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.

<table>
<thead>
<tr>
<th>Nutrient Yield(^1)</th>
<th>Low → High</th>
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</thead>
<tbody>
<tr>
<td>Nitrogen</td>
<td></td>
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<tr>
<td>Phosphorus</td>
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</table>

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.

\(^1\)Ator and others, 2011.
Reductions in nitrogen and phosphorus loads have been observed in some streams in recent years. 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](https://www.sciencebase.gov/catalog/item/59403814e4b0764e6c63121b)

- Total nitrogen loads have improved at 50%, degraded at 31%, and have no trend at 19% of monitored stations.
- Total phosphorus loads have improved at 38%, degraded at 36%, and have no trend at 24% of monitored stations.

Pie charts represent the number of streams with a given trend in each river basin.
What are the primary drivers of nutrient 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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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. 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. 

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**BMP Implementation History**

- **Expected reduction of nutrients** to streams, in millions of pounds
- **Nitrogen**
- **Phosphorus**
- **Stream Trend Period (05 to 14)**
- **TMDL Baseline (09)**

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*Sekellick and others, in review*  
*Staver and Brinsfield, 1998*  
*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?

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

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.
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.

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.

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**Footnotes:**

1. Ator and others, 2011.
3. 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.

9Falcone, 2015.
Reduced atmospheric deposition of nitrogen has improved nitrogen loads in some forested watersheds\textsuperscript{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\textsuperscript{11}.
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\(^\text{12}\).

Intensification of animal agricultural practices has most commonly occurred from poultry expansion\(^\text{12}\).

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

Nitrogen

\[\text{Inputs}\quad \text{Higher in 2012}\]
\[\text{Inputs}\quad \text{Lower in 2012}\]

\[\text{+- 20 lb/ac}\]

Phosphorus

\[\text{+- 12 lb/ac}\]

Change in agricultural inputs between 1985 and 2012\(^\text{7}\)

\[\text{Inputs}\quad \text{Higher in 2012}\]
\[\text{Inputs}\quad \text{Lower in 2012}\]

\[\text{+- 12 lb/ac}\]

\(^{7}\text{Sekellick, 2017}\quad ^{12}\text{Keisman and others, in review}\quad ^{13}\text{Denver and others, 2010}\quad ^{14}\text{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.

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Figure adapted from

15 Ator and Denver, 2015
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\(^\text{16}\).

Low denitrification rates are associated with geologic properties such as sinkholes and porous soils. These features result in increased groundwater nitrogen transport\(^\text{16}\).

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 its movement to groundwater.

Probability of nitrate concentrations in groundwater exceeding 3 mg/L as N\(^\text{16}\)

Average Yield of Total Nitrogen between 2005 and 2014, in lb/ac\(^2\)
- 1.19 to 6.88
- 6.89 to 13.75
- 13.76 to 33.44

References:
\(^2\)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. 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.

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Estimated median age of groundwater, in years
- 1 to 5
- 6 to 10
- 11 to 20
- 21 to 30
- 31 to 45

Total Nitrogen Trend
Direction between 2005 and 2014
- No Trend
- Improving
- Degrading

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2 Moyer and others, 2017
15 Ator and Denver, 2015
18 Lindsey and Phillips, 2003
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\(^2\).

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.

<table>
<thead>
<tr>
<th>Average phosphorus balance in 2012, in pounds per acre</th>
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<tbody>
<tr>
<td>15</td>
</tr>
<tr>
<td>10</td>
</tr>
<tr>
<td>5</td>
</tr>
<tr>
<td>0</td>
</tr>
<tr>
<td>-5</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Average yield of total phosphorus between 2005 and 2014, in pounds per acre(^2)</th>
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</thead>
<tbody>
<tr>
<td>0.13 to 0.50</td>
</tr>
<tr>
<td>0.51 to 1.00</td>
</tr>
<tr>
<td>1.01 to 2.31</td>
</tr>
</tbody>
</table>

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.\(^{21,22}\)

Phosphorus

Percent of nutrient load delivered to downstream receiving waters.\(^1\)

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

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.
References Cited


(6) Atmospheric nitrogen deposition derived from the National Atmospheric Deposition Monitoring Program, http://nadp.sws.uiuc.edu/


(8) Point source inputs derived from the Chesapeake Bay Program Nutrient Point Source Database, http://www.chesapeakebay.net/data/downloads/bay_program_nutrient_point_source_database


(10) Eshelman, K.M., Sabo, R.D., and Kline, K.M., 2013, Surface water quality is improving due to declining atmospheric N deposition: Environmental Science and Technology 47, 12193–12200, dx.doi.org/10.1021/es4028748


(22) Zhang, Q., Brady, D. C., and Ball, W. P. 2013. Long-term seasonal trends of nitrogen, phosphorus, and suspended sediment load from the nontidal Susquehanna River Basin to Chesapeake Bay. Sci. Total Environ. 452–453, 208–221.