

Dissecting Drivers of Nutrient Trends in Chesapeake Bay Streams

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

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.

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:

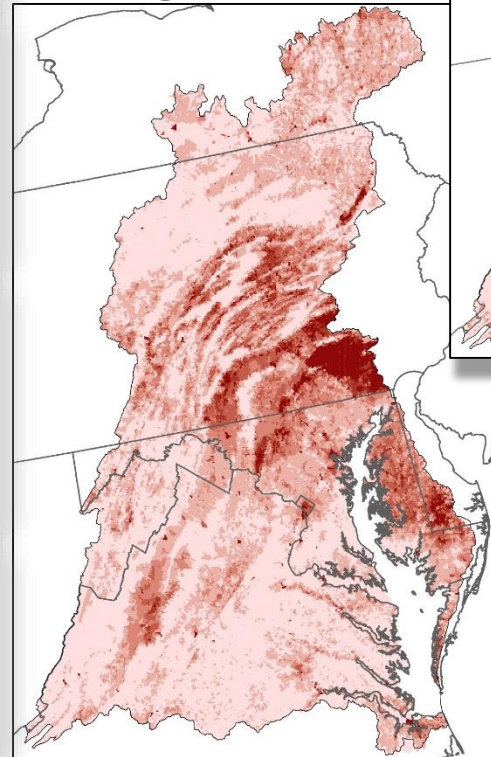
1. The amount of nutrients applied to the landscape or added directly to streams ("*nutrient inputs*"), which reflects the intensity of human activities.
2. The movement of nutrients from the landscape to streams ("*nutrient transport*"), which is primarily a function of geologic setting and climatic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

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

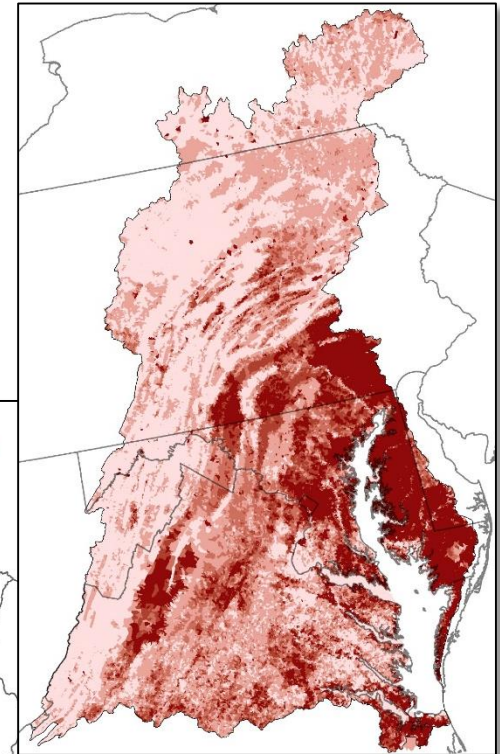
Nutrient Yield¹
Low → High



Nitrogen



Phosphorus



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

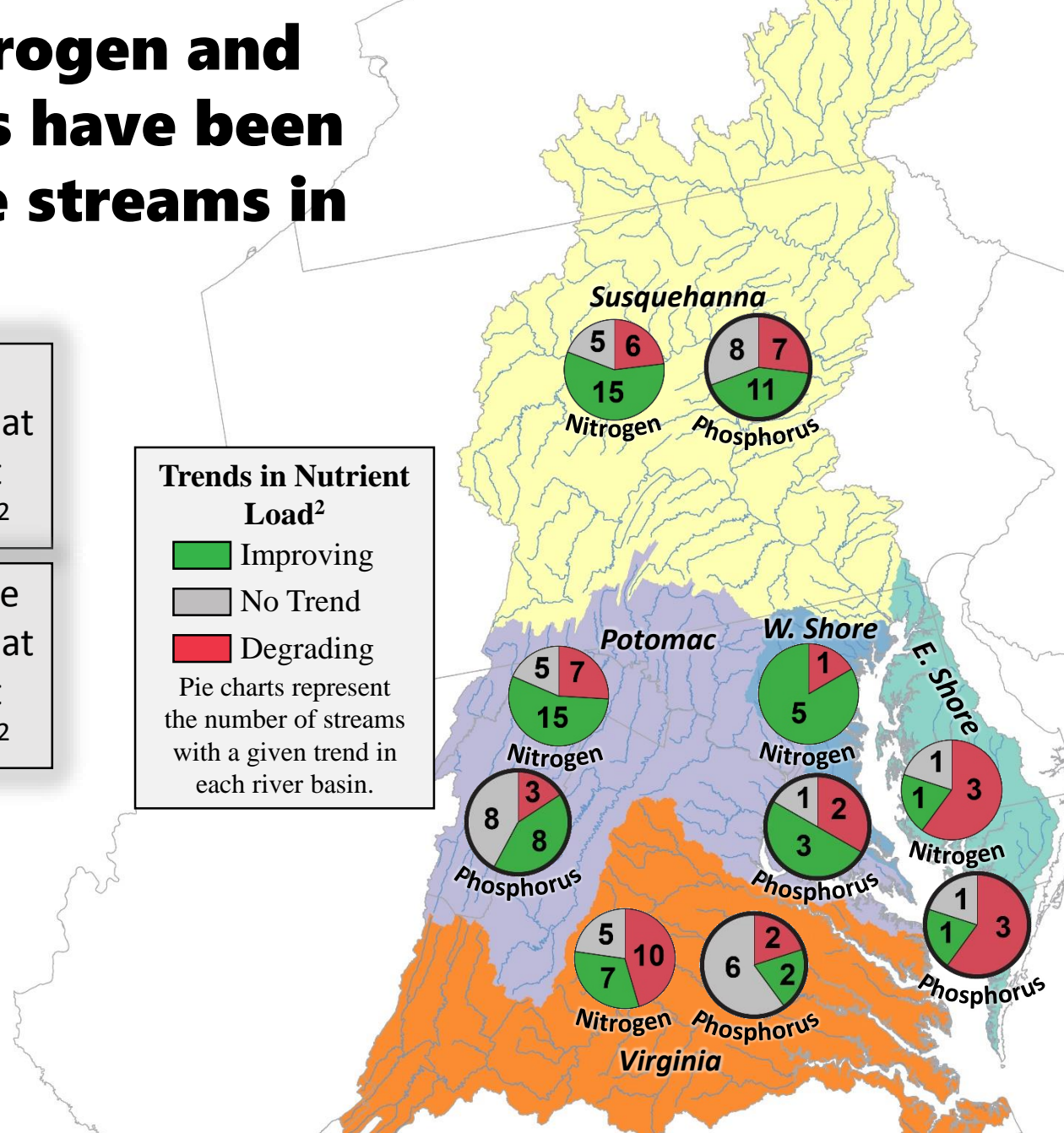
Total nitrogen loads have improved at **50%**, degraded at **31%**, and have no trend at **19%** of monitored stations²

Total phosphorus loads have improved at **38%**, degraded at **26%**, and have no trend at **36%** of monitored stations²

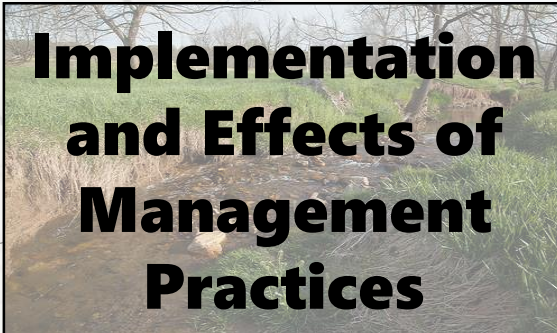
Trends in Nutrient Load²

- Improving
- No Trend
- Degrading


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



What are the primary drivers of nutrient trends?



**Implementation
and Effects of
Management
Practices**



**Point and
Non-Point
Inputs**



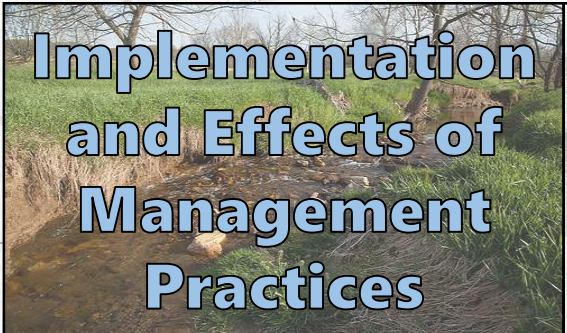
**Fate and
Transport**



**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.

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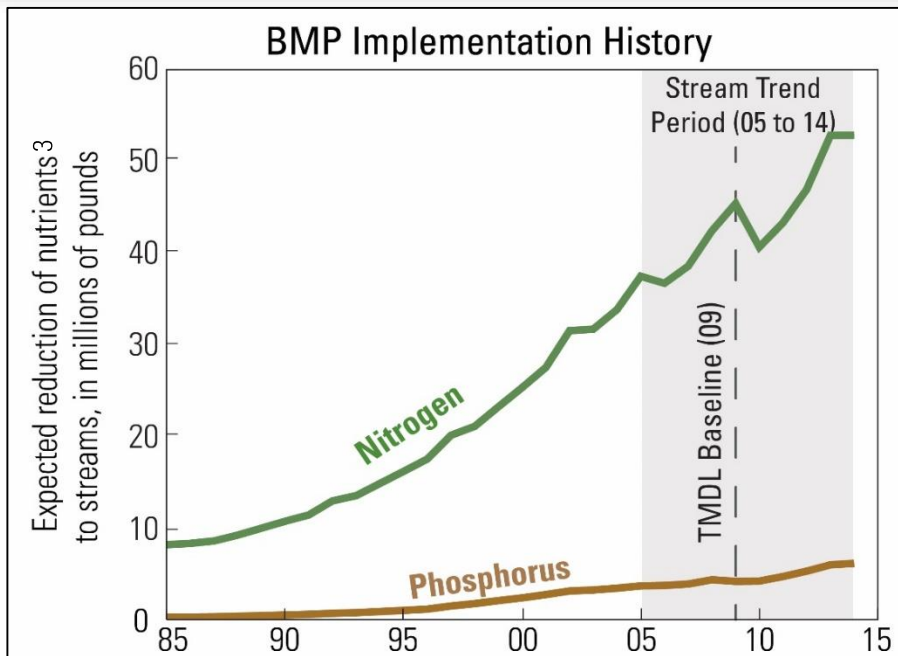
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The implementation of management practices intended to reduced nutrient transport has increased through time, but expected reductions have not occurred in all streams.

In 2014, management practices are estimated to have reduced **11%** of the nitrogen and **19%** the phosphorus load in Chesapeake Bay streams³.

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}.



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.

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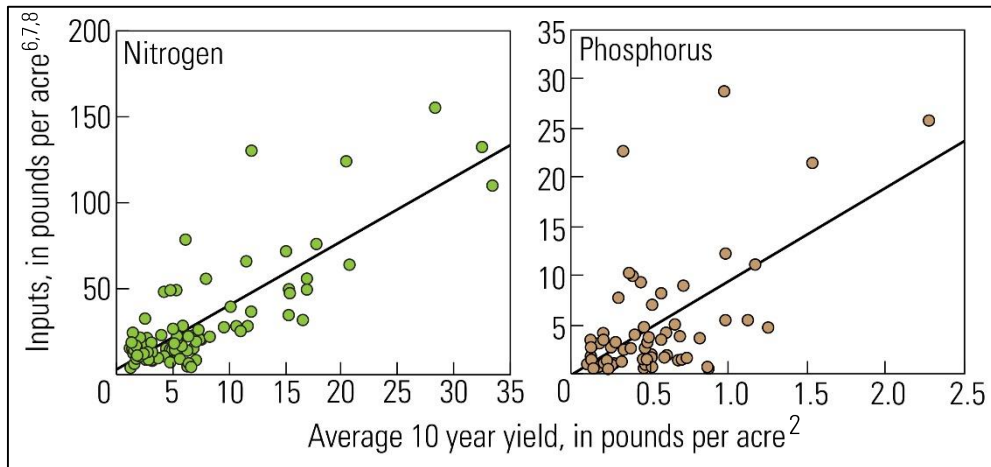
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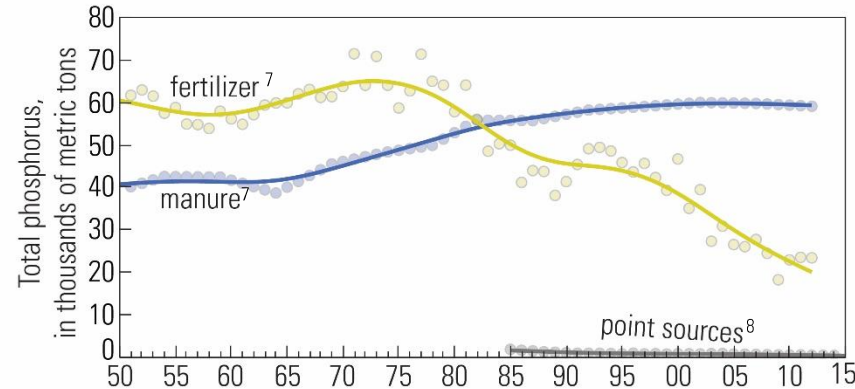
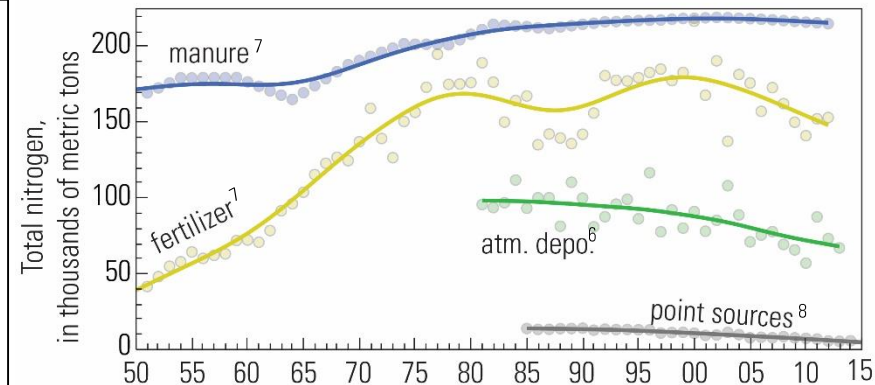
The load of nutrients delivered to streams is primarily determined by the mass of nutrients applied in the watershed



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.



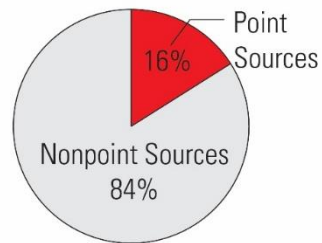
Additional nutrient sources include inputs from urban areas and naturally occurring phosphorus in sedimentary rocks.

Reduced point source inputs have improved nutrient loads in some streams

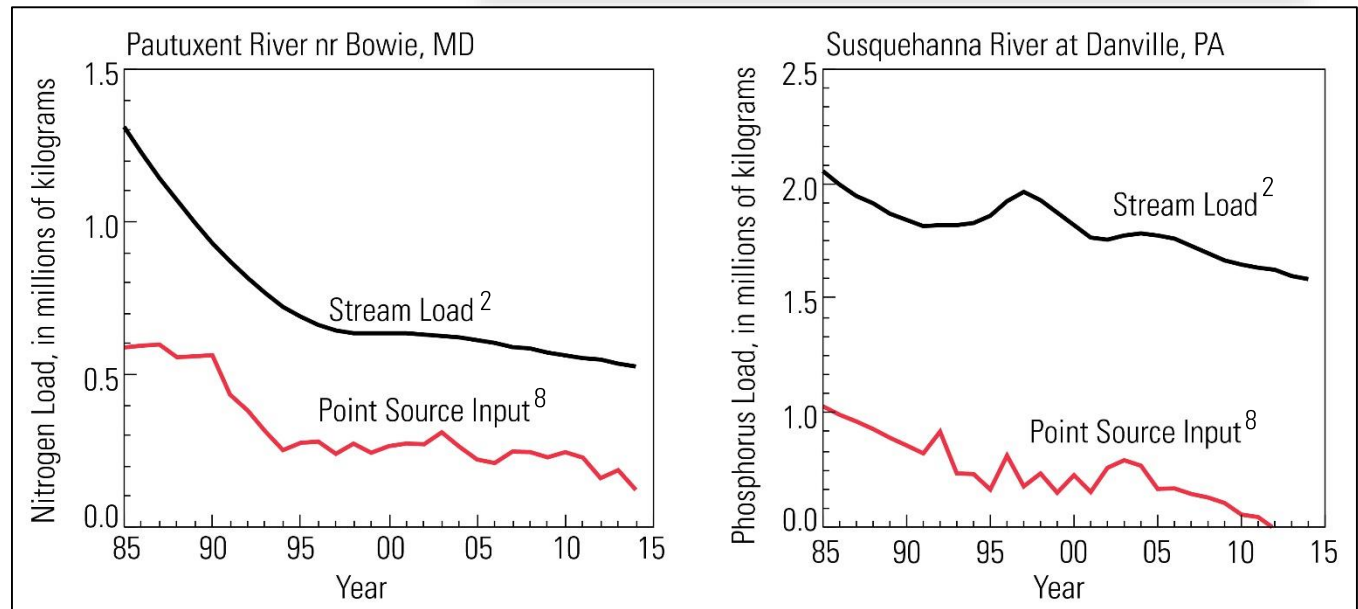
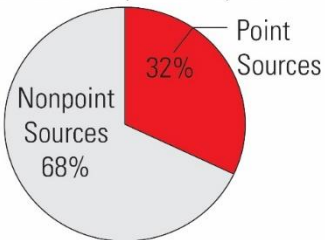
Point source inputs include industrial and municipal wastewater discharges and combined sewer overflows.

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 2002¹



Load of Phosphorus Delivered to the Chesapeake Bay in 2002¹

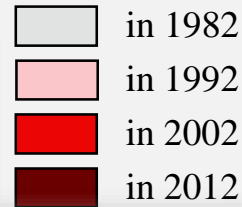


Continued improvements in wastewater treatment may be limited by available technology. Declines in non-point source inputs will be necessary to achieve continued nutrient reductions.

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 land⁹.

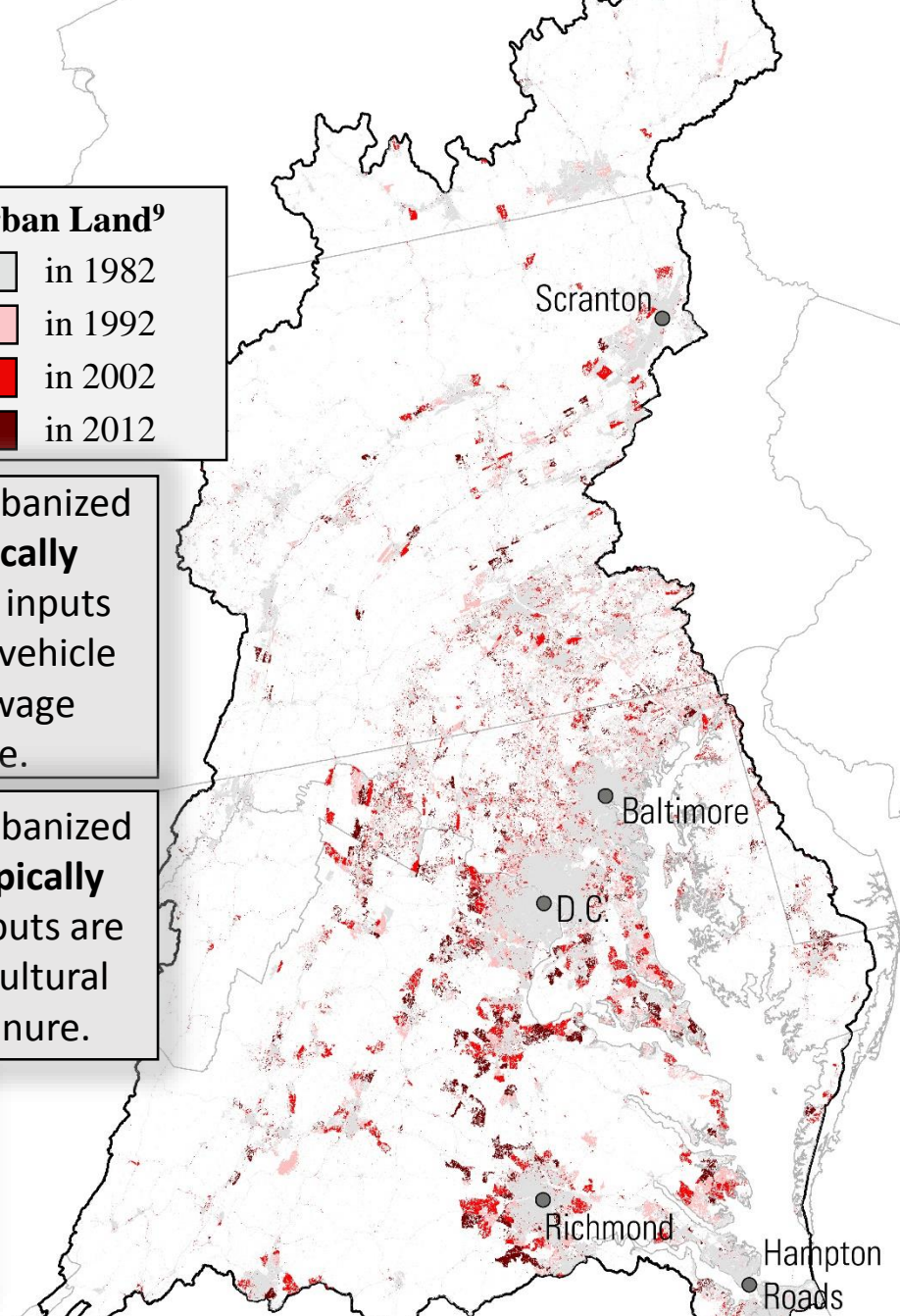
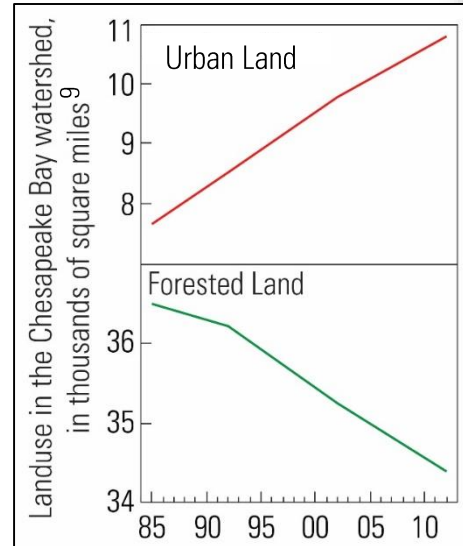
Urban Land⁹



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.

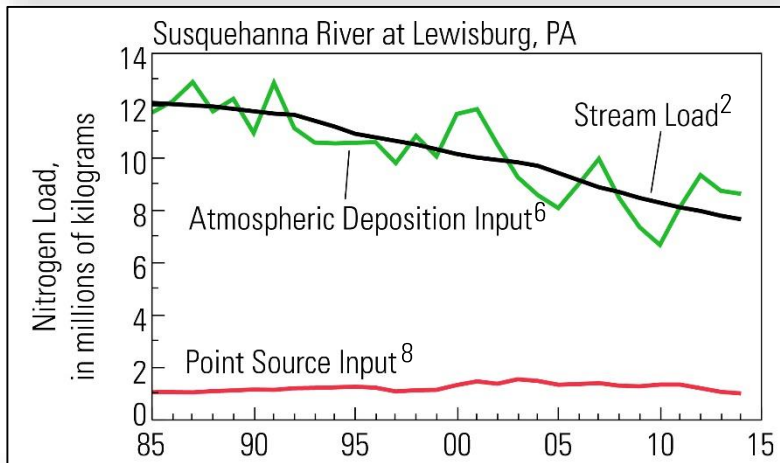
Nutrient loads in recently urbanized agricultural watersheds **typically decrease** because urban inputs are typically smaller than agricultural inputs of fertilizer and manure.

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



Reduced atmospheric deposition of nitrogen has improved nitrogen loads in some forested watersheds¹⁰

Atmospheric deposition is a relatively minor source of nitrogen to the bay, but can be a large 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 houses¹¹.

Forested land in 2012⁹

Total Nitrogen Trend Direction in Forested Watersheds²

- No Trend
- ▼ Improving
- ▲ Degrading

Susquehanna River at Lewisburg, PA

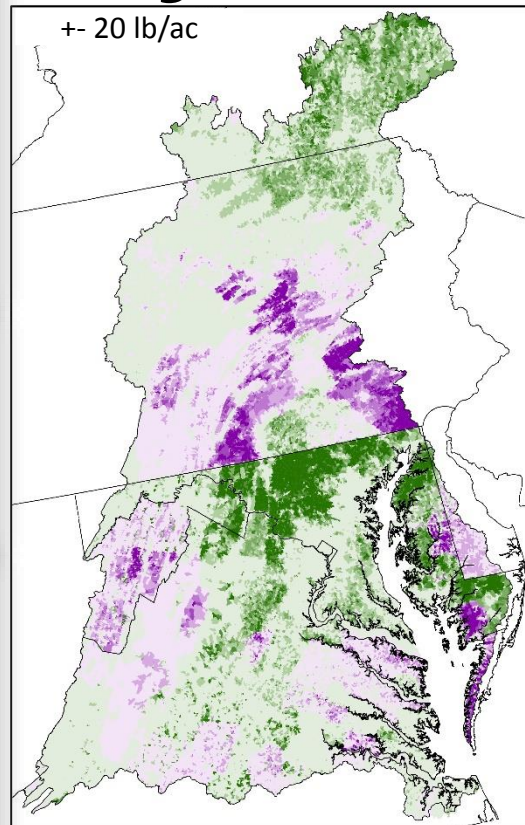
The intensity and location of agricultural practices has been redistributed throughout the watershed

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 watershed¹².

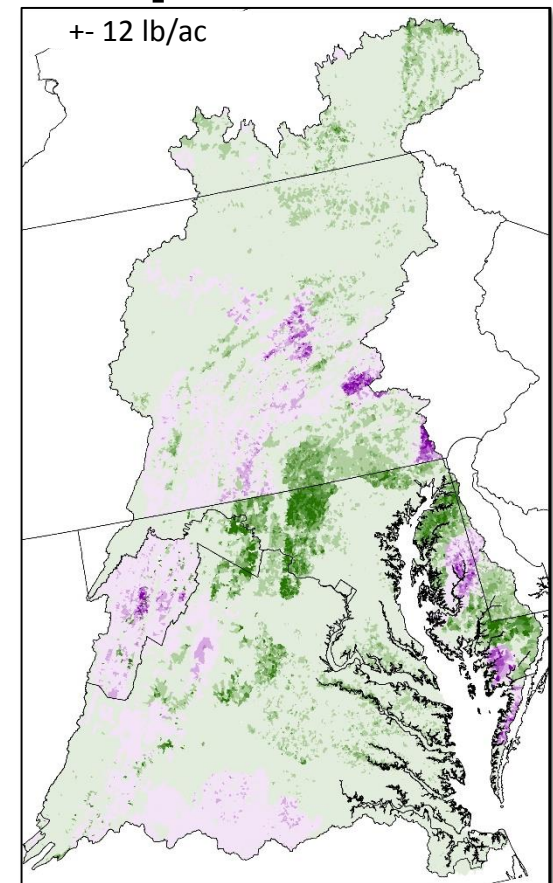
Intensification of animal agricultural practices has most commonly occurred from poultry expansion¹².

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

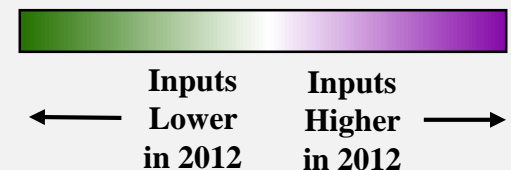
Nitrogen



Phosphorus



Change in agricultural inputs between 1985 and 2012⁷

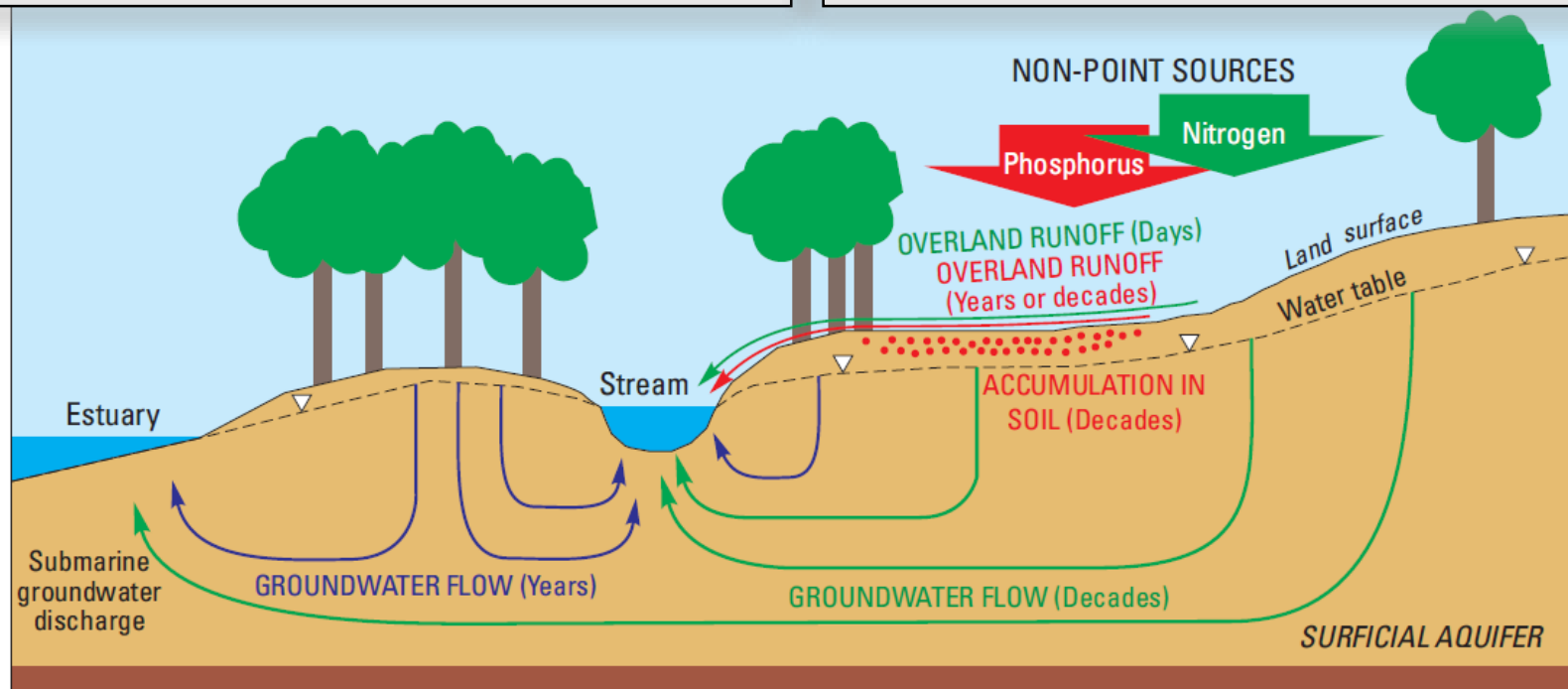


Reductions in nutrient inputs do not always result in improved loads

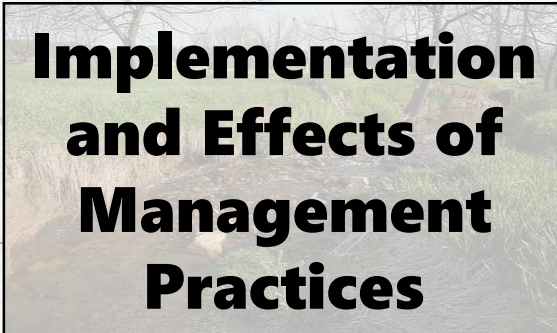
Why?

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.



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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) can result in large nitrogen loads

Groundwater nitrogen concentrations are highest in **agricultural watersheds** because inputs of fertilizer and manure commonly exceed crop needs¹⁶.

Low denitrification rates are associated with geologic properties such as sinkholes and porous soils. These features result in increased groundwater nitrogen transport¹⁶.

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.

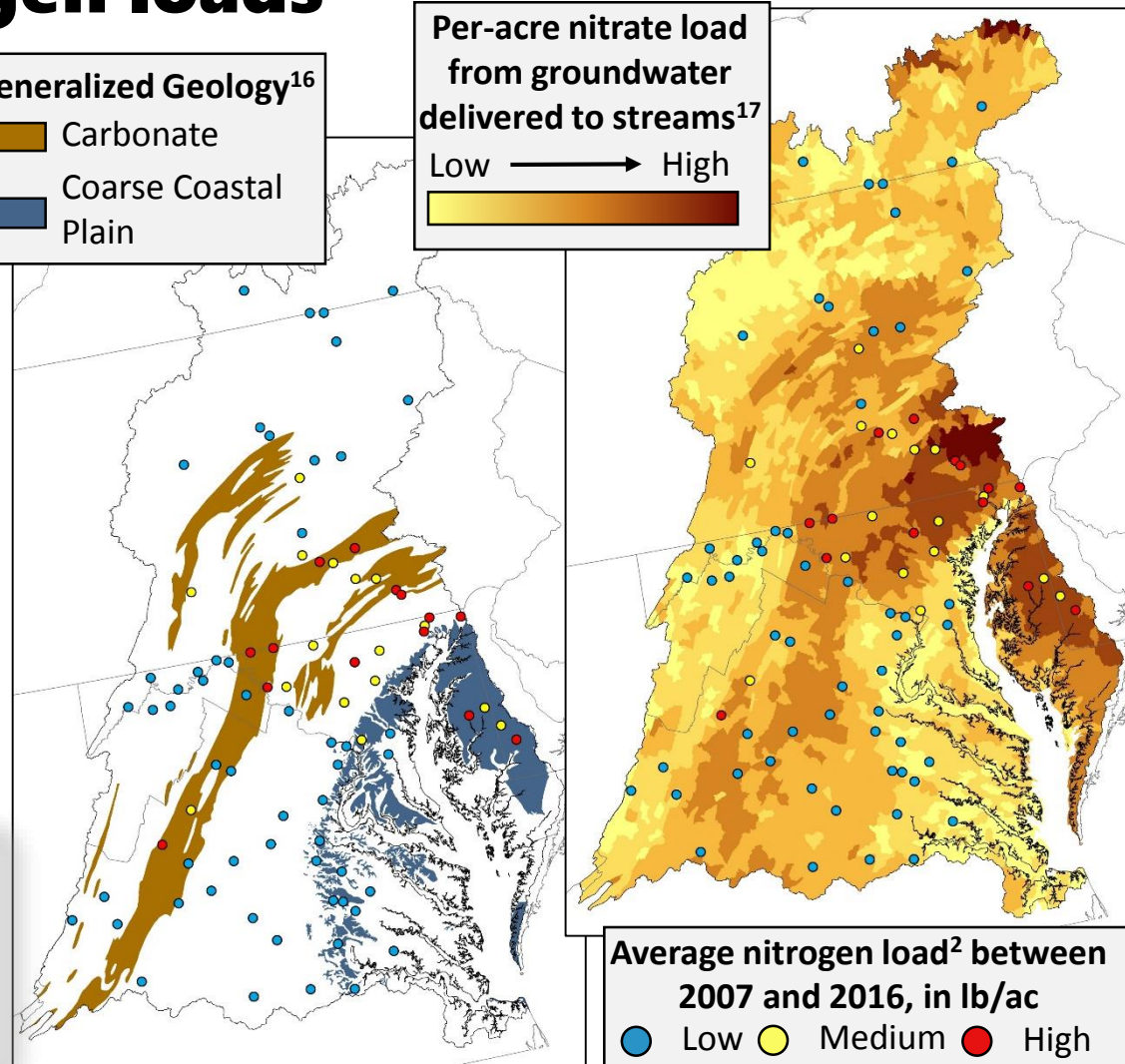
Effective management actions would target these areas by implementing practices that better control the application of nitrogen and its movement to groundwater.

Generalized Geology¹⁶

- Carbonate
- Coarse Coastal Plain

Per-acre nitrate load from groundwater delivered to streams¹⁷

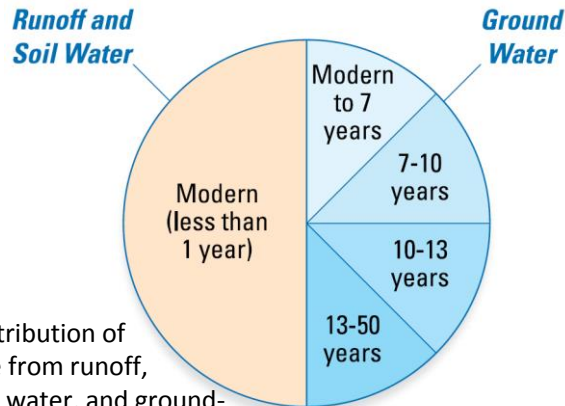
Low → High



Average nitrogen load² between 2007 and 2016, in lb/ac

Low Medium High

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 watershed¹⁸

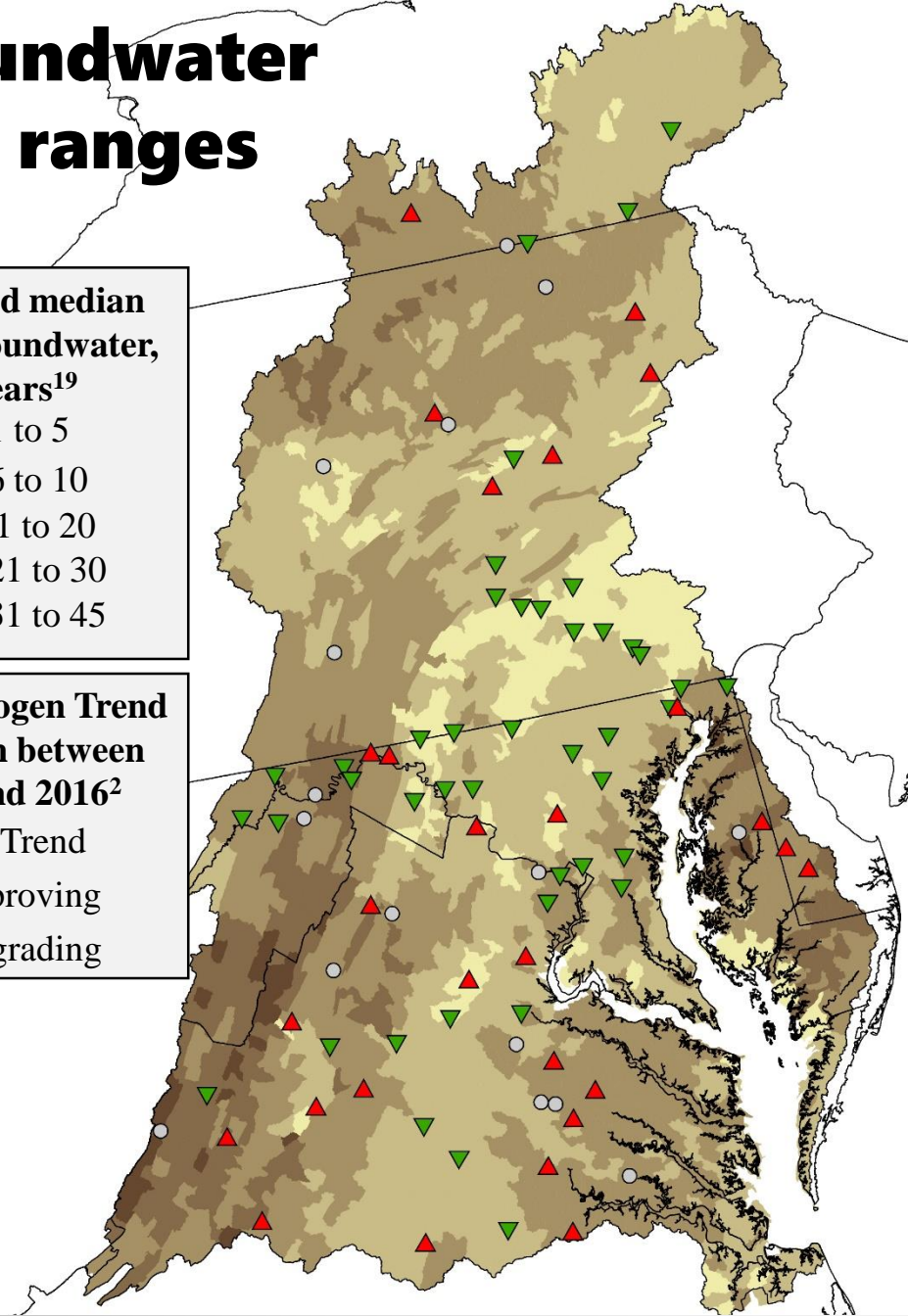
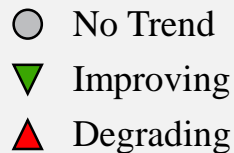
Groundwater contributions of nitrate to streams may mitigate the observed effects of BMPs in areas with long residence times.

The residence time of groundwater in carbonate areas tends to be shorter than on the Coastal Plain, where decades-old nitrate can contribute to streams¹⁵.

Estimated median age of groundwater, in years¹⁹



Total Nitrogen Trend Direction between 2007 and 2016²



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 saturated²¹.

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

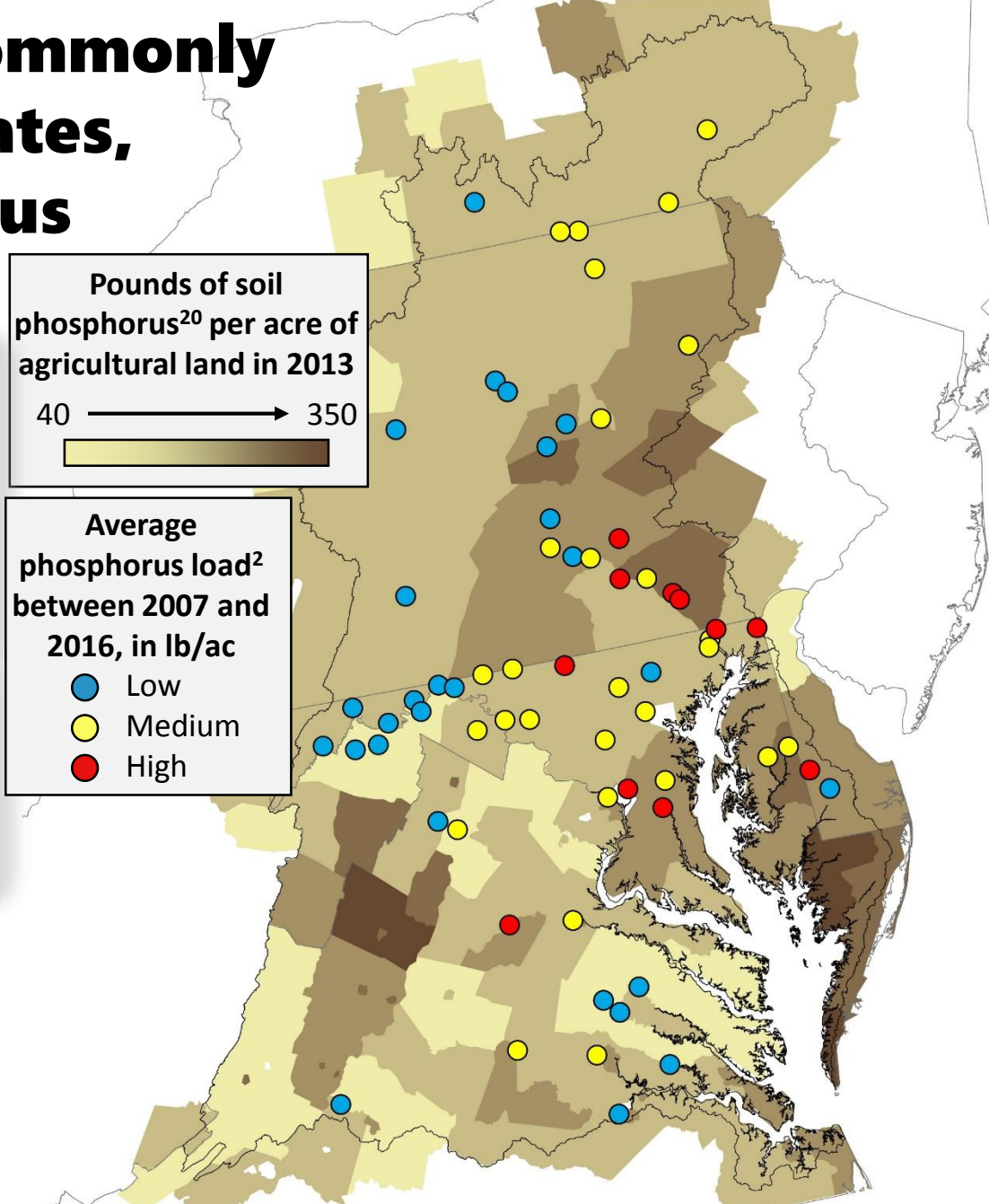
Effective phosphorus management in agricultural settings will need to implement practices that address dissolved and sediment-bound phosphorus.

Pounds of soil phosphorus²⁰ per acre of agricultural land in 2013

40 —————> 350

Average phosphorus load² between 2007 and 2016, in lb/ac

- Low
- Medium
- High



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.

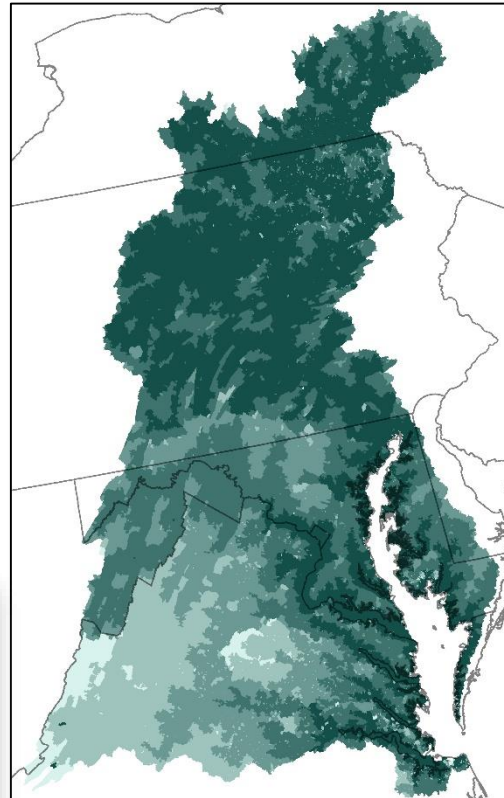
These processes tend to be greater in warmer streams and can be influenced by climatic variability¹.

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

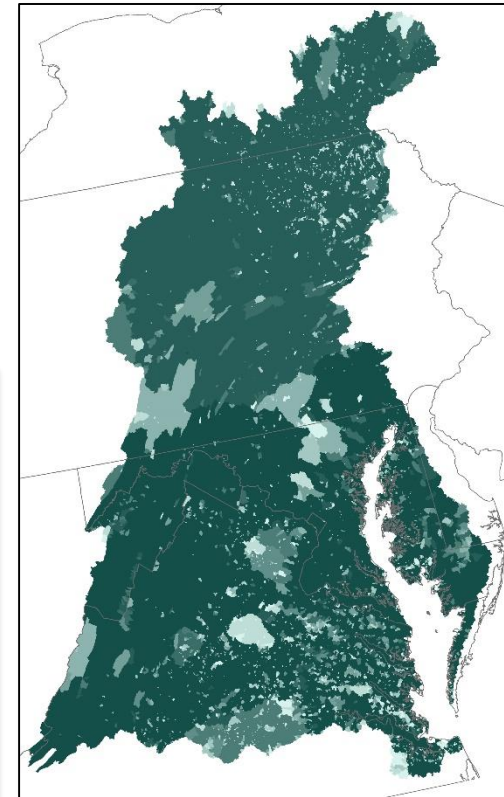
Sediment bound phosphorus can be stored behind impoundments or in streambeds and floodplains and can be remobilized during high flow¹.

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

Nitrogen



Phosphorus



Percent of nutrient load delivered to downstream receiving waters¹

20 40 60 80 100



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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.

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