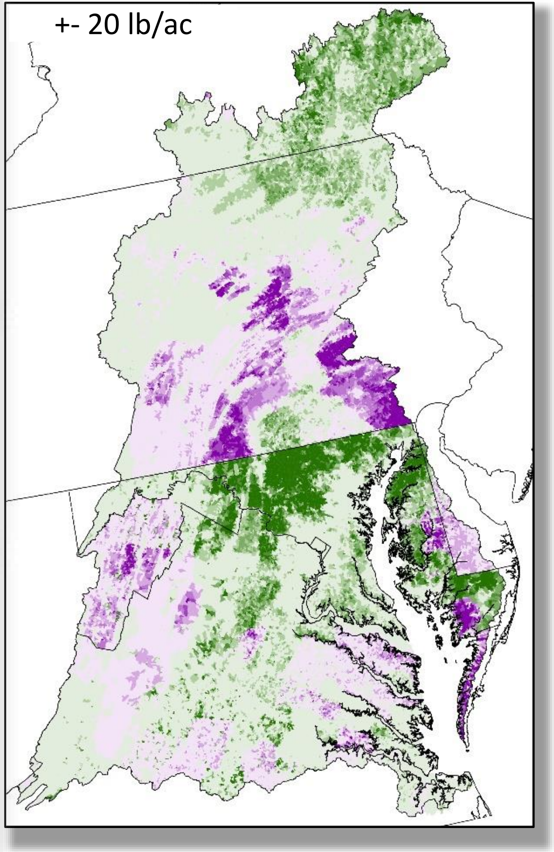
The intensity and location of agricultural practices has been redistributed throughout the watershed

Manure and fertilizer are the largest nutrient sources in the watershed and, despite an increase in management practices, inputs have not been consistently reduced throughout the watershed[12].

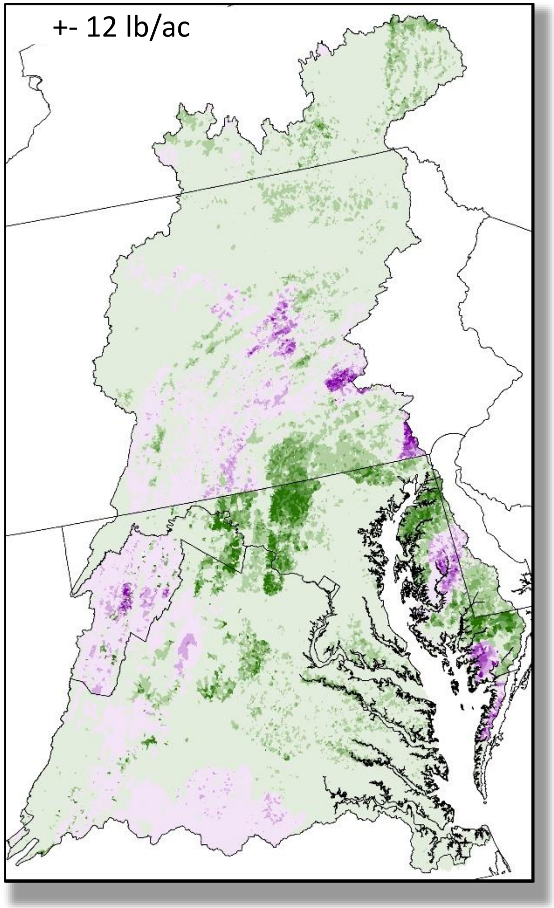
Intensification of animal agricultural practices has most commonly occurred from poultry expansion[12].

Field-scale studies have demonstrated that long-term, significant reductions of agricultural inputs will eventually result in reduced nutrient loads[13,14].

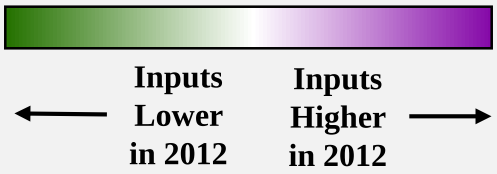
Nitrogen



Phosphorus



Change in agricultural inputs between 1985 and 2012[7]



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[7] Sekellick, 2017

[12] Keisman and others, in review

[13] Denver and others, 2010

[14] McCoy and others, 2010

Reductions in nutrient inputs do not always result in improved loads

Why?

Historical agricultural inputs of fertilizer and manure have resulted in **nitrogen storage in groundwater** and **phosphorus storage in soils**. The legacy effects of these processes can have major impacts on contemporary nutrient trends.

The **geology** and **climate** of the watershed can strongly influence the transport of nutrients from the landscape to streams. These factors can mitigate the benefits of or exacerbate the consequences of management actions.

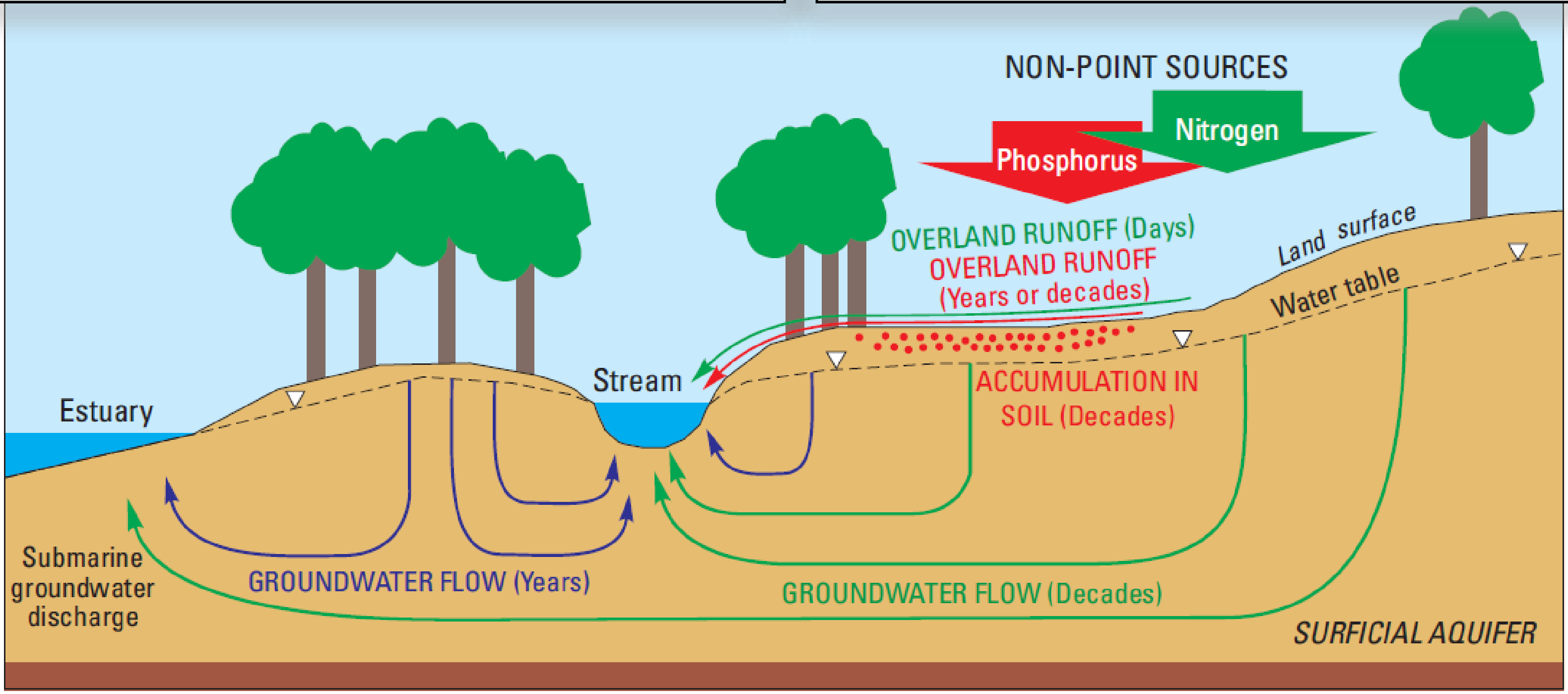
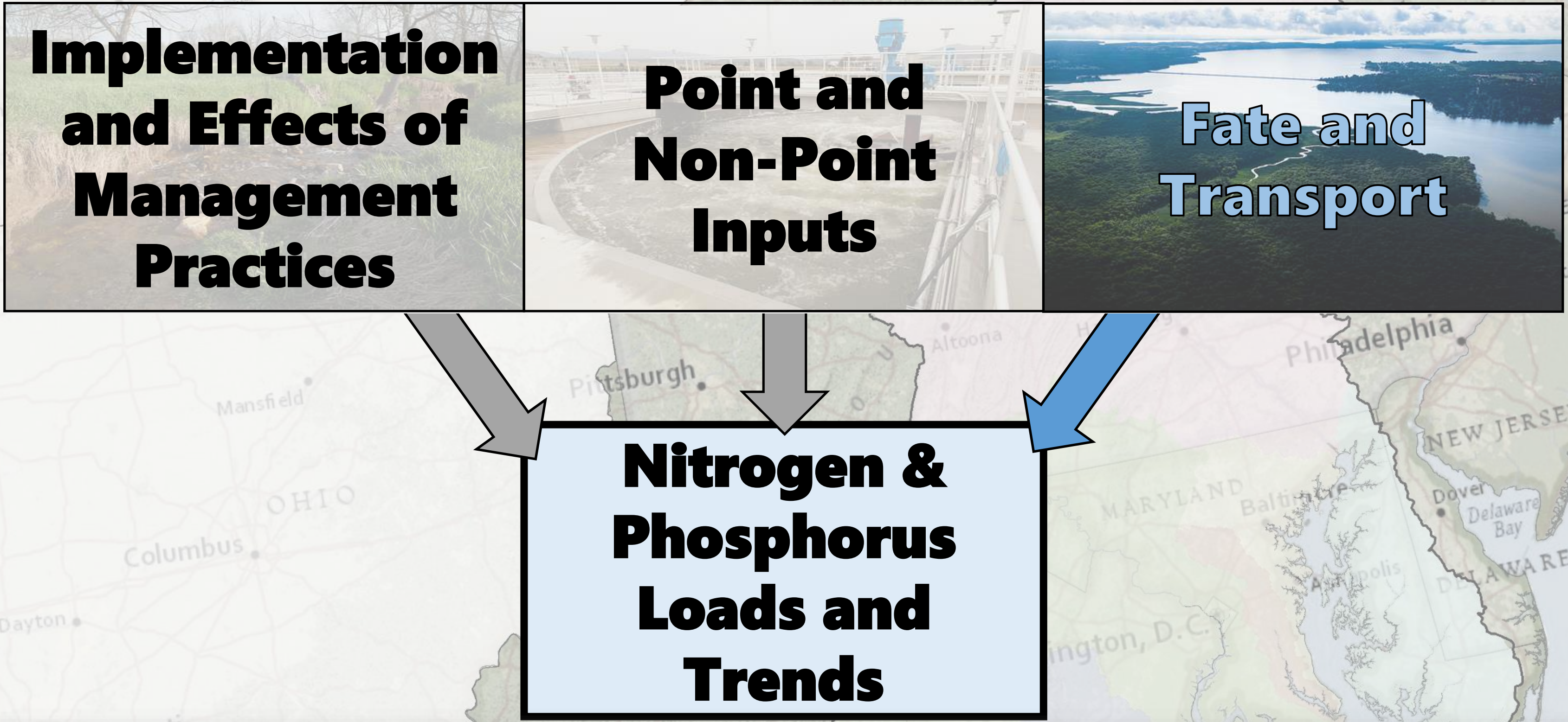


Figure adapted from
[15]Ator and Denver, 2015

What are the primary drivers of nutrient trends?



Implementation and Effects of Management Practices

Point and Non-Point Inputs

Fate and Transport

Nitrogen & Phosphorus Loads and Trends

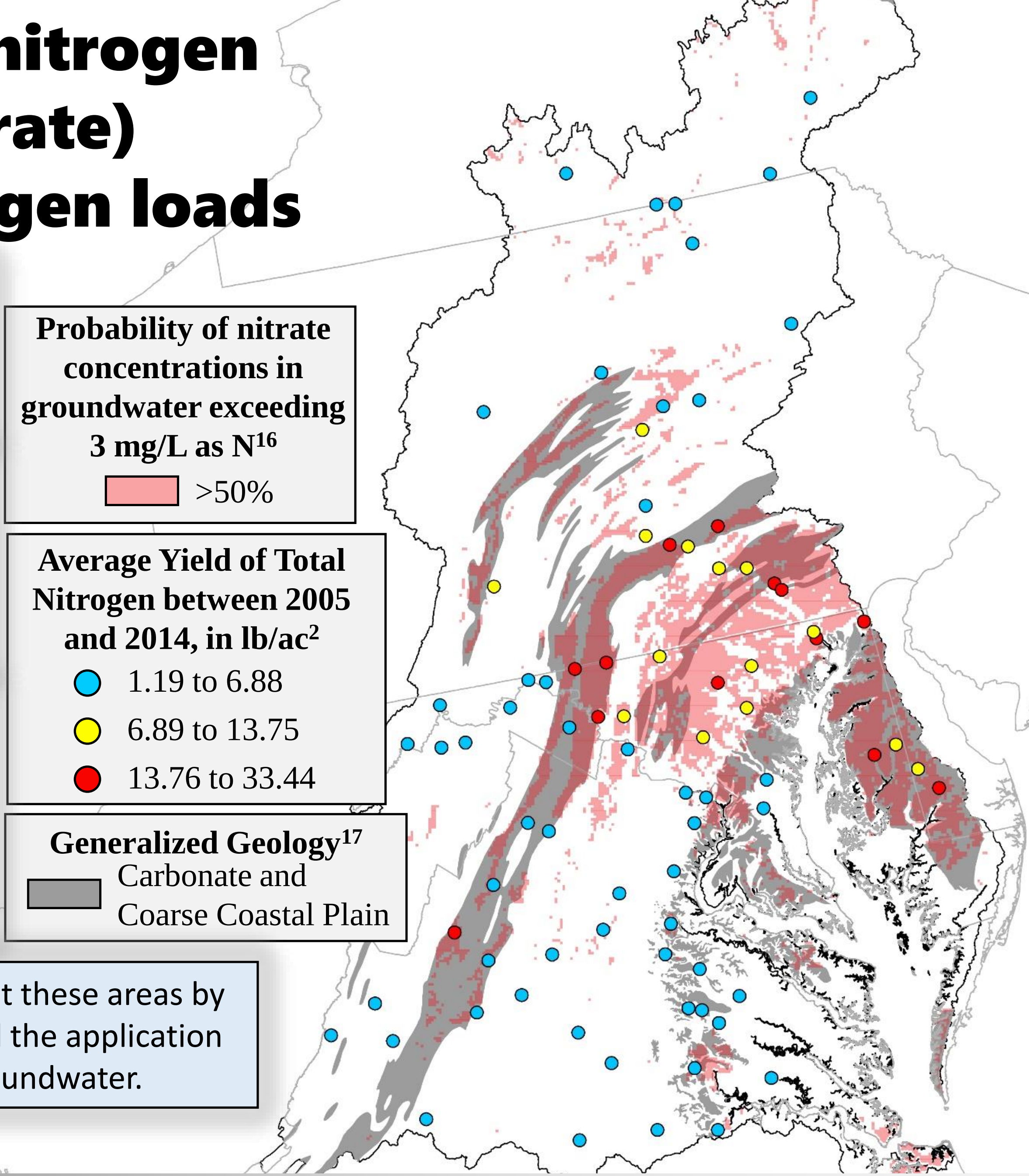
Nutrient loads and trends are a function of highly variable land use, inputs, and environmental settings. Integrative tools have been developed that account for many of these interactions.

High groundwater nitrogen concentrations (nitrate) result in large nitrogen loads

Groundwater nitrogen concentrations are highest in **agricultural watersheds** because inputs of fertilizer and manure commonly exceed crop needs[16].

Low denitrification rates are associated with geologic properties such as sinkholes and porous soils. These features result in increased groundwater nitrogen transport[16].

The largest nitrogen loads occur in **carbonate** and **coastal plain** streams because intense agricultural activities and low denitrification rates result in high amounts of nitrogen in the groundwater.



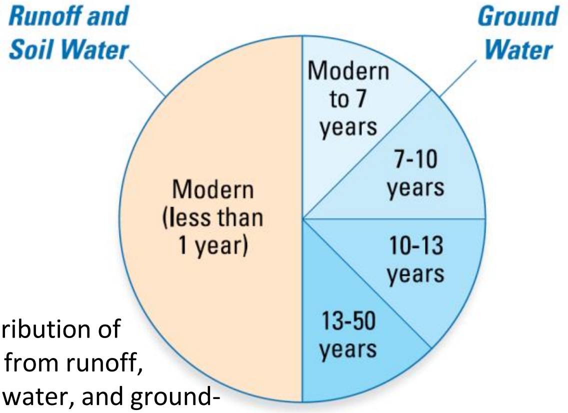
Effective management actions would target these areas by implementing practices that better control the application of nitrogen and it’s movement to groundwater.

[2] Moyer and others, 2017

[16] Greene and others, 2005

[17] King and Biekman, 1974

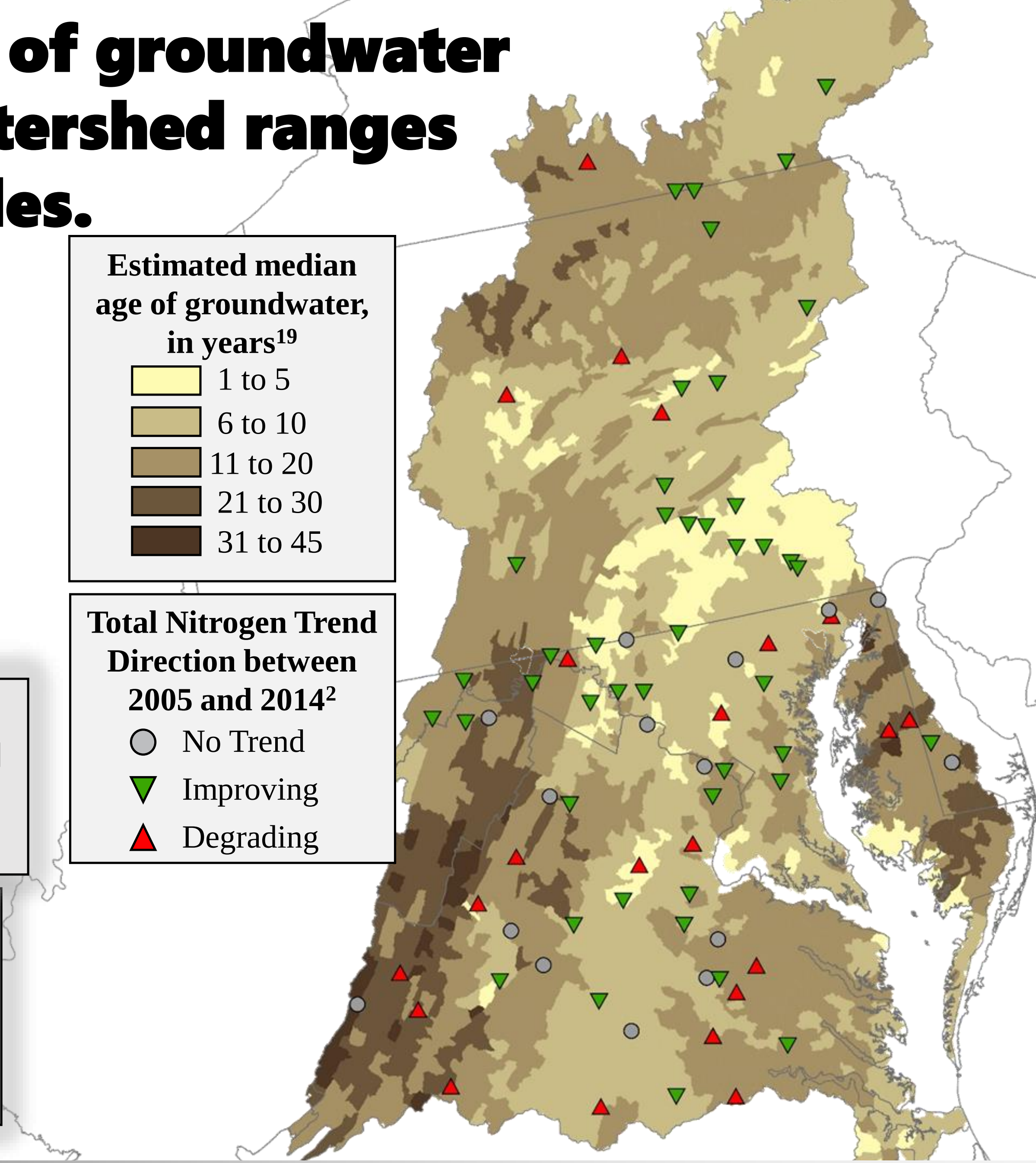
The residence time of groundwater throughout the watershed ranges from days to decades.



Distribution of age from runoff, soil water, and groundwater entering a typical stream in the Bay watershed[18]

Groundwater contributions of nitrate to streams may mitigate the observed effects of BMPs in areas with long residence times.

The residence time of groundwater in carbonate areas tends to be shorter than on the Coastal Plain, where decades-old nitrate can contribute to streams[15].



Estimated median age of groundwater, in years[19]

🟨	1 to 5
▨	6 to 10
▨	11 to 20
▨	21 to 30
■	31 to 45

Total Nitrogen Trend Direction between 2005 and 2014[2]

○	No Trend
▽	Improving
🔺	Degrading

[2]Moyer and others, 2017

[15]Ator and Denver, 2015

[18]Lindsey and Phillips, 2003.

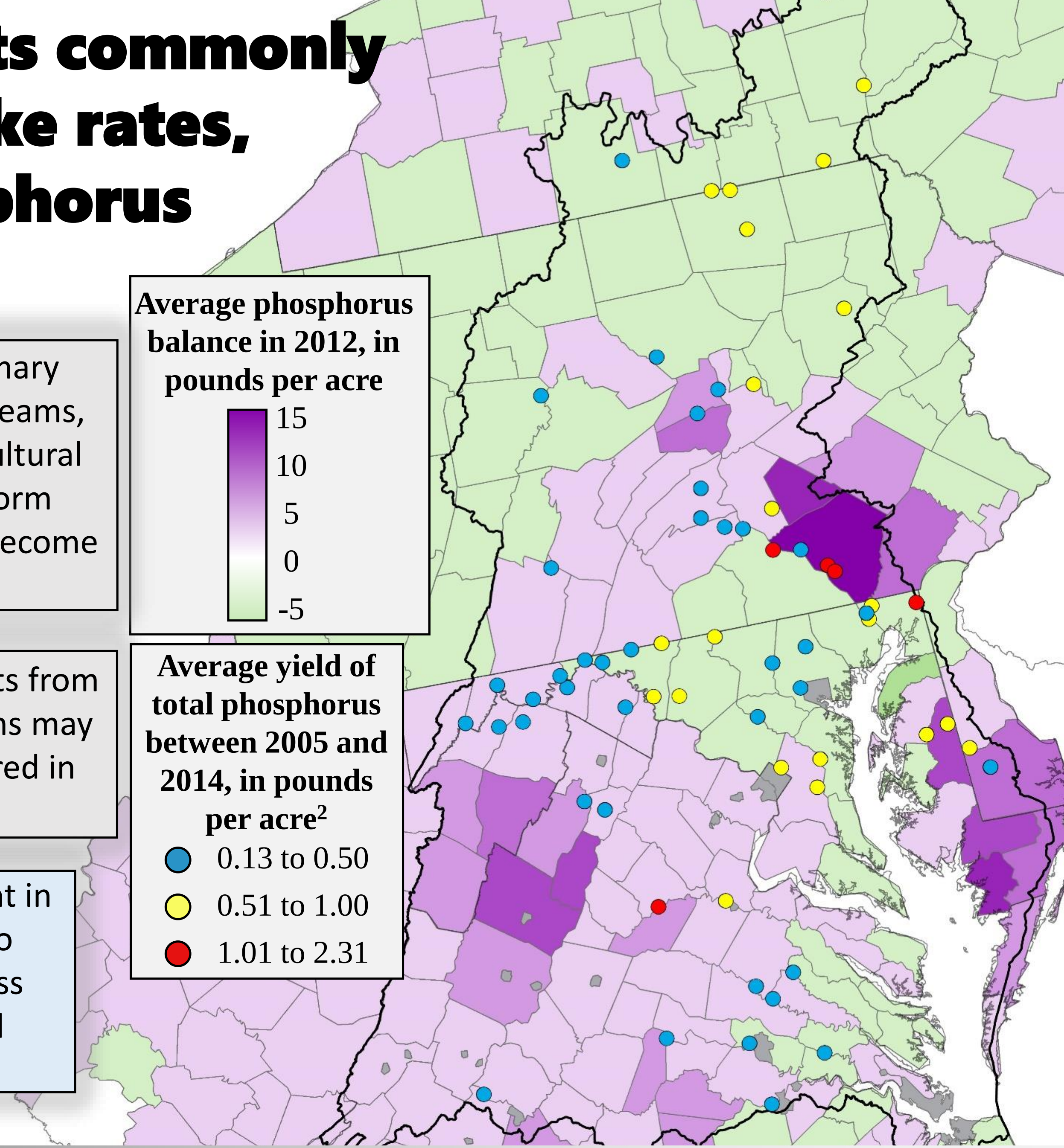
[19]Bhatt and others, 2017.

Agricultural inputs commonly exceed crop uptake rates, resulting in phosphorus saturated soils

While sediment erosion is the primary delivery vector of phosphorus to streams, up to half of the load in some agricultural streams is exported in dissolved form (orthophosphate) where soils have become phosphorus saturated[20].

Expected water-quality improvements from manure and fertilizer input reductions may be offset by legacy phosphorus stored in soils.

Effective phosphorus management in agricultural settings will need to implement practices that address dissolved and sediment-bound phosphorus.



P balance is computed as the difference between ag. inputs ([7]Sekellick, 2017) and crop uptake. Crop uptake rates are based on methods presented in [15]Ator and Denver, 2015.

[2]Moyer and others, 2017

[20]Fanelli and others, 2017

The delivery of nutrients from streams to the estuary varies throughout the watershed

Nitrogen may be lost in streams as a result of biological processing and denitrification.

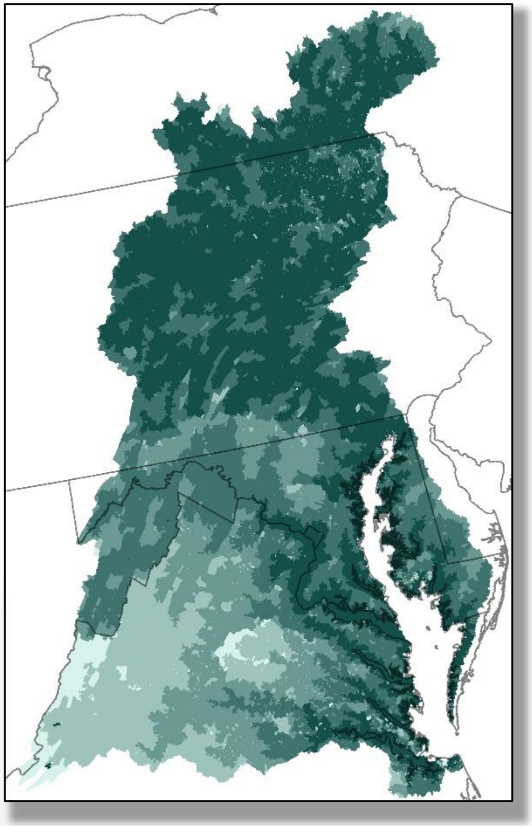
These processes tend to be greater in warmer streams and can be influenced by climatic variability[1].

Chemical and physical processes can **retain** phosphorus in-stream, but there are no natural processes that **remove** phosphorus from the stream corridor.

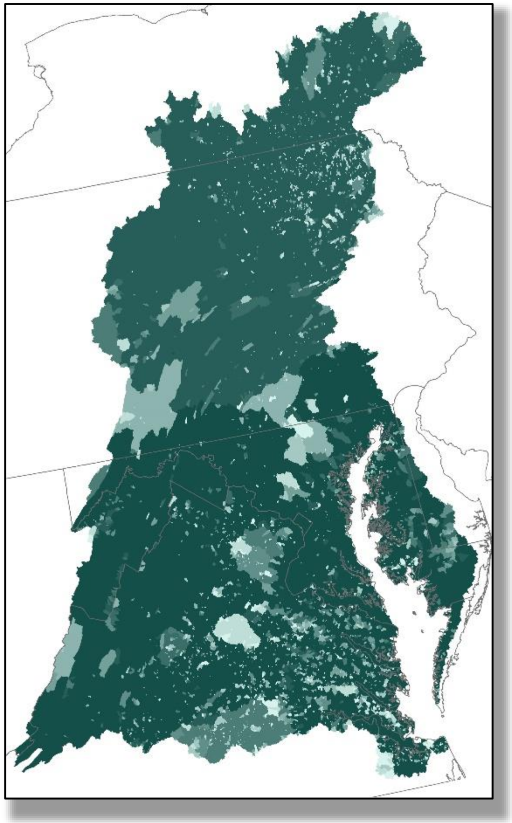
Sediment bound phosphorus can be stored behind impoundments or in streambeds and floodplains and can be remobilized during high flow[1].

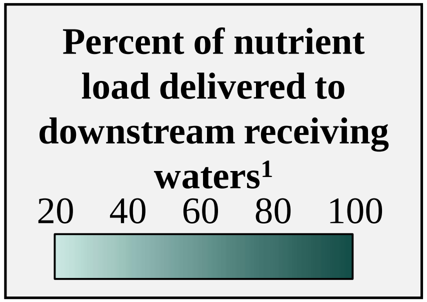
Reservoirs on the lower Susquehanna, including the Conowingo Dam, have reached their capacity for retaining sediment and attached phosphorus[21,22]

Nitrogen



Phosphorus





A USGS webinar on the water-quality effects of the Conowingo reservoir infilling is available online: http://epawebconferencing.acms.com/p29j5g7he49/

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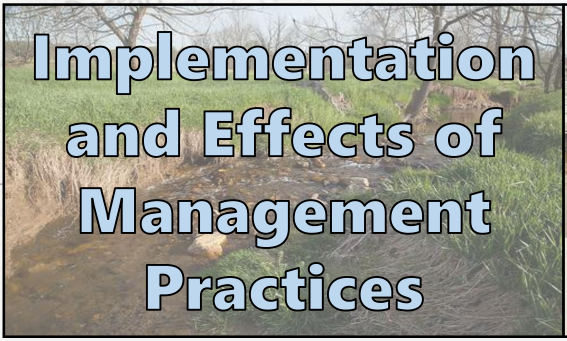
[1] Ator and others, 2011.

[21] Hirsch, 2012

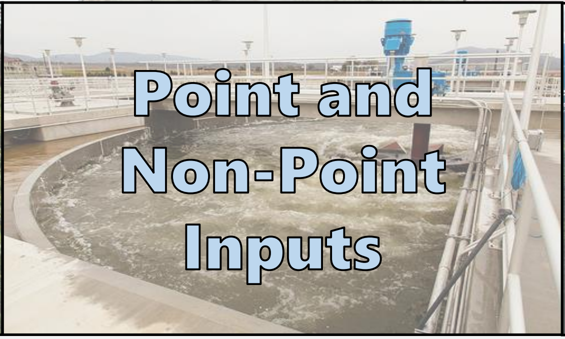
[22] Zhang and others, 2013

Dissecting Drivers of Nutrient Trends in Chesapeake Bay Streams



Implementation and Effects of Management Practices

While the implementation of management practices has increased through time, nutrient trends do not consistently align with expected reductions.



Point and Non-Point Inputs

Changes in nutrient inputs do not fully explain nutrient trends, but a significant, long-term reduction of nutrient inputs is the most effective way to improve nutrient loads.

Fate and Transport

The movement of nutrients from the land to streams to the bay is unequal throughout the watershed and is heavily influenced by geology, climate, and impoundments.

Nutrient loads and trends are a function of highly variable land use, inputs, and environmental settings. Integrative tools have been developed that account for many of these interactions.

Jimmy Webber, jwebber@usgs.gov

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