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Nitrogen in the Chesapeake Bay Watershed

A Century of Change 1950-2050

Presented by
John Clune, PhD, Hydrologist

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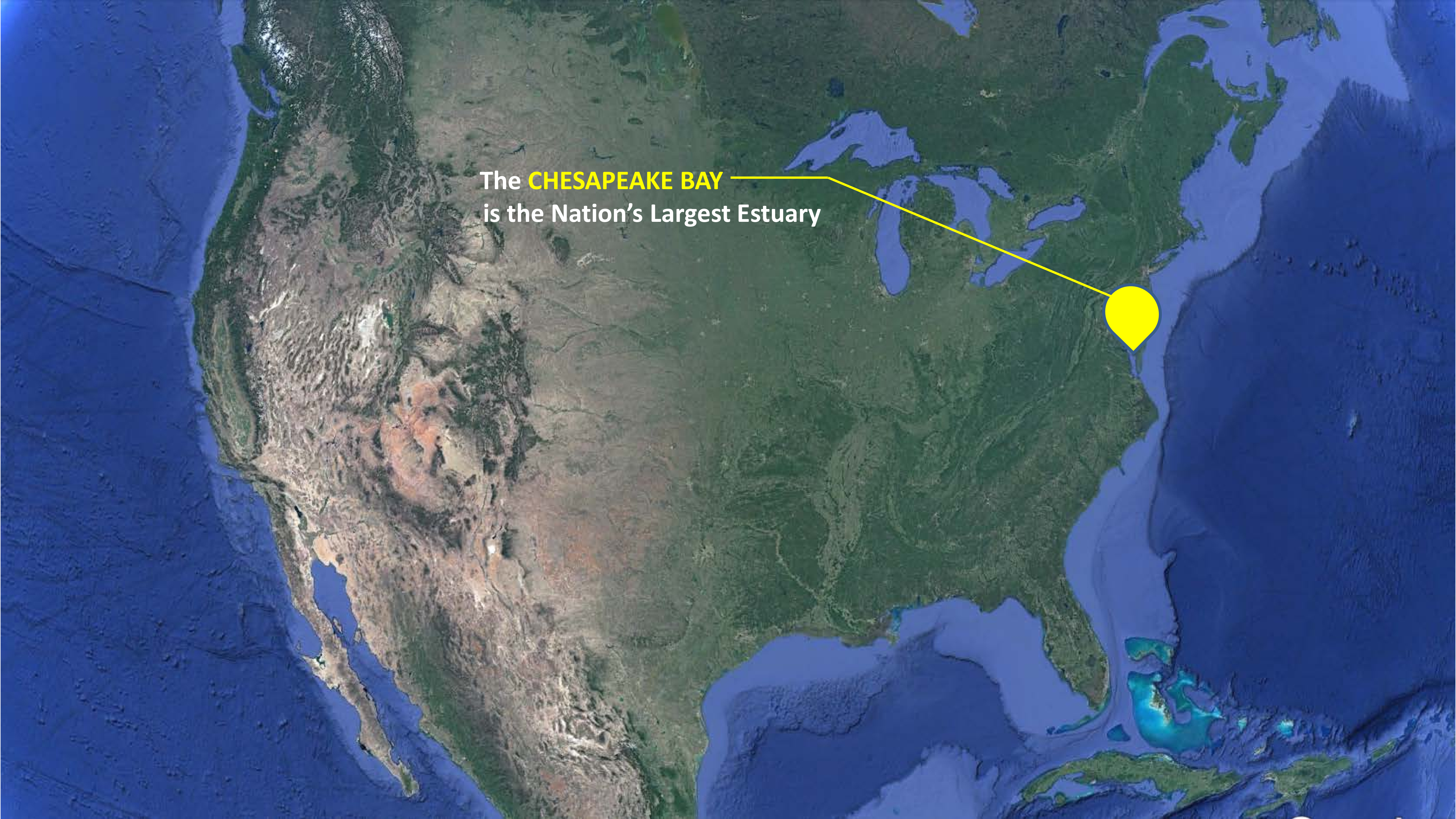
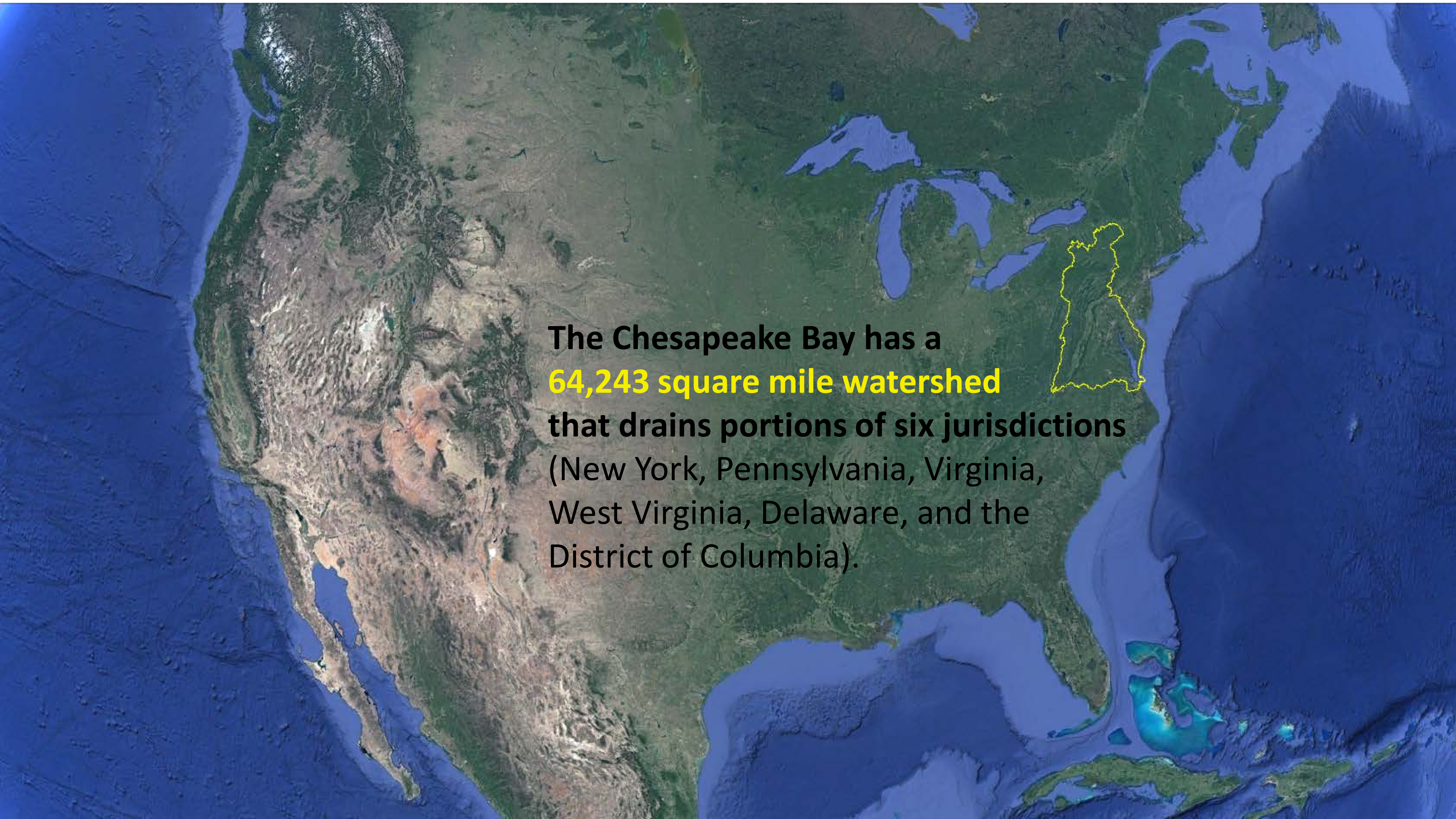
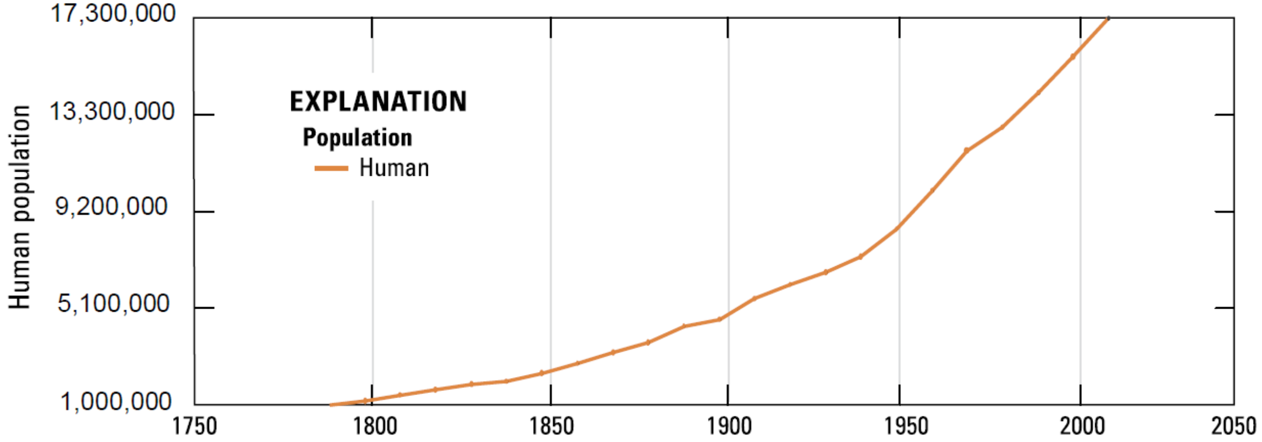

The CHESAPEAKE BAY
is the Nation's Largest Estuary

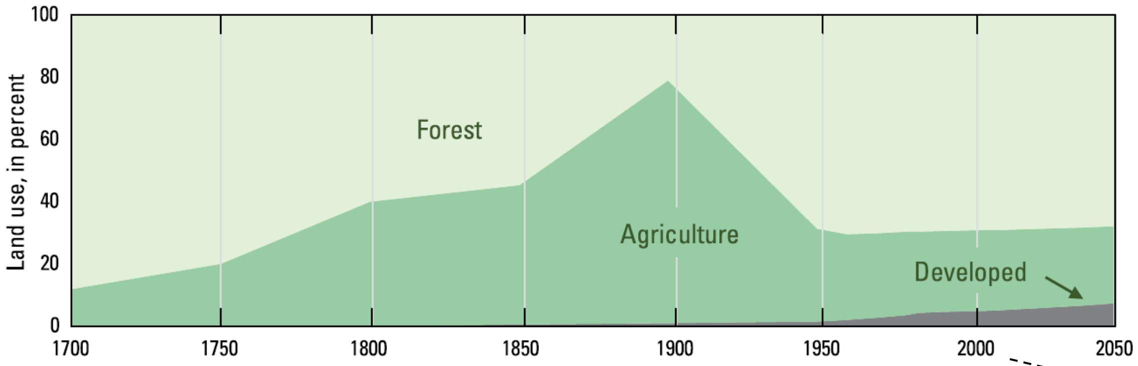

The Chesapeake Bay has a
64,243 square mile watershed
that drains portions of six jurisdictions
(New York, Pennsylvania, Virginia,
West Virginia, Delaware, and the
District of Columbia).

Courtesy National Gallery of Art

For just a moment, imagine yourself in the Chesapeake Bay Watershed in the early 1800s during a period of great change

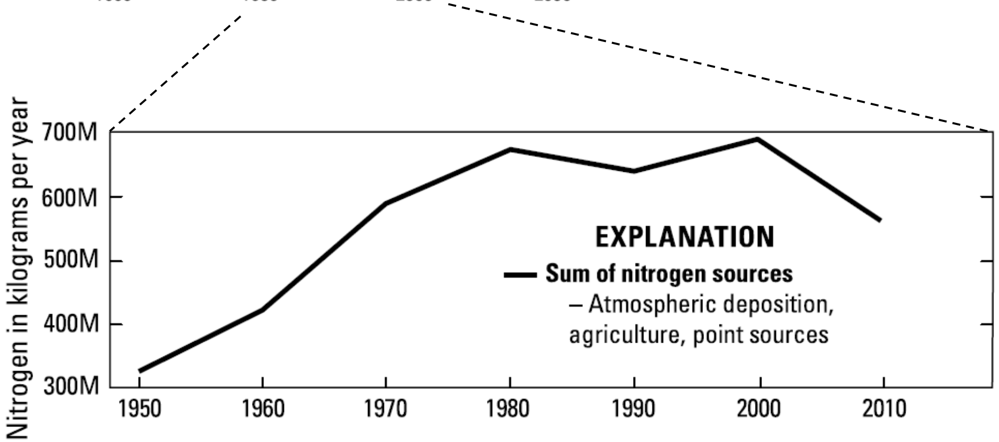


As human population has increased in the Chesapeake Bay watershed over the past centuries …



.. land use has changed from primarily undeveloped (forested) to agricultural and developed land

These changes have led to increases in **nitrogen** inputs



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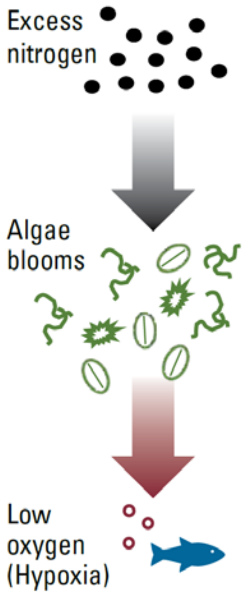
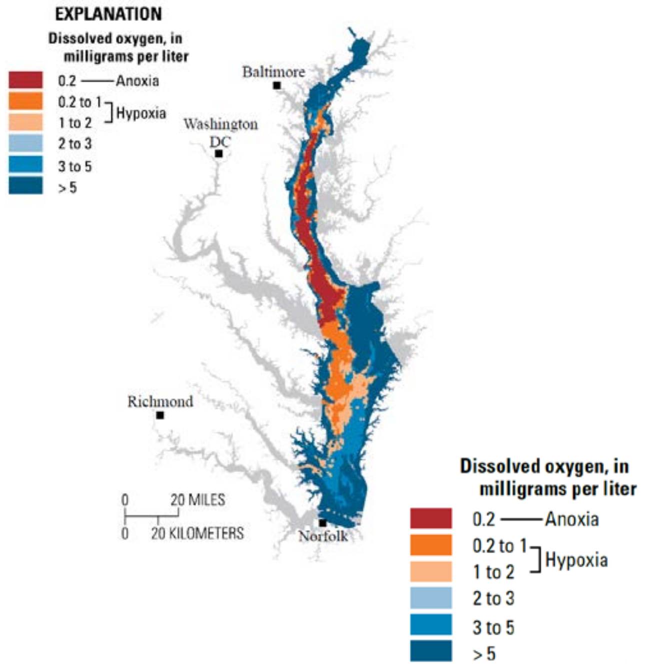
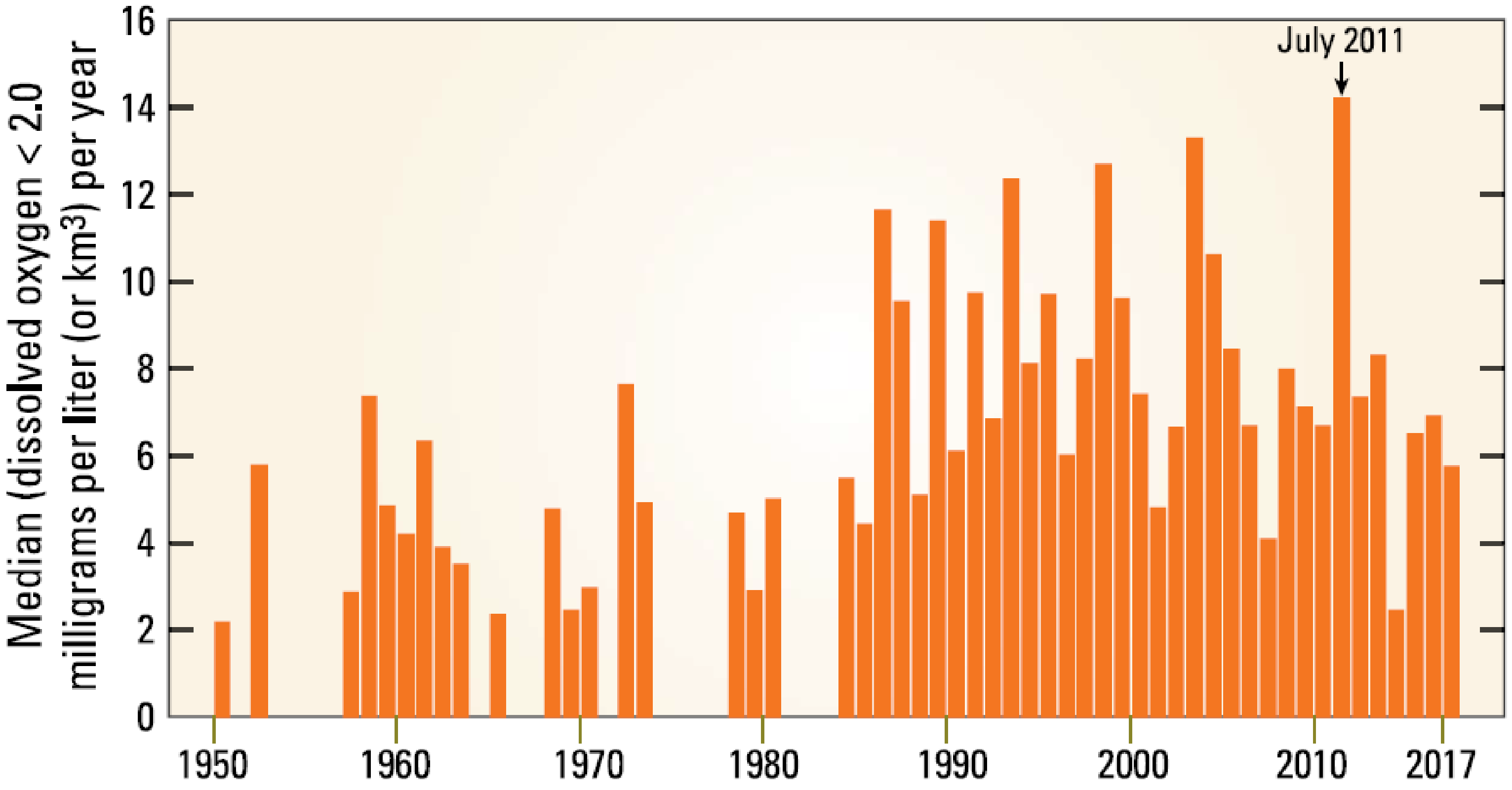
Nutrients (nitrogen and phosphorus) are major macronutrients necessary for plant growth ….

.. but excessive nutrient amounts create increased algae growth, decay and low oxygen for aquatic life

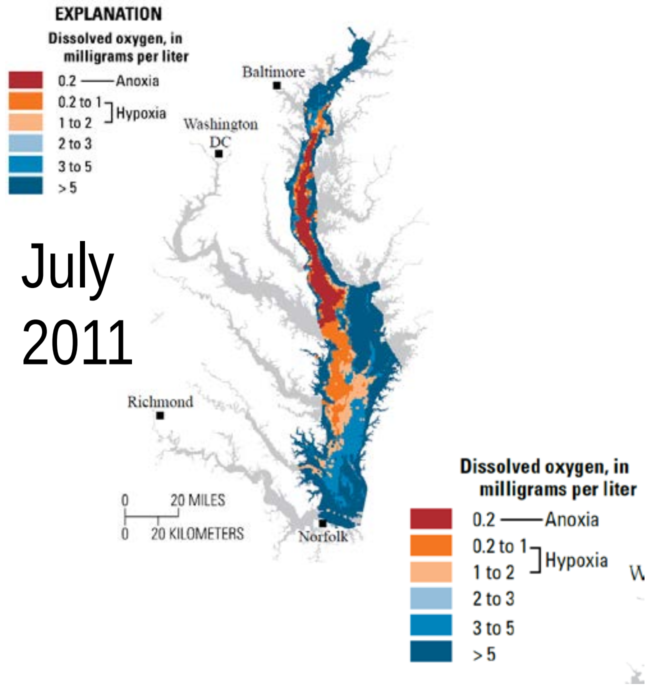




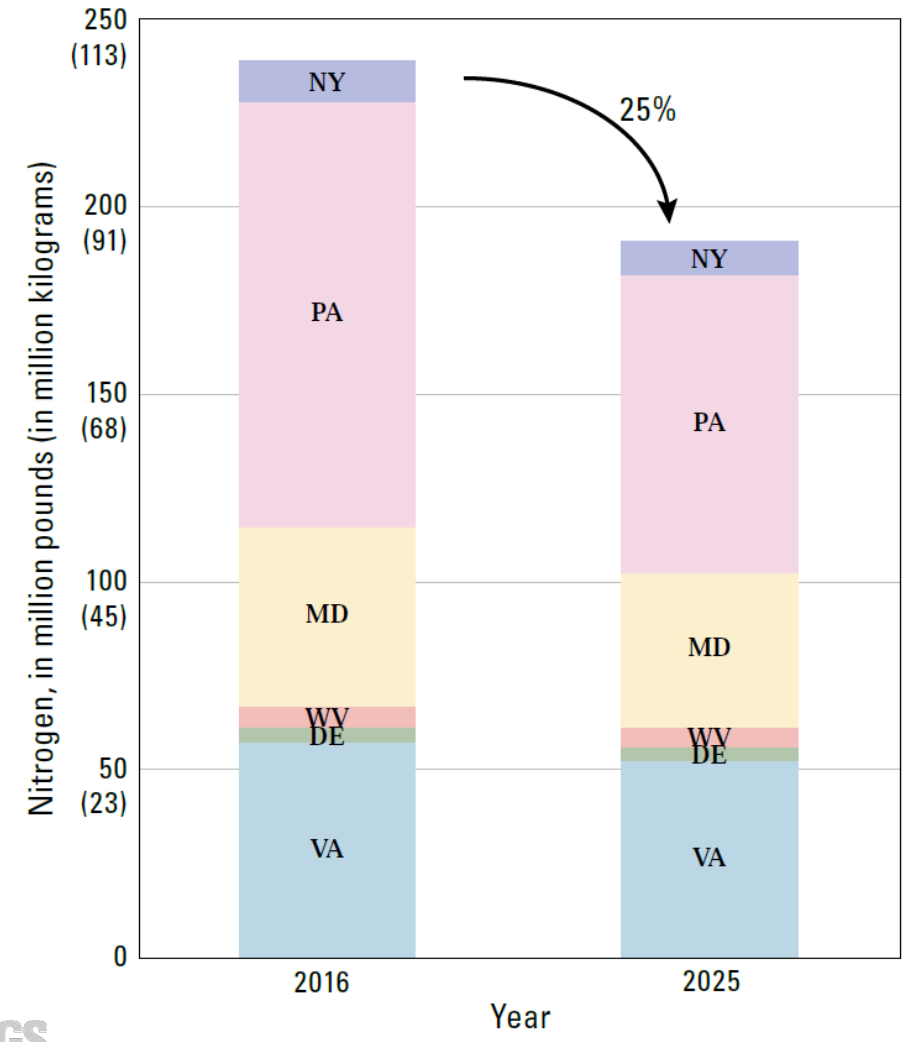
In 2011, this increased algal productivity from nutrient enrichment (**eutrophication**) resulted in the most expansive low oxygen (hypoxia) conditions, also known as dead zones, in the Chesapeake Bay



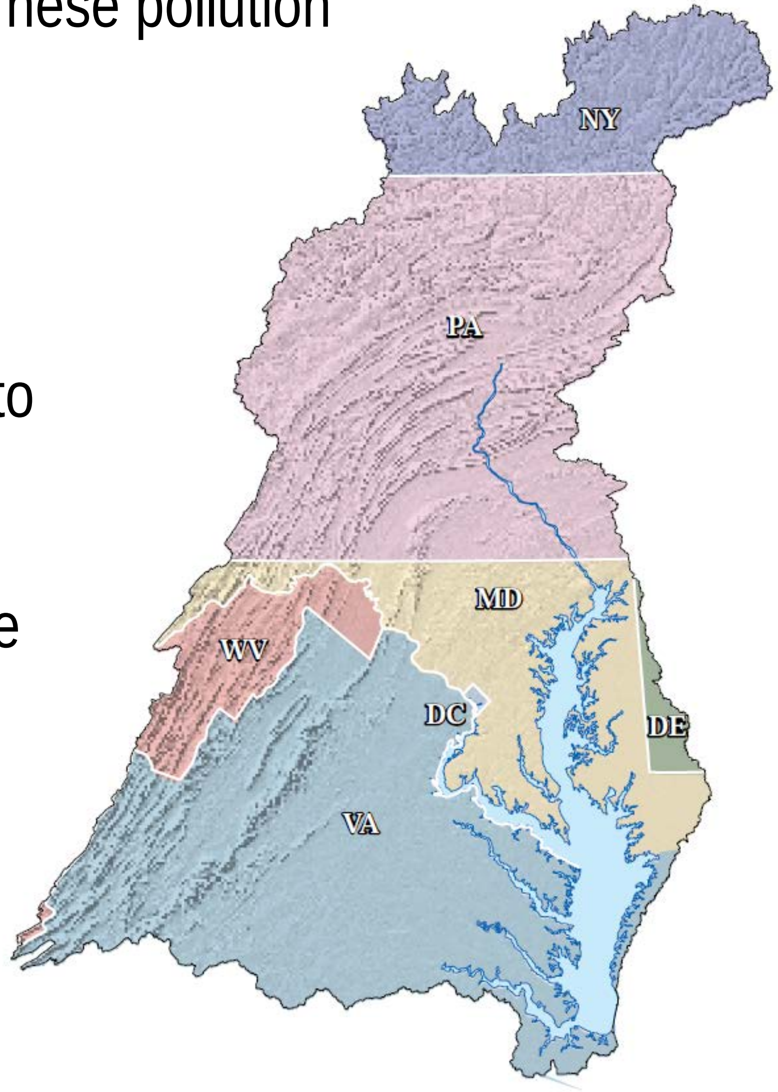
In fact, hypoxic volumes in the Chesapeake Bay have increased since the 1950s



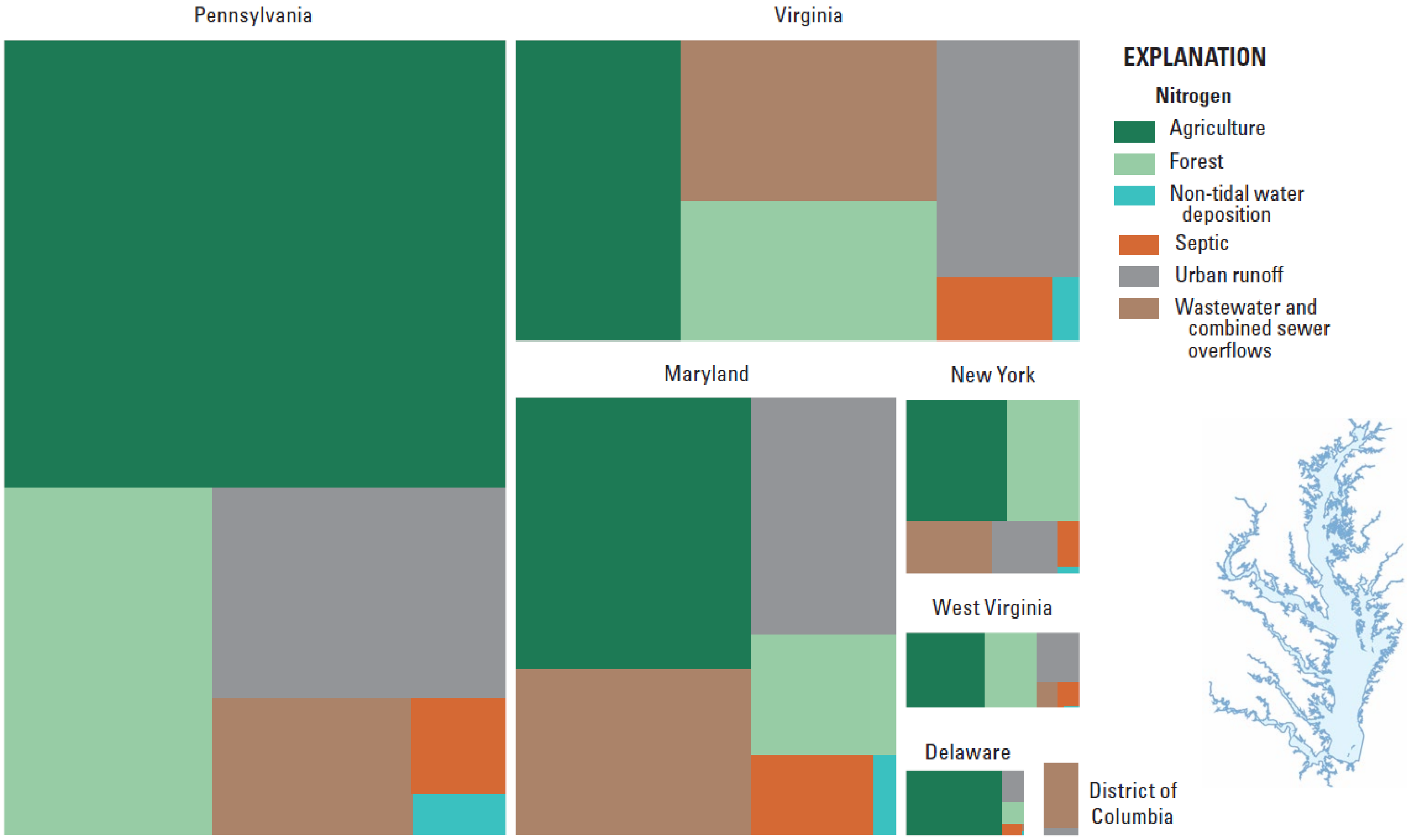
In 2010, the largest Total Maximum Daily Load (TMDL) in the Nation was developed for the Chesapeake Bay for nitrogen, phosphorus, and sediment. These pollution allocations were further divided by major river basins and **States**.



Management practices expected to eventually reduce nitrogen by 25 percent are set to be implemented in the Bay watershed by 2025.



The proportional sources of nitrogen load delivered to the Chesapeake Bay varies by state



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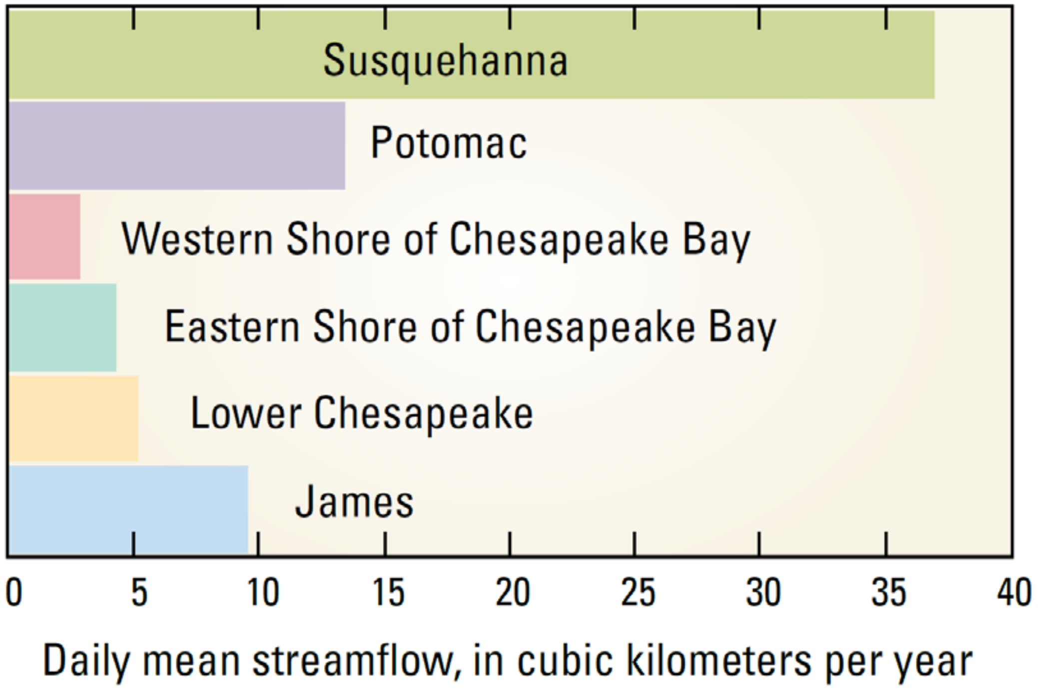
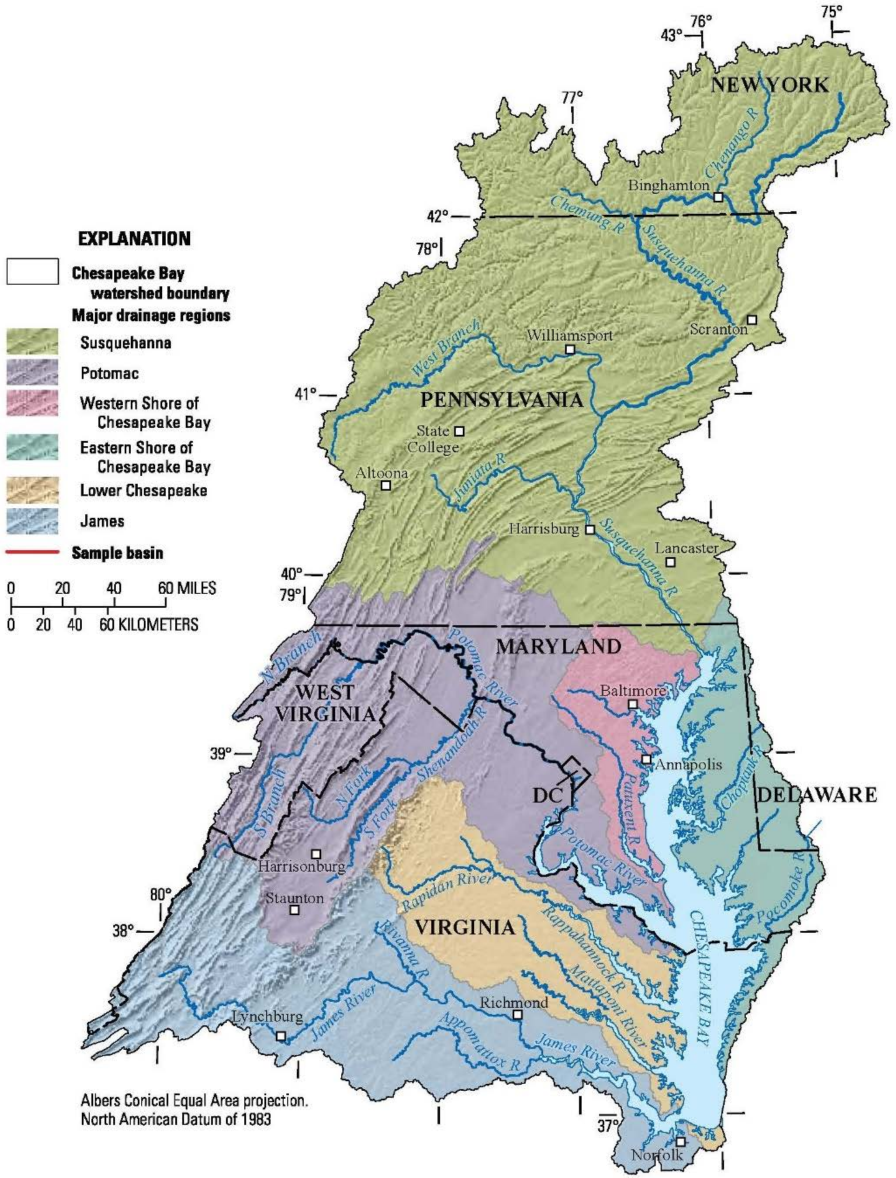
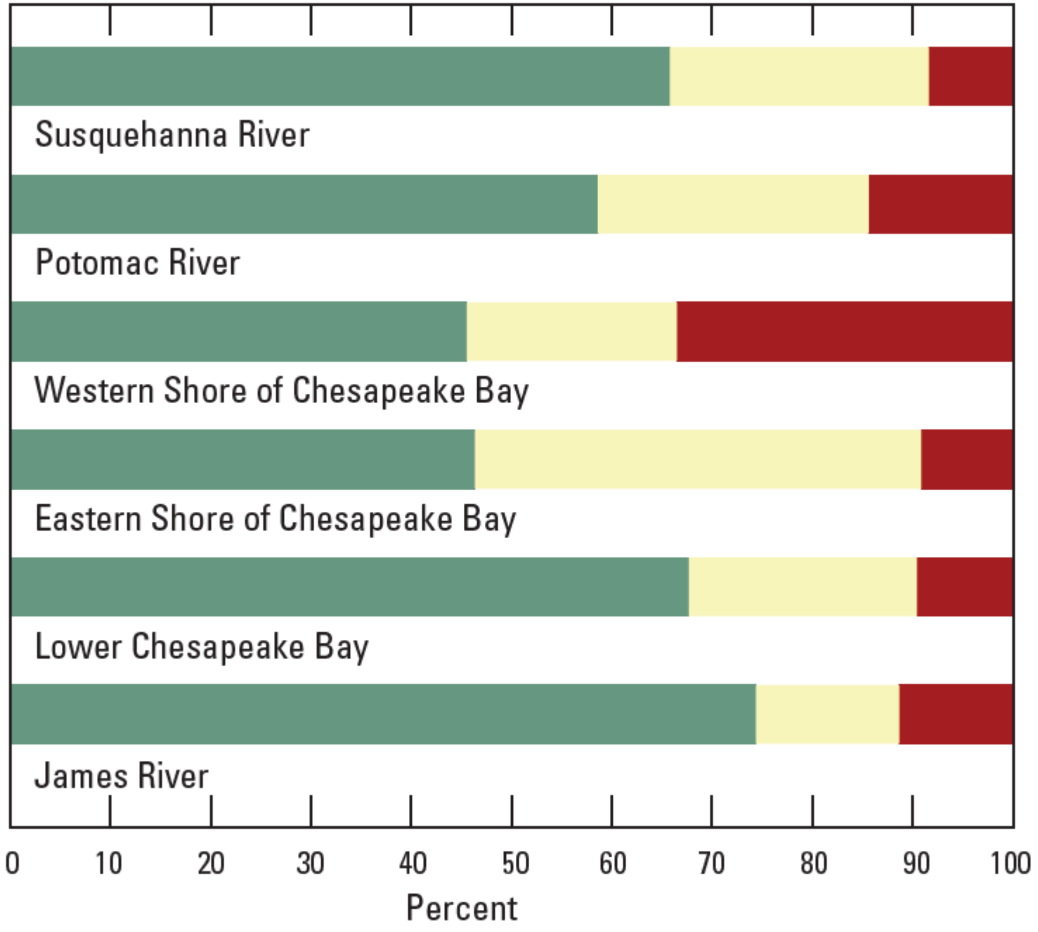
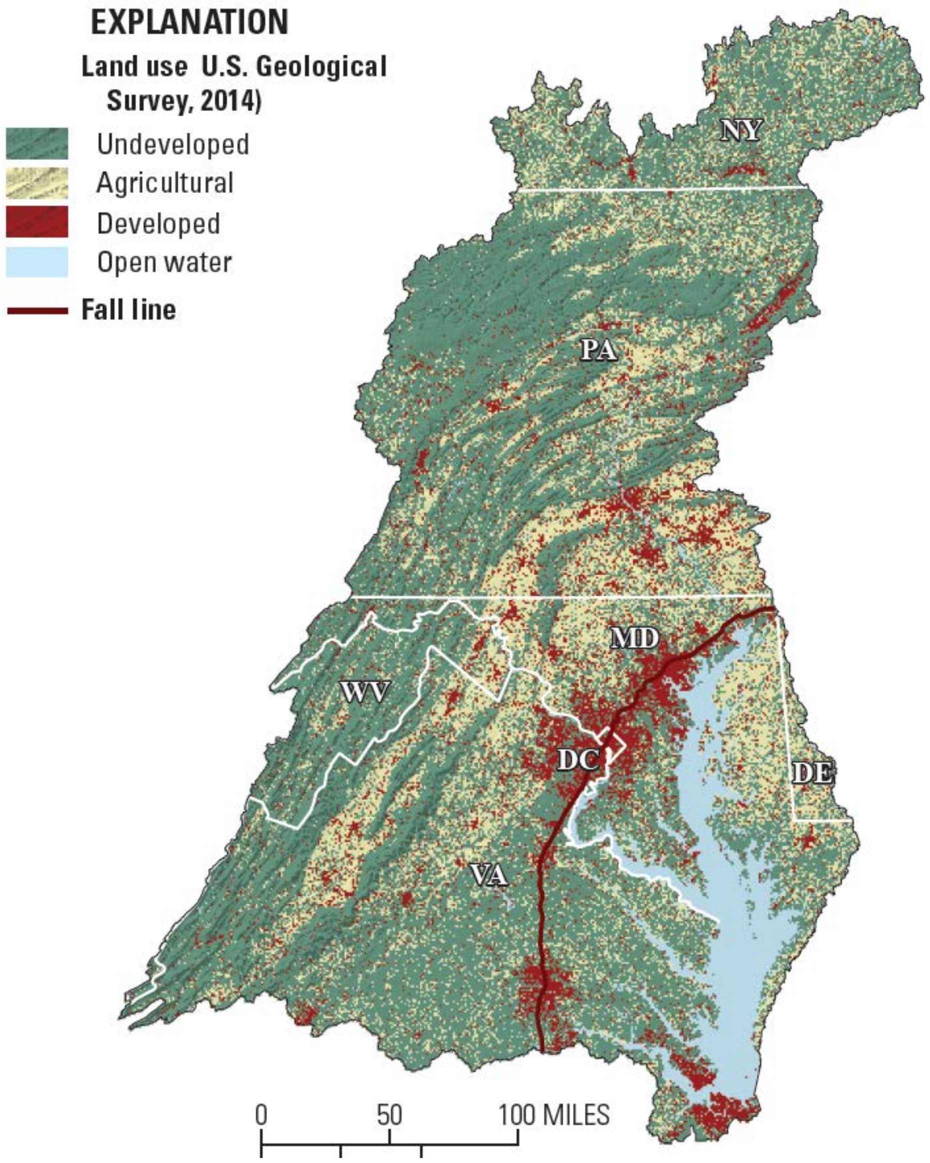
The Chesapeake Bay watershed consists of six major river drainage regions that contribute varying streamflow to the Bay



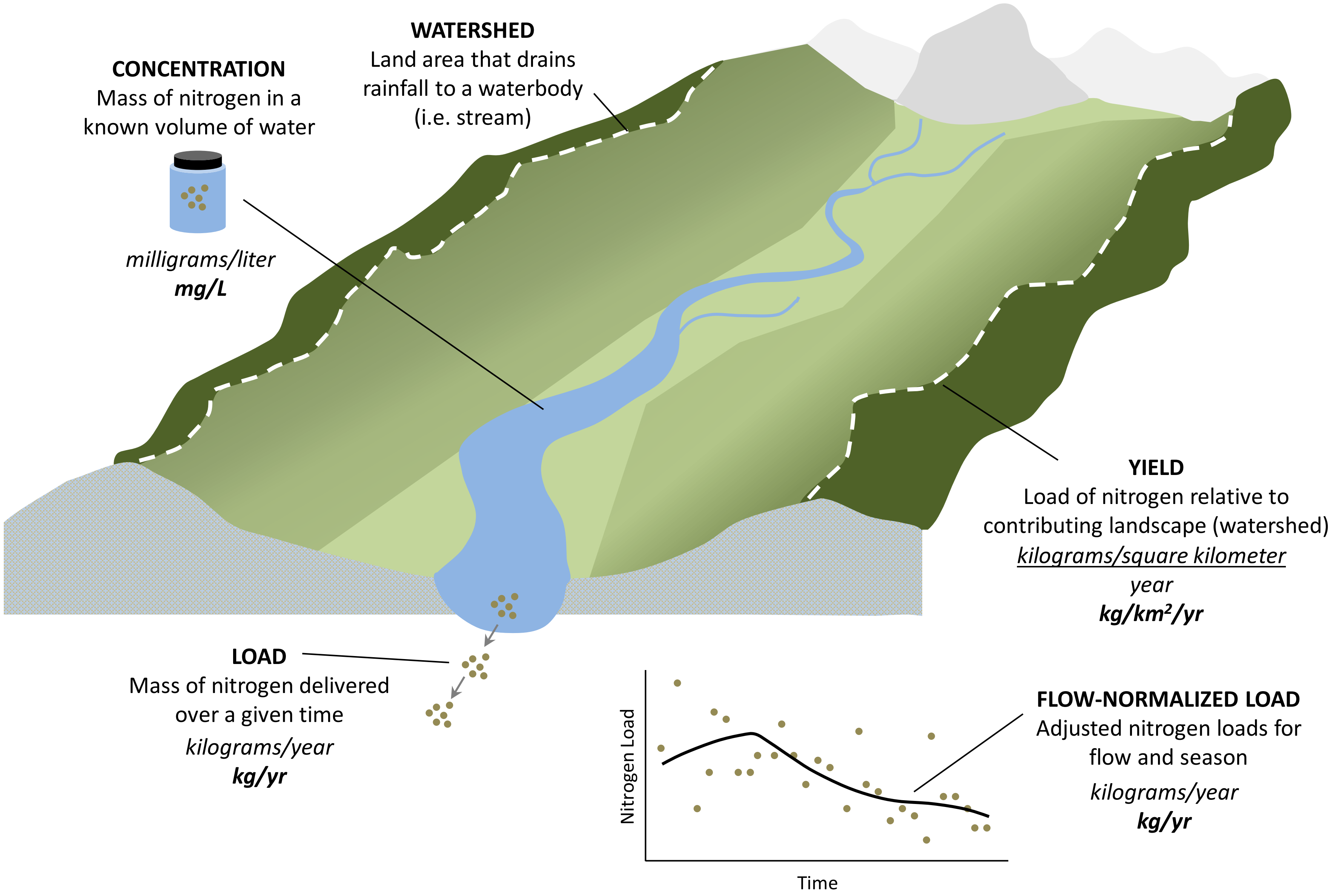


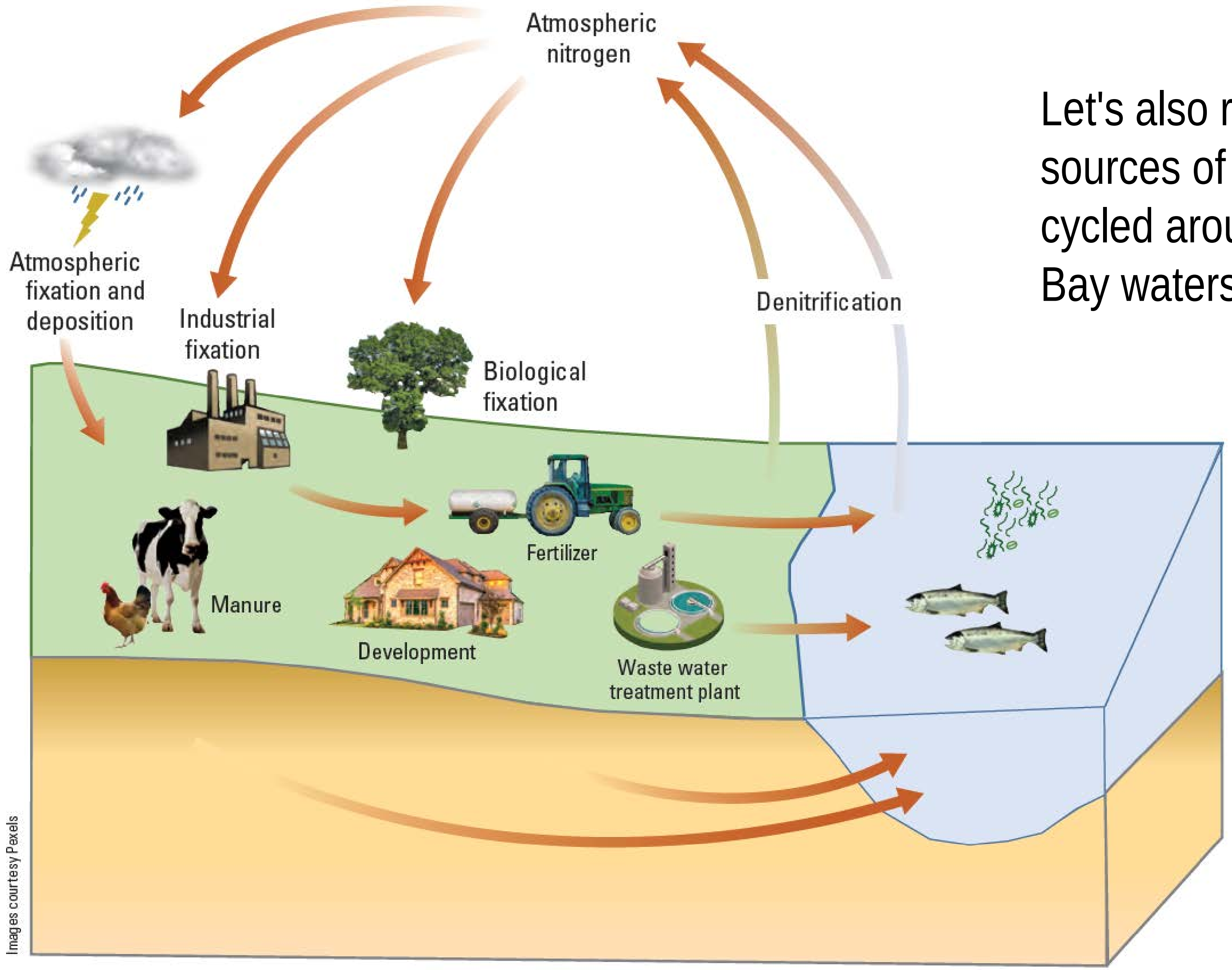
Land use in the Chesapeake Bay watershed is predominantly undeveloped, along with agricultural and developed areas





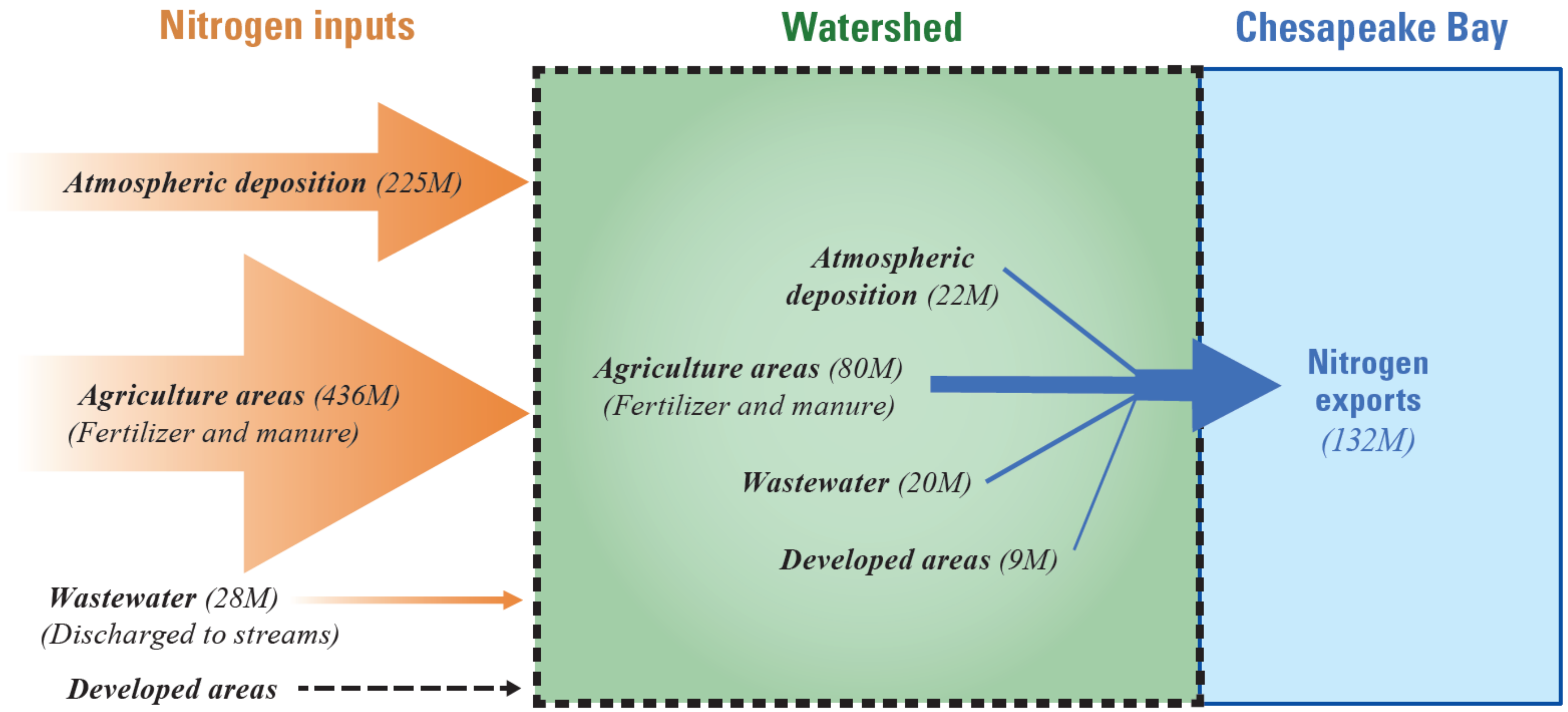
Before we talk about the various drivers of change that affect the delivery of nitrogen to the Chesapeake Bay, let's define some important terms and units of measurement





Let's also review, the major sources of nitrogen and how it’s cycled around the Chesapeake Bay watershed.

Lastly, its important to understand the magnitude of those sources as inputs to the watershed and exports to the Bay



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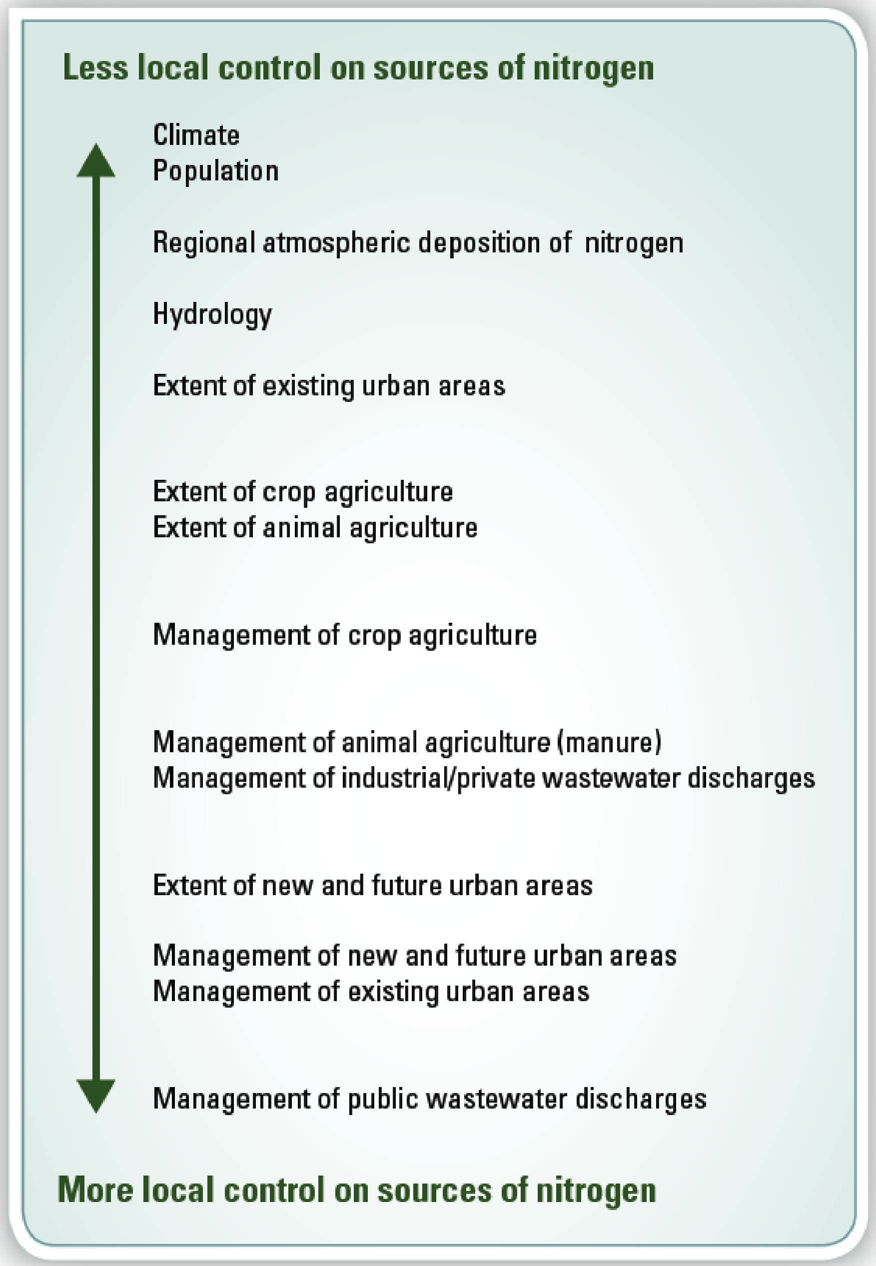
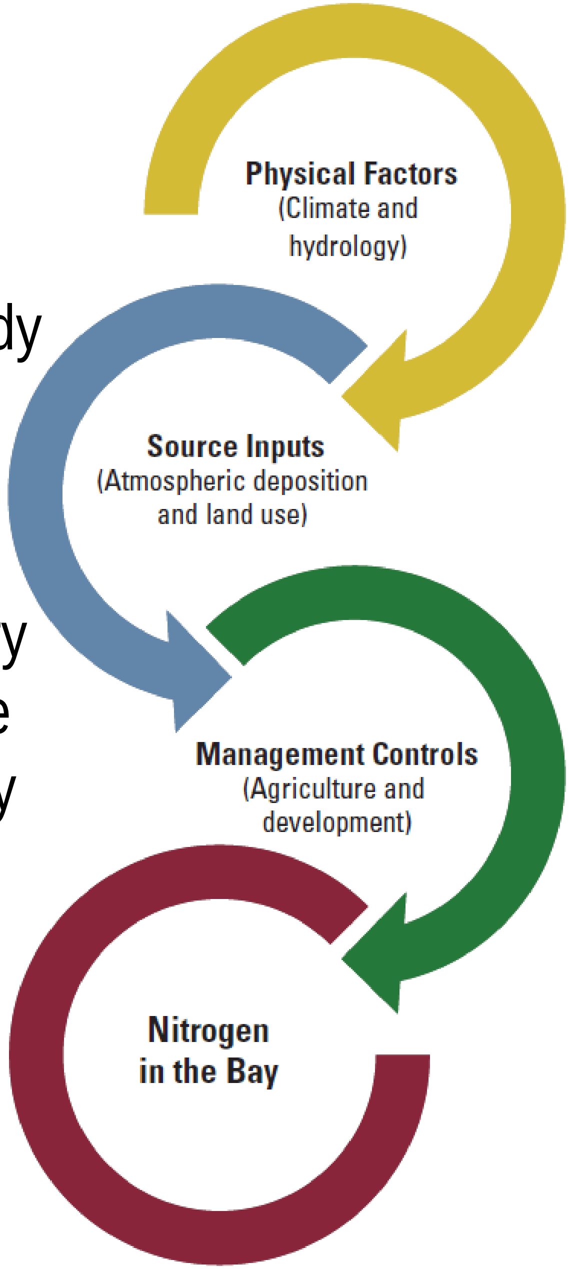
Those responsible for management decisions have varying degrees of influence on the changes that control the movement of nitrogen

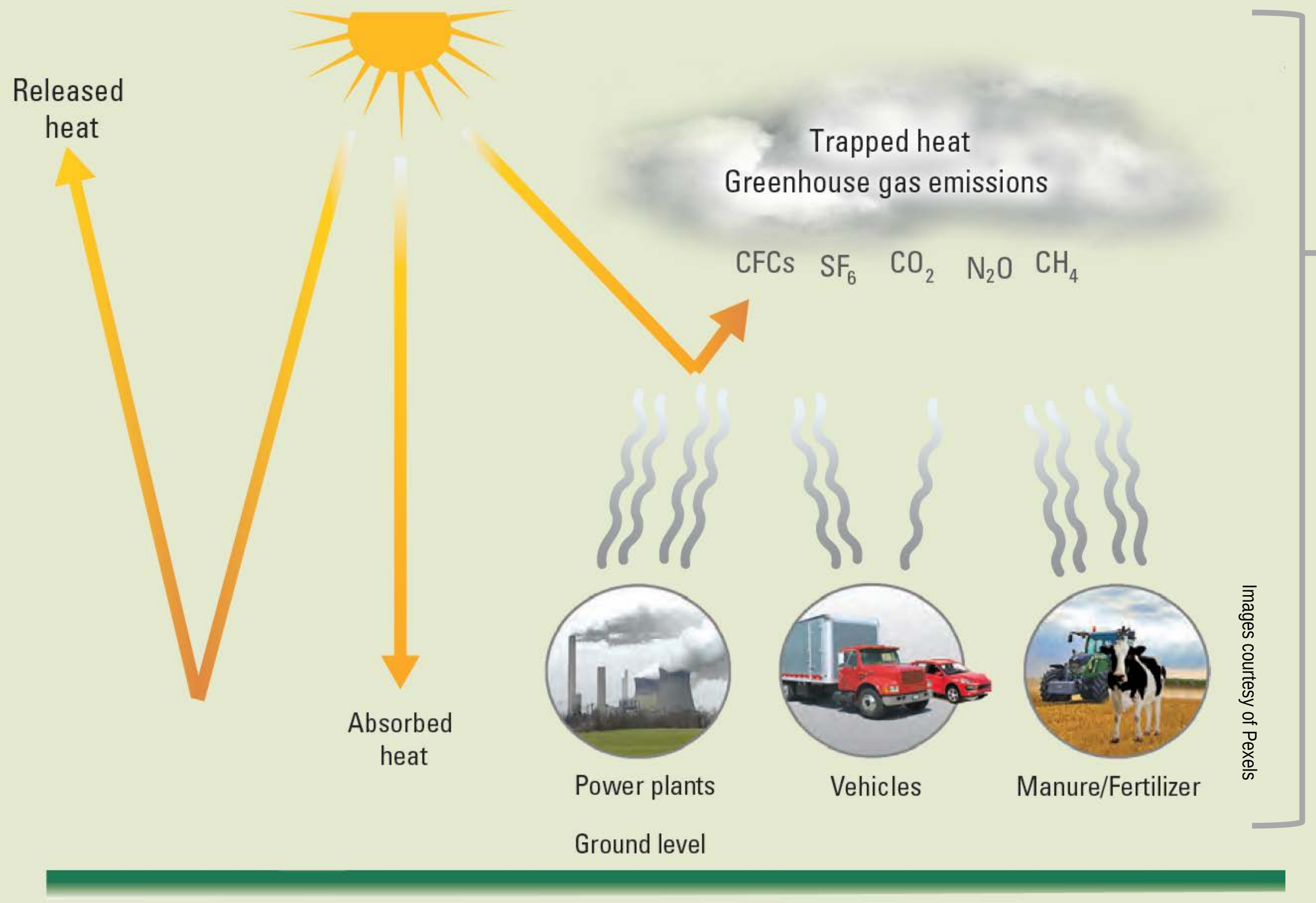


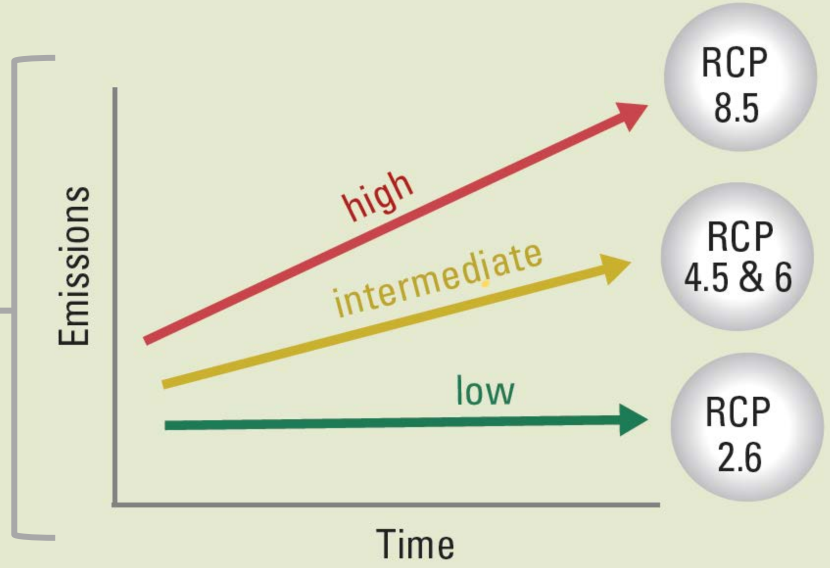
We are now ready to discuss the various **factors** that affect the delivery of nitrogen to the Chesapeake Bay



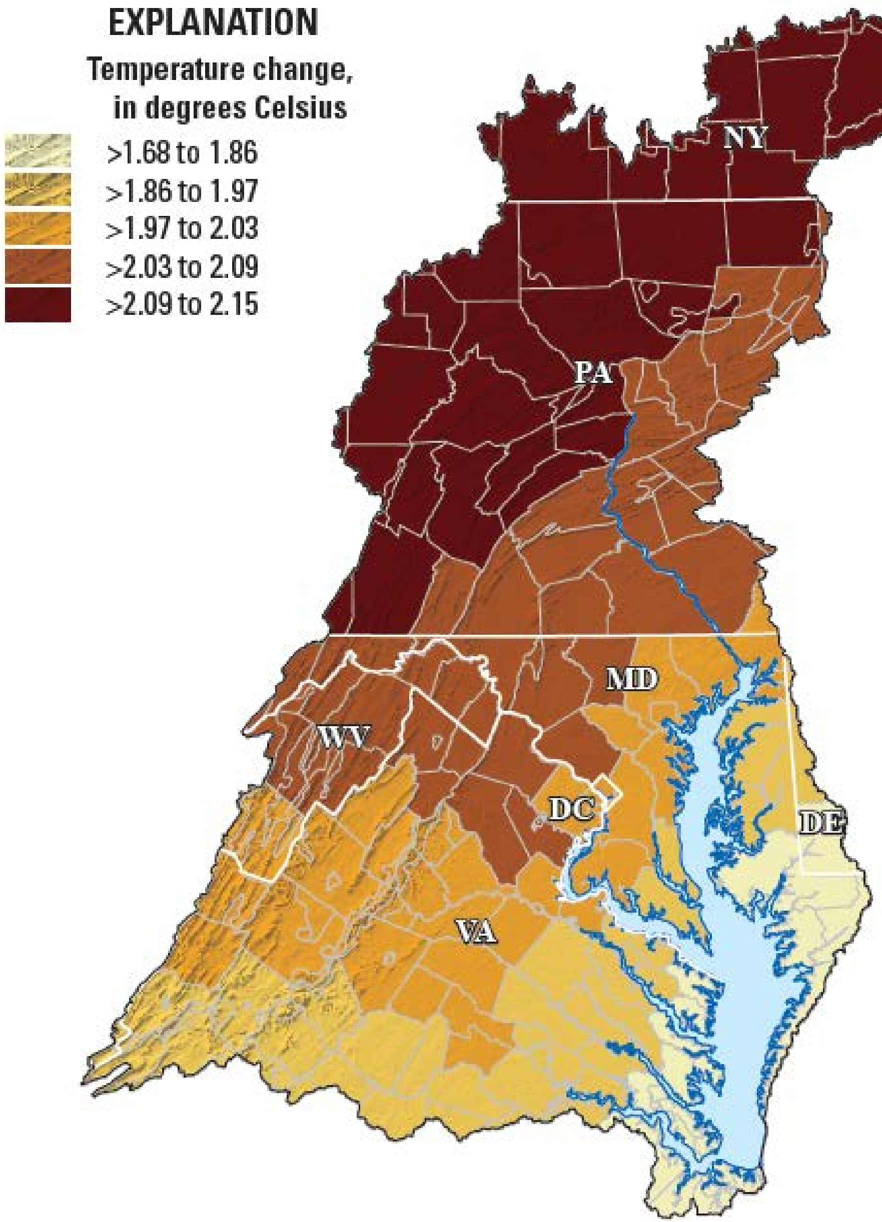
Local resource managers have less control over the climate and hydrology

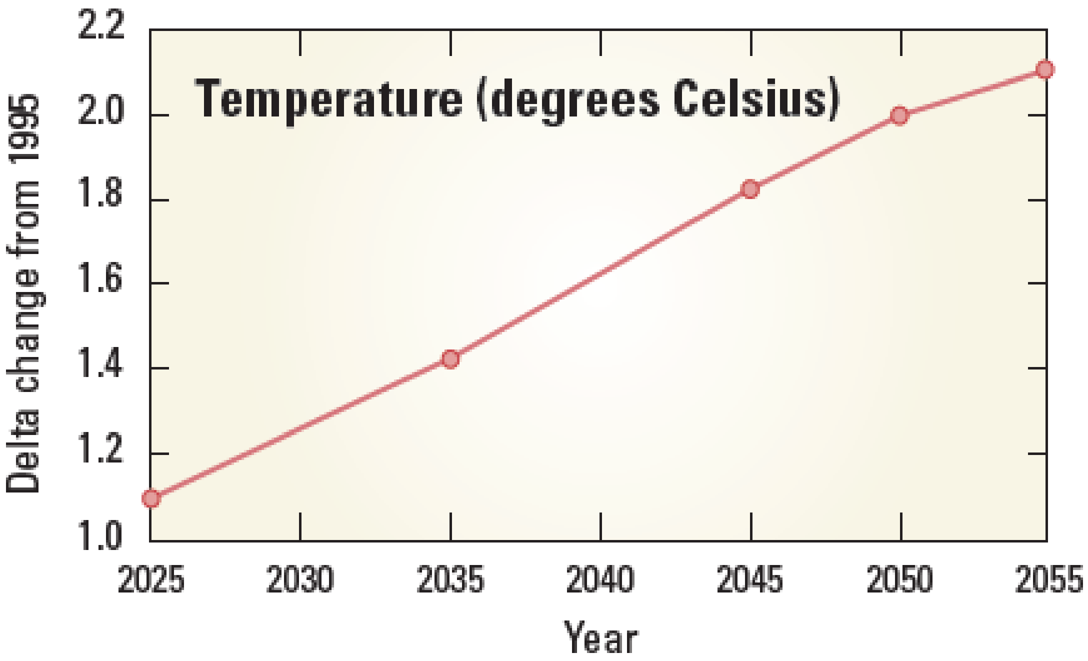
So let's talk first about climate and how increasing concentrations of greenhouse gases like carbon dioxide that trap heat close to the Earth's surface have caused increases in mean annual temperature





Climate scientists use four major emission scenarios (representative concentration pathways [RCPs] of 2.6, 4.5, 6 or 8.5 watts per square meter) for how increasing amounts of greenhouse gases could trap heat





* Predictions are based of an intermediate emission scenario (RCP 4.5)

The mean annual temperature across the entire Chesapeake Bay watershed is expected to increase by 2.0 °C by 2050 compared to 1995, with larger differences likely in the northernmost part of the watershed

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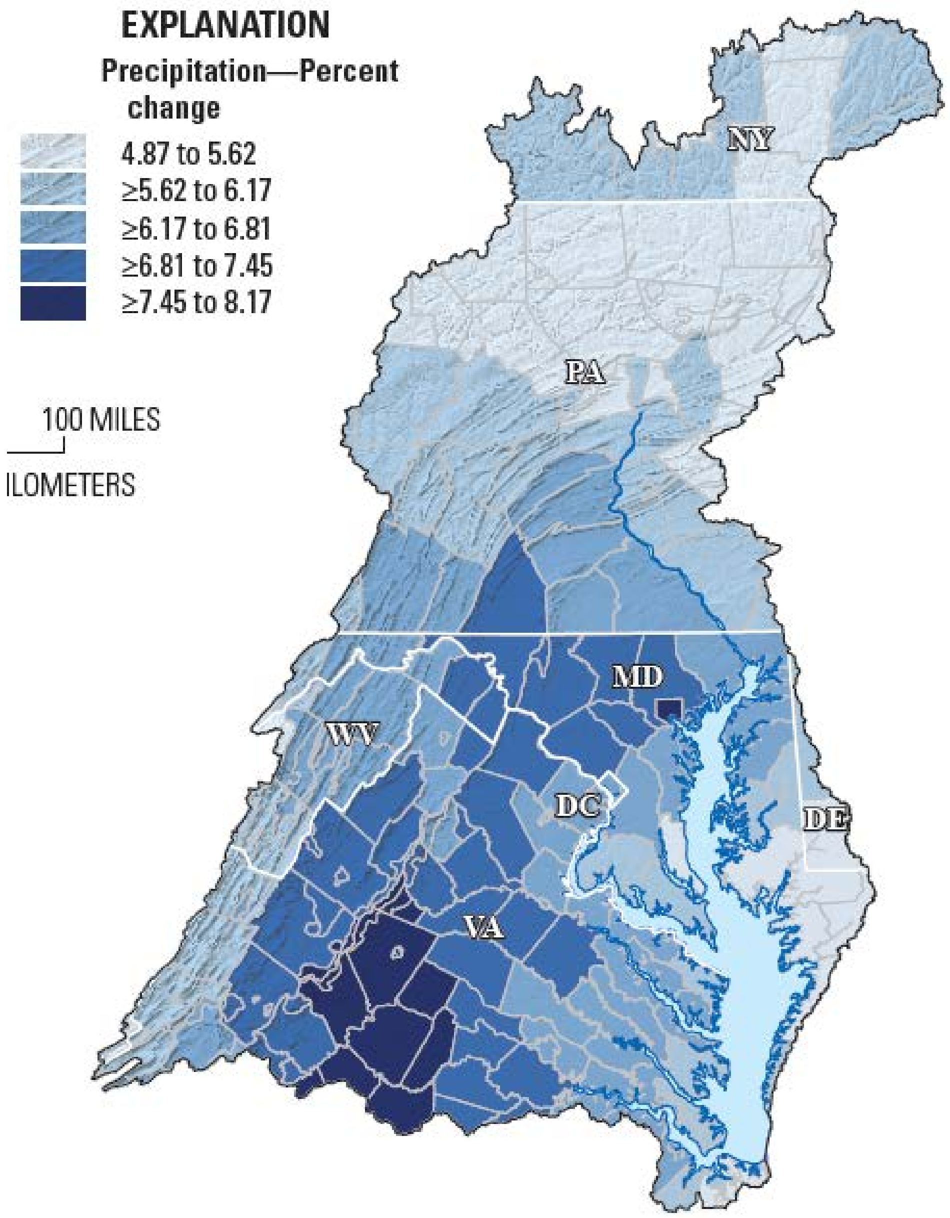

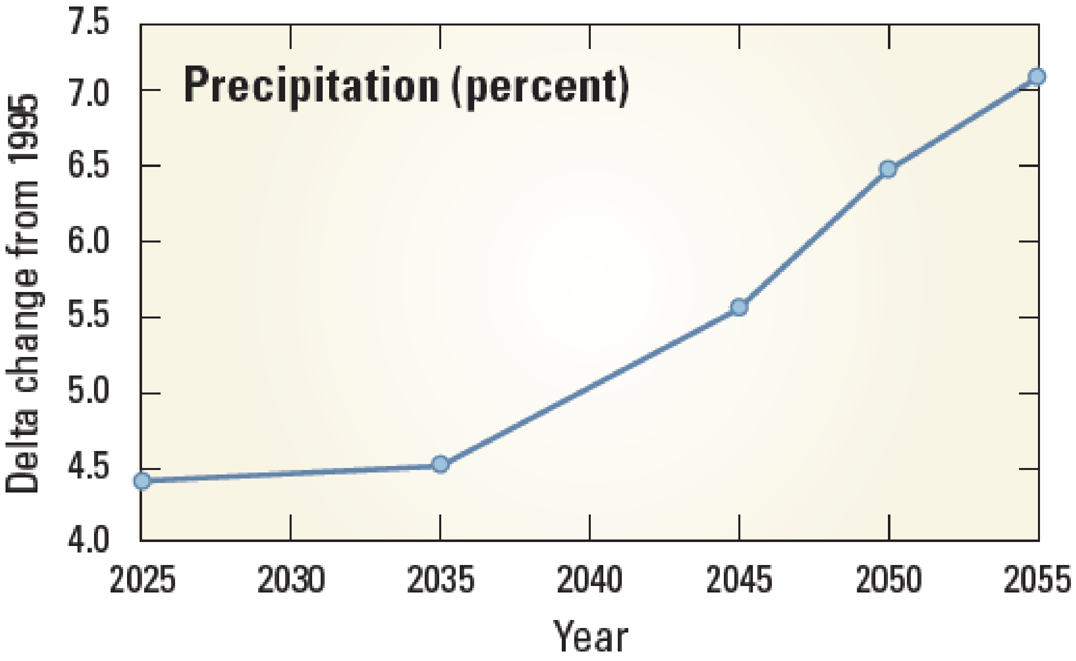

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Projected precipitation changes from 1995 to 2050 for the Chesapeake Bay watershed show a 6.3 percent increase in average annual precipitation, with the largest increases occurring in the southern states

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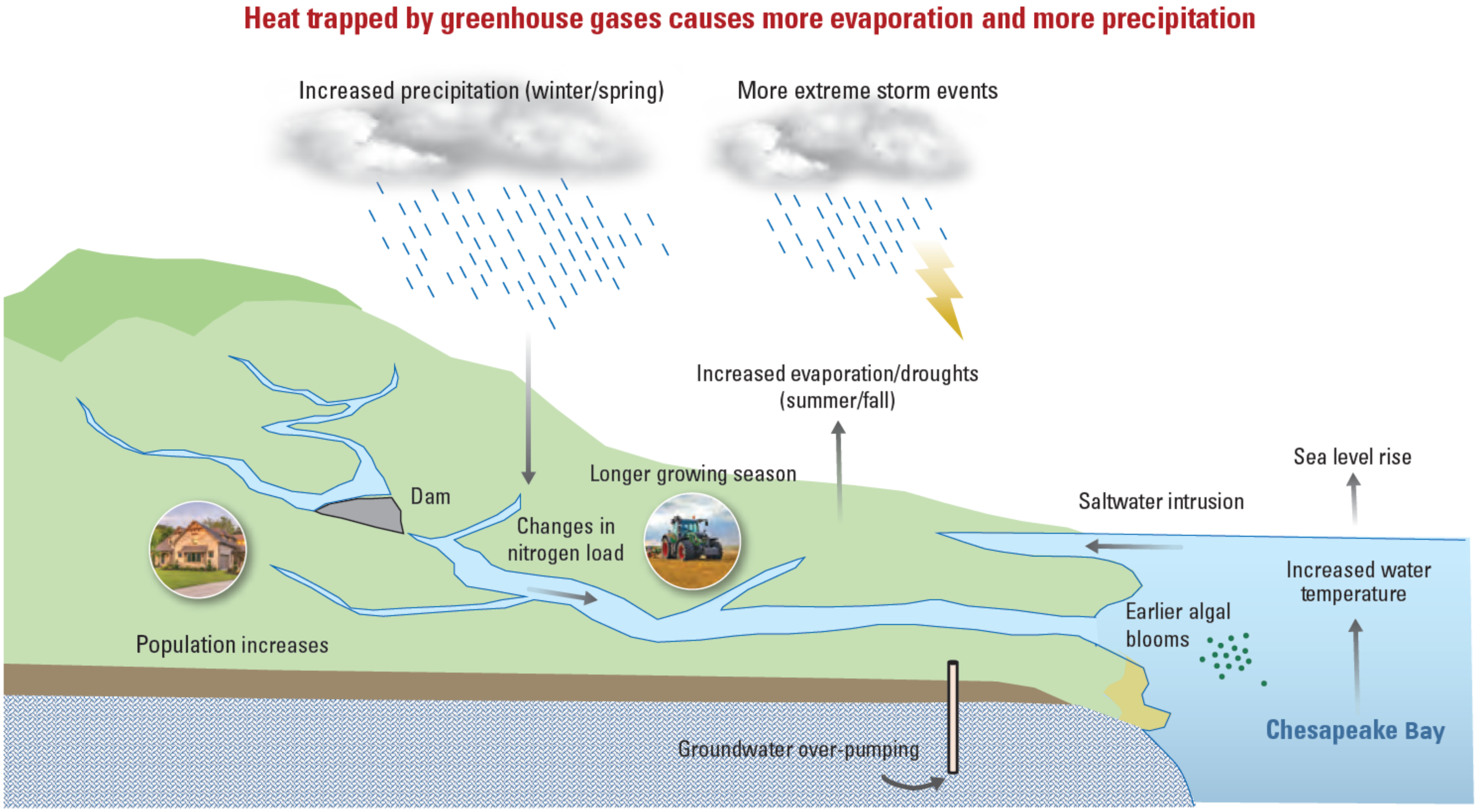
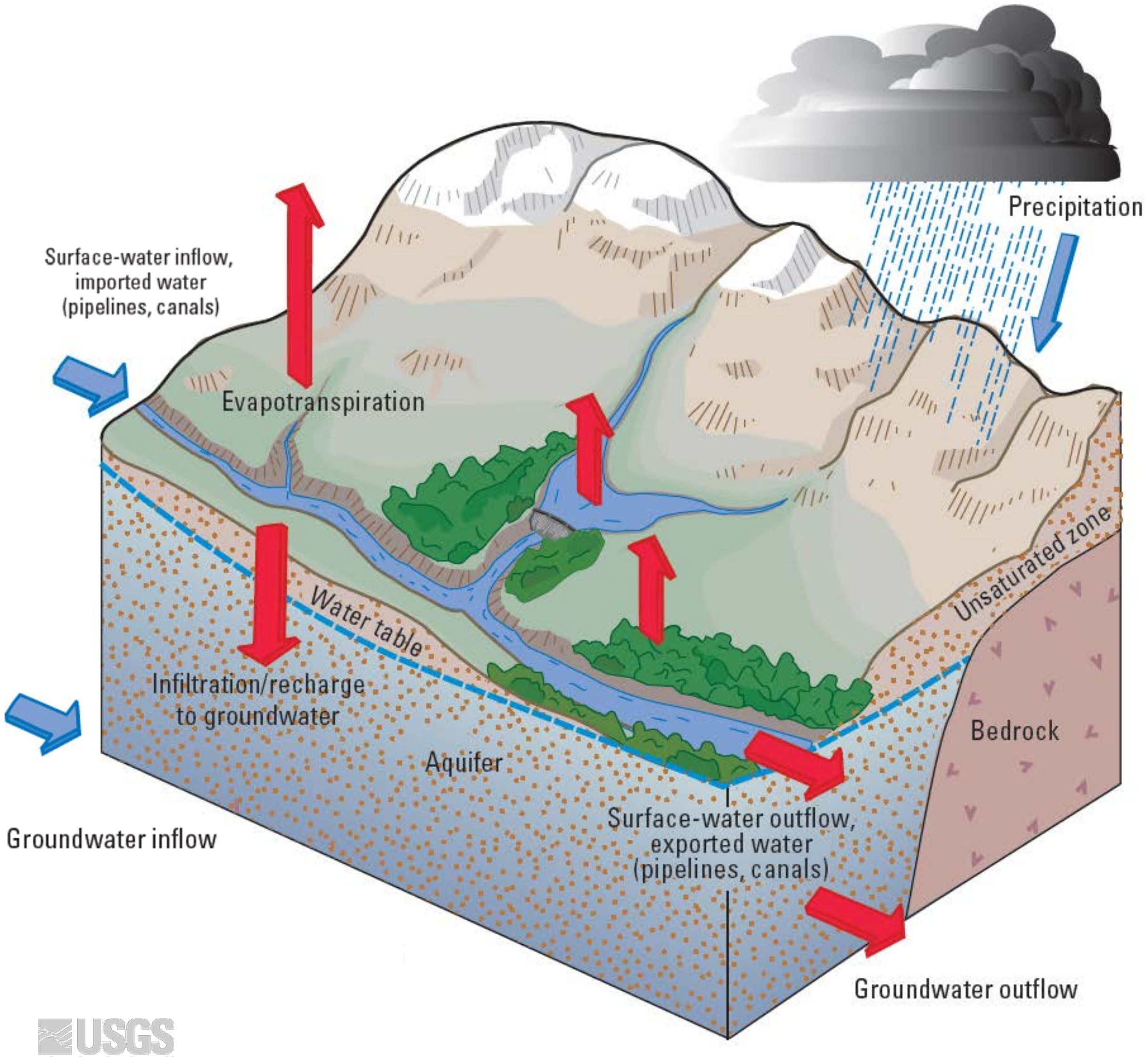
Overall, the Chesapeake Bay is experiencing a warming trend with shifts to drier summer and fall seasons followed by wetter winter and spring seasons



Images courtesy of Pexels



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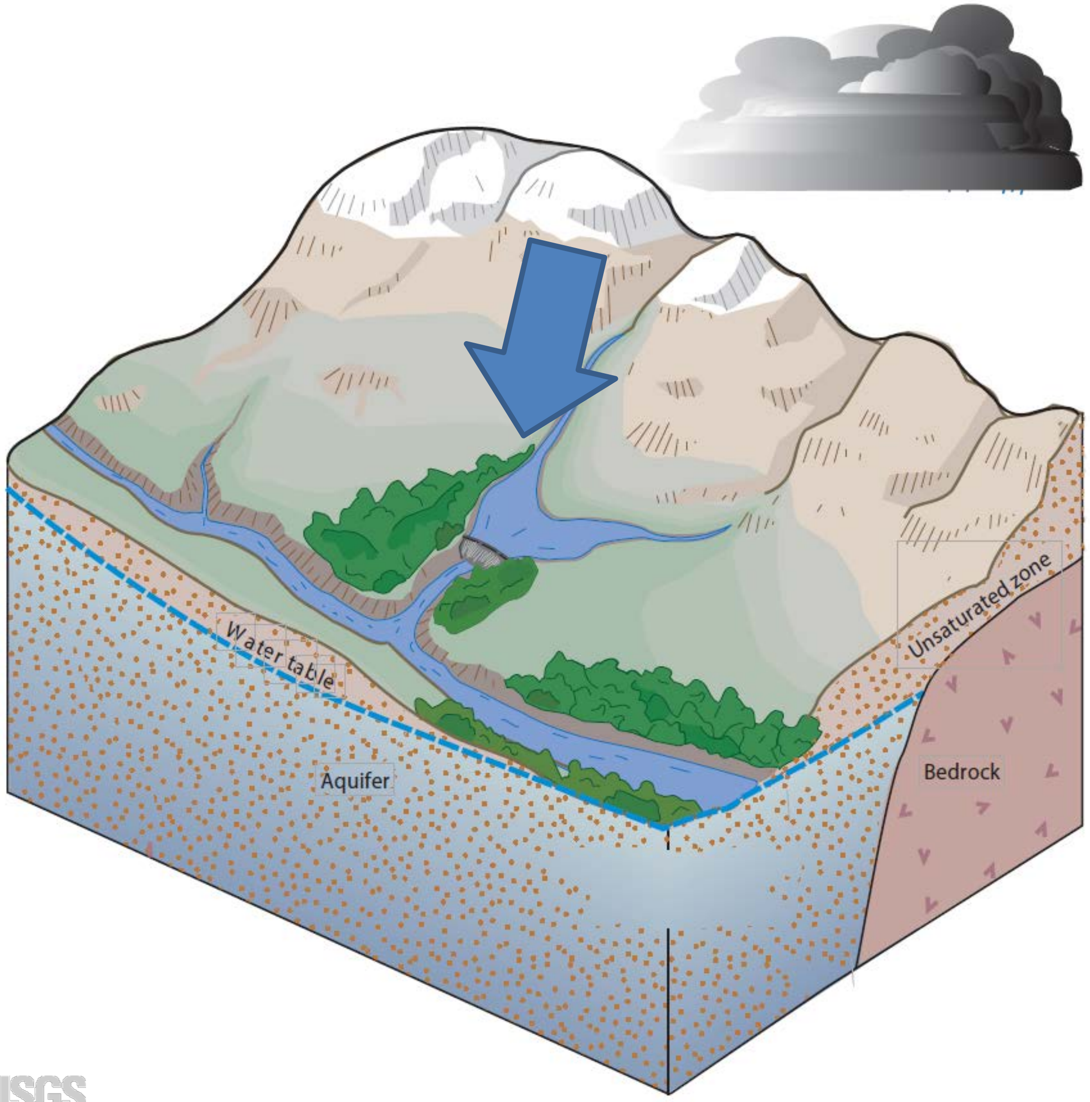
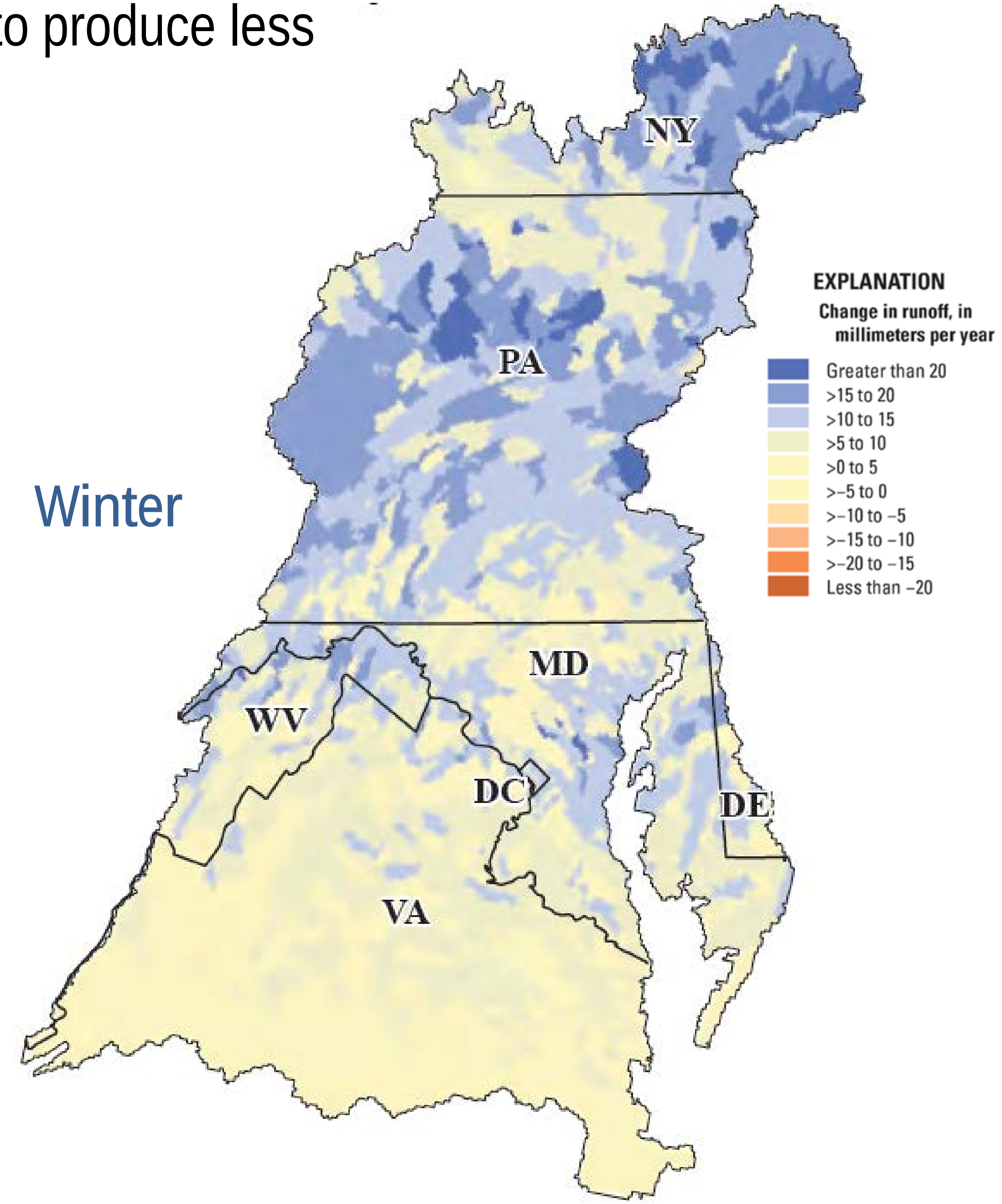
The components of the **hydrologic cycle** (precipitation, evapotranspiration, runoff, recharge, groundwater discharge, and streamflow) store, process, and ultimately transport water and nitrogen to the Chesapeake Bay

Continued warming temperature trends are projected to produce less snowpack and earlier runoff in the winter



Winter



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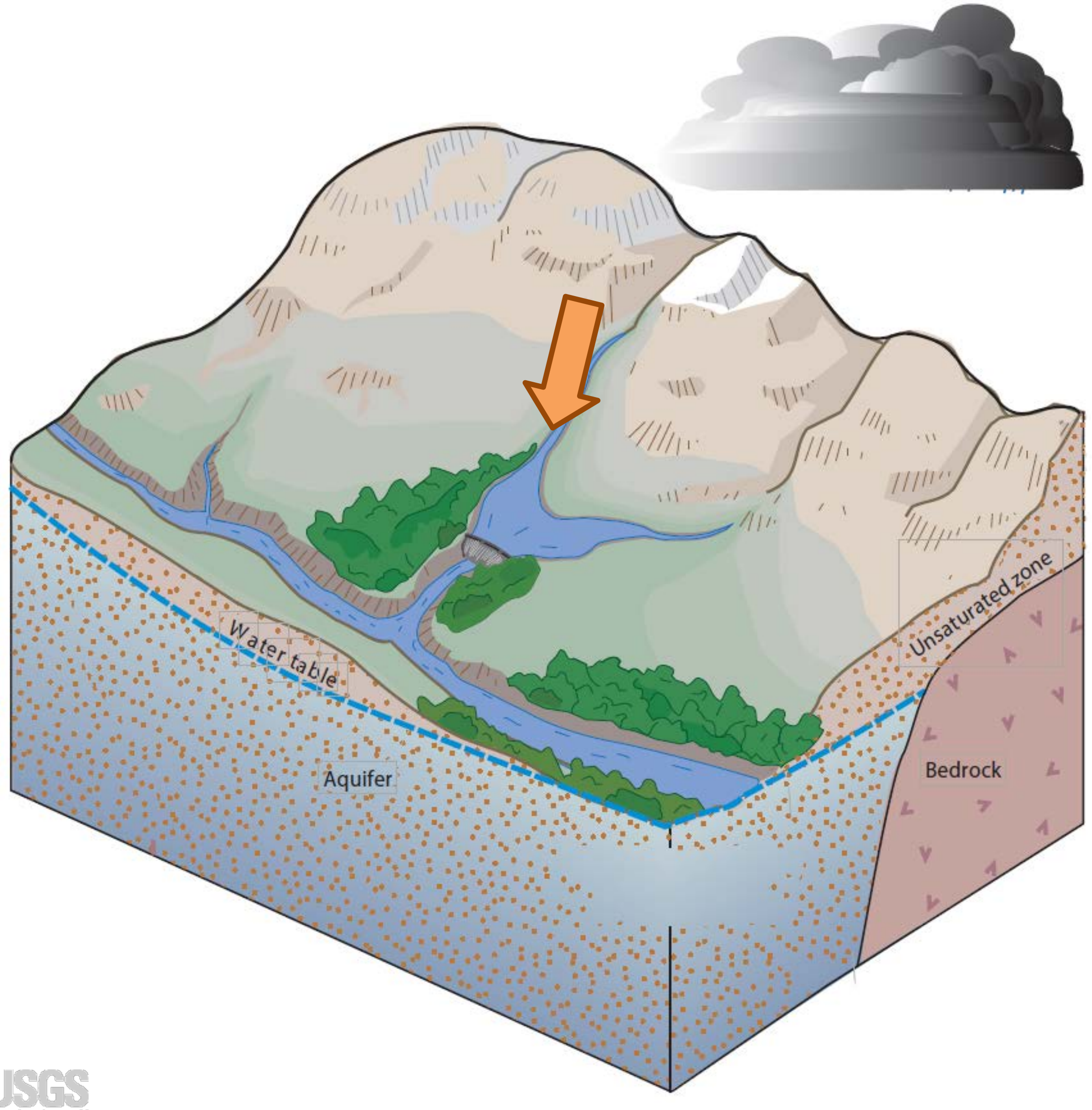
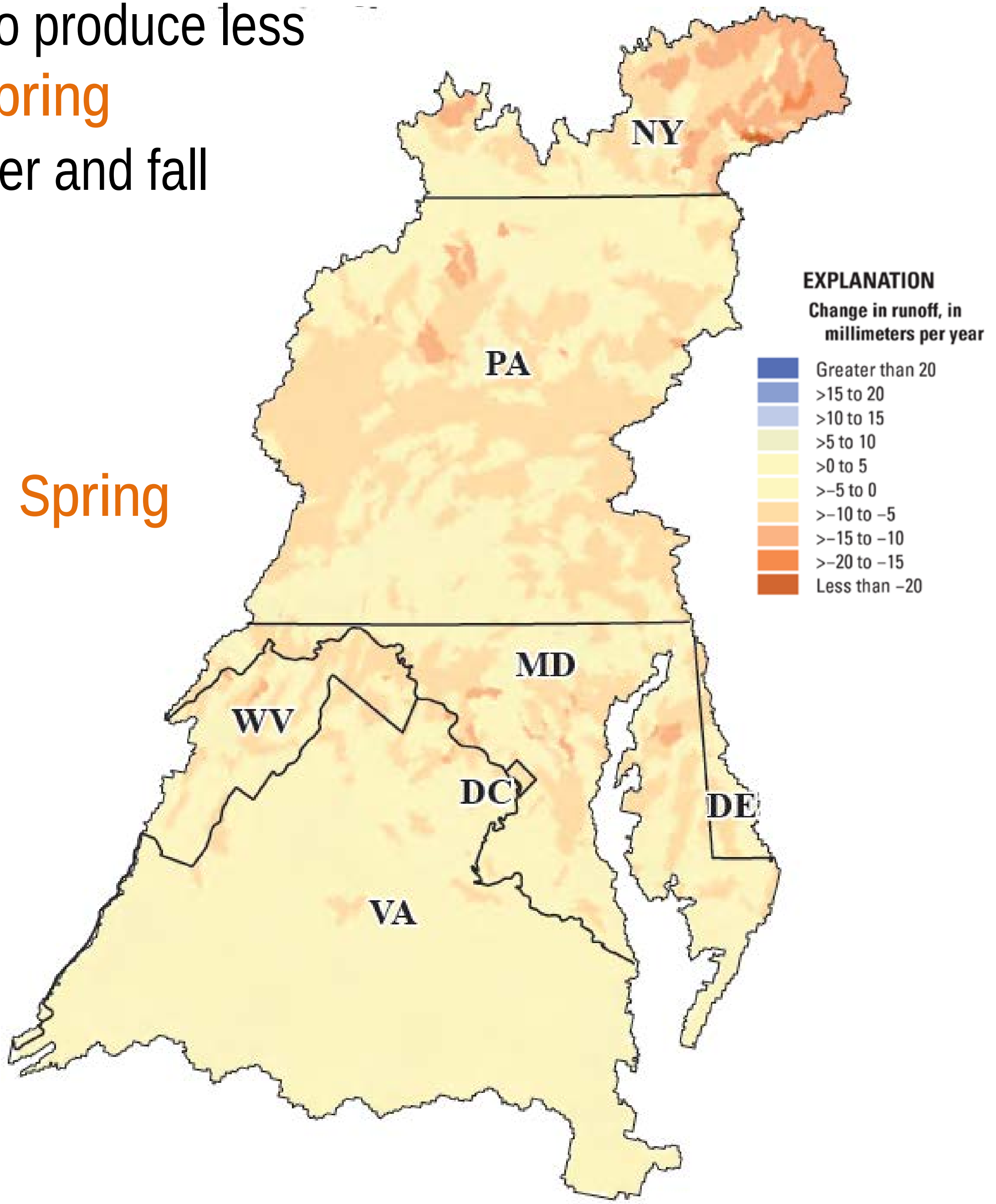
Continued warming temperature trends are projected to produce less snowpack and earlier runoff in the winter versus the spring followed by less of a change in runoff during the summer and fall



Spring



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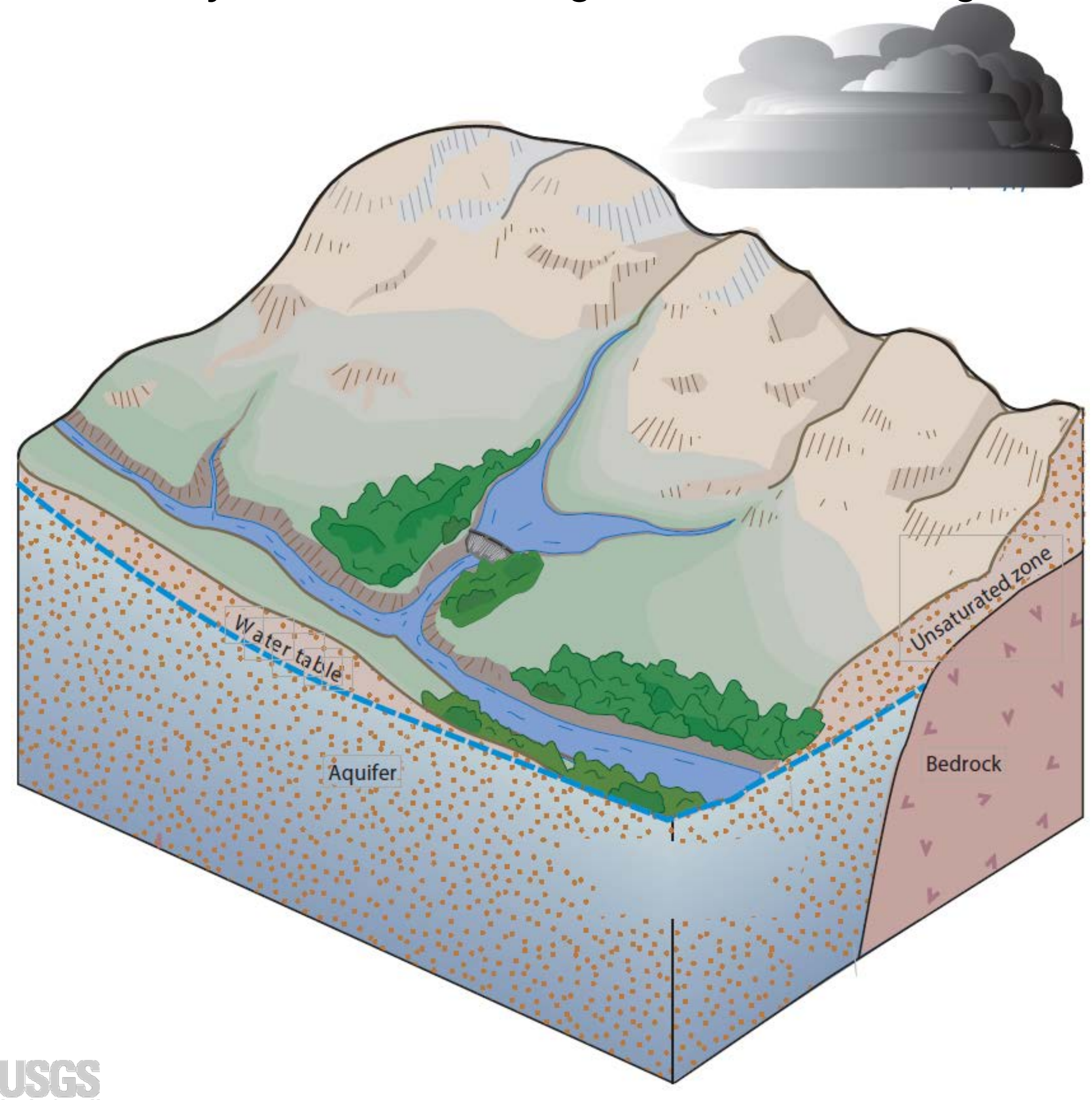
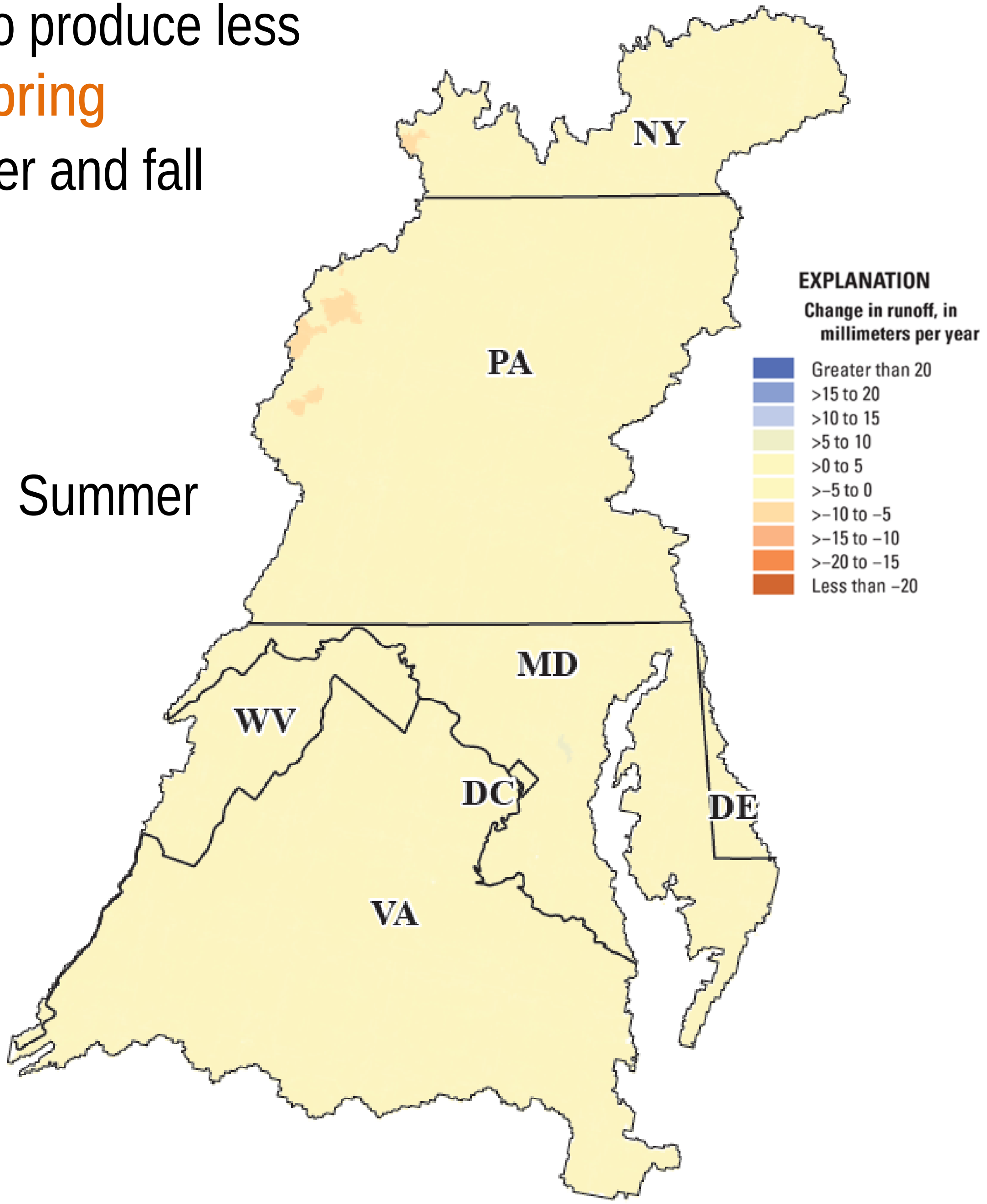


Summer



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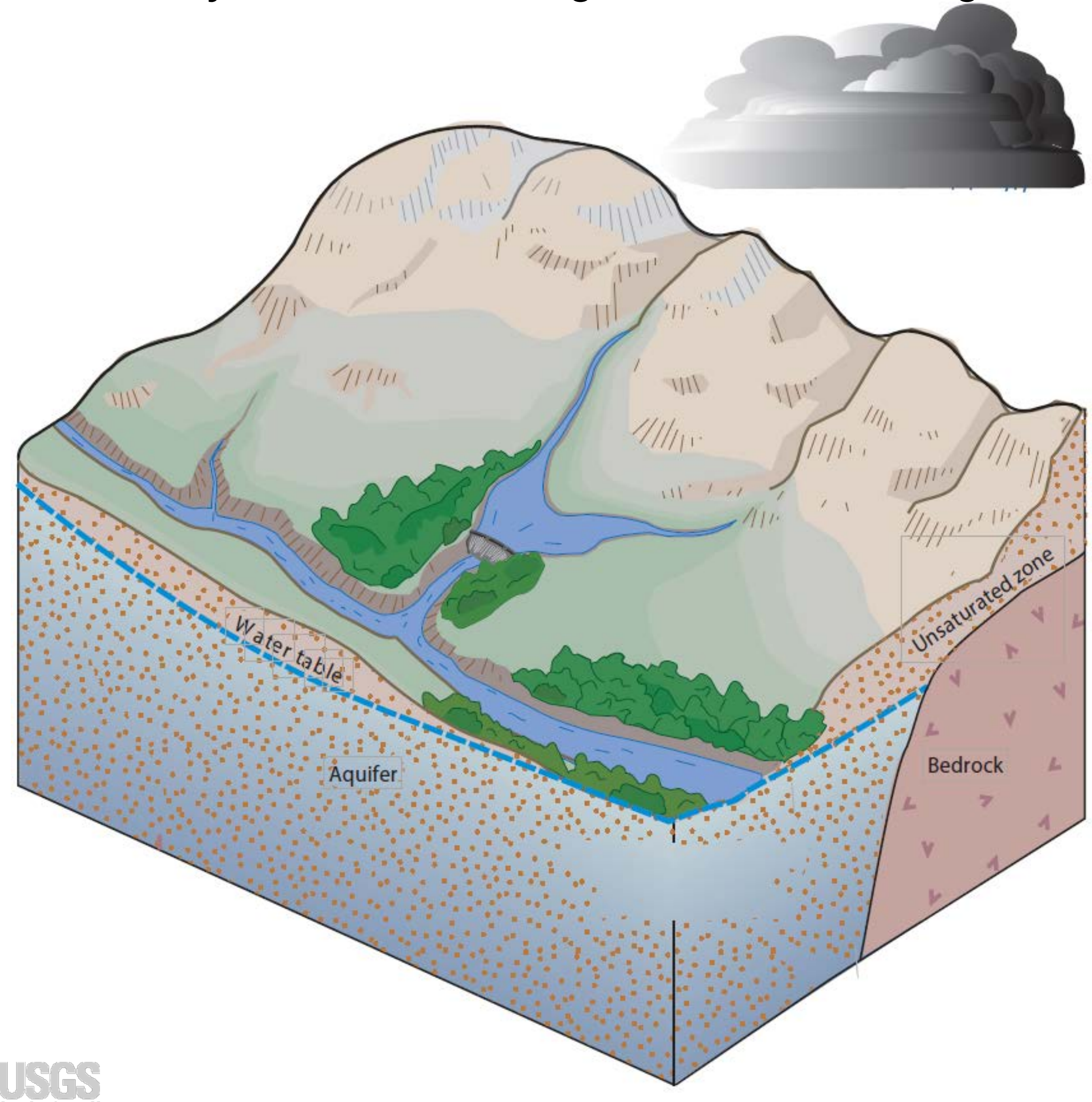
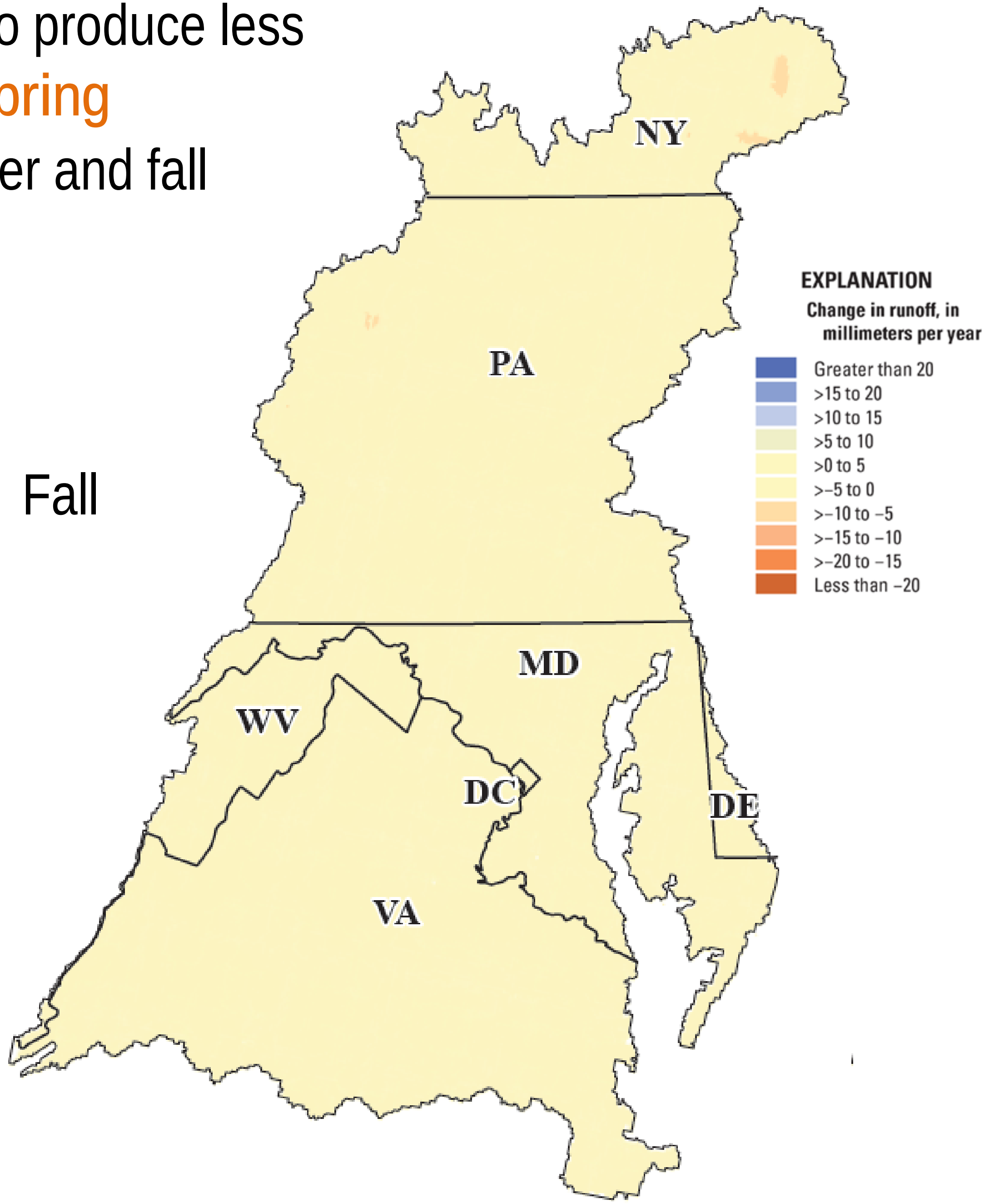
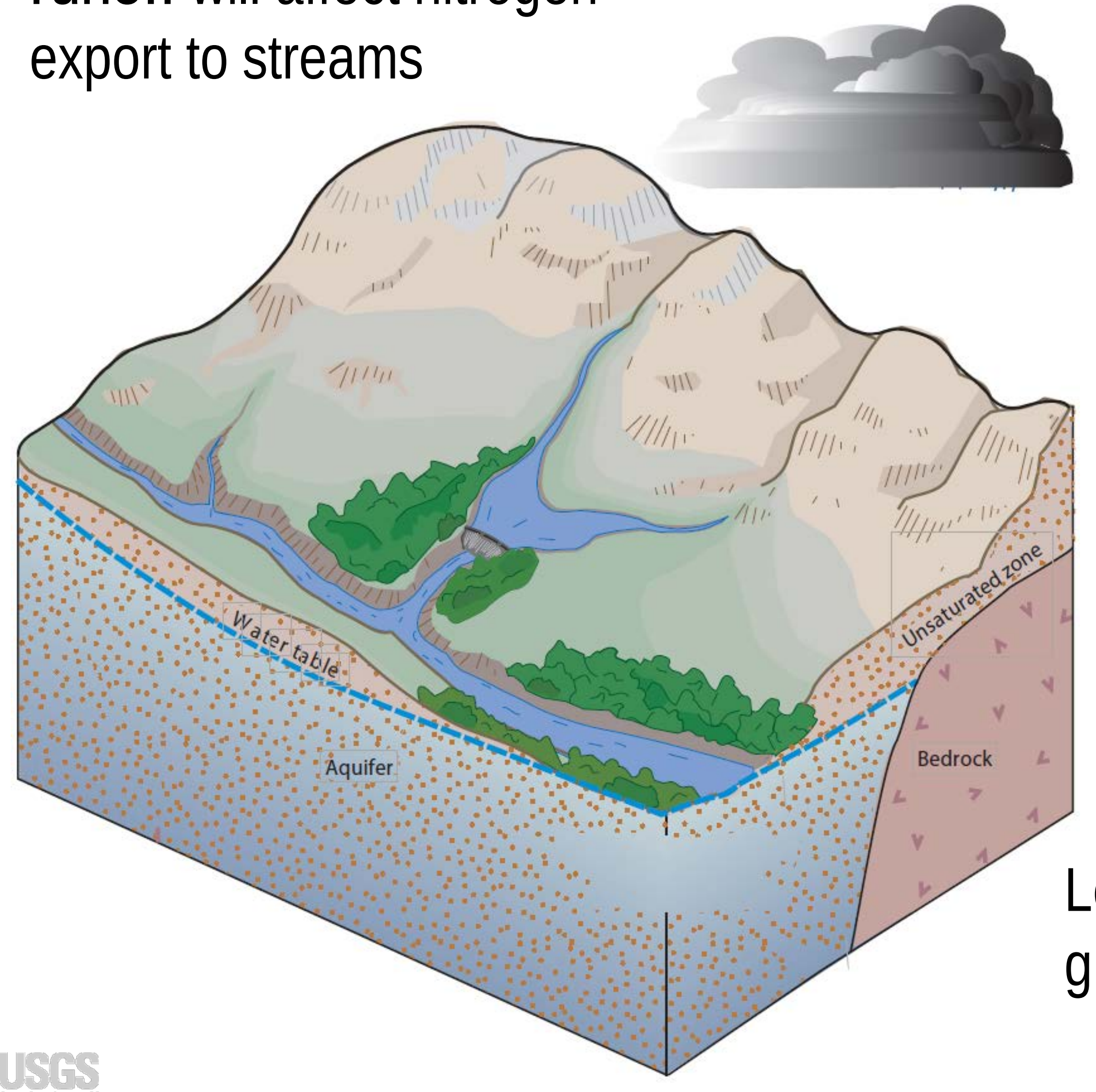


Fall



These seasonal shifts in **runoff** will affect nitrogen export to streams



Let's not forget about the groundwater transport of nitrogen

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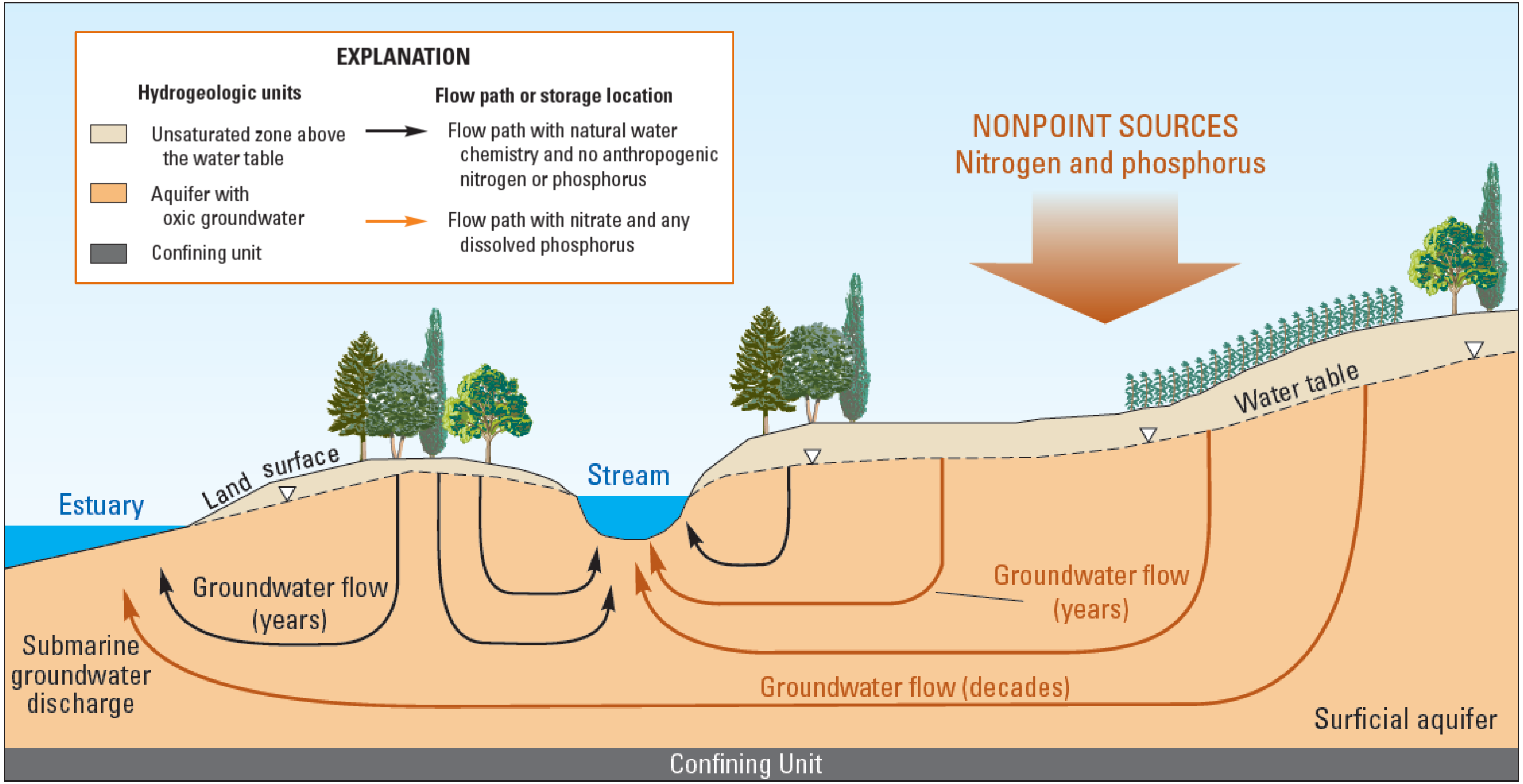
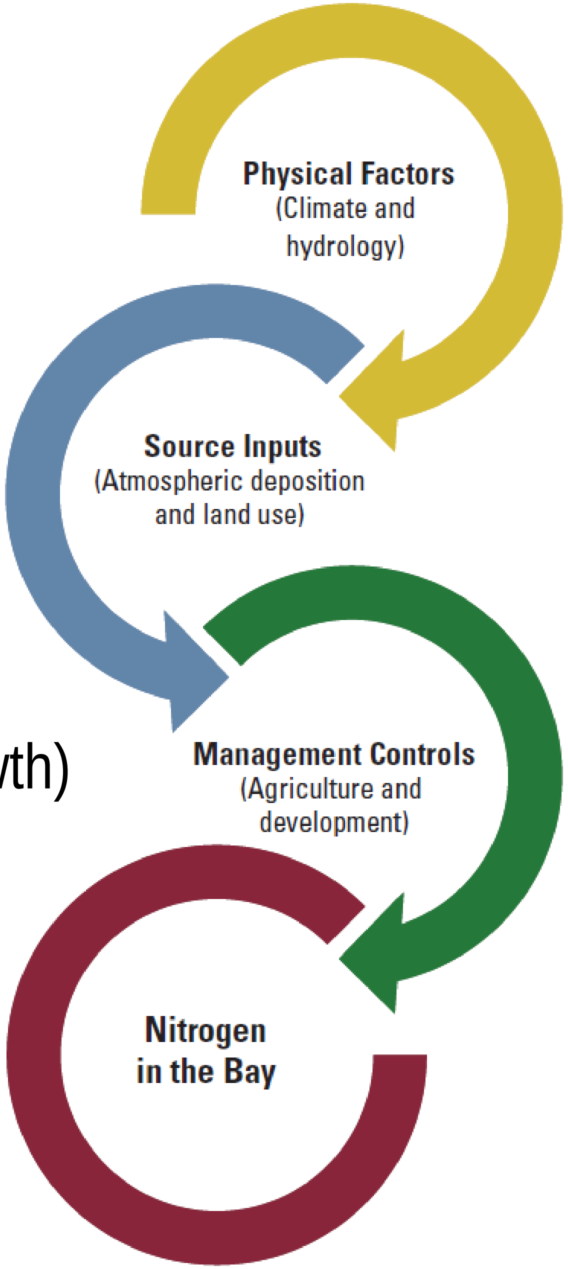
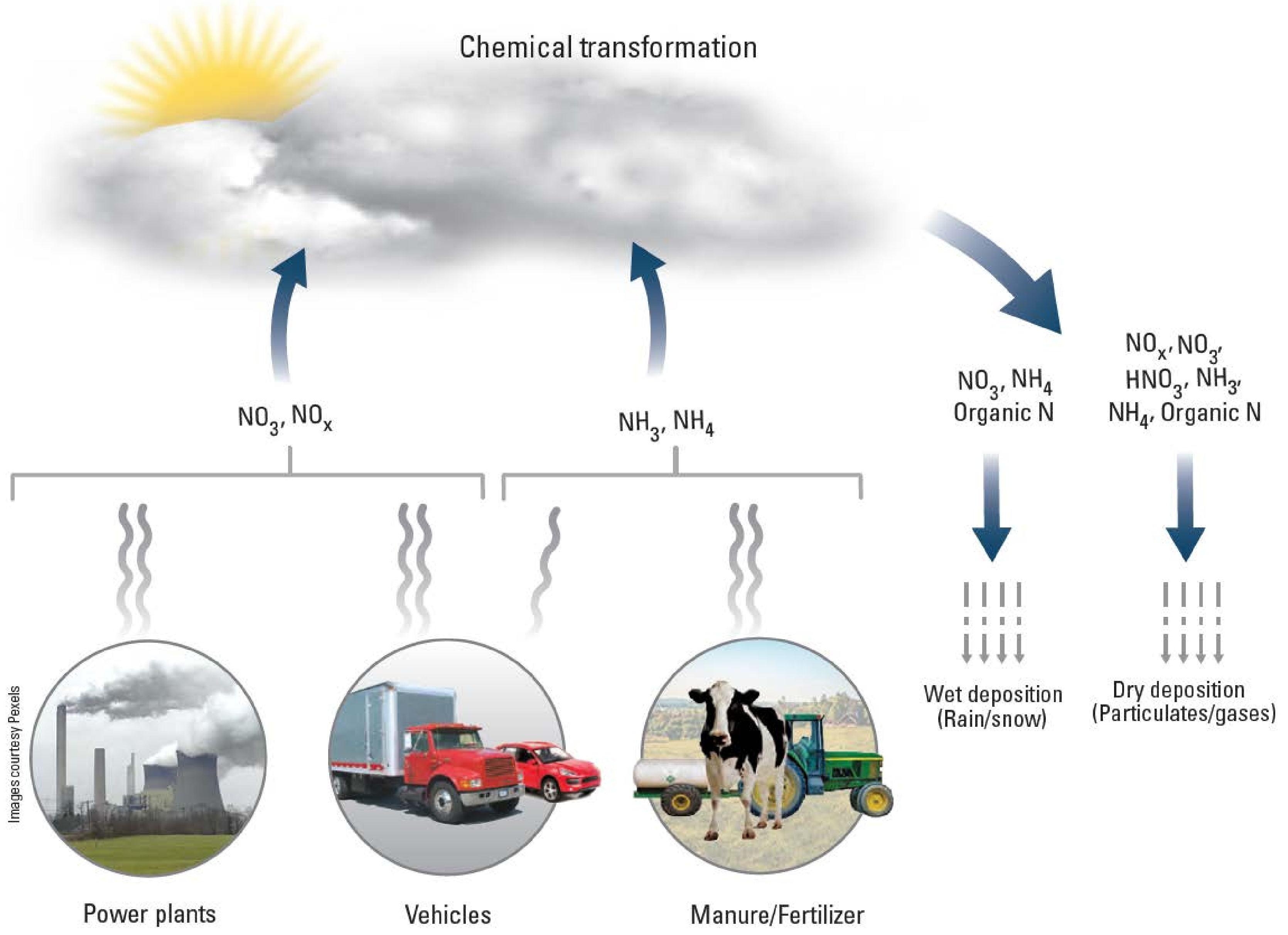


The time it takes for groundwater and nitrogen to reach streams (lag time) can range from days to years. This means that, in some areas, the effect of management actions may not be realized for decades to come.

At the regional level, local resource managers also have less control over atmospheric deposition and land use changes (driven by population growth)





Emissions can lead to the atmospheric deposition of nitrogen (wet and dry) downwind from the sources after being transformed and transported in the atmosphere.

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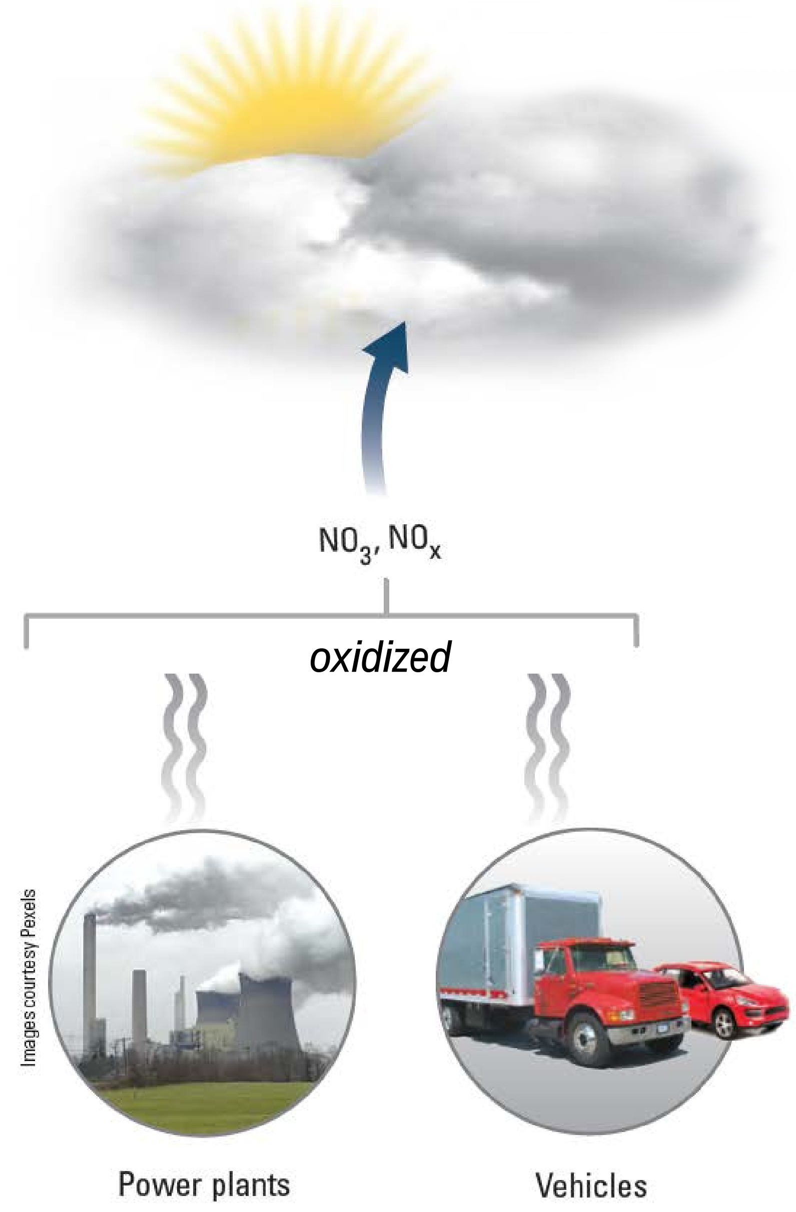
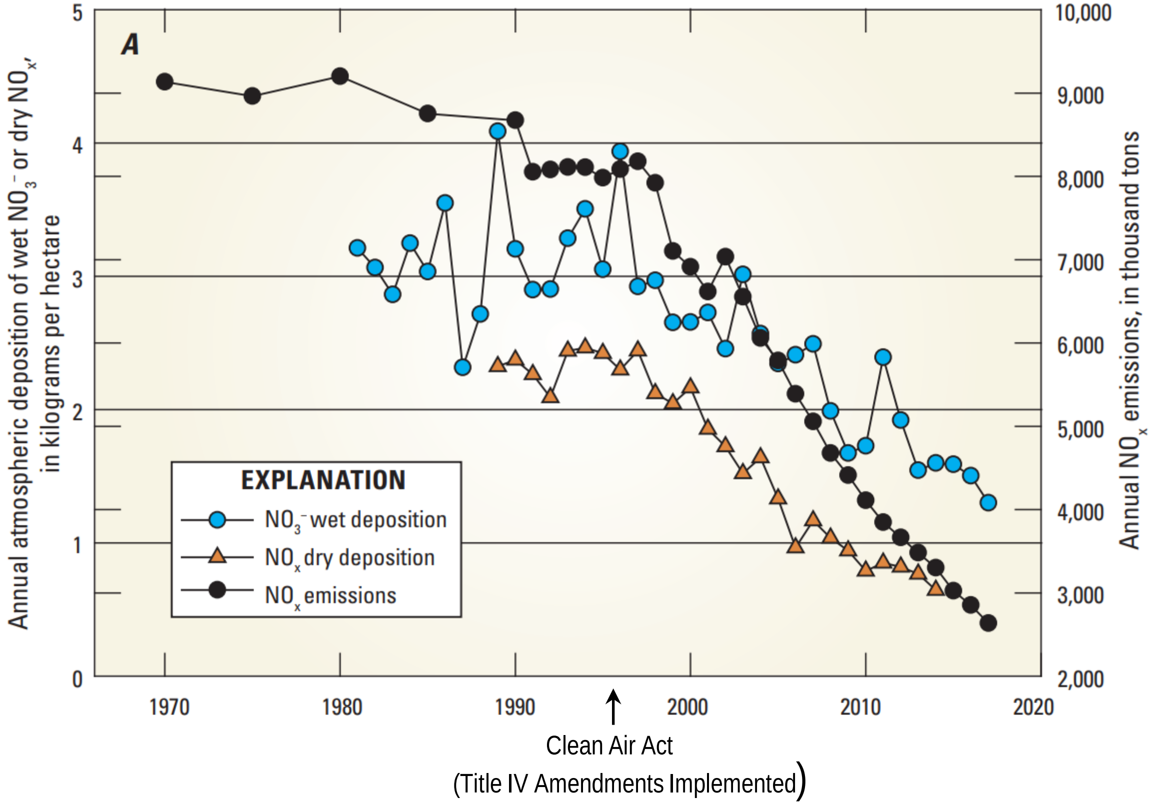
Atmospheric **oxidized nitrogen deposition,** across the Bay watershed has shown a declining trend since the 1990s largely due to the air quality management actions required by the Clean Air Act





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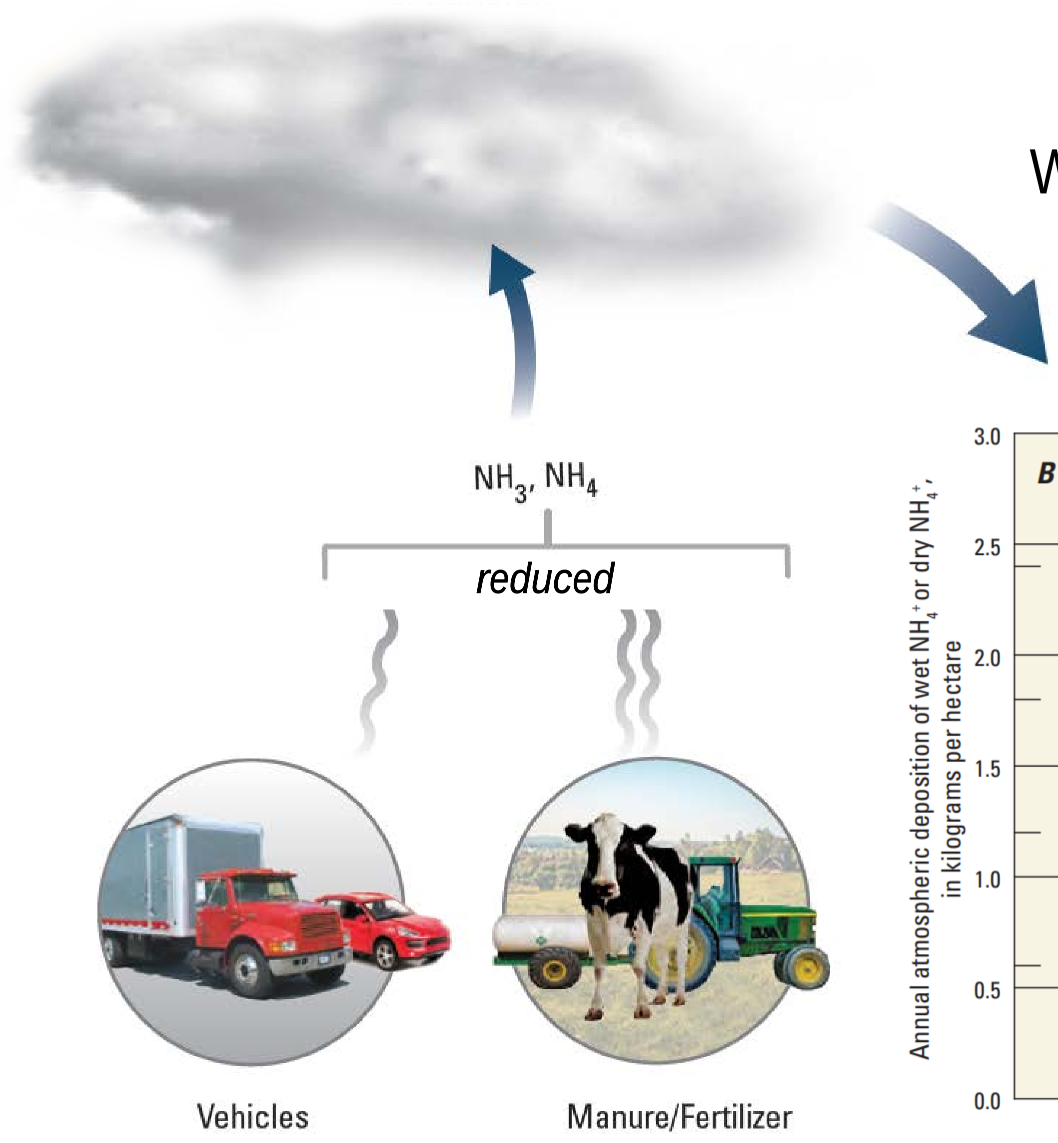
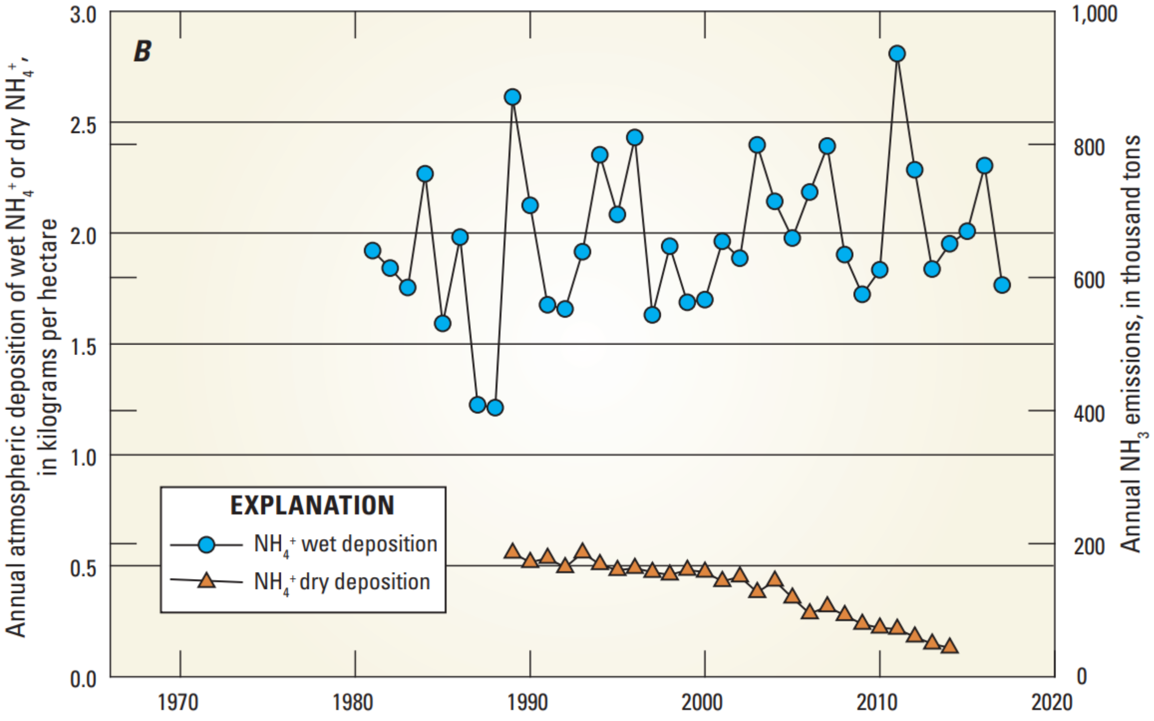
Whereas, chemically **reduced nitrogen deposition**, across the Bay watershed has shown a slight decline or no trend





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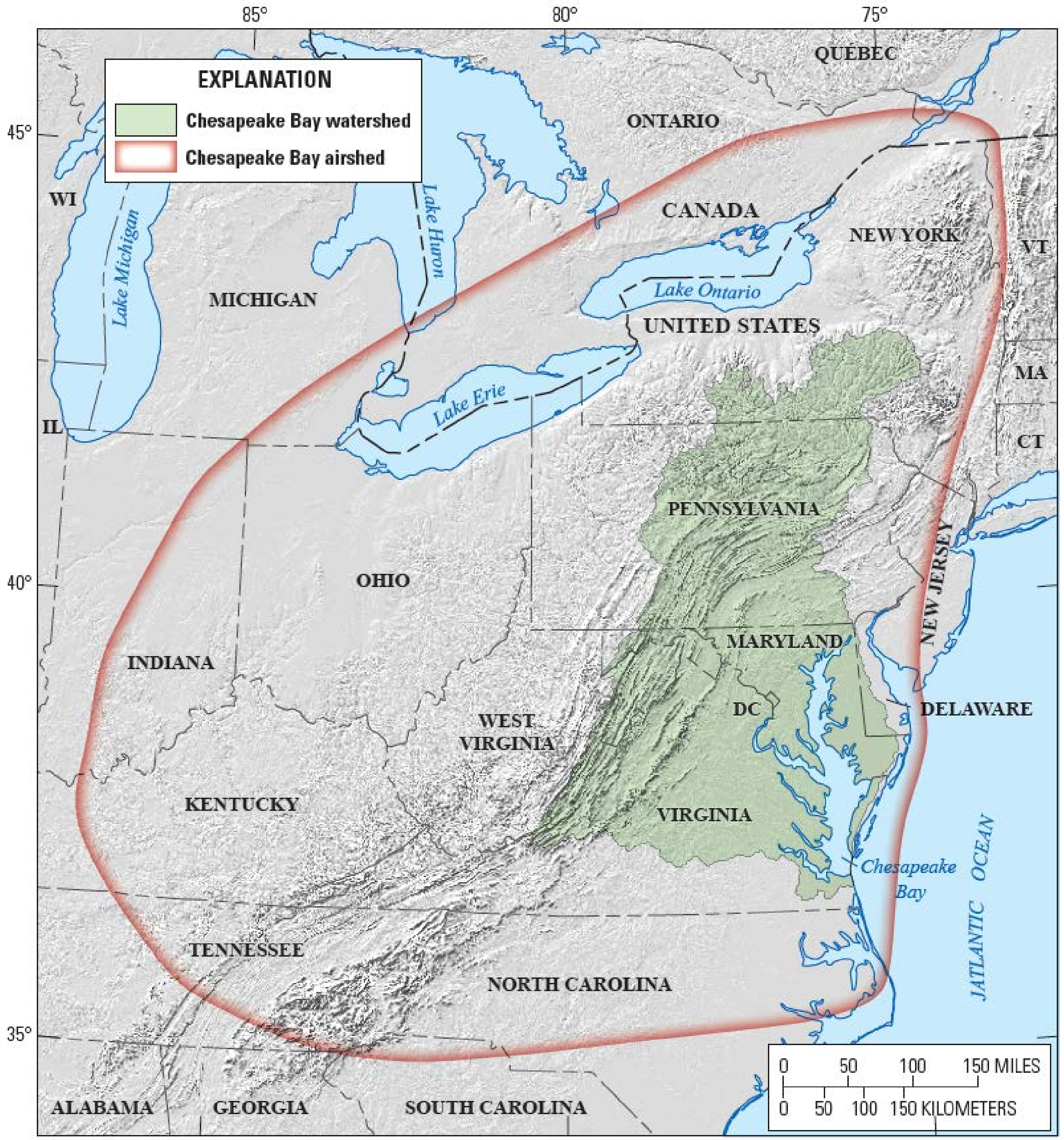
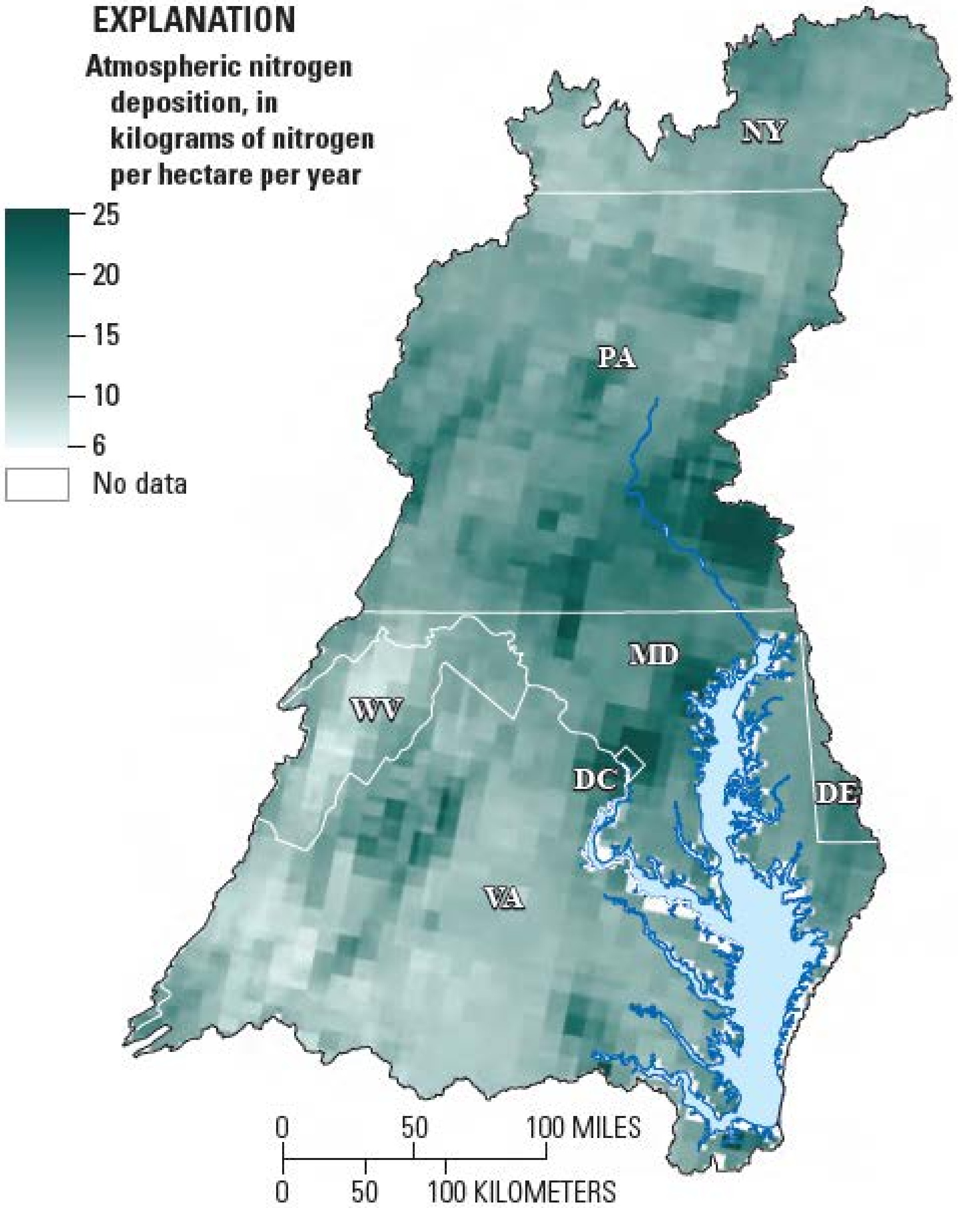
About half of the oxidized nitrogen emissions that contribute to atmospheric deposition nitrogen loads to the Chesapeake Bay originate from an airshed that is much larger than the actual watershed

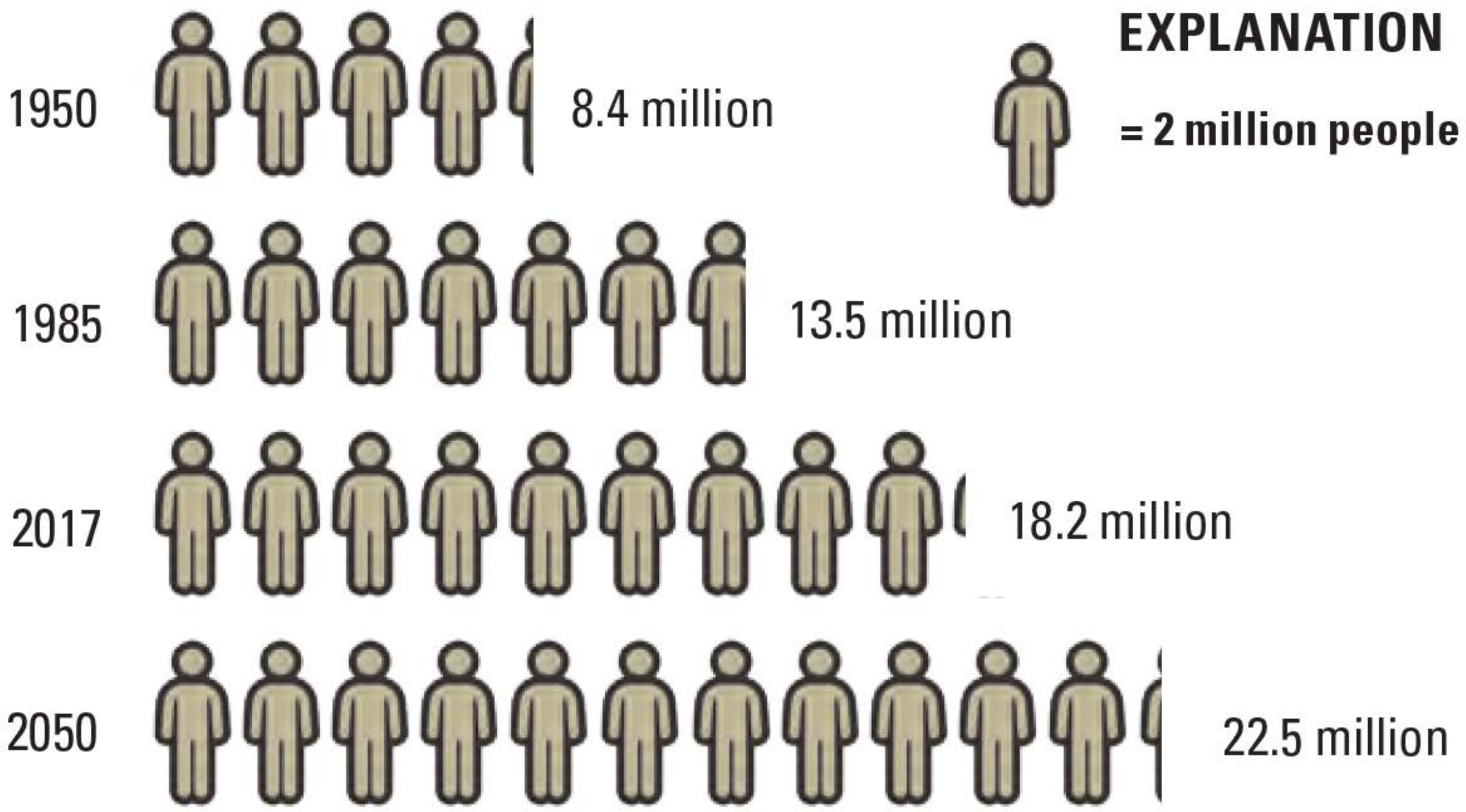


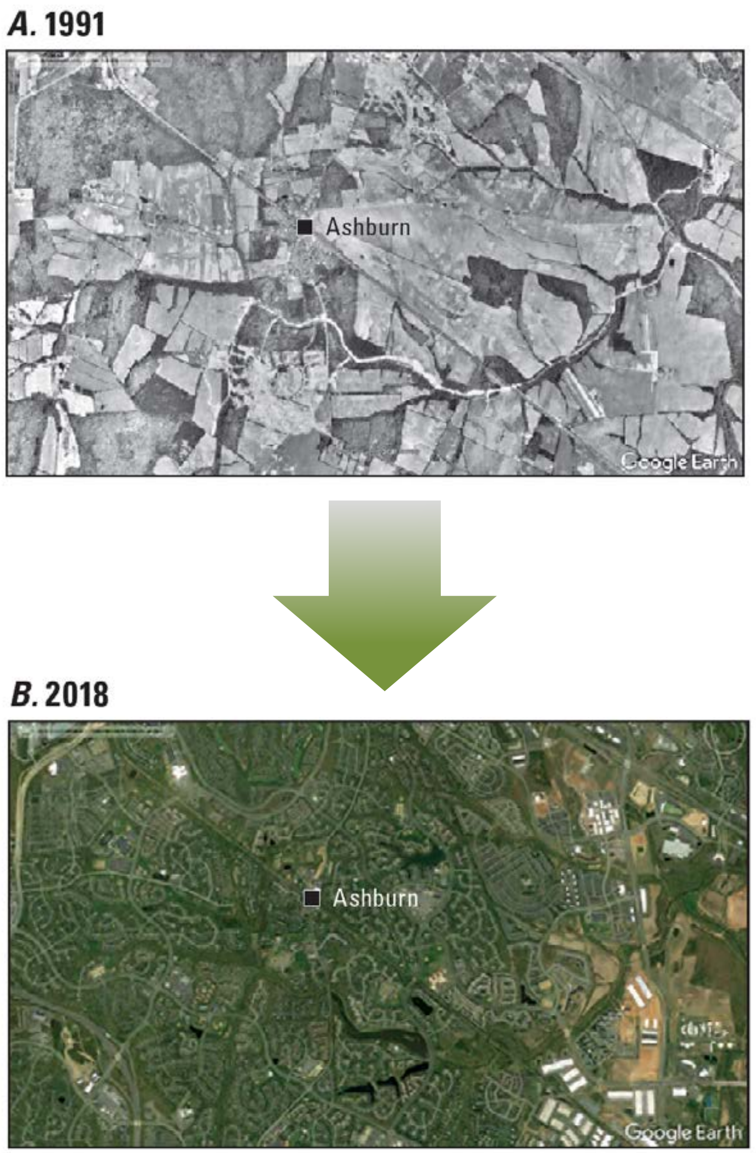
Albers Conical Equal Area projection.
North American Datum of 1983



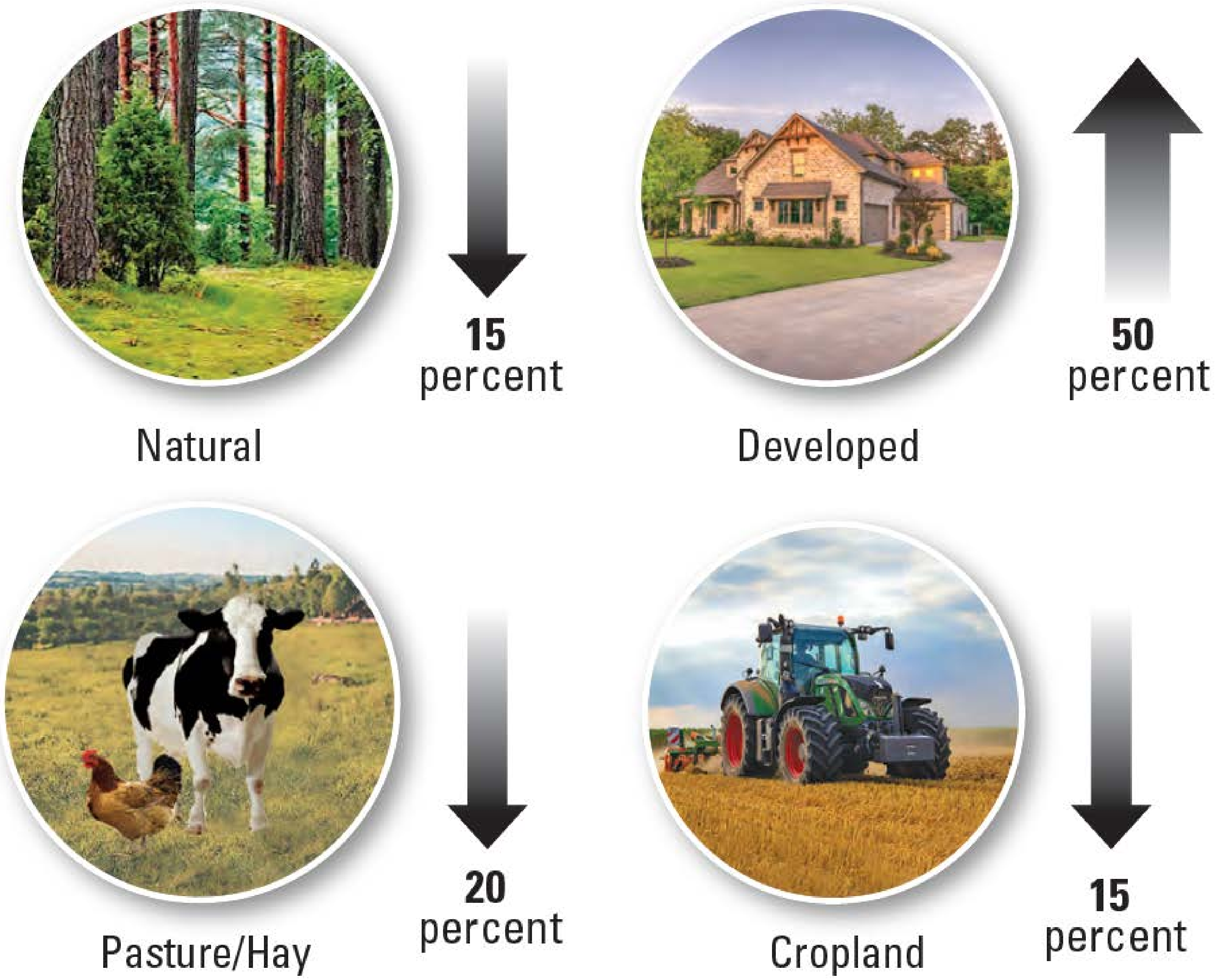
Atmospheric deposition of nitrogen is widespread across the Bay watershed. The highest values occur in developed areas such as Washington, D.C., and Baltimore, Maryland, and areas of intensive agriculture such as southeastern Pennsylvania

Regarding land use, since 1950, population growth has increased exponentially in the Bay watershed generating activities that have produced excessive nutrient and sediment inputs to rivers and streams



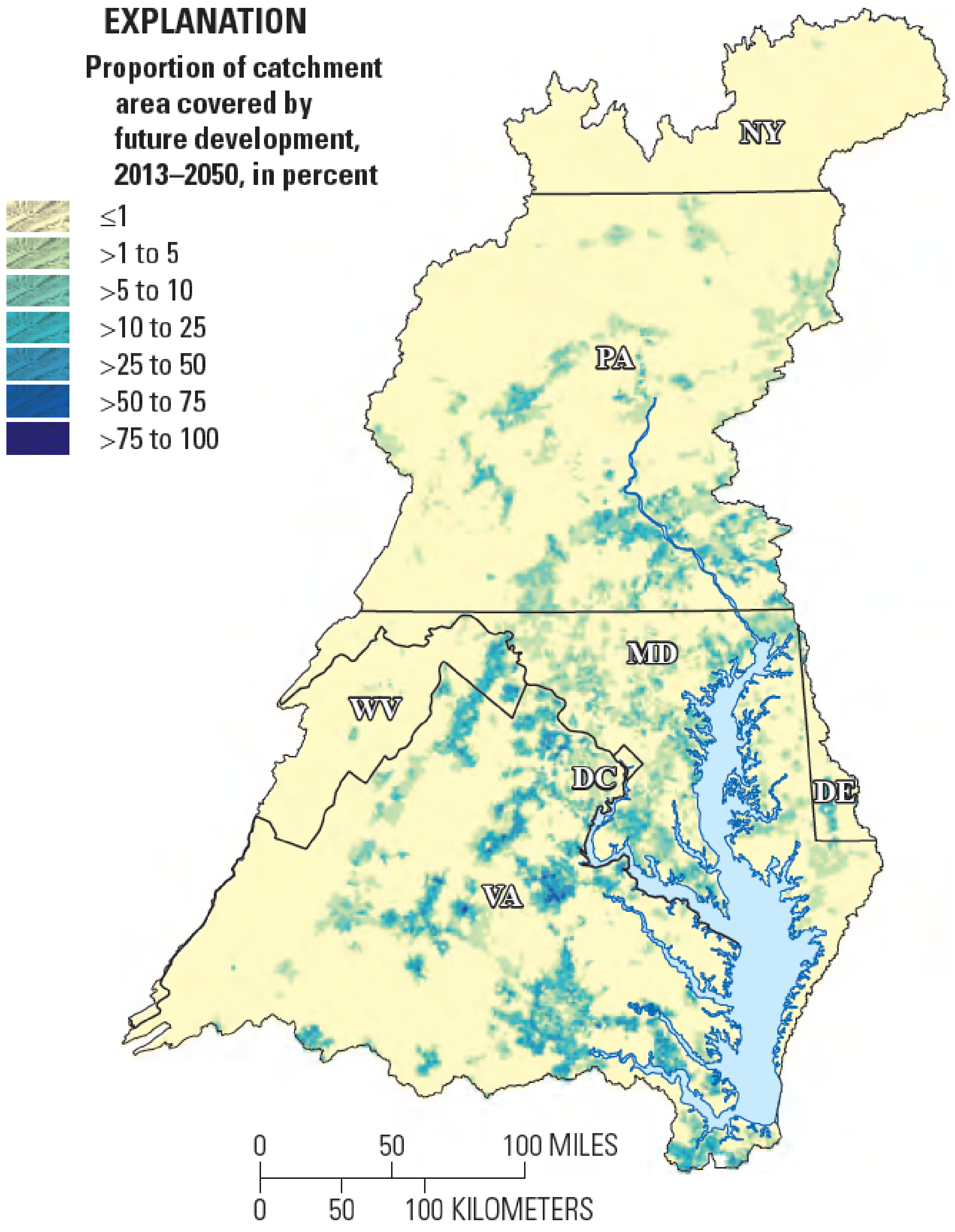


Since 1985, **development** has occurred mostly at the expense of natural and agricultural areas (pasture and cropland)



Images courtesy of Pexels

If the trends of the 1980s through 2010s continue, then future growth will be focused in suburban and adjacent counties, with an emphasis on developing large-lot, single-family homes



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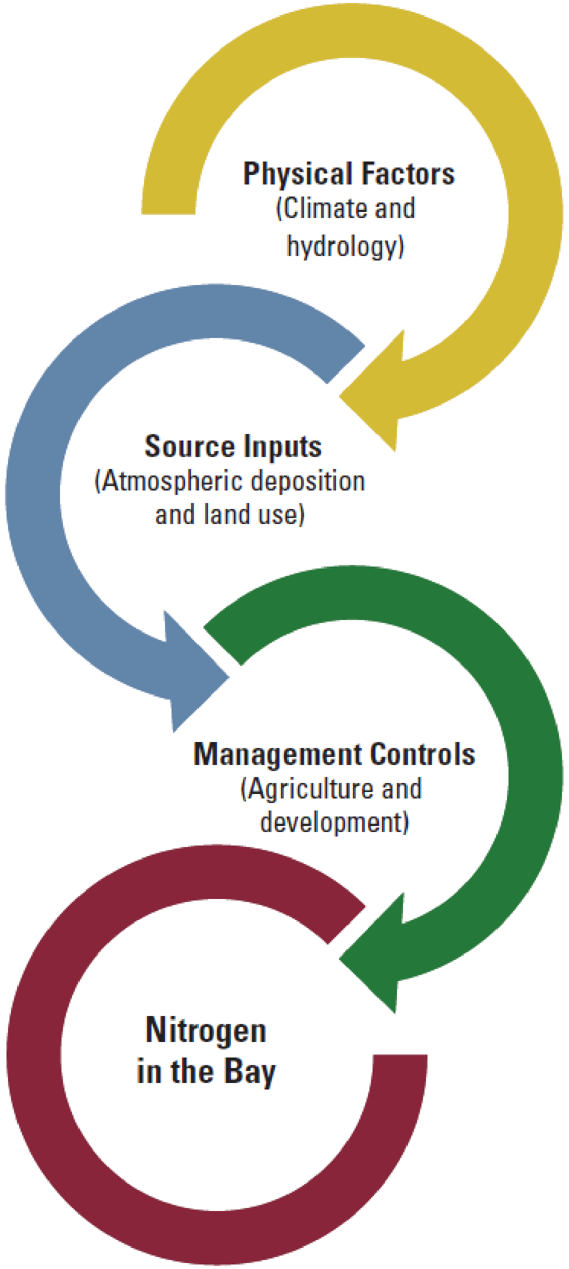
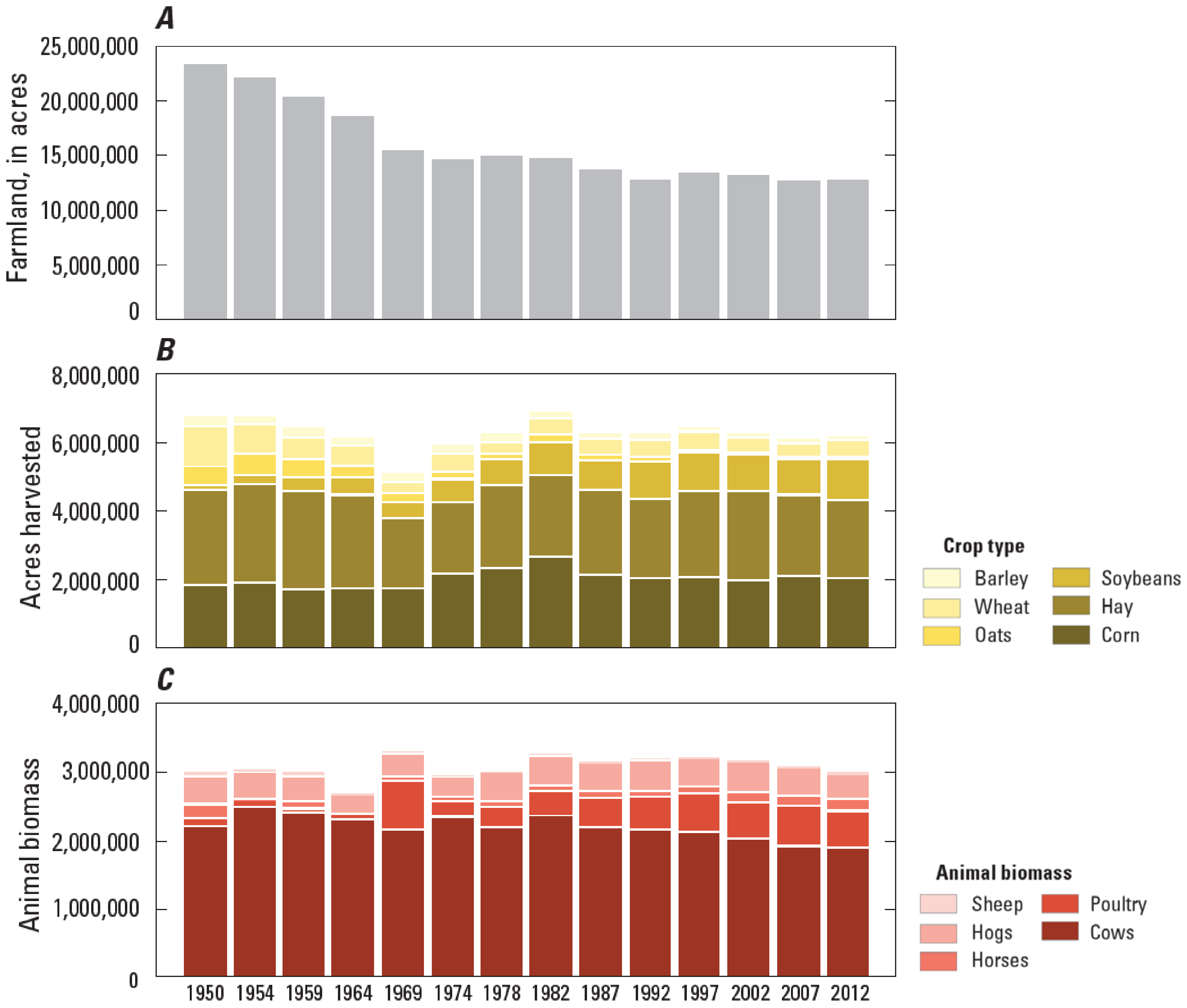


Local resource managers have the most control over agriculture and development

Since 1950, acres in farmland has deceased,

but crop and animal production has remained relatively constant due in large part to the intensification of agriculture



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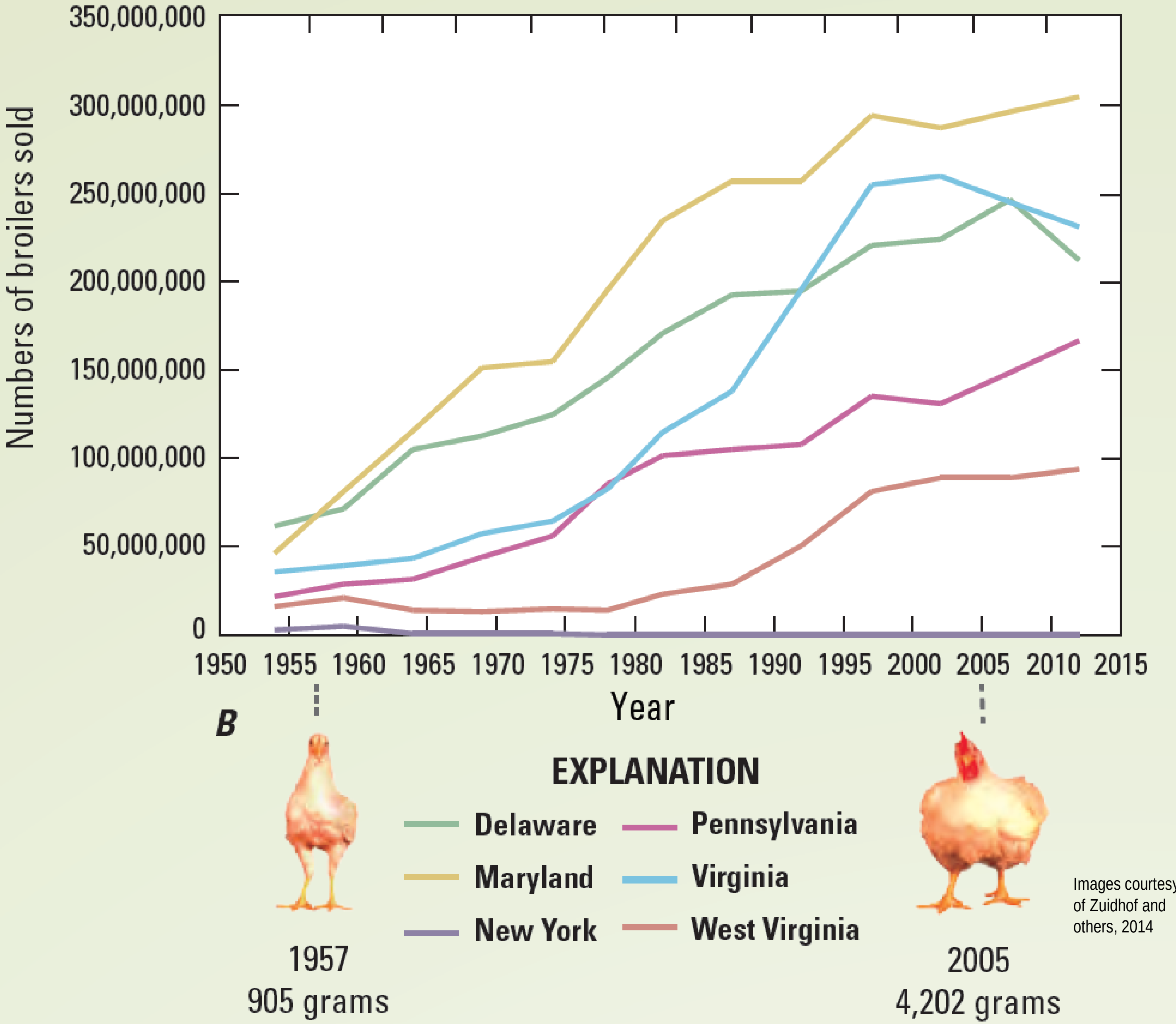
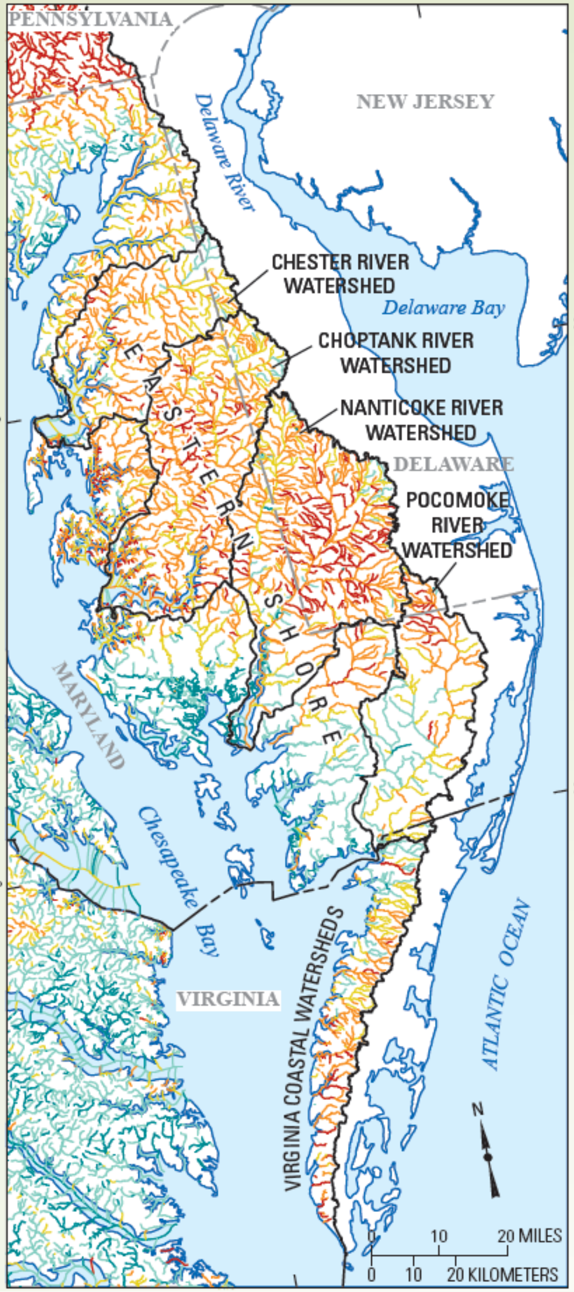
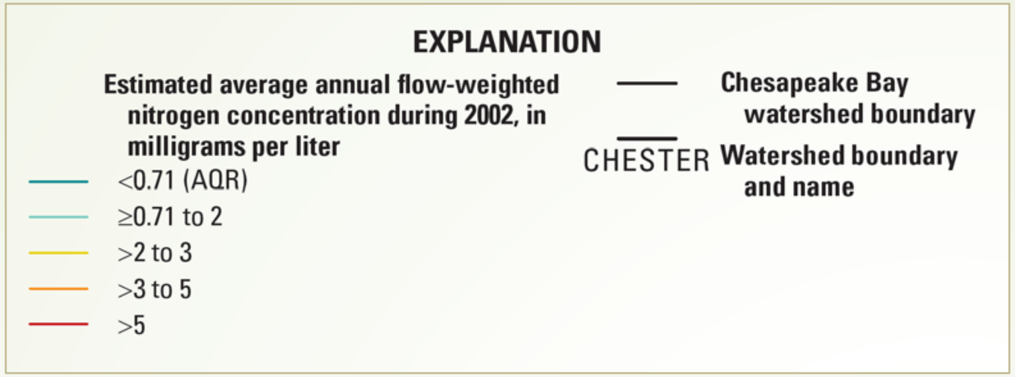
For example, there has been a substantial increase in the number of **broiler chickens** sold in the Chesapeake Bay watershed from 1954 to 2012 and selective breeding and nutrition improvements have more than doubled the weight of broilers



Images courtesy of Zuidhof and others, 2014

This has led to increases in nitrogen related impacts to water quality in agricultural areas. For instance, nitrogen concentrations in streams of the Eastern Shore of the Chesapeake Bay commonly exceed water-quality criterion recommended to protect aquatic organisms





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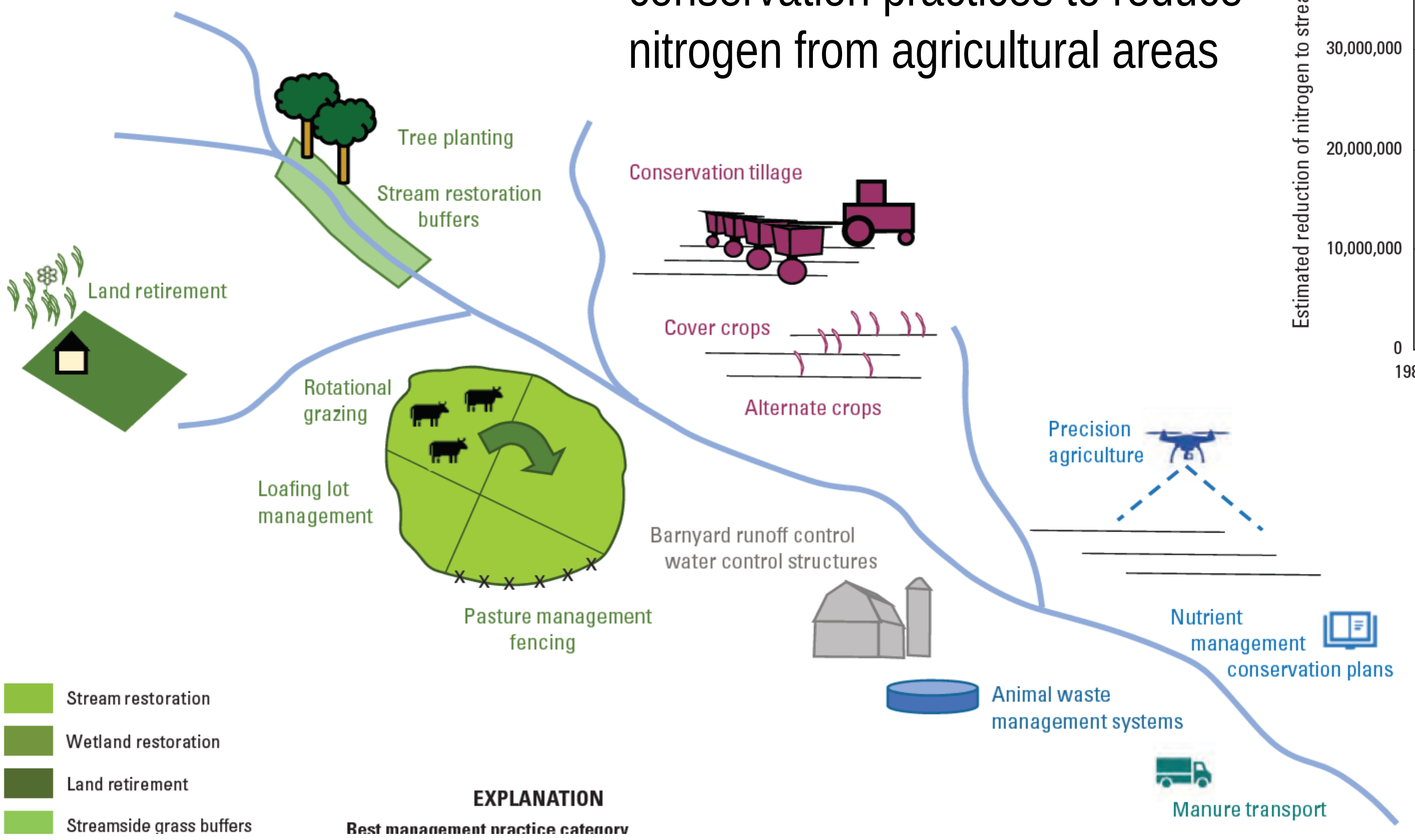
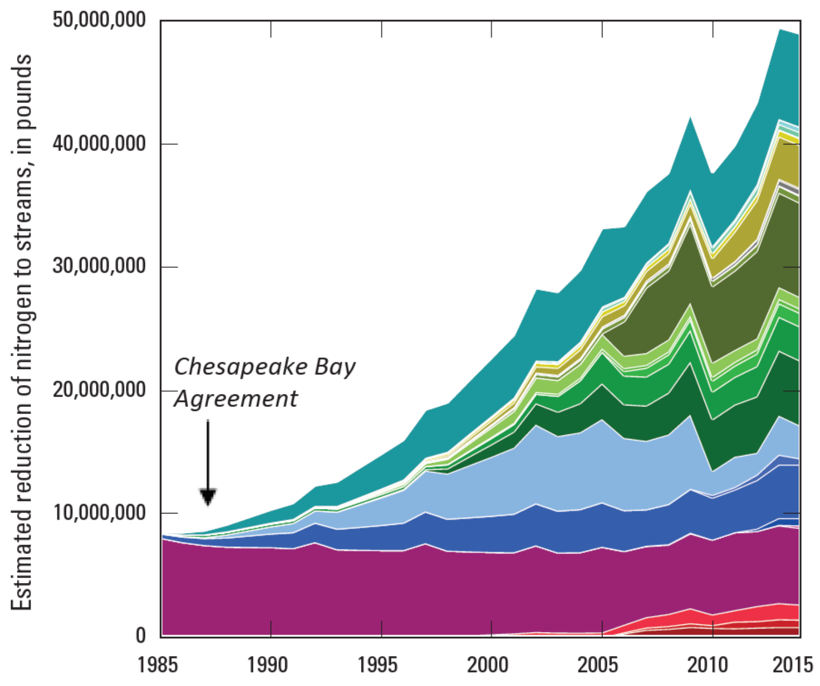
There has also been an increase in the variety and quantity of conservation practices to reduce nitrogen from agricultural areas





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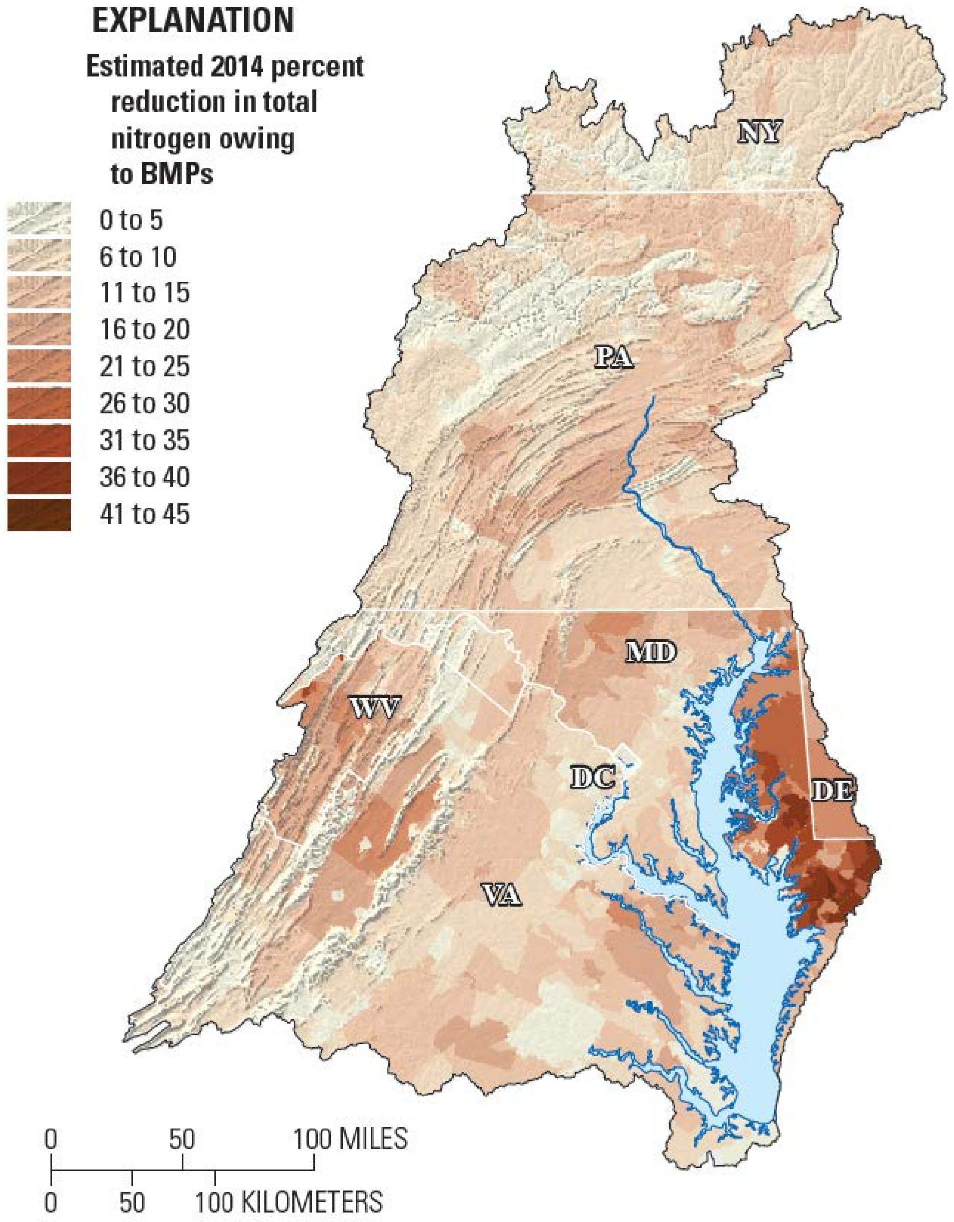


An expected eventual nitrogen reduction of 11% from 1985 to 2014 has been estimated for conservation practices and land retirement

Despite these estimates, nitrogen loads to streams in most agricultural areas did not change substantially during this time period possibly due to the lag time needed to see the effects of nutrient reduction efforts. More research is needed to better understand the water quality response of conservation practices for planning

The expansion of developed land is a major driver of nitrogen in the Chesapeake Bay watershed

Development →

Images courtesy of Chesapeake Bay Program

Low density (rural)

Hampshire County, West Virginia
Frostburg, Maryland
Union Dale, Pennsylvania

Medium density (suburban)

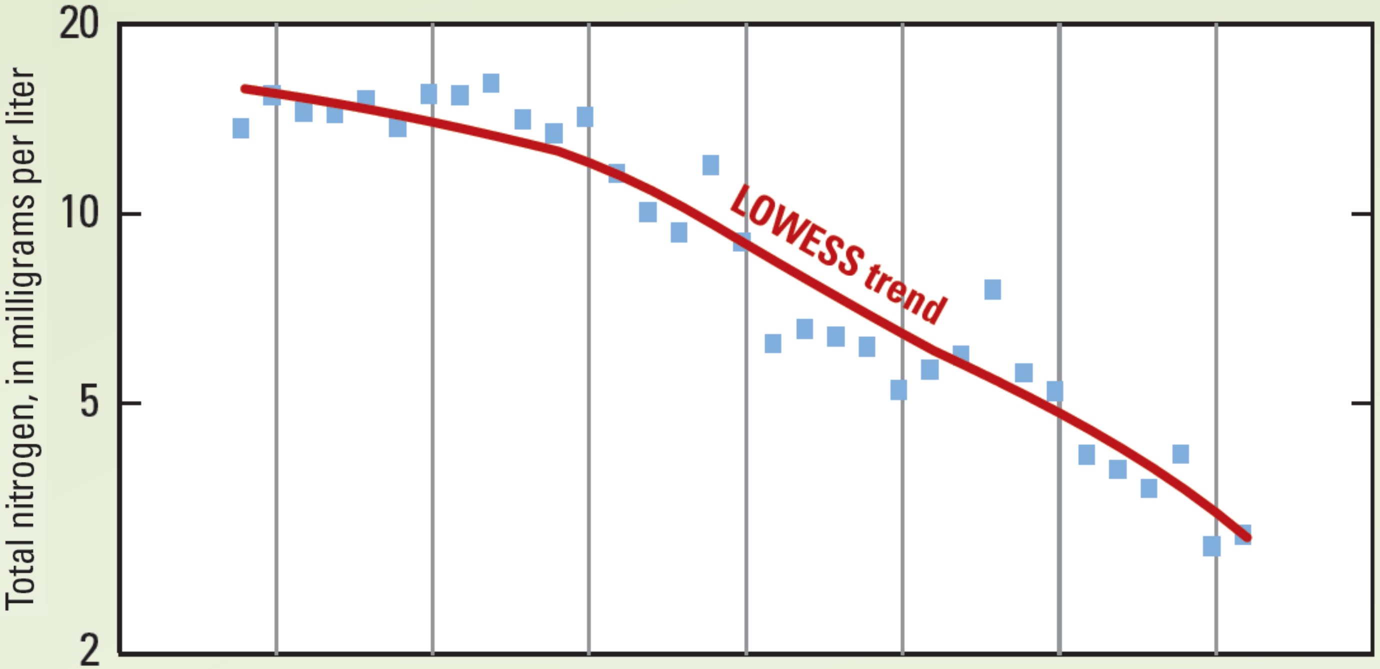
Easton, Maryland
Colonial Park, Pennsylvania
Manassas, Virginia

High density (urban core)

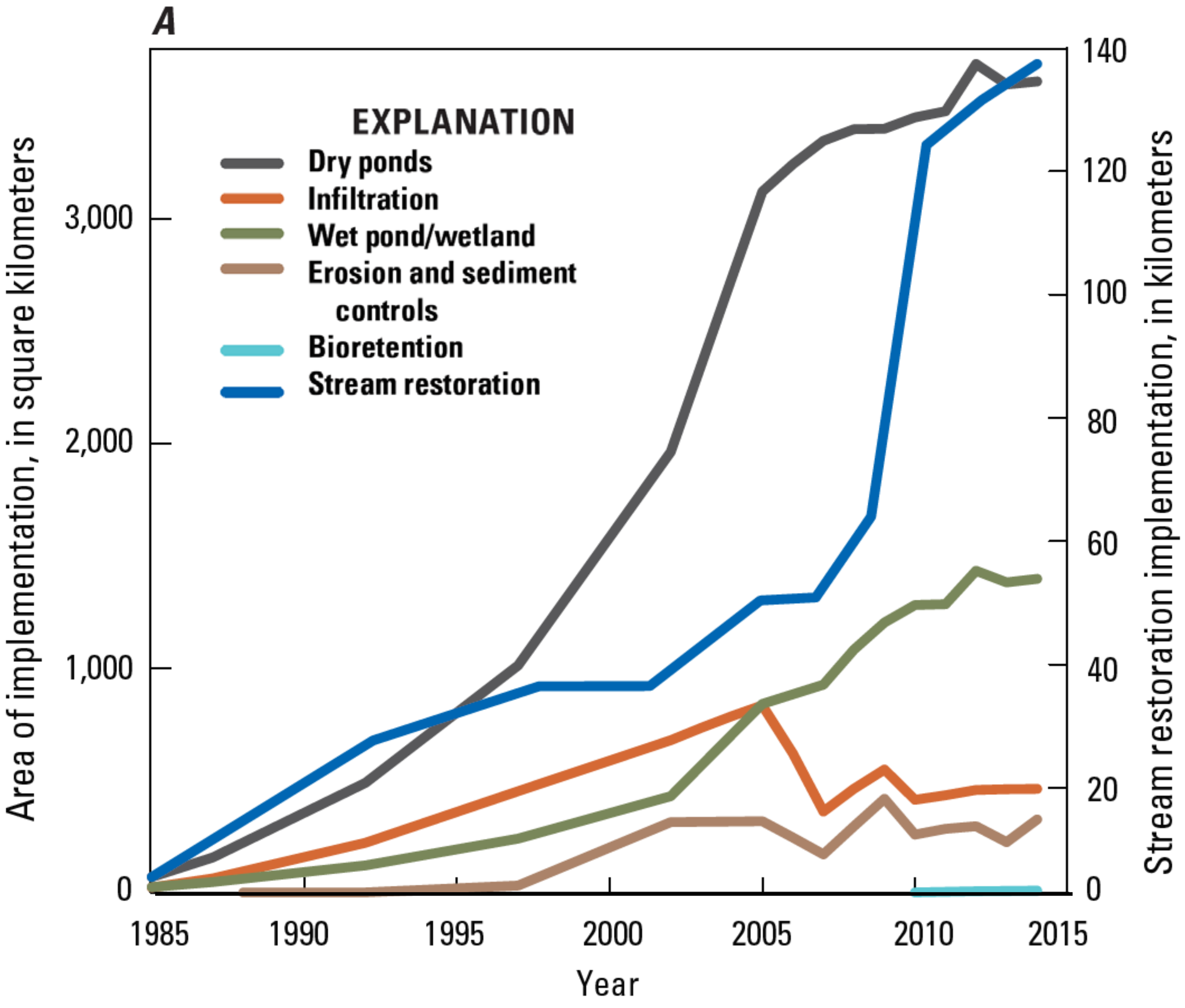
Baltimore, Maryland
Washington, District of Columbia
Richmond, Virginia

Nitrogen from point sources such as **wastewater** has declined, controlled through regulations and technology, and will likely continue to be important in controlling nitrogen loads in urban streams

Blue Plains Advanced Wastewater Treatment Plant, Washington DC



Management of urban nonpoint sources such as **stormwater** of nitrogen has been a more recent focus and will likely continue as urban centers expand across the watershed in coming decades

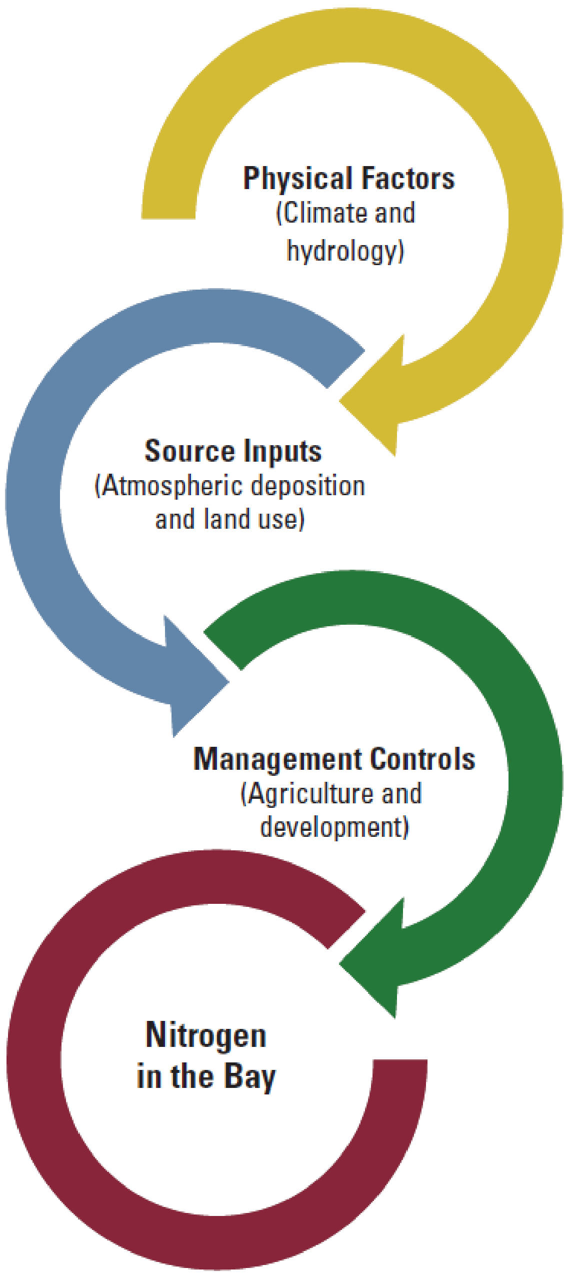


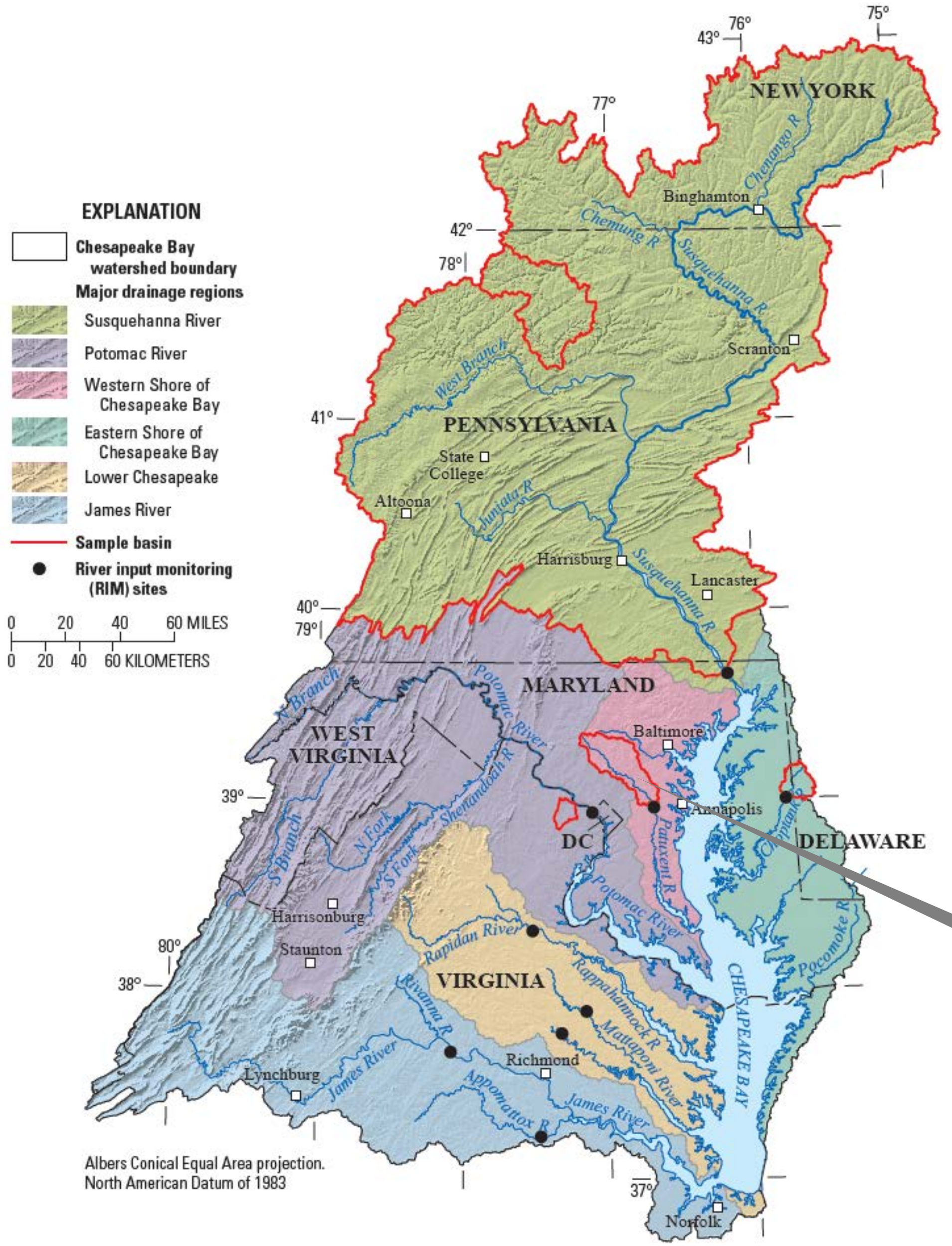
Detention Basin

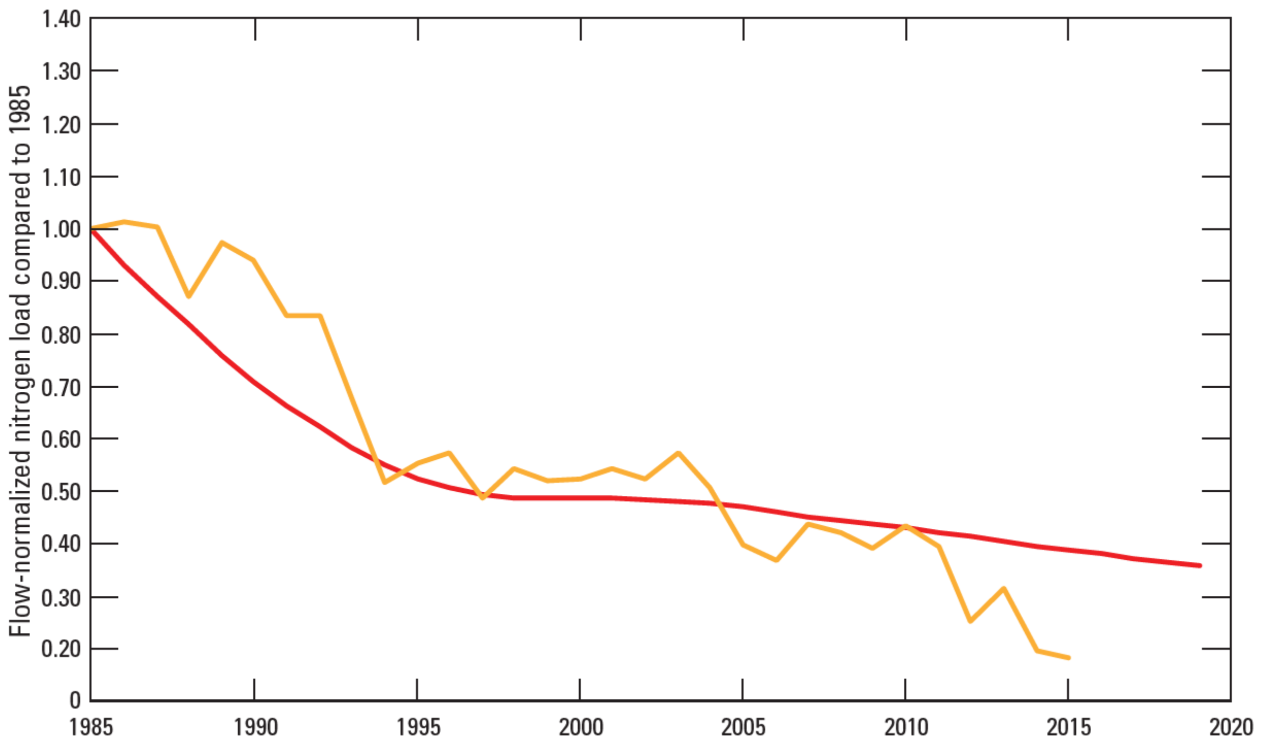
Stream Restoration

Bioretention

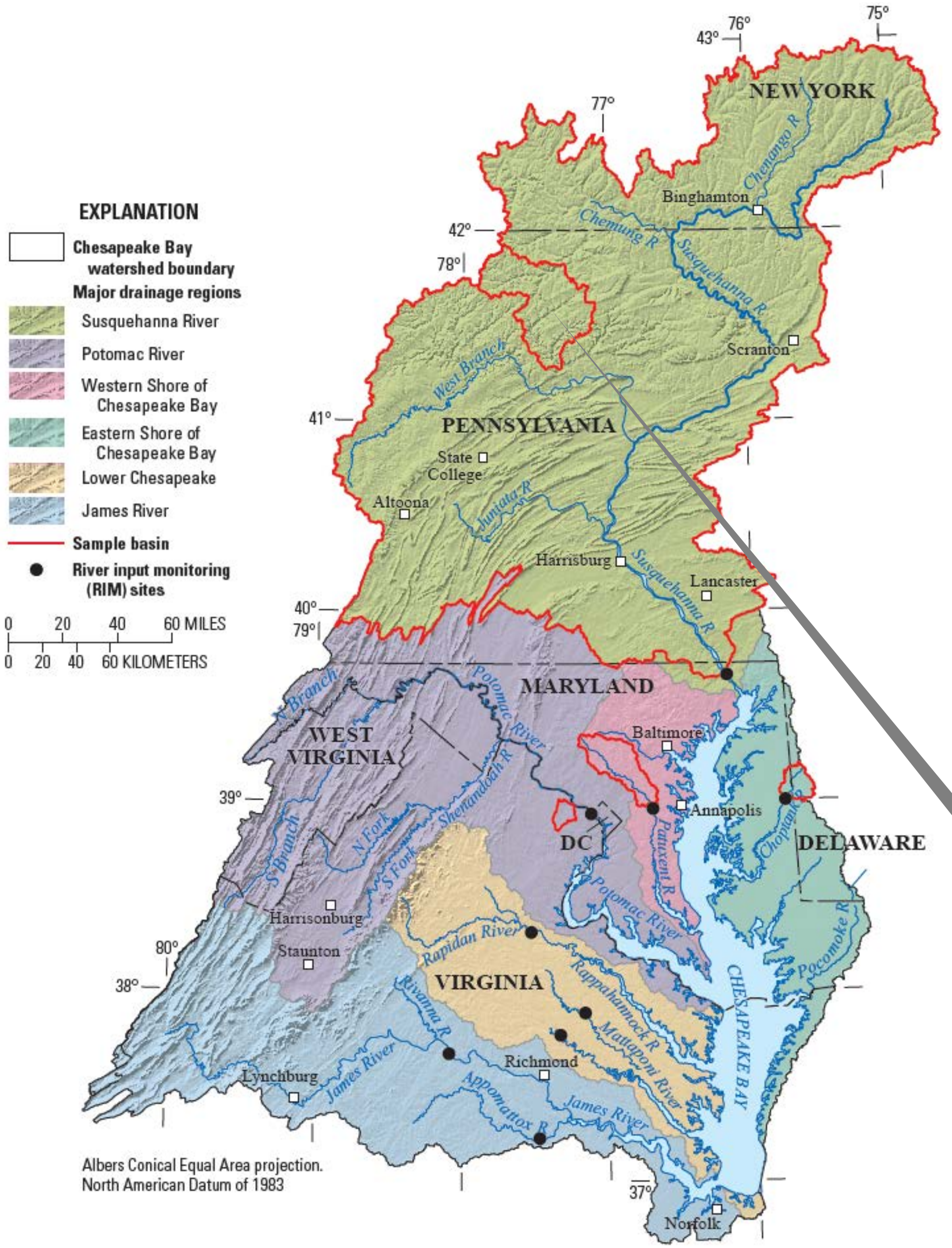
Now let's look at some examples of how these **factors** affect the delivery of nitrogen around the Chesapeake Bay watershed

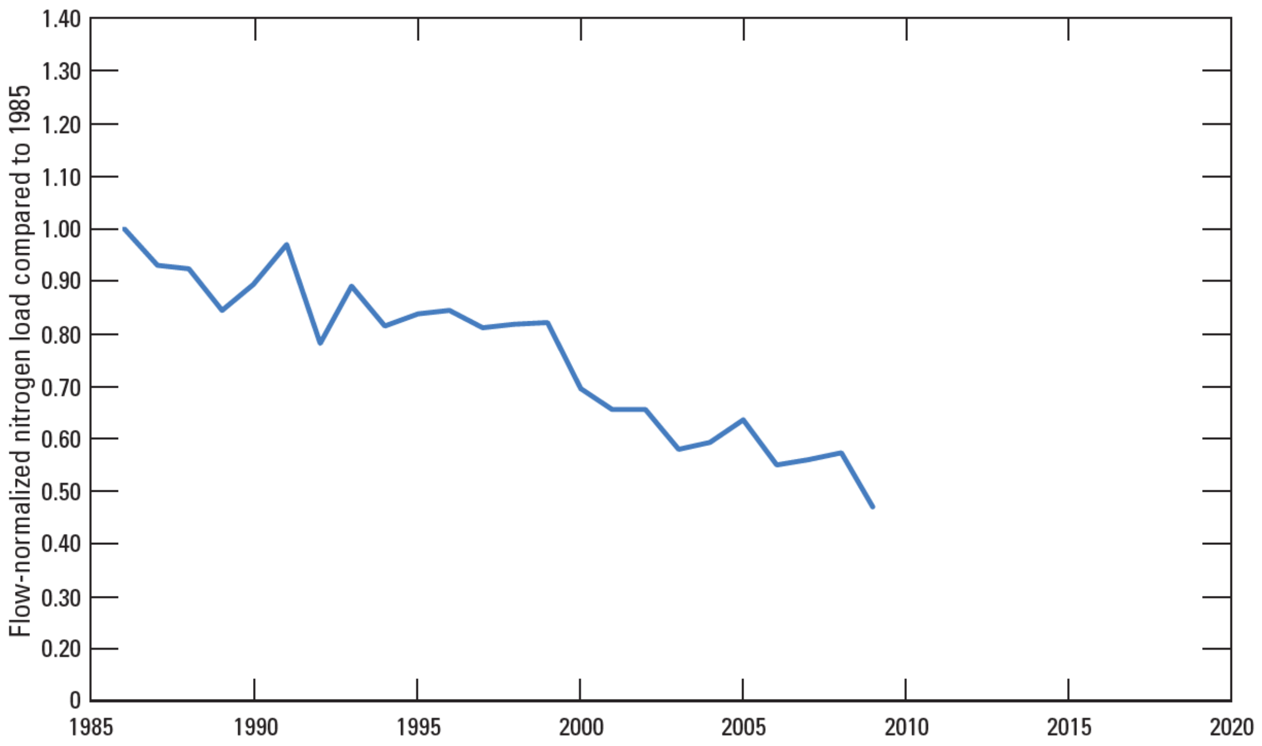






Patuxent River: Demonstrates the clear connection between improved wastewater treatment and nitrogen loads





Pine Creek: The main source of nitrogen to this forested watershed is from atmospheric deposition, which has been decreasing since the 1980s. As a result, Pine Creek has shown a reduction in nitrogen exports

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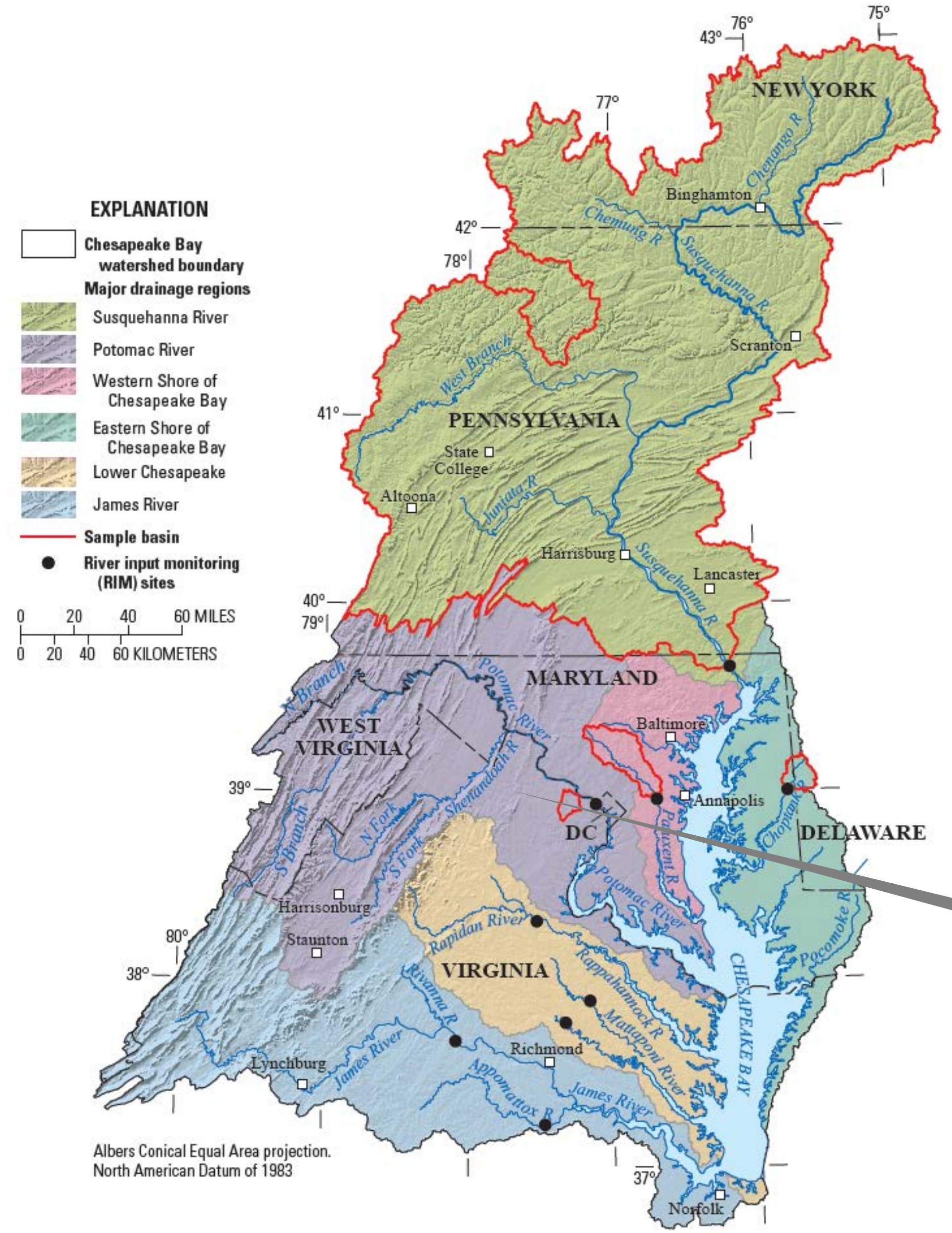
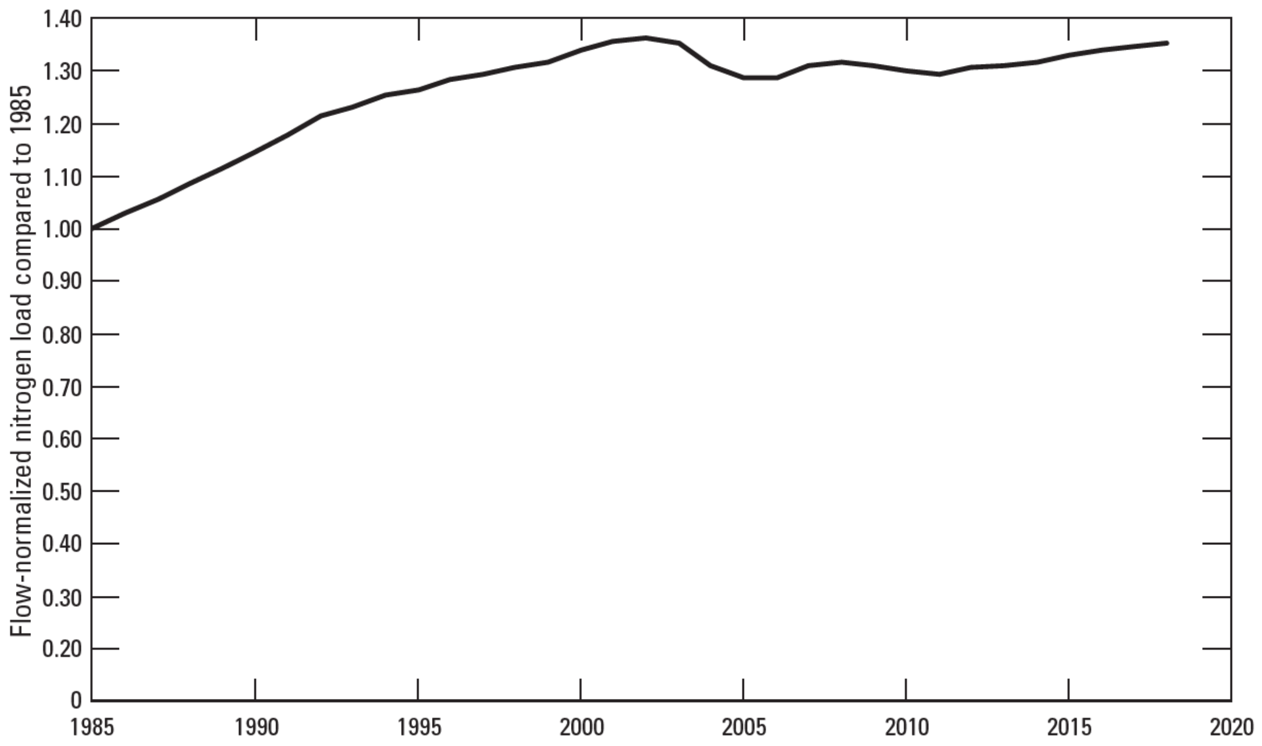
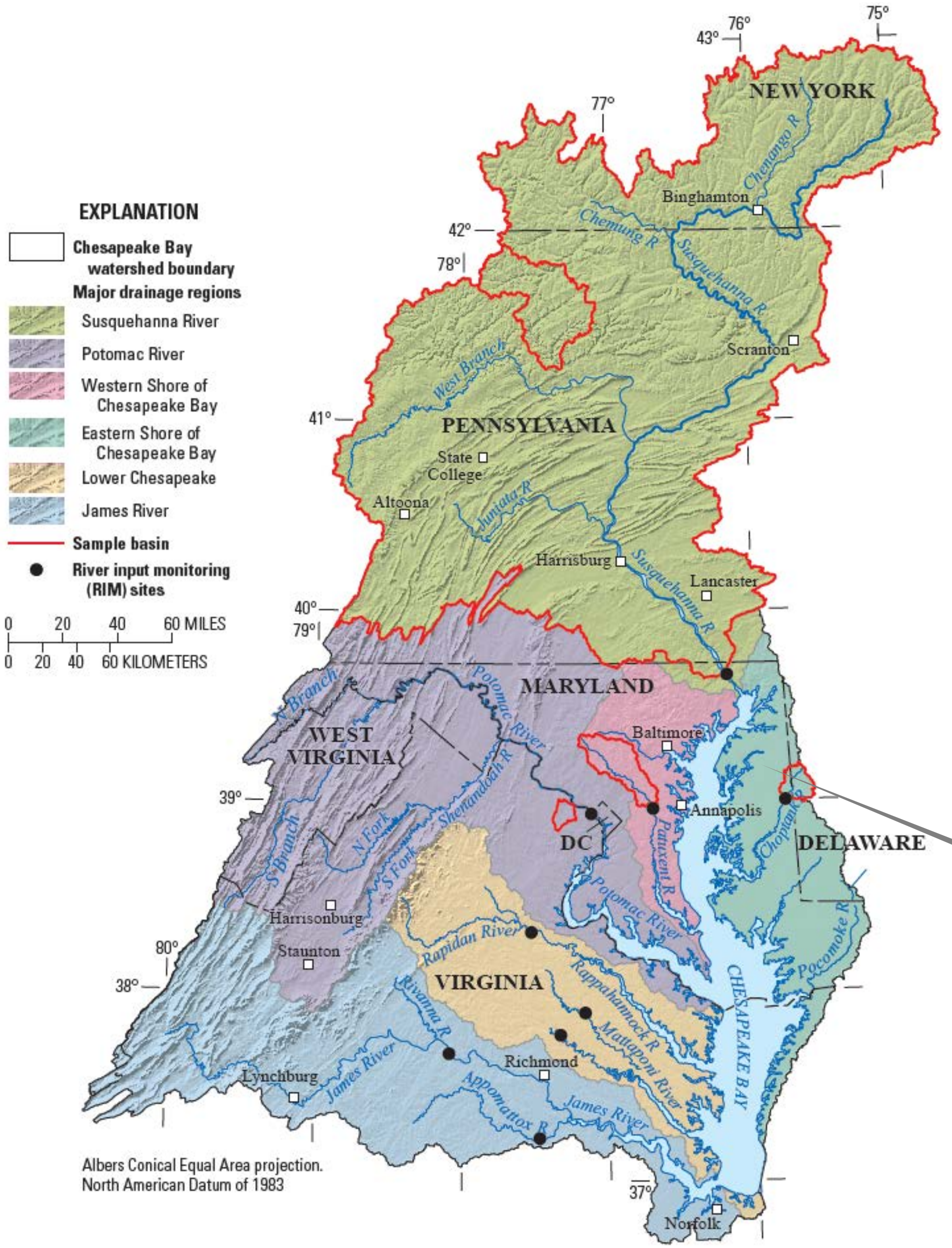
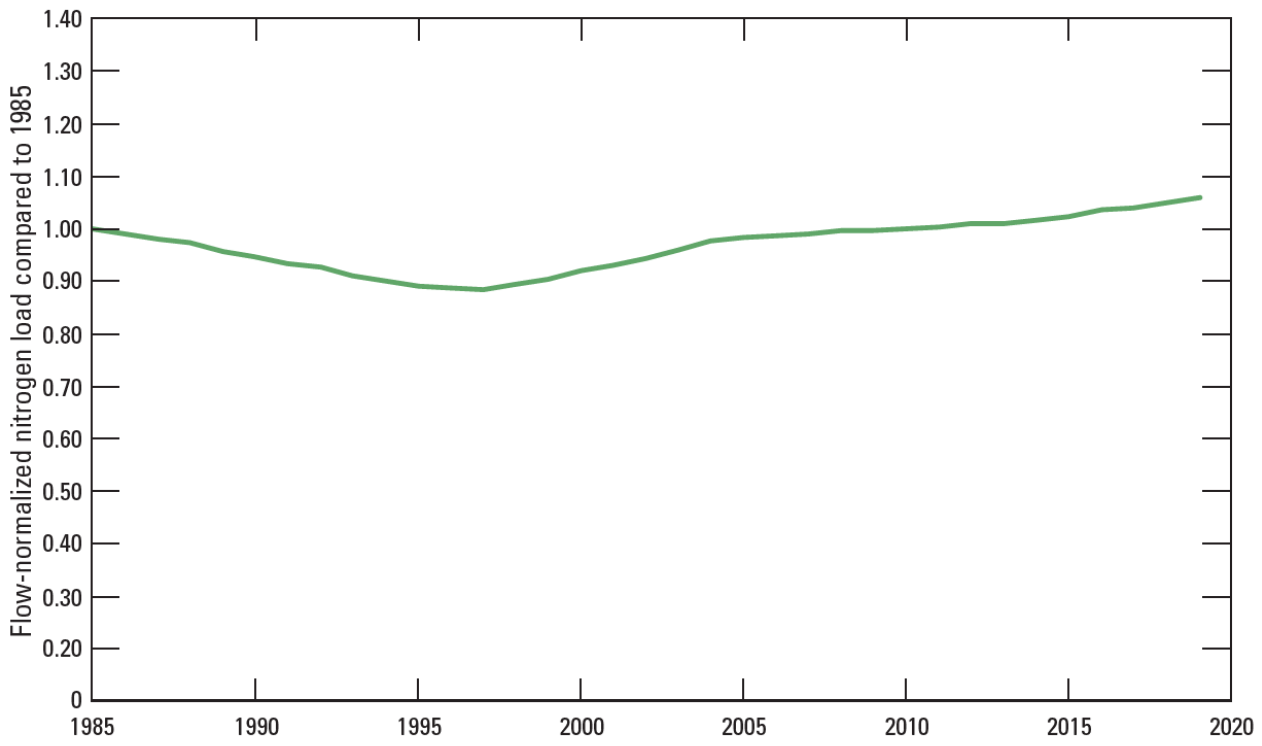




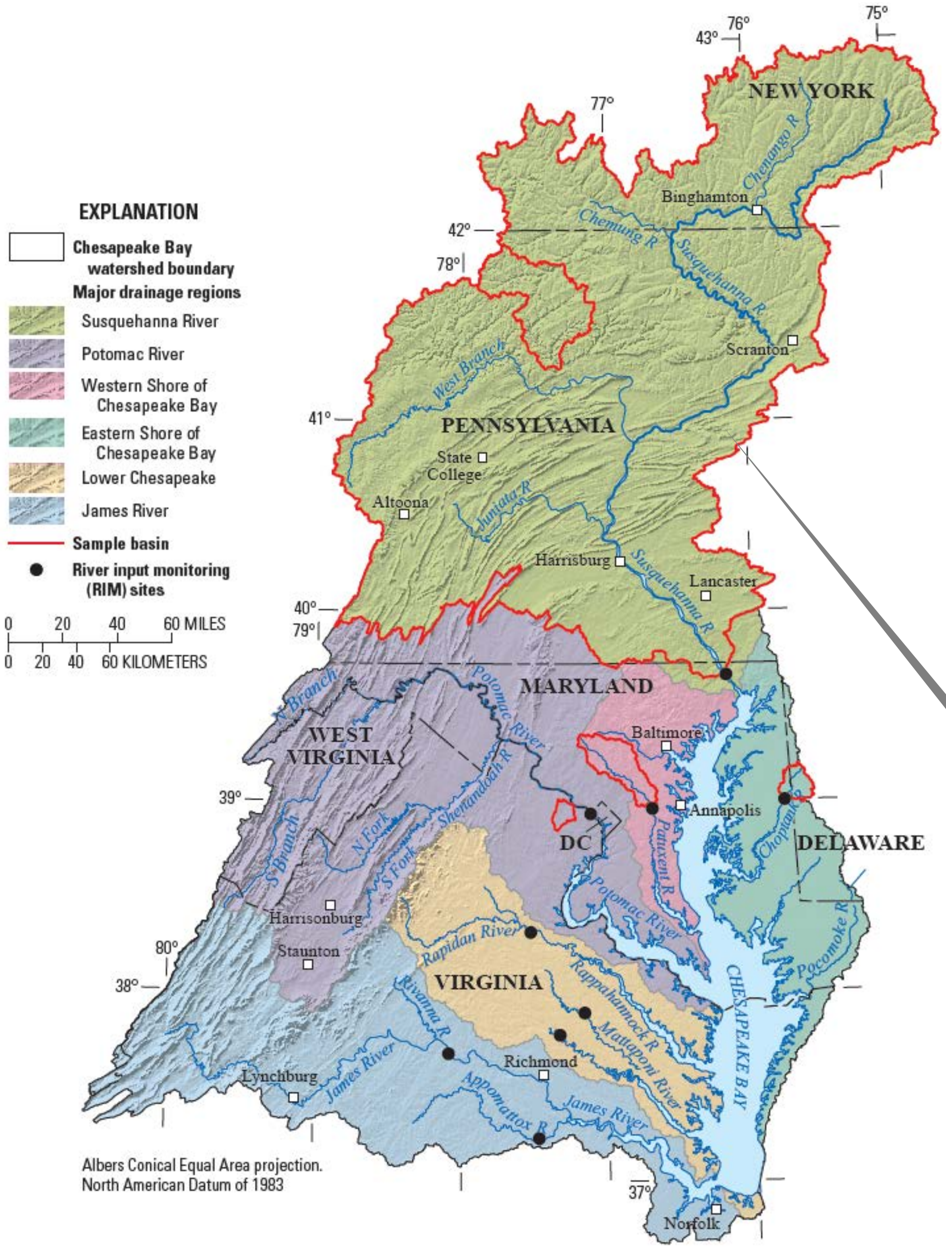
Difficult Run: Urbanized watershed with increasing nitrogen loads, most likely as a result of septic discharges and new construction

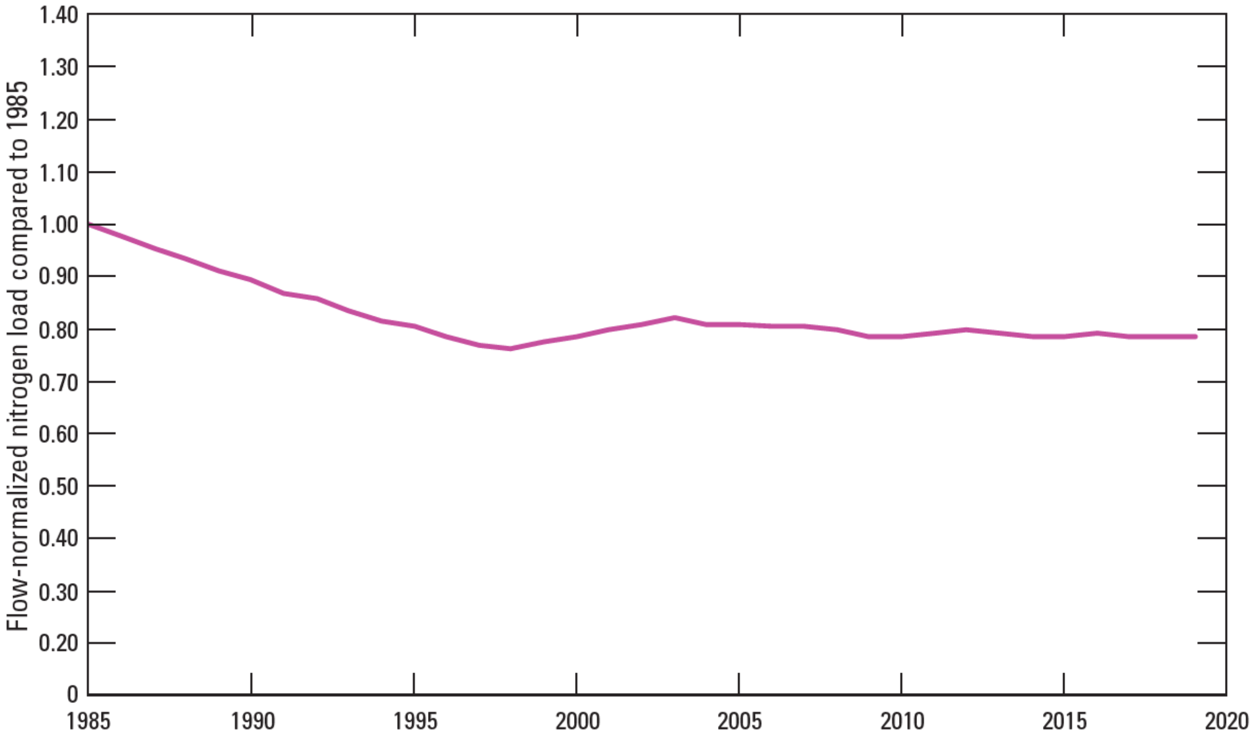




Choptank River: Nitrogen loads originating mainly from agricultural fertilizer have continued to increase despite conservation efforts owing to the long groundwater transit time of legacy nitrate contamination

USGS

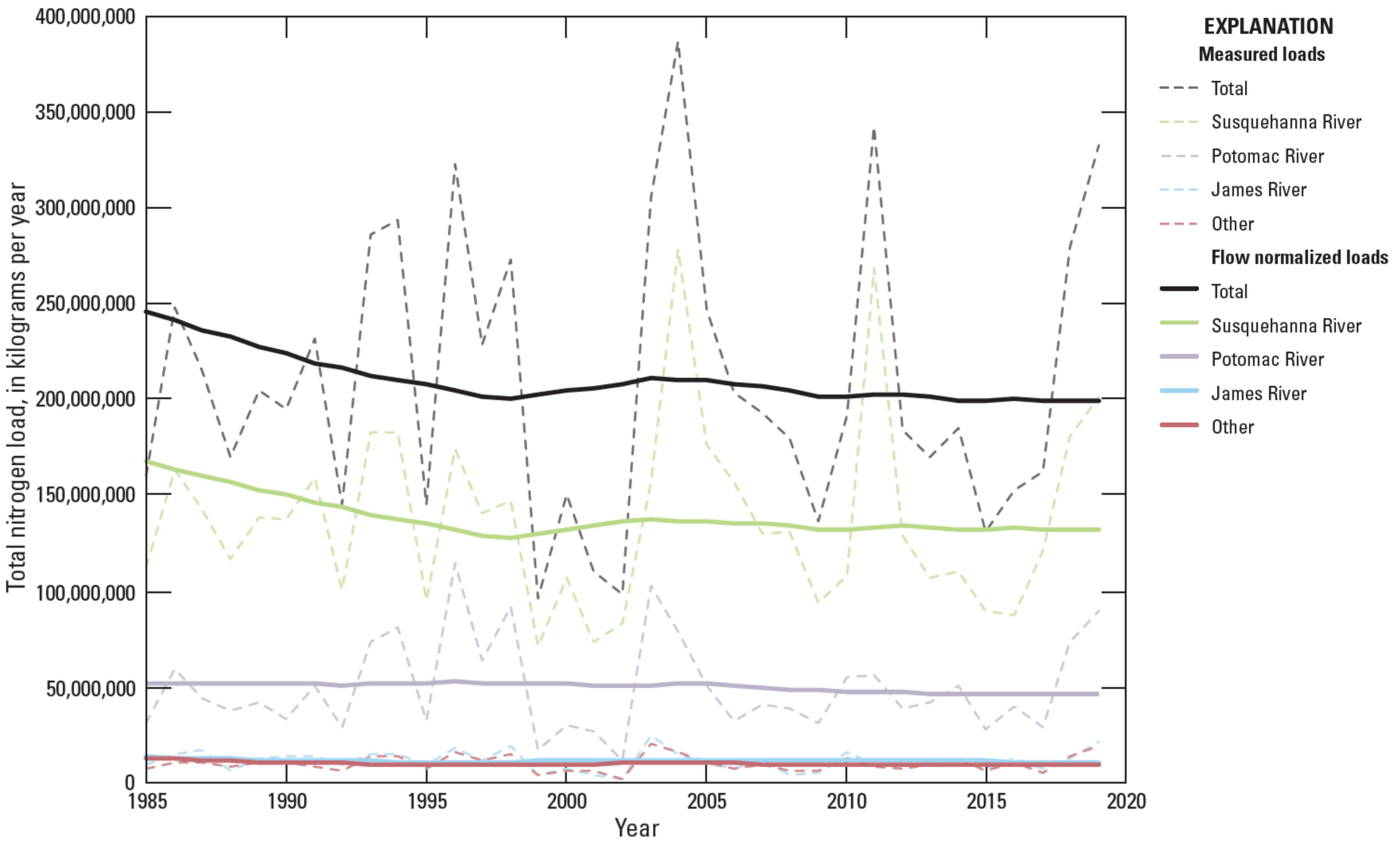




Susquehanna River: A large watershed that has shown a promising decline in nitrogen loads since the 1980s as a result of improvements in wastewater and implementation of management practices, but loads have remained consistent in recent decades

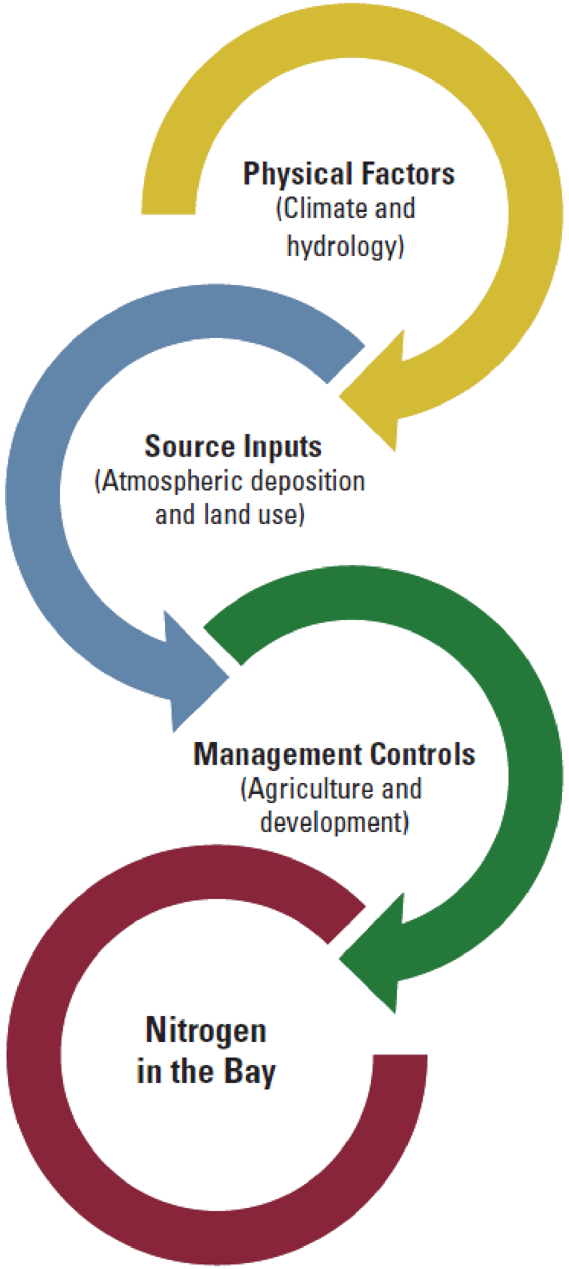
Total nitrogen loads have decreased from the major rivers to the Chesapeake Bay

The Susquehanna River, with the largest annual load over time, continues to be a major challenge with respect to reaching the goal of the TMDL



USGS

Before you go, lets look at a **long-term perspective** of the major drivers of nitrogen change up to the present, and a forecast into the future for the Chesapeake Bay watershed



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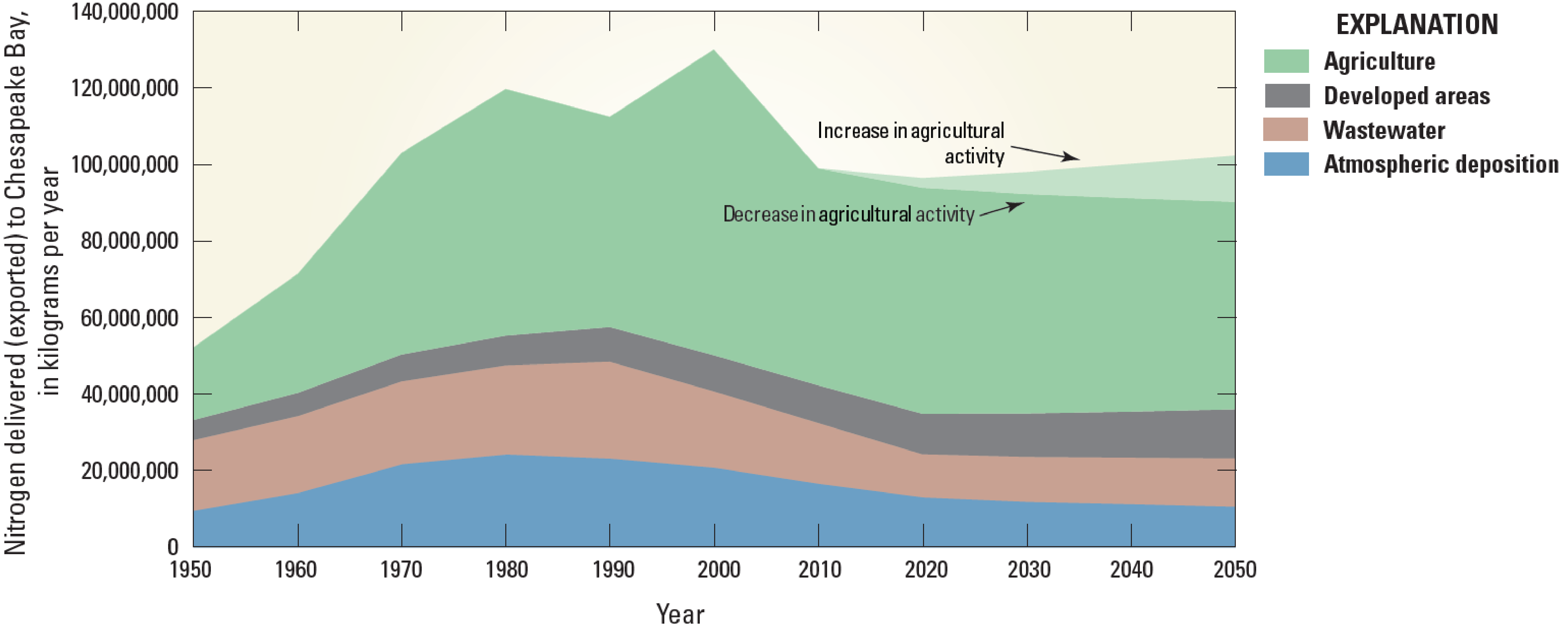
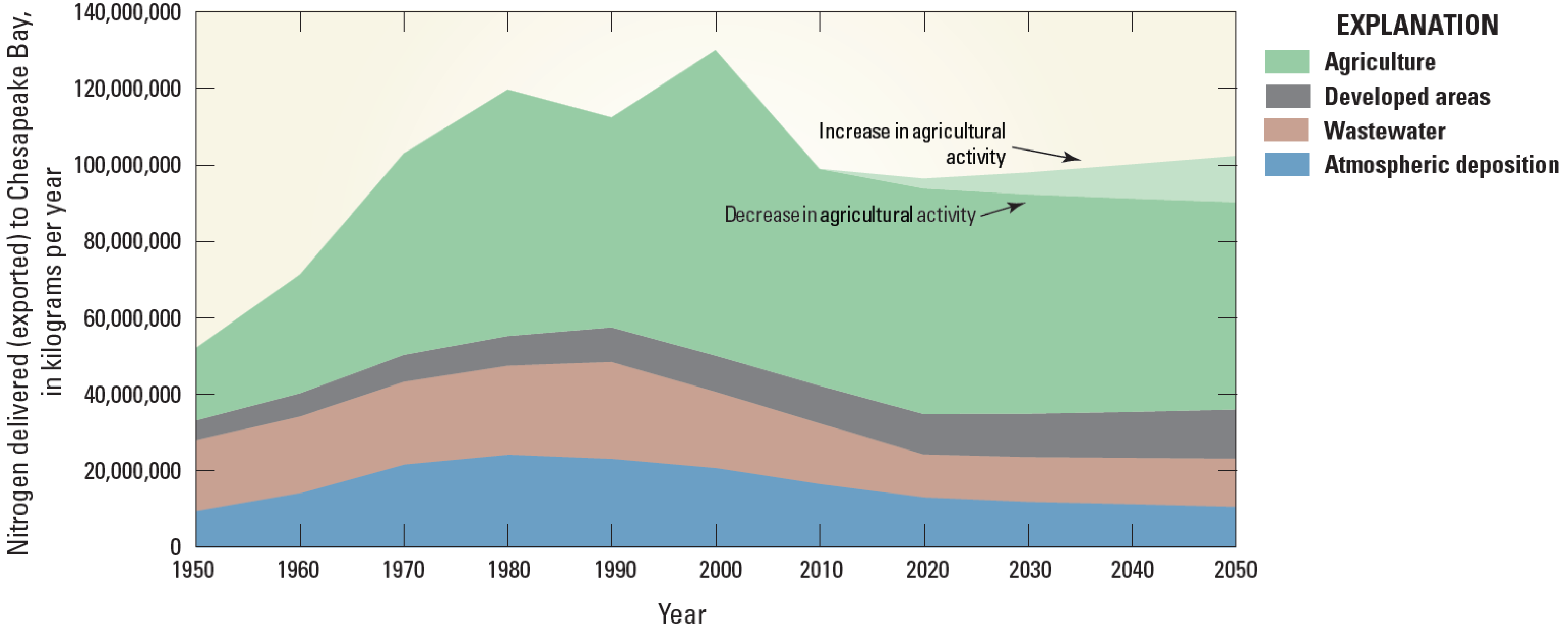
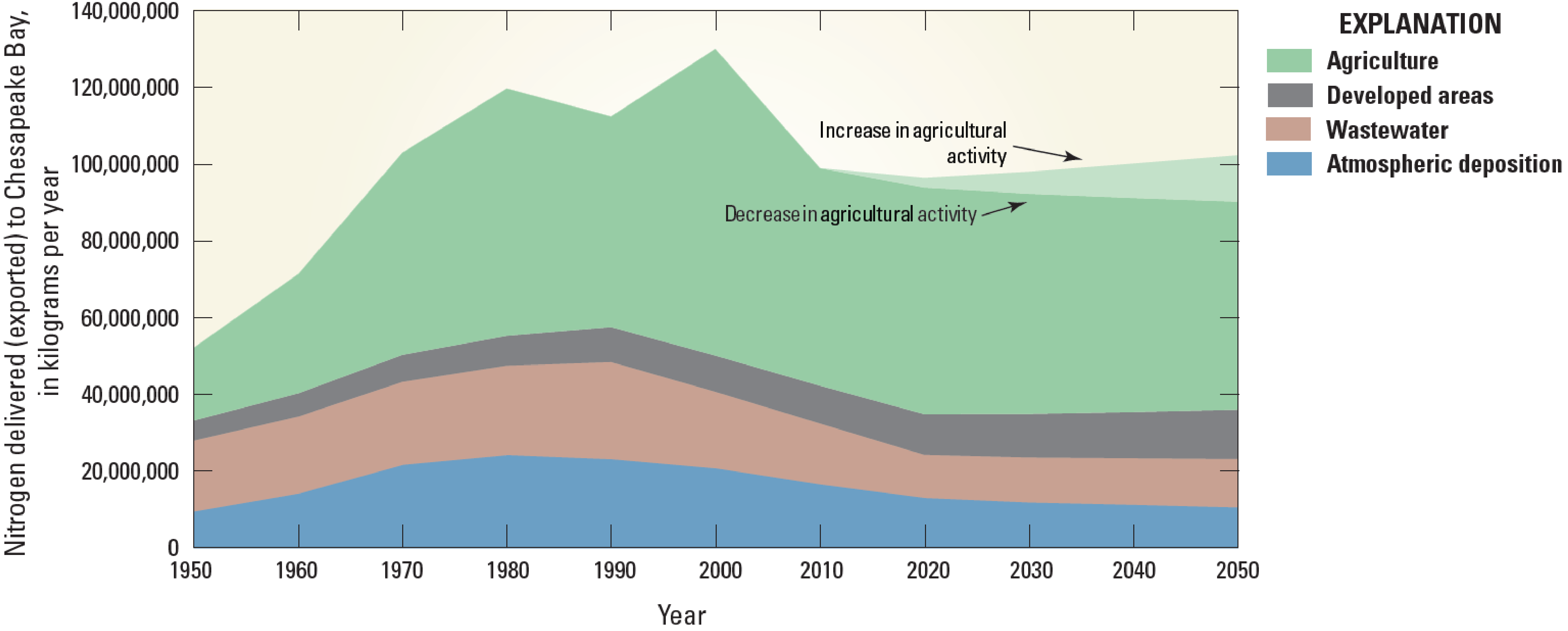
The sum of all the sources of nitrogen to the Bay increased substantially from 1950 until the 1980s, but varied afterwards



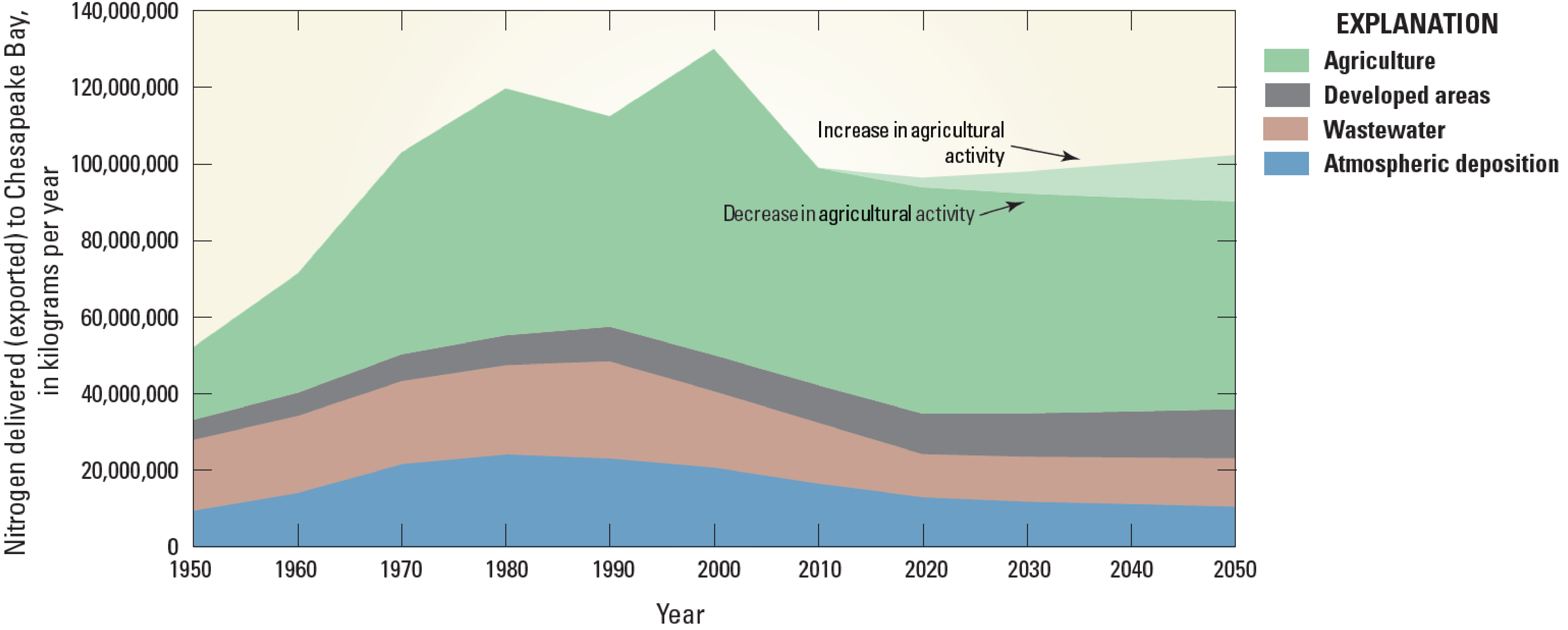
Nitrogen from atmospheric deposition and wastewater increased substantially from 1950, but started to decrease in more recent decades owing to the effects of the Clean Air Act and implementation of enhanced nitrogen removal technologies



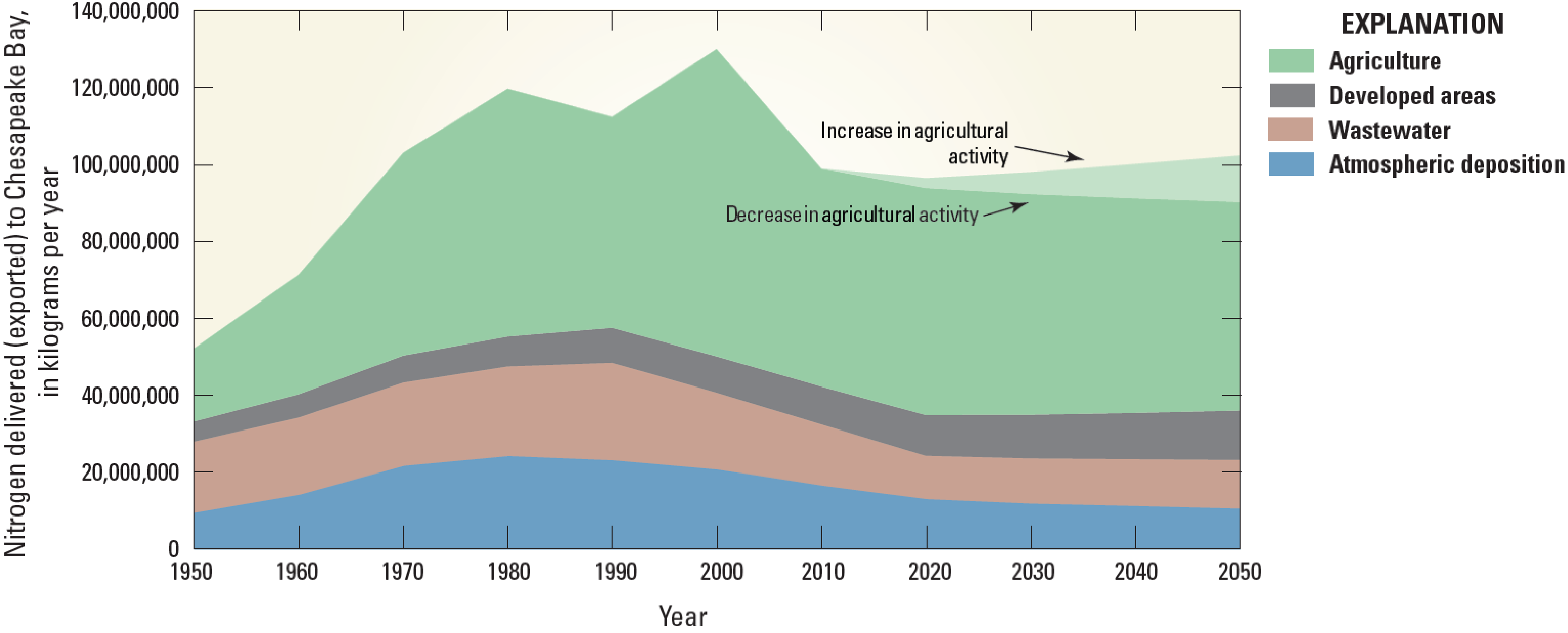
Nitrogen from developed areas have increased along with population growth and this trend is projected to continue



Nitrogen from agriculture has continually increased from 1950 owing to the widespread use of chemical fertilizer and manure from the intensification of animal agriculture in some areas



Future scenarios for agriculture, which is the largest source of nitrogen in the watershed, include both increasing and decreasing amounts from fertilizer and manure sources, suggest the export of nitrogen to the Bay presents a challenge to nitrogen load targets



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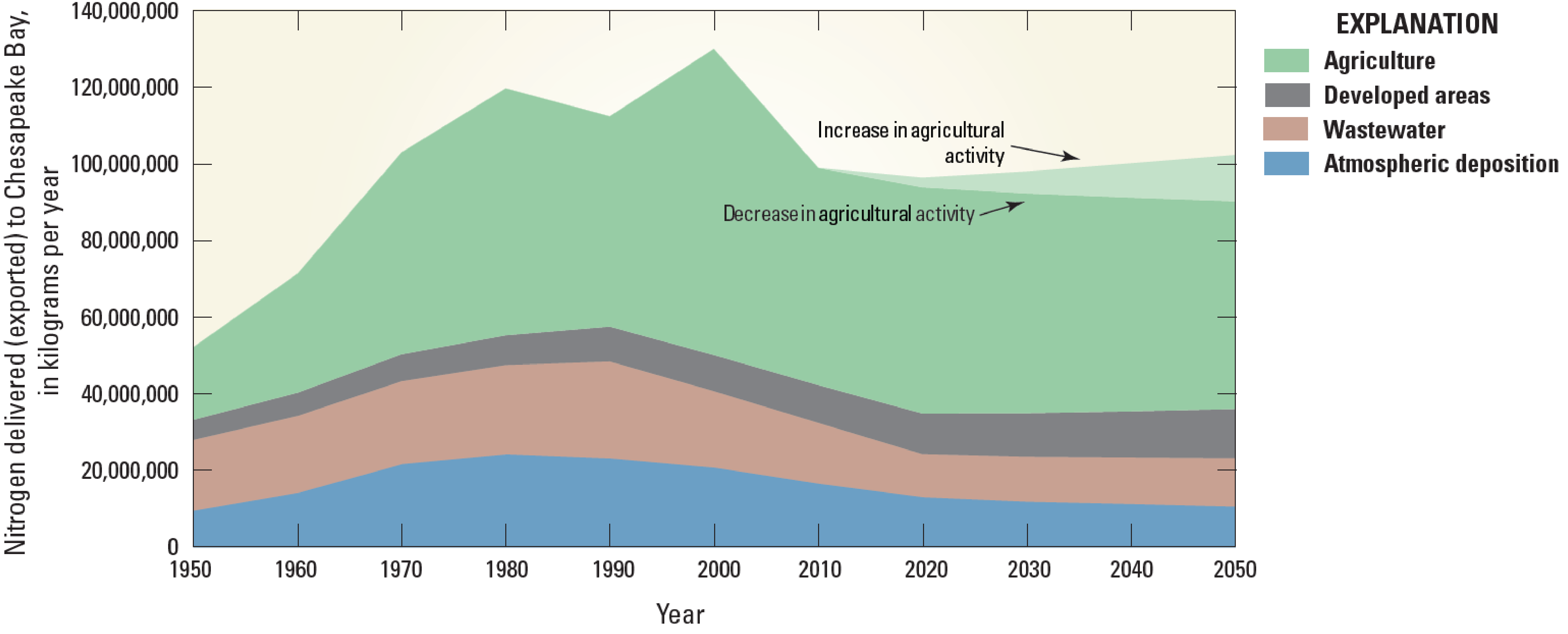
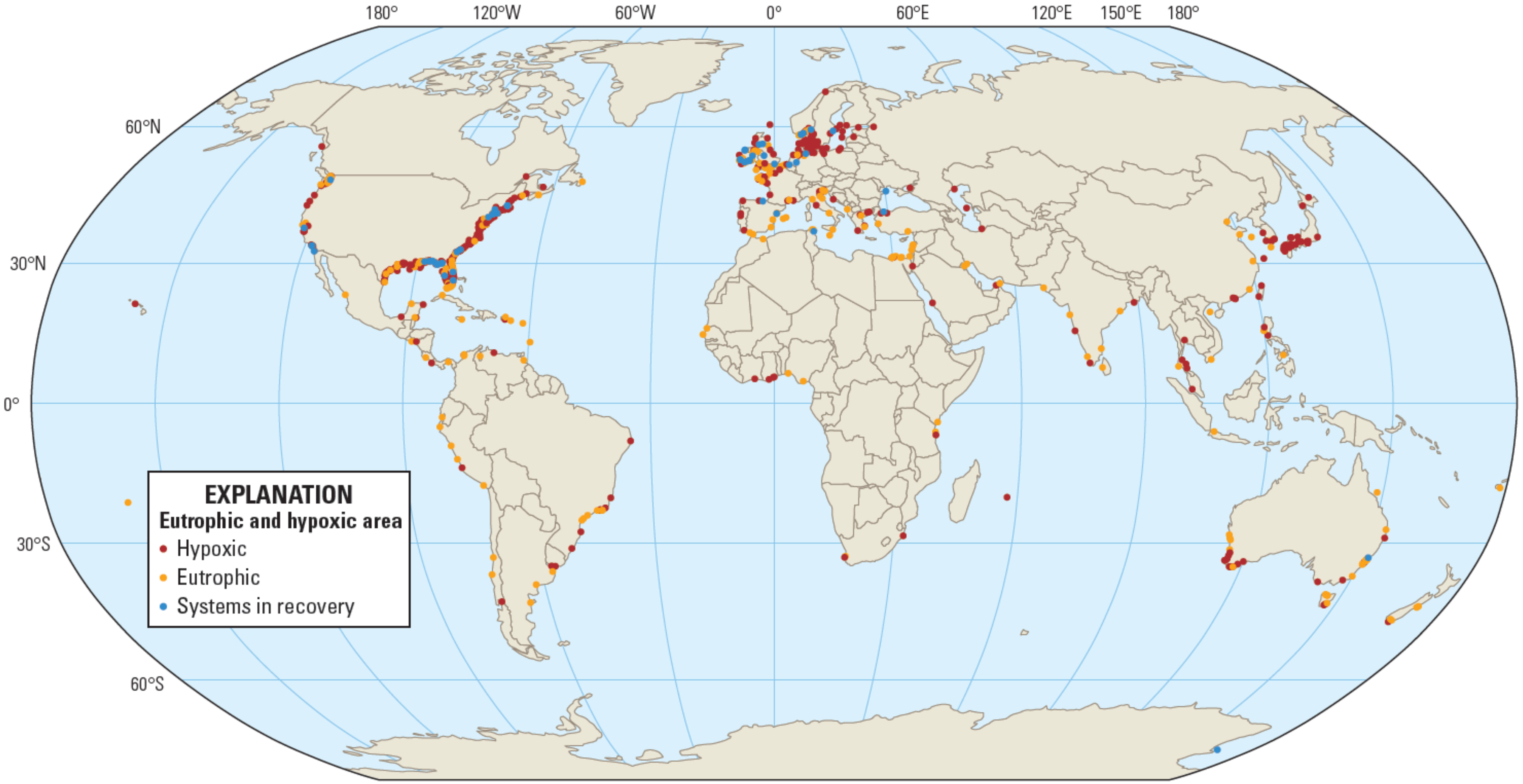
In summary, the greatest opportunities for future nitrogen reductions to the Chesapeake Bay watershed are in developed and agricultural areas



There are numerous coastal areas around the world that have been impacted by excess nitrogen



Base map from Natural Earth. Data source: Diaz, R., M. Selman. and C. Chique. 2011. Global Eutrophic and Hypoxic Coastal Systems. World Resources Institute (2013). Eutrophication and Hypoxia: Nutrient Pollution in Coastal Waters. docs.wri.org/wri_eutrophic_hypoxic_dataset_2011-03.xls Robinson projection, WGS 1984

The science, management, and regulation efforts to save the Chesapeake Bay are unprecedented and if the Nation’s largest estuary can rebound, it will serve as a model for the world

For more information on the science provided in this presentation please reference the following U.S. Geological Survey publication:

Nitrogen in the Chesapeake Bay Watershed: A Century of Change 1950-2050

https://pubs.er.usgs.gov/publication/cir1486

John W. Clune, Paul D. Capel, Matthew P. Miller, Douglas A. Burns, Andrew J. Sekellick, Peter R. Claggett, Richard H. Coupe, Rosemary M. Fanelli, Ana Maria Garcia, Jeff P. Raffensperger, Silvia Terziotti, Gopal Bhatt, Joel D. Blomquist, Kristina G. Hopkins, Jennifer L. Keisman, Lewis C. Linker, Gary W. Shenk, Richard A. Smith, Alexander M. Soroka, James S. Webber, David M. Wolock, and Qian Zhang