# Atmospheric Deposition of Nitrogen in the Chesapeake: Integrating Air & Water Environmental Management

Chesapeake Bay TMDL 2017 Midpoint Assessment Webinar Series

October 31, 2017

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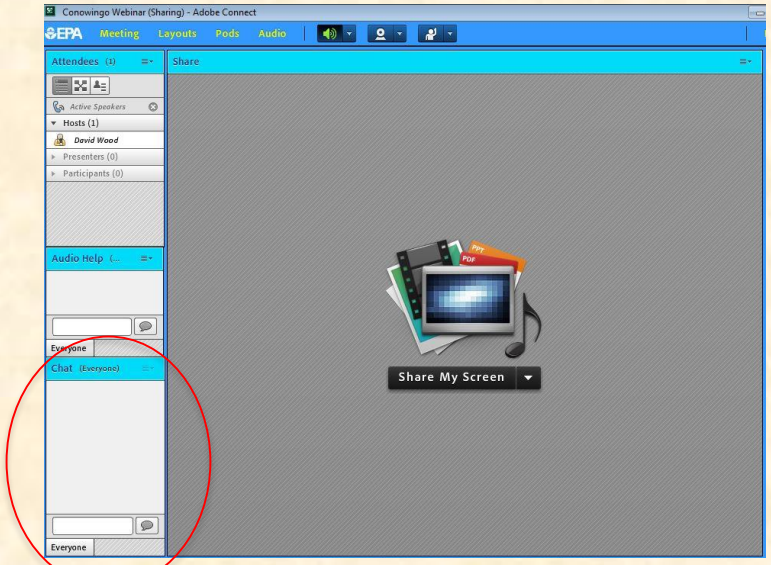
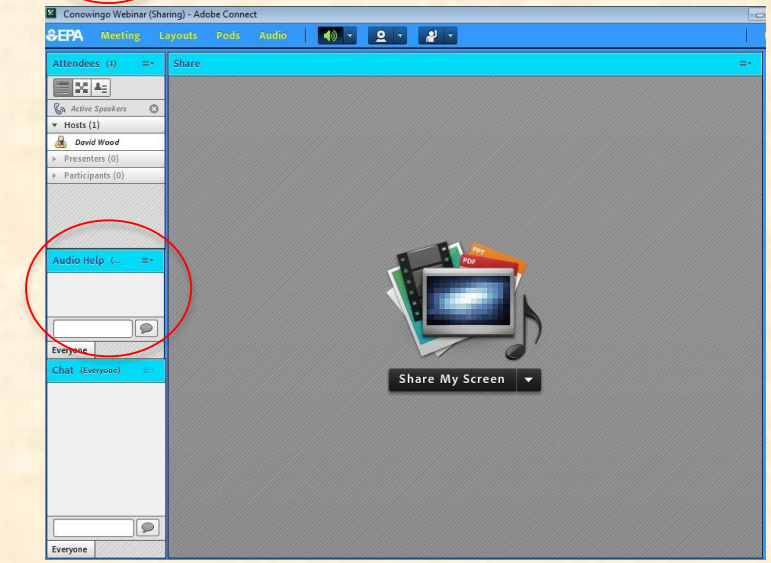
**Chesapeake Bay Program**
***Science, Restoration, Partnership***

# Welcome to the Atmospheric Deposition of Nitrogen in the Chesapeake Webinar

- To Ask a Question
  - Submit your question in the chat box, located in the bottom left of the screen, at any time during the webinar. We will answer as many as possible during a Q&A session following the presentation.




- For A/V Help
  - For audio or visual questions, please use the "Audio Help" box in the center-left of the screen.



# Welcome to the Atmospheric Deposition of Nitrogen in the Chesapeake Webinar

- We ARE Recording this Session
  - The recording and related resources will be available on the Chesapeake Bay Program's calendar page for today's webinar.
  - http://www.chesapeakebay.net/calendar/event/24340/

# Goals for Today's Webinar

- Increasing understanding of what current research, modeling and monitoring is telling us about changes in the atmospheric deposition of nitrogen to the Chesapeake watershed and tidal Bay.
- Insights on how these findings could influence the Phase 3 Watershed Implementation Plans and the restoration of the Chesapeake watershed and tidal waters.
- Insights into the changes in nitrogen deposition species and atmospheric deposition estimates for 2020, 2030, and 2050.

# Today's Speakers

**Lew Linker**
U.S. Environmental Protection Agency
CBP Modeling Workgroup Coordinator

**Jesse Bash**
U.S. EPA National Exposure Research Laboratory, Research Triangle Park, NC

**Michelle Williams**
Chesapeake Research Consortium
CBP Water Quality Goal Implementation Team Staff

# Trends in Atmospheric Deposition of Nitrogen IN the Chesapeake

**Lew Linker**

Chesapeake Bay Program Modeling Workgroup Coordinator

# Overview of Trends in Atmospheric Deposition

- Cleaner air means cleaner water. The Clean Air Act has helped Americans breathe easier and live healthier, reducing illnesses and premature deaths and contributing to a stronger economy and better quality of life. At the same time, the Act has helped protect our waters by reducing NOx emissions. Air pollution contributes about one third of the total nitrogen loads delivered to the lands and tidal waters of the Bay watershed.

- Load reductions tracked in the Chesapeake Bay watershed take into account the national nitrogen emission reductions and subsequent Chesapeake watershed deposition reductions that are due to national programs.

- Trends in NOx and ammonia - Loads of oxidized nitrogen (NOx) are decreasing and are estimated to continue to decrease until 2025 and beyond. Loads of reduced nitrogen or ammonia are steady or increasing.

# A Short History of the Assessment of Atmospheric Deposition of Nitrogen in the Chesapeake Bay Program

1985 – “There is no atmospheric deposition of nitrogen.”

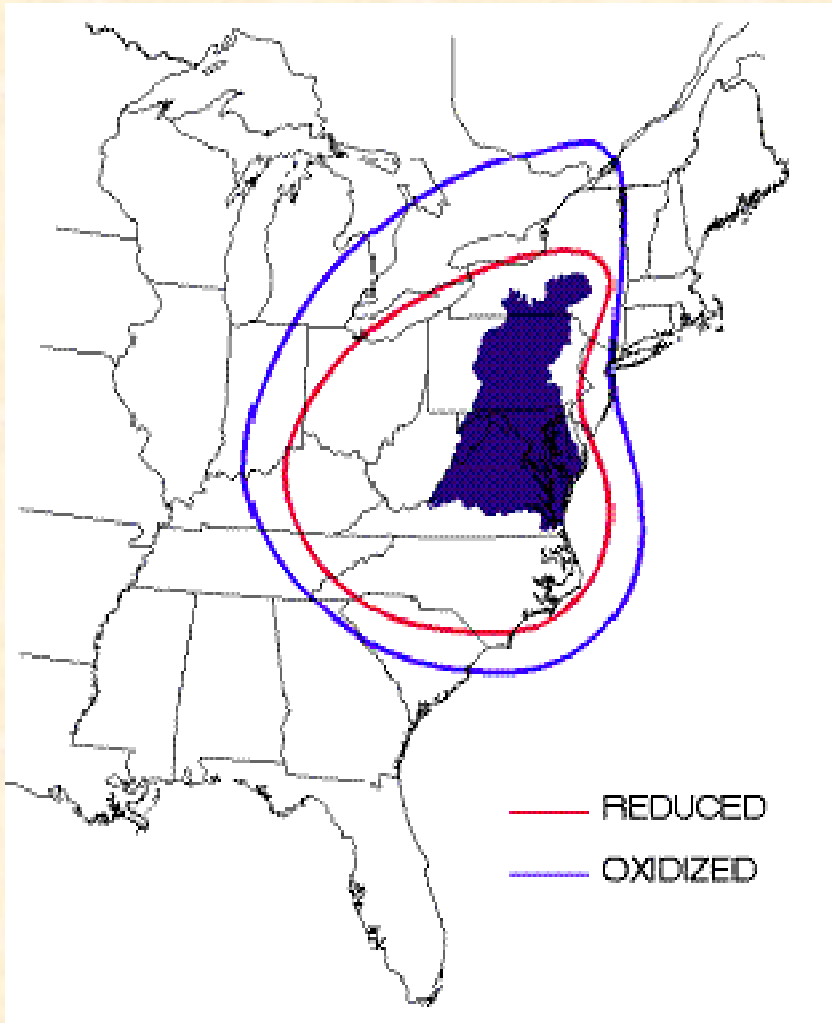
1995 – “Ok, there is some atmospheric deposition of nitrogen……but its uncontrollable.” (M. Tylor, 1988; Fisher and Oppenheimer, 1991)

2005 – “Wow! The CAA national program is sure removing a lot of nitrogen from the Chesapeake watershed.” (and other coastal watersheds too).

2015 – The atmospheric deposition of nitrogen to tidal water is an important component of the TMDL allocations. “We couldn’t have done the restoration without the air reductions.”

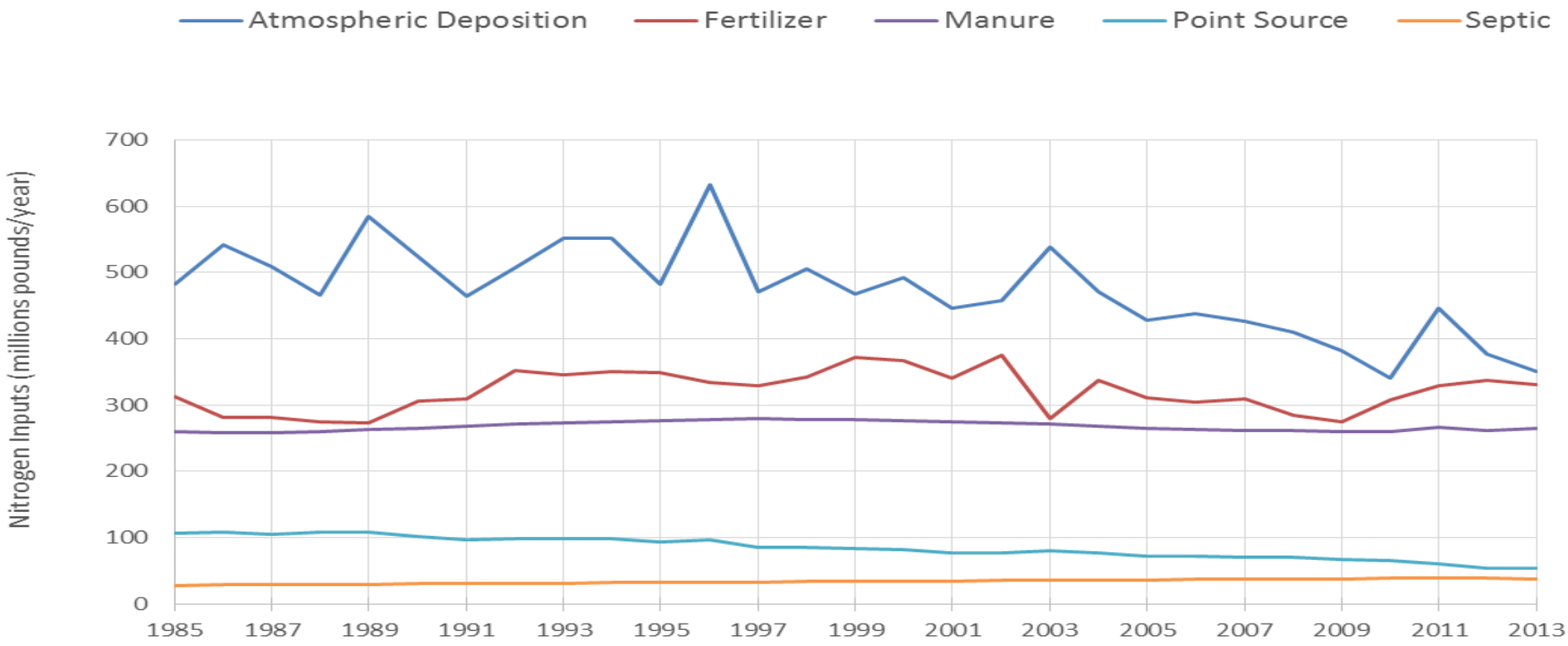
# Chesapeake Bay Airshed

The Bay's NOx airshed—the area where emission sources that contribute the most airborne nitrates to the Bay originate—is about 570,000 square miles, or nine times the size of the Bay's watershed. About 50 percent of the nitrate deposition to the Bay is from air emission sources in Bay watershed jurisdictions. Another 25 percent of the atmospheric deposition load to the Chesapeake watershed is from the remaining area in the airshed. The remaining 25 percent of deposition is from the area outside the Bay airshed. The ammonia airshed is similar to the NOx airshed, but slightly smaller.



# Atmospheric deposition is the greatest nitrogen load source to the Chesapeake

**Time series of estimated atmospheric, fertilizer, manure, point source, and septic nitrogen input loads to the Chesapeake watershed and tidal waters.**




Atmospheric deposition has been the highest source of nitrogen load to the Chesapeake watershed and tidal Bay, but also is the load with the most rapid rate of reduction.

# Trends in Atmospheric Deposition of Nitrogen IN the Chesapeake

**Lew Linker**

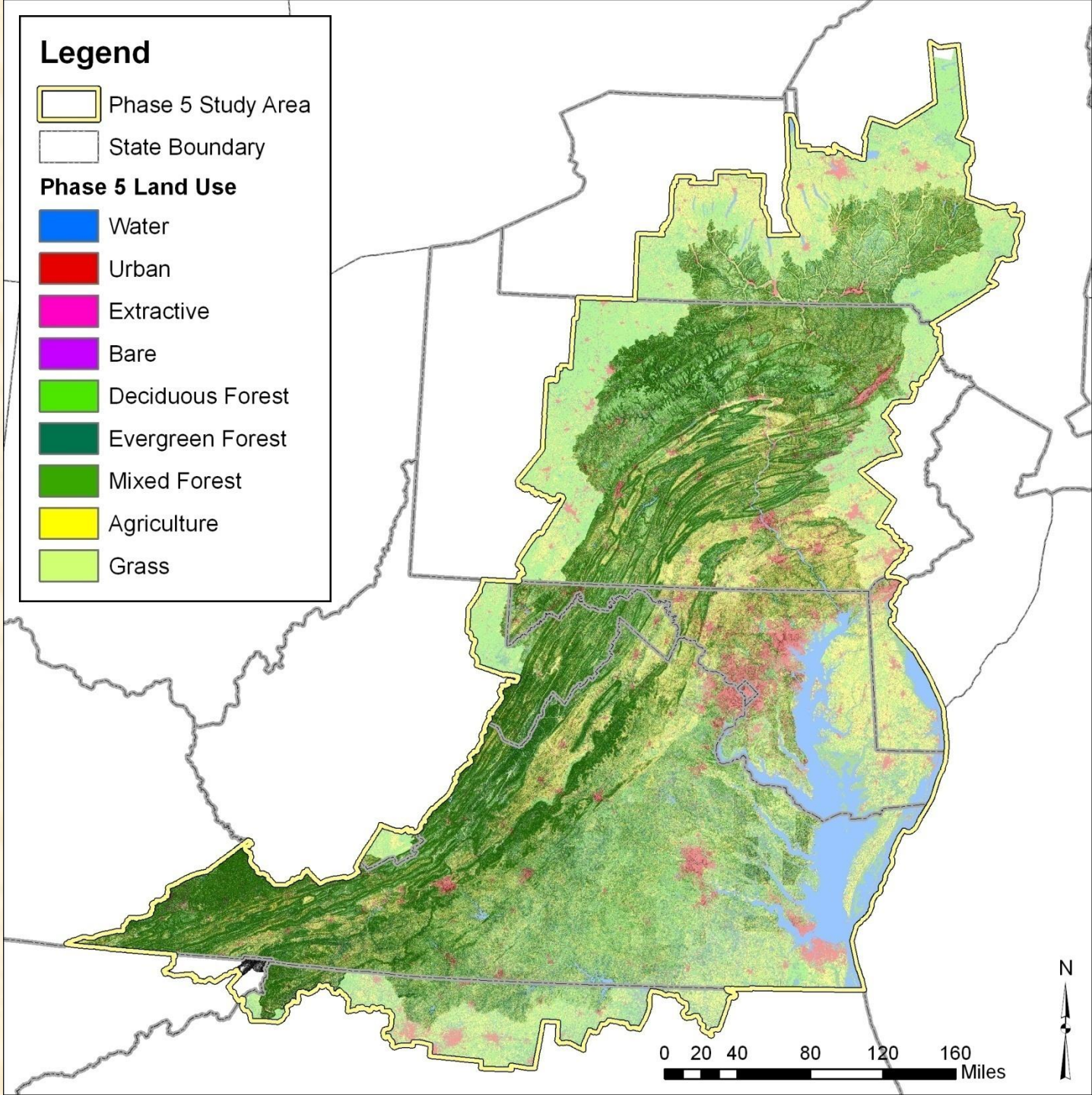
Chesapeake Bay Program Modeling Workgroup Coordinator

# Overview:

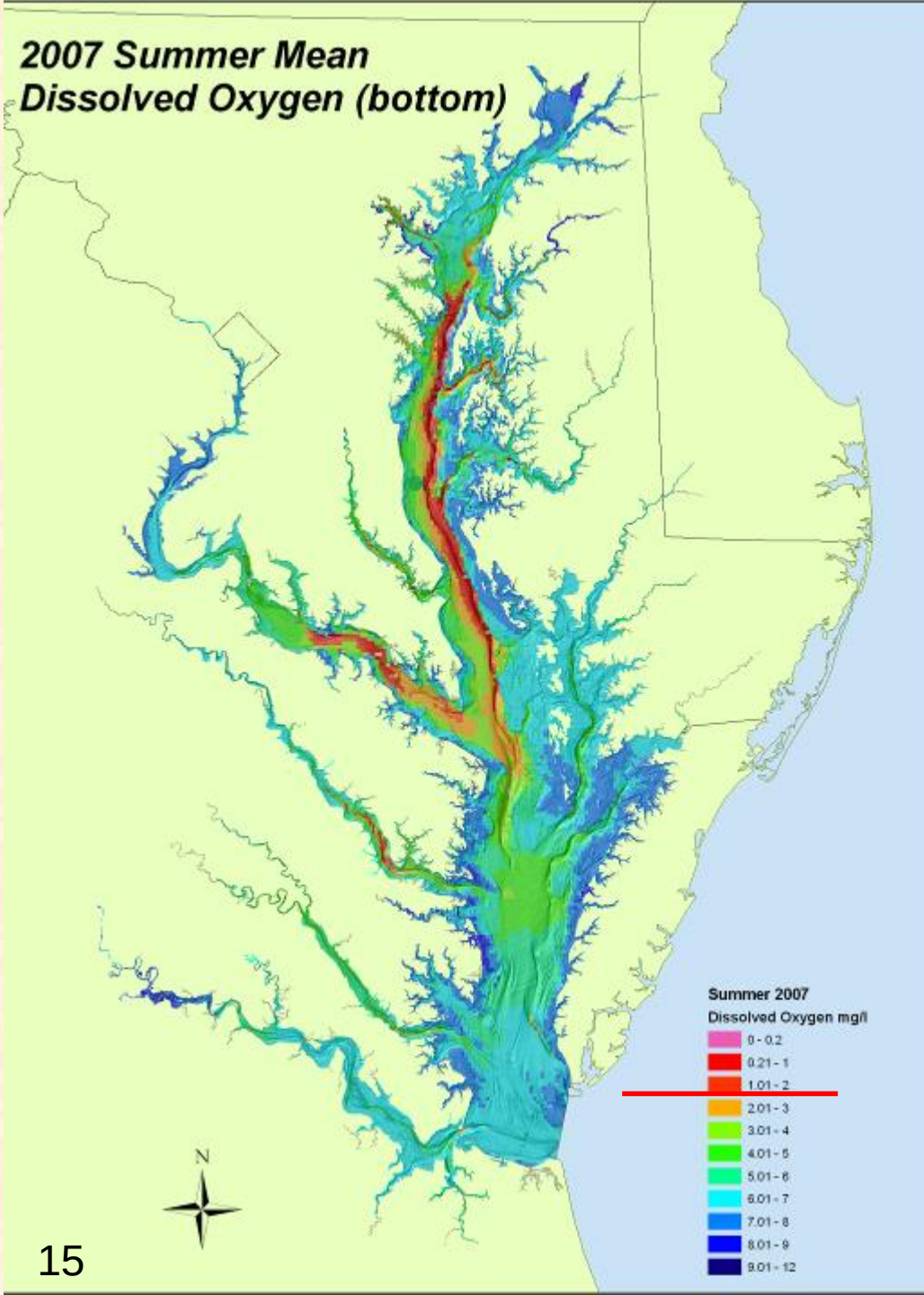
- **Problem Introduction and the Watershed-Airshed Management Approach in the Chesapeake.**
- **Introduction To Key Models and Management Process.**
- **Trends and Results in the Chesapeake**
- **Conclusions**

# Problem Introduction and Watershed Management Approach

We need to view the CBP integrated models of the airshed, watershed, and tidal Bay models as a whole. Together they relate the watershed and airshed loads to water quality impairments in the Chesapeake.

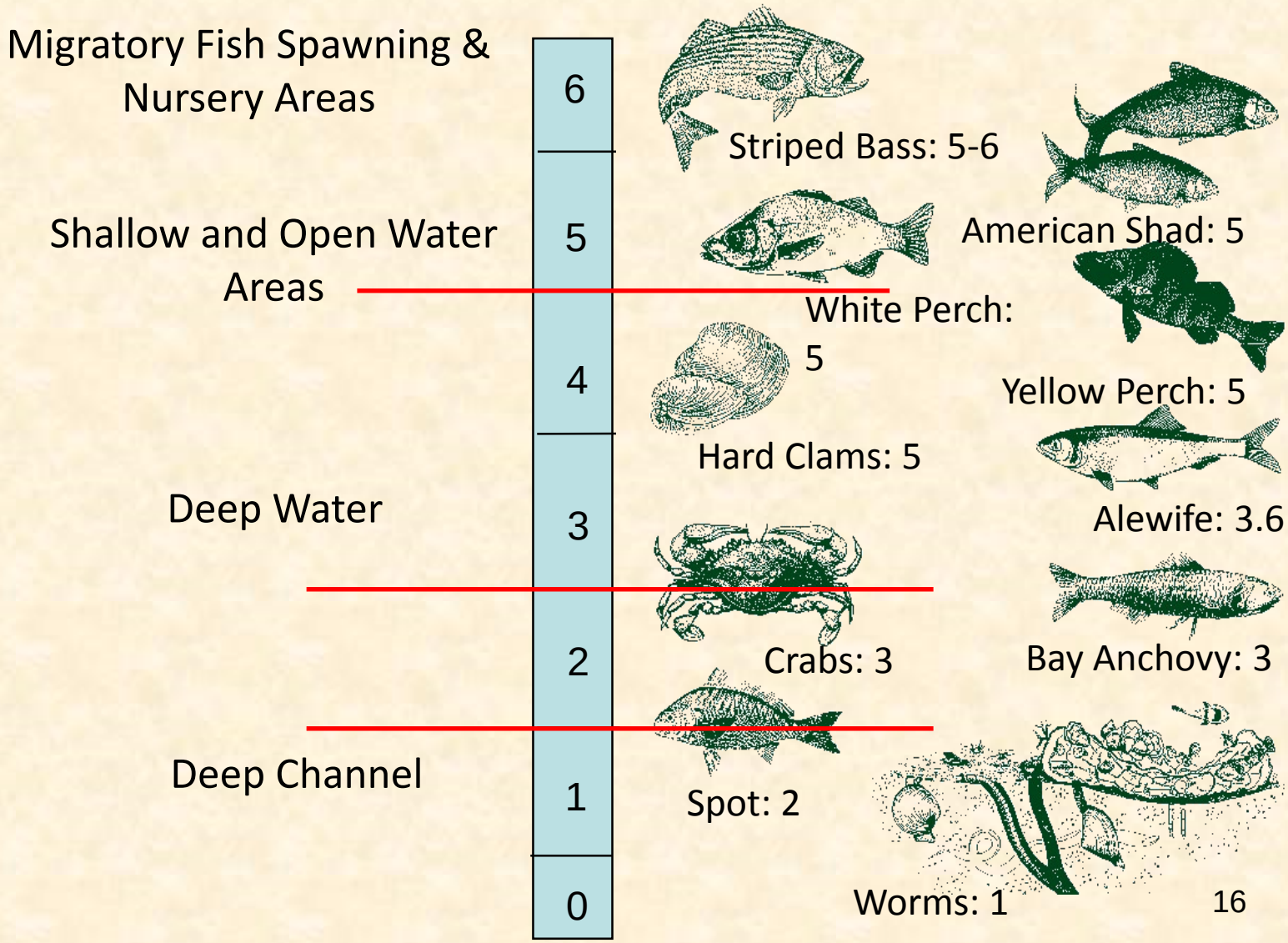


**Low to no dissolved oxygen in the Bay and tidal rivers is a recurring problem every summer in the Chesapeake.**

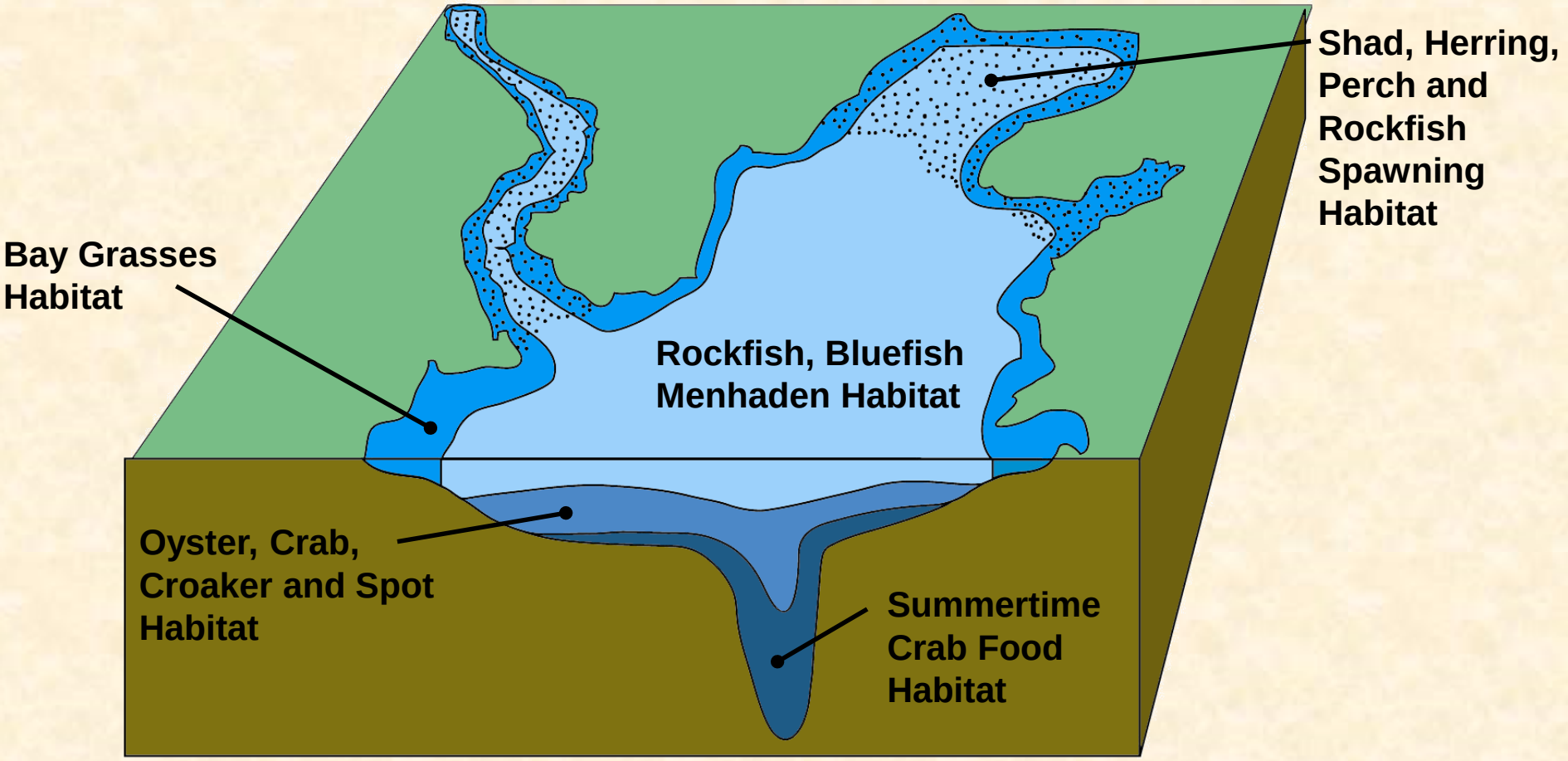


# Bay Dissolved Oxygen Criteria

Minimum Amount of Oxygen (mg/L) Needed to Survive by Species



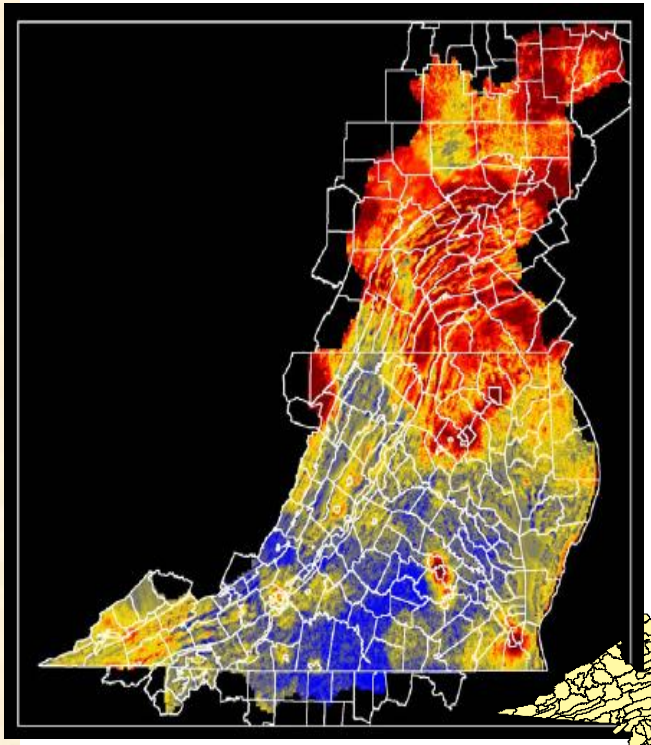
# Local “Zoning” for Bay and Tidal River Fish, Crab and Grasses Habitats

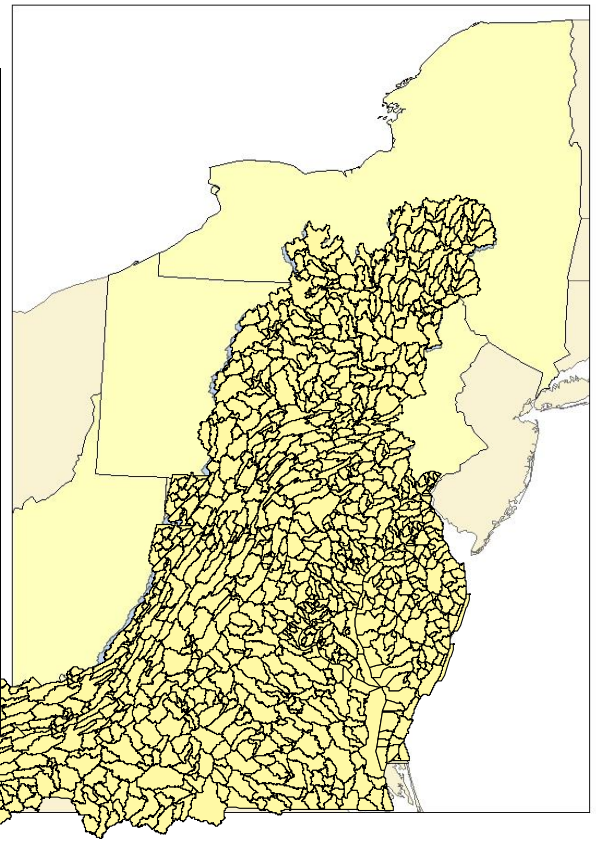


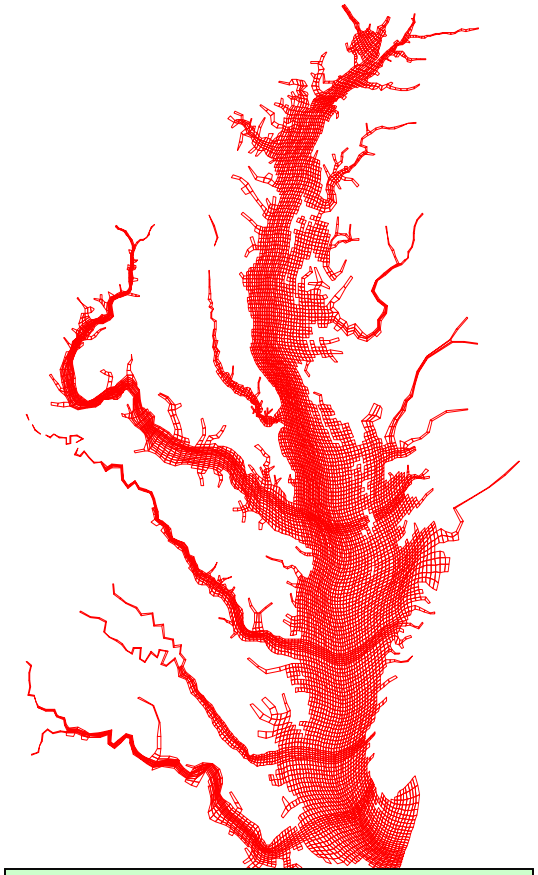
# Introduction To Key Models and Process

# An Overview of the CBP Integrated Models:

## Current Chesapeake Bay Modeling Structure





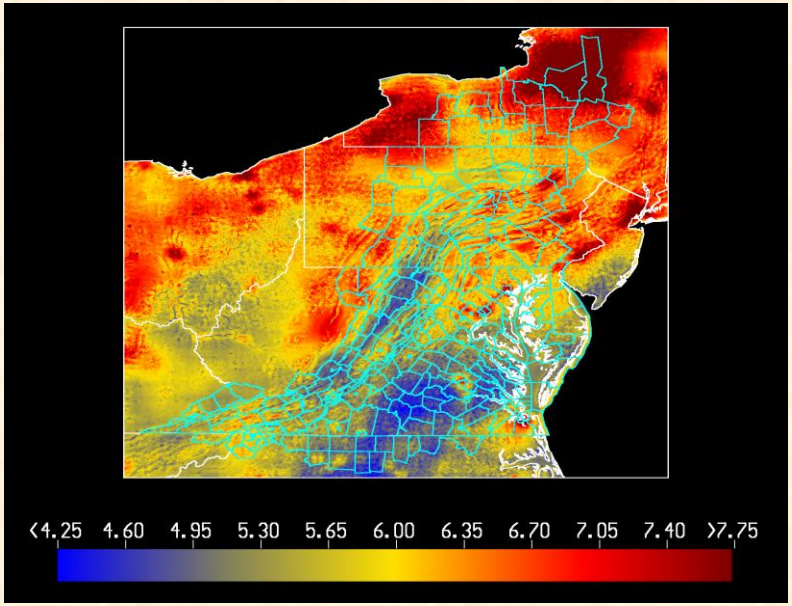


**Nitrate and ammonia deposition from improved Daily Nitrate and Ammonium Concentration Models using 35 monitoring stations over 18 simulation years. Adjustments to deposition from the Community Multi-scale Air Quality (CMAQ) Modeling System**

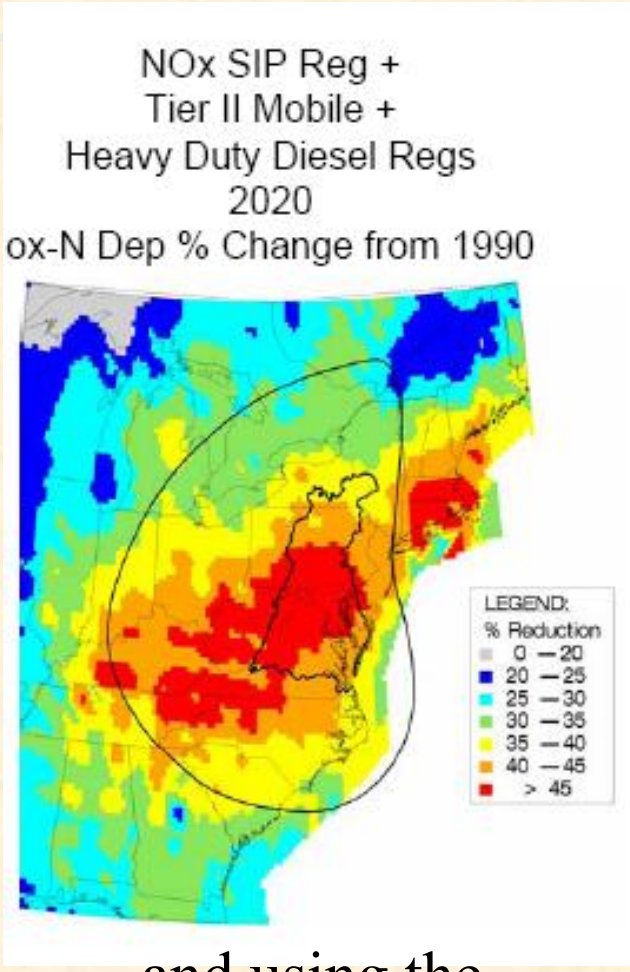
**Phase 5 Watershed Model**
**Year-to-year changes in land use and BMPs; 899 segments; 24 land uses; 296 calibration stations; 21 simulation years; sophisticated calibration procedures; calibration demonstrably better in quality and scale**

**Chesapeake Bay Estuary Model**
**Detailed sediment input; Wave model for resuspension, Full sediment transport; Filter feeder simulation; Simulation of Potomac algal blooms; 54,000 model cells; 18 simulation years**

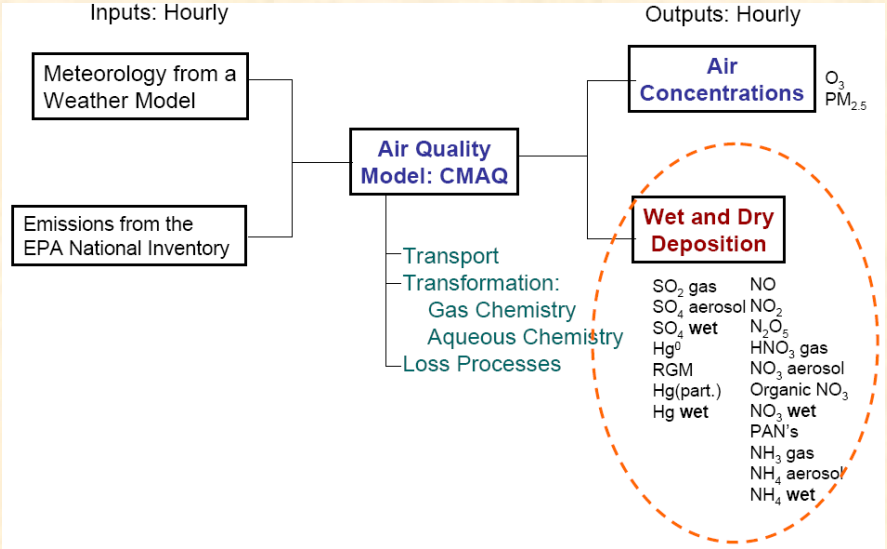
# The Airshed Model - CMAQ




Combining a regression model of wetfall deposition...



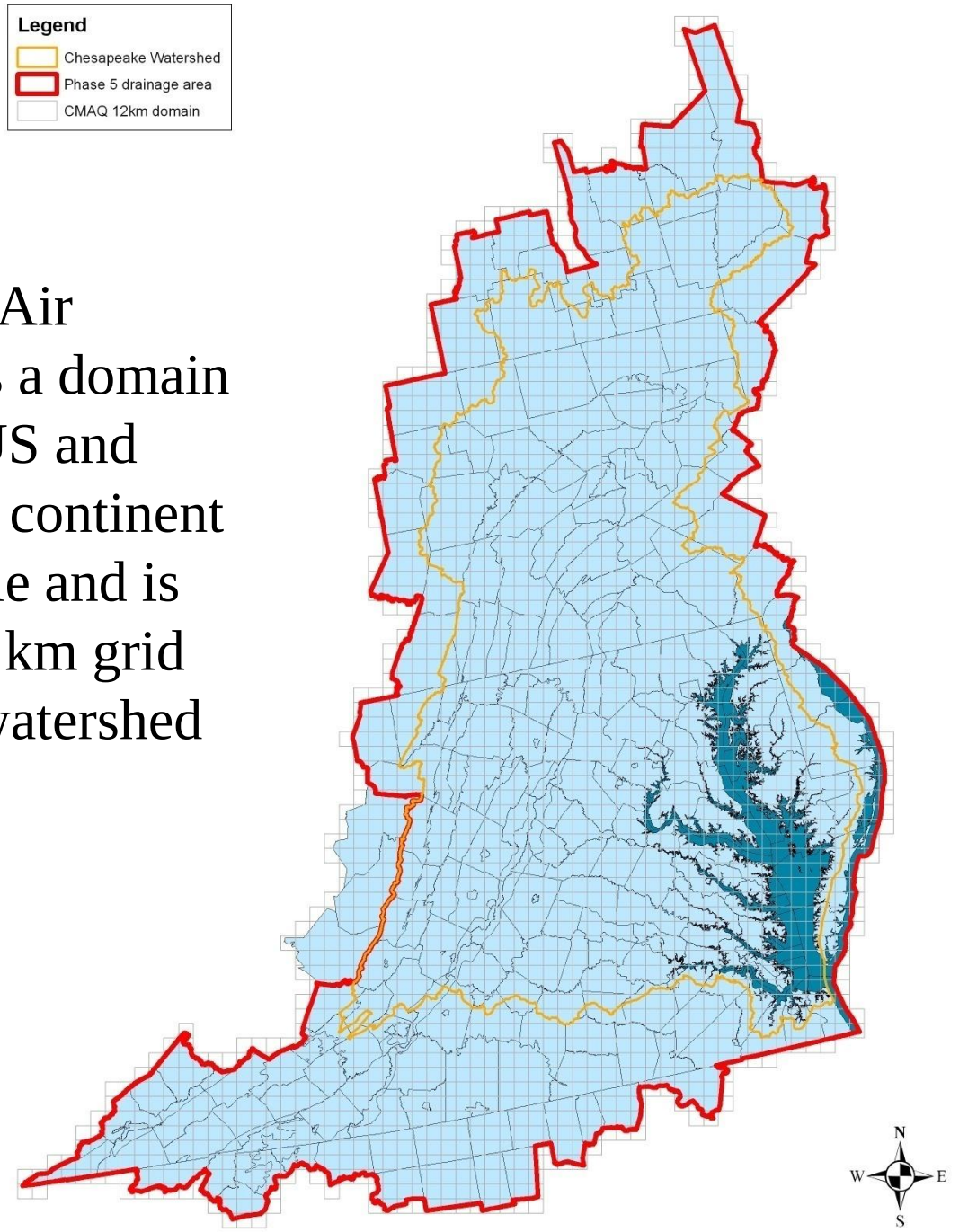

…with CMAQ estimates of dry deposition for the base…



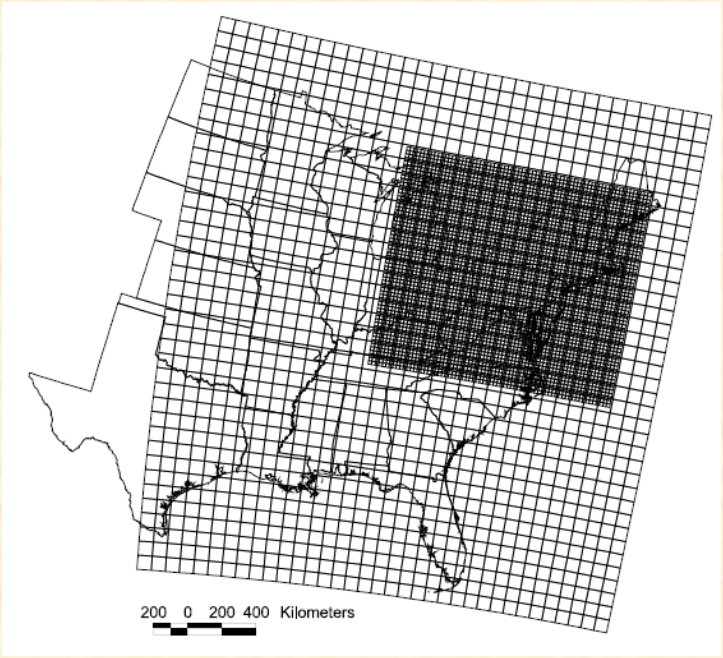

…and using the power of the CMAQ model for scenarios.

# CMAQ Model

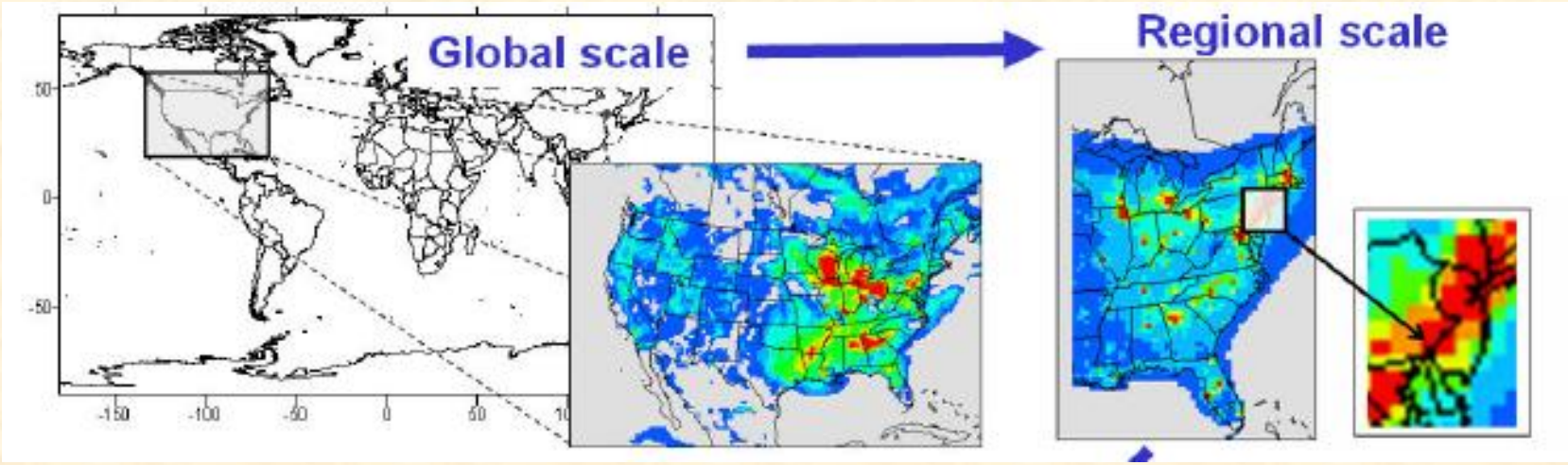
The Community Multiscale Air Quality Model (CMAQ) has a domain that covers the contiguous US and most of the North American continent at a 36 km x 36 km grid scale and is nested at a finer 12 km x 12 km grid scale over the Chesapeake watershed and Bay.



# History of CBP Airshed Model

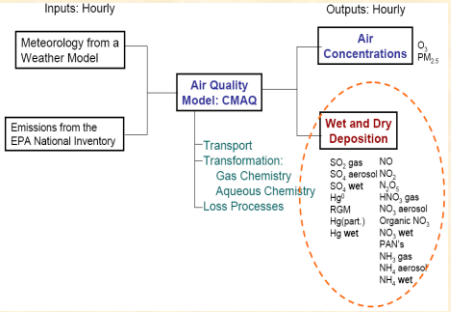


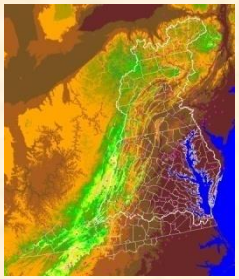

The 1st generation CBP Airshed Model (RADM) covered only the Eastern US. The current 2nd generation CBP Airshed Model, CMAQ, is a continental scale "one-model" design and uses a nested grid of 36 km in the US and a 12 km fine grid for the Chesapeake watershed.



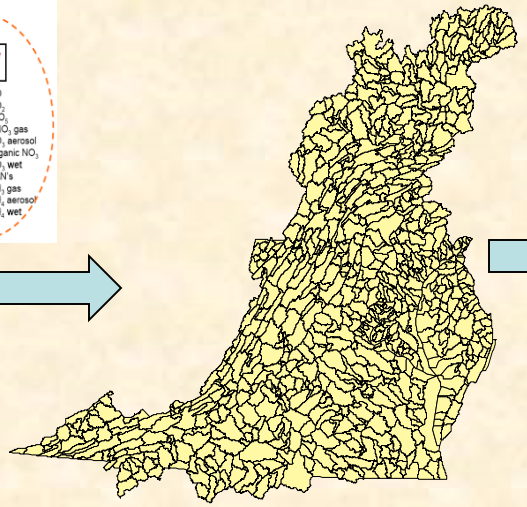
# 2017 Midpoint Assessment Nutrient Load Target Decision Support System

Airshed Model

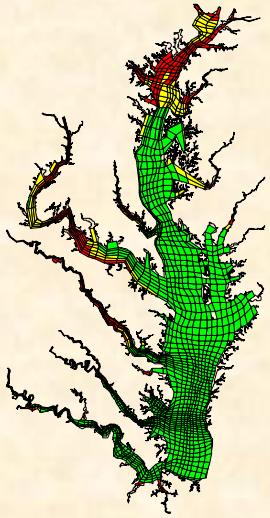


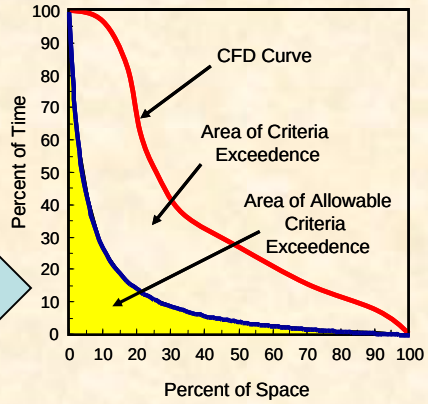
Watershed Model



Bay Model



Criteria Assessment Procedures

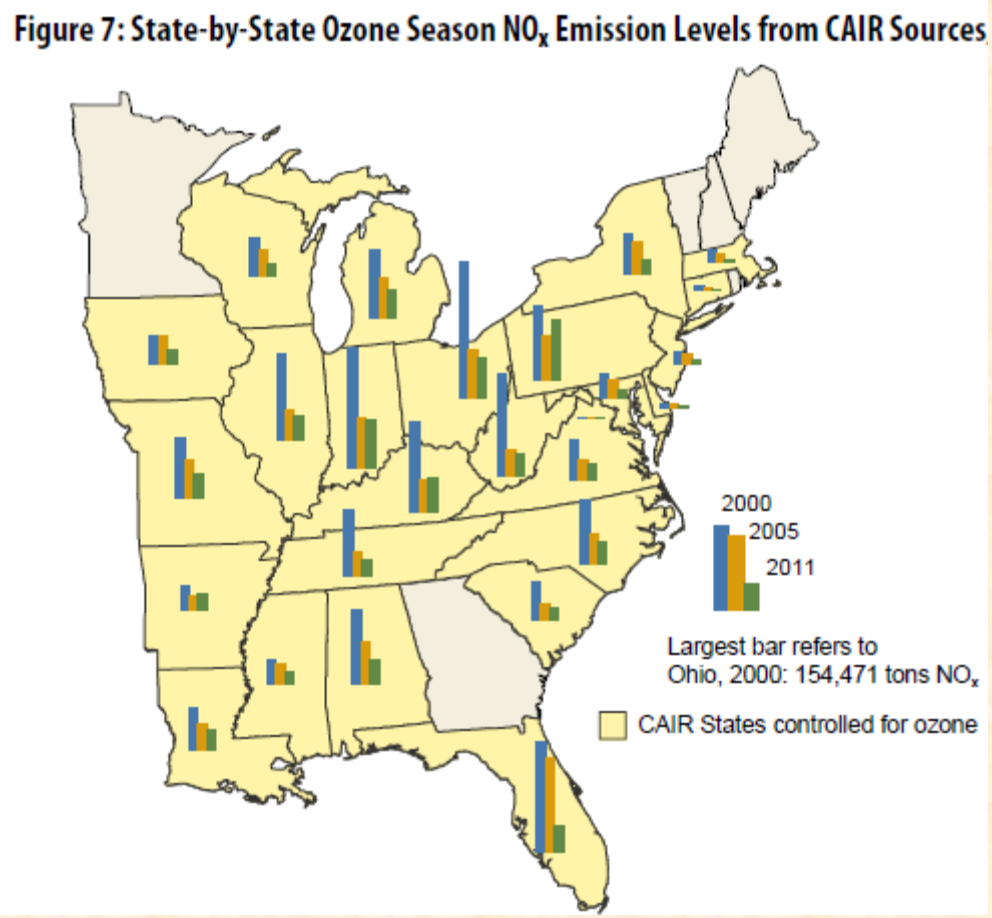



Effects

Targets

# Trends and Results

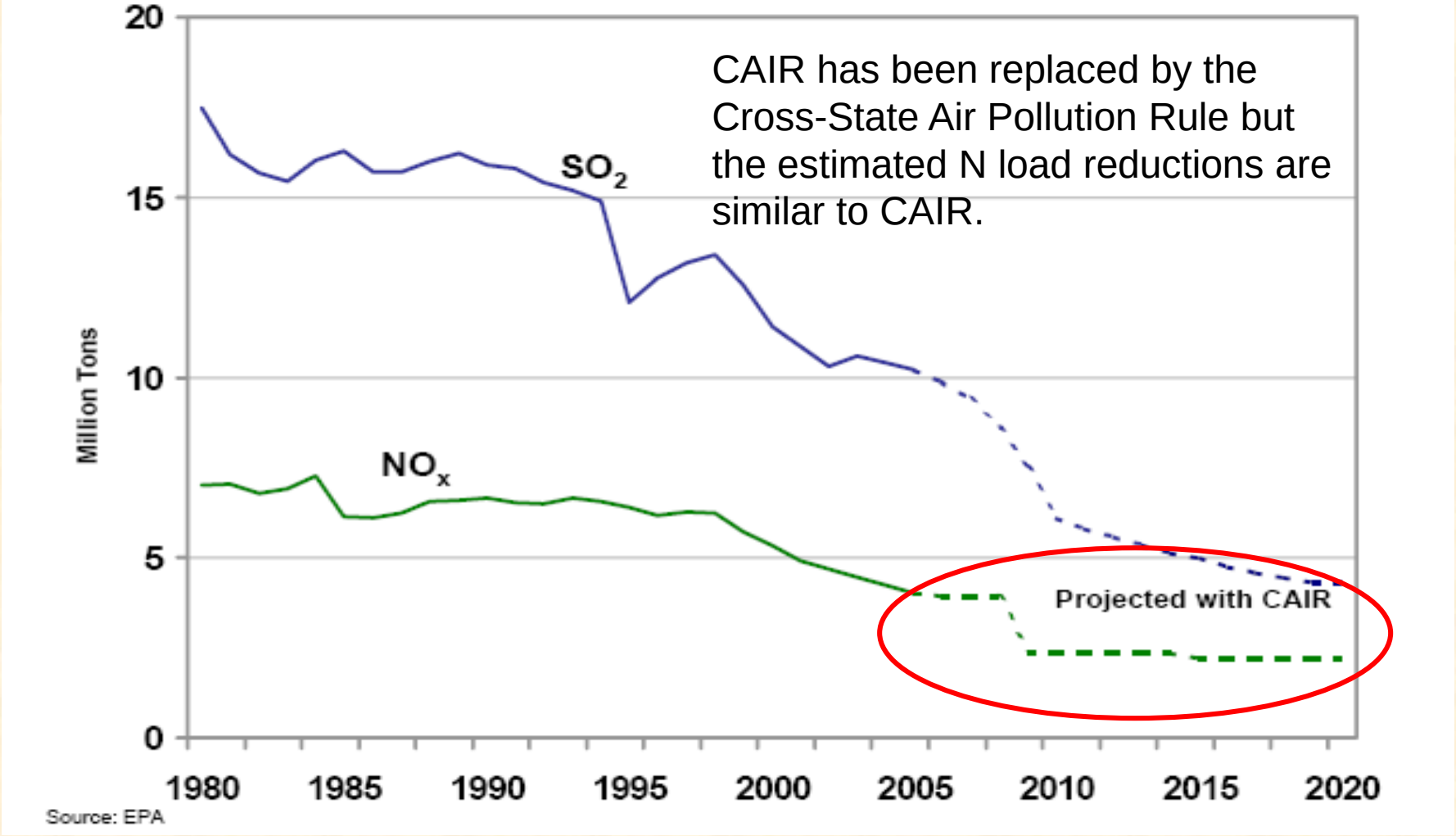
# Progress Storyline: air emissions declining….

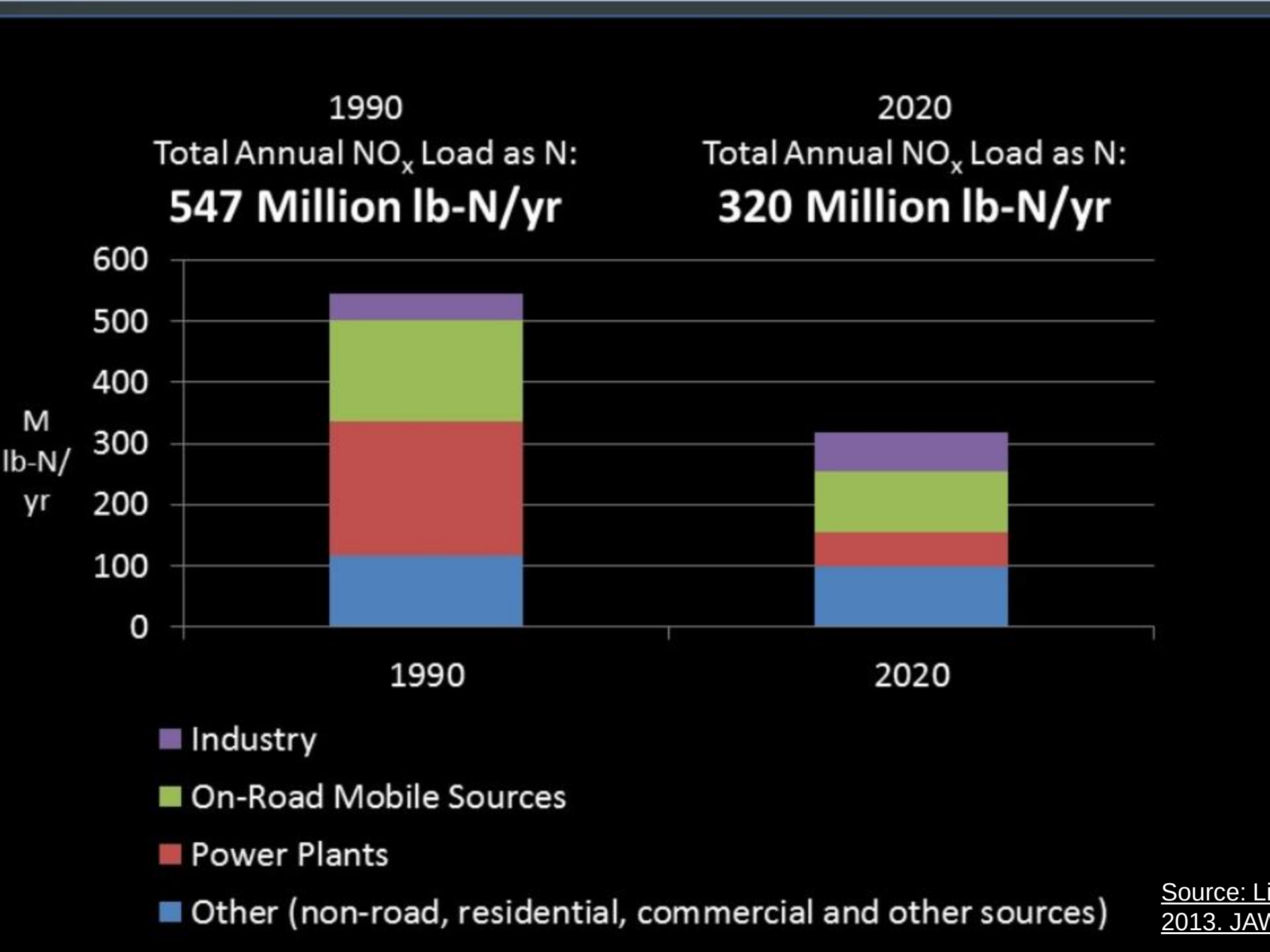



Source: U.S. EPA "SO2 and NOx Emissions, Compliance, and Market Analyses" 2013.

# …. and atmospheric loads of NOx are decreasing.

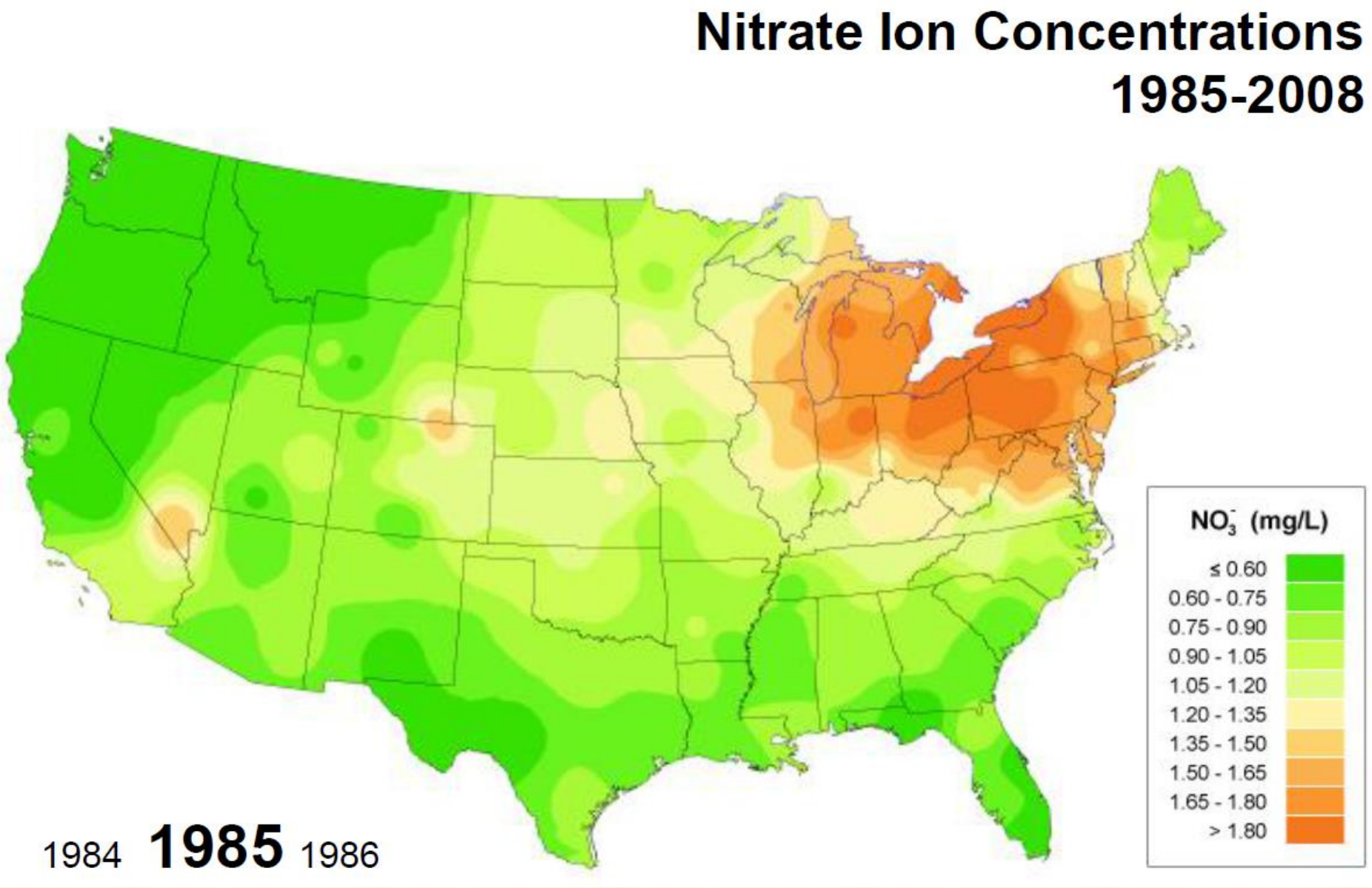
**Estimated nationwide emissions of NOx and $SO_2$ from electric generating units (EGUs) since 1980 and estimated emissions to 2020.**





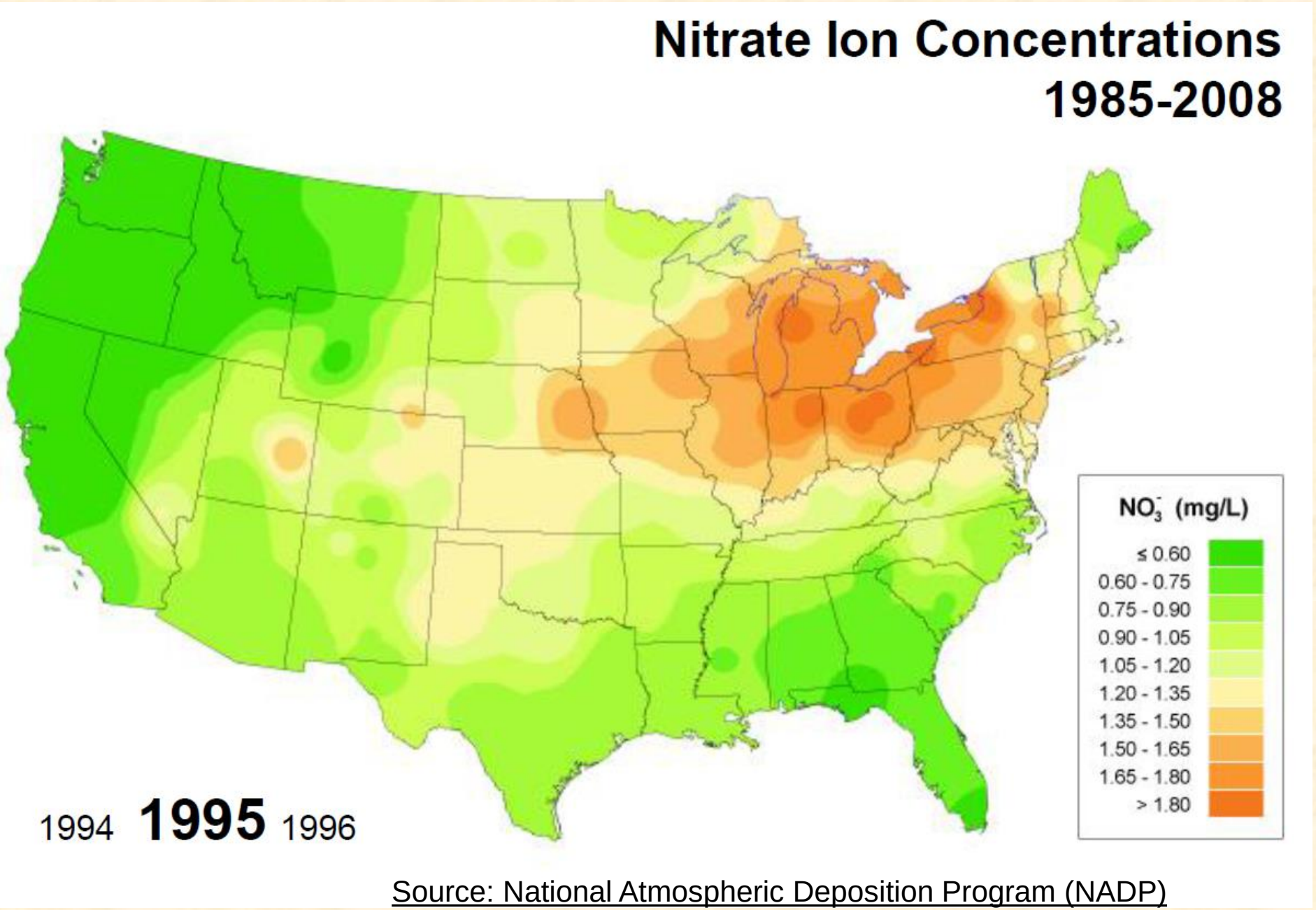

Source: Li
2013. JAW

# Progress Storyline: air nitrogen deposition declining



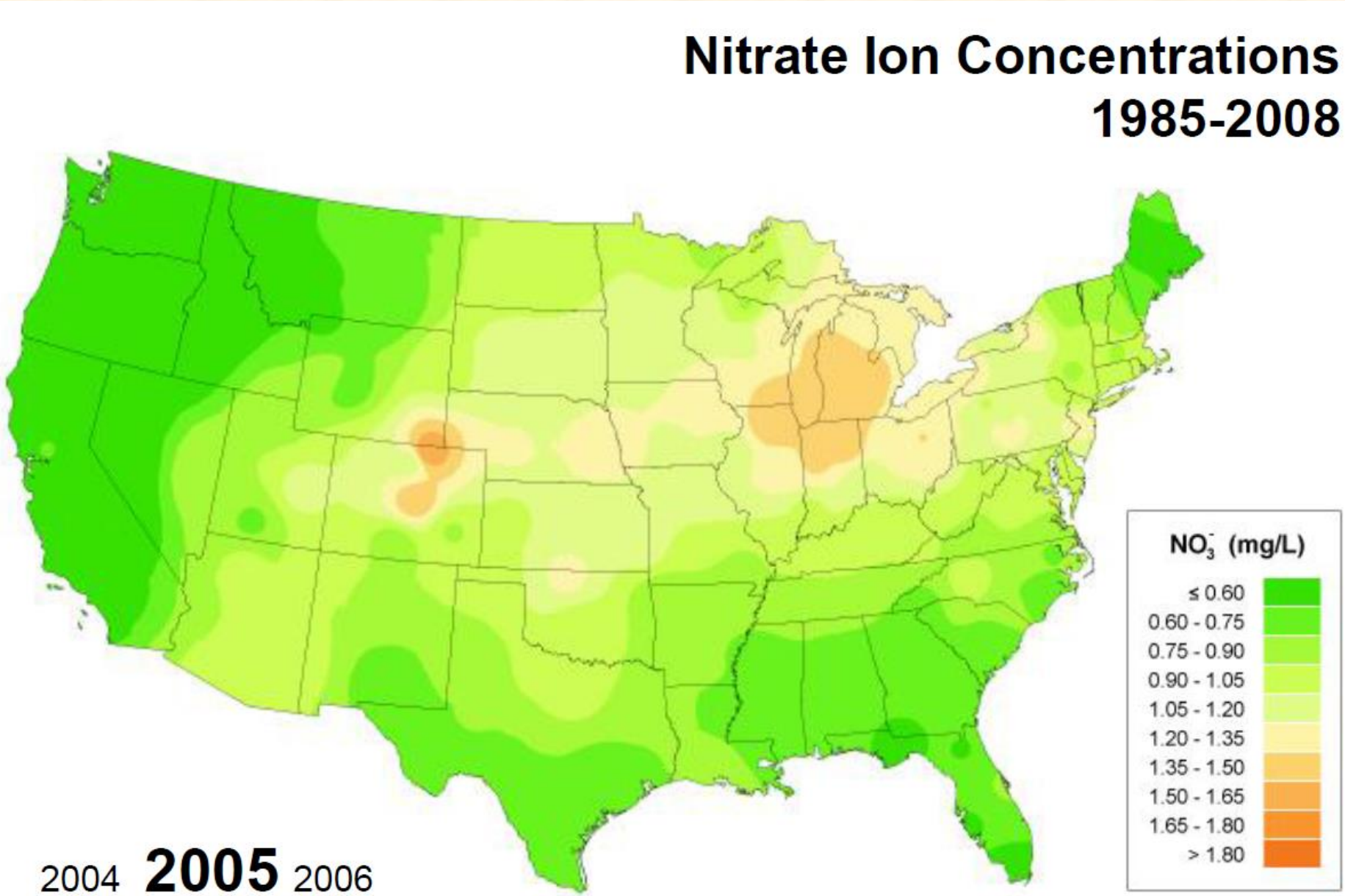

Source: National Atmospheric Deposition Program (NADP)

# Progress Storyline: air nitrogen deposition declining



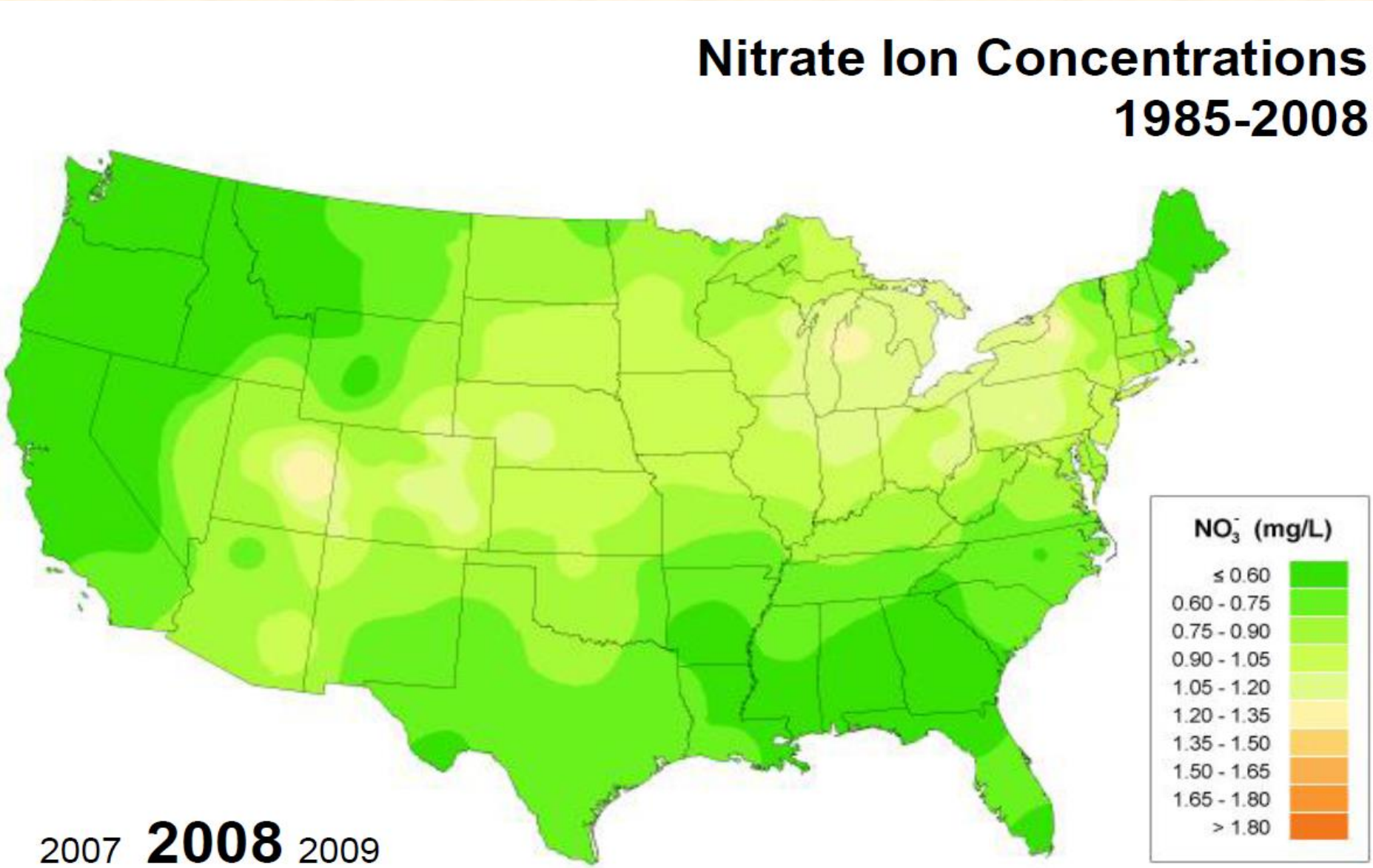

Source: National Atmospheric Deposition Program (NADP)

# Progress Storyline: air nitrogen deposition declining



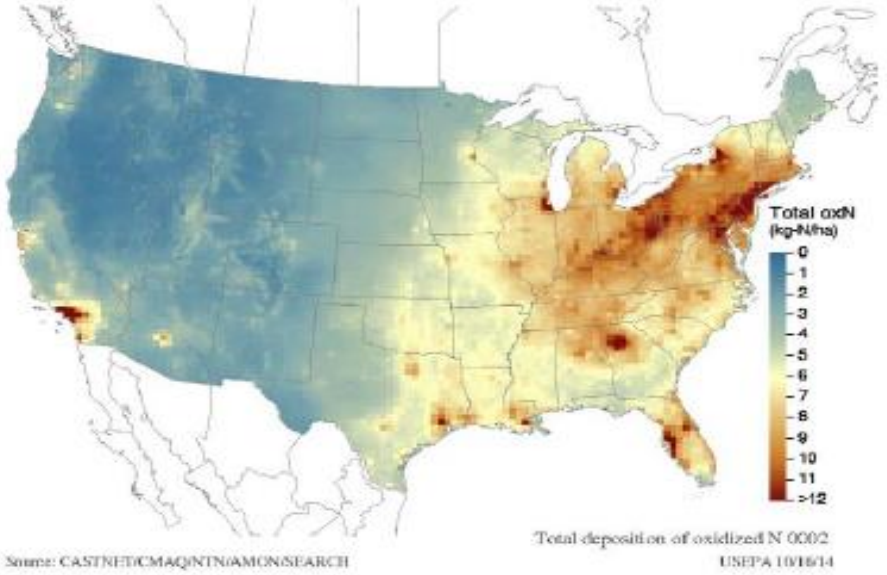

Source: National Atmospheric Deposition Program (NADP)

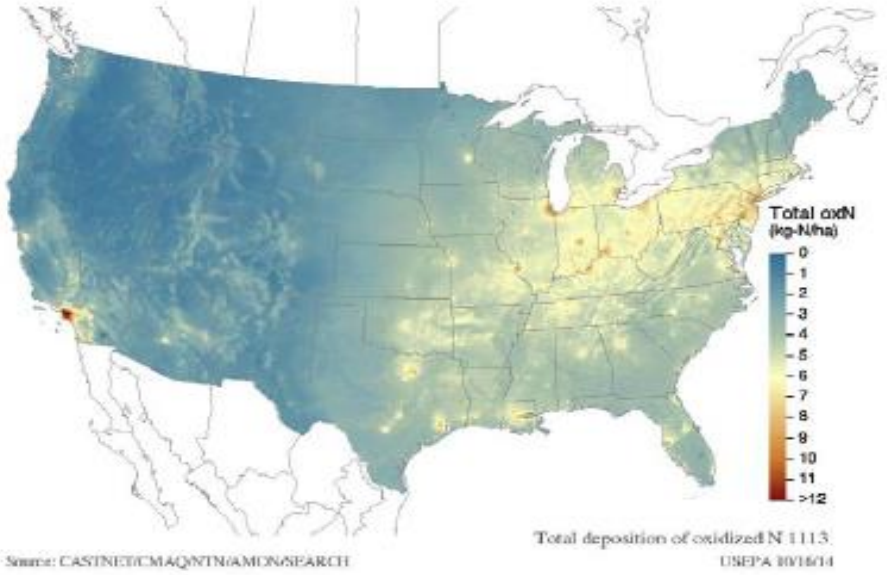
# Progress Storyline: air nitrogen deposition declining




Source: National Atmospheric Deposition Program (NADP)

**Source: Integrated Science Assessment for Oxides of Nitrogen, Oxides of Sulfur, and Particulate Matter—Ecological Criteria (First External Review Draft) EPA/600/R-16/372 February 2017 www.epa.gov/ncea/isa**




oxN = oxidized nitrogen.
Source: CASTNET/CMAQ/NTN/AMON/SEARCH.

**Figure A-5** **Wet plus dry deposition of oxidized nitrogen over 3-year periods. Top: 2000–2002; Bottom: 2011–2013.**

# Progress Storyline: better than expected responses

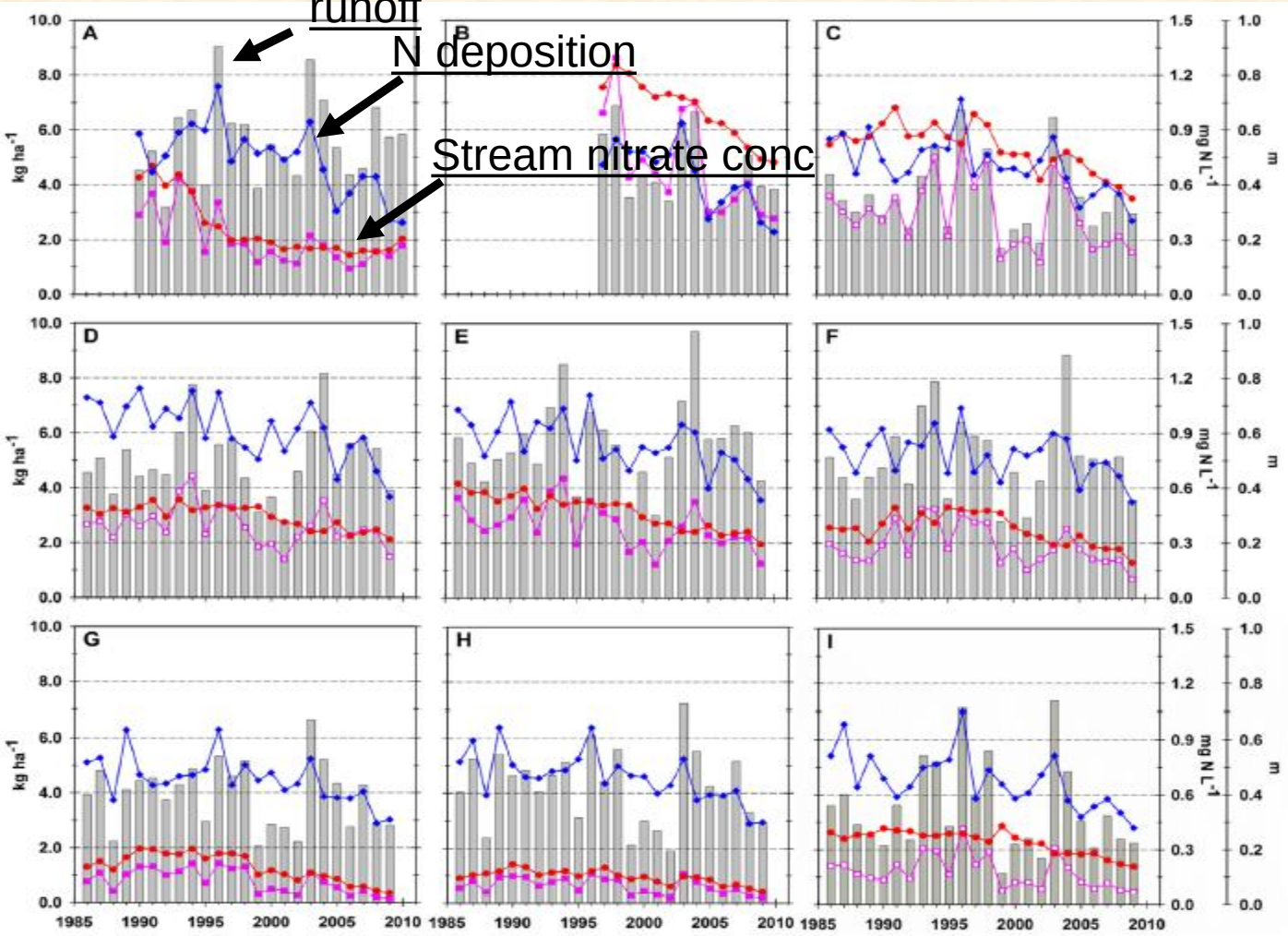
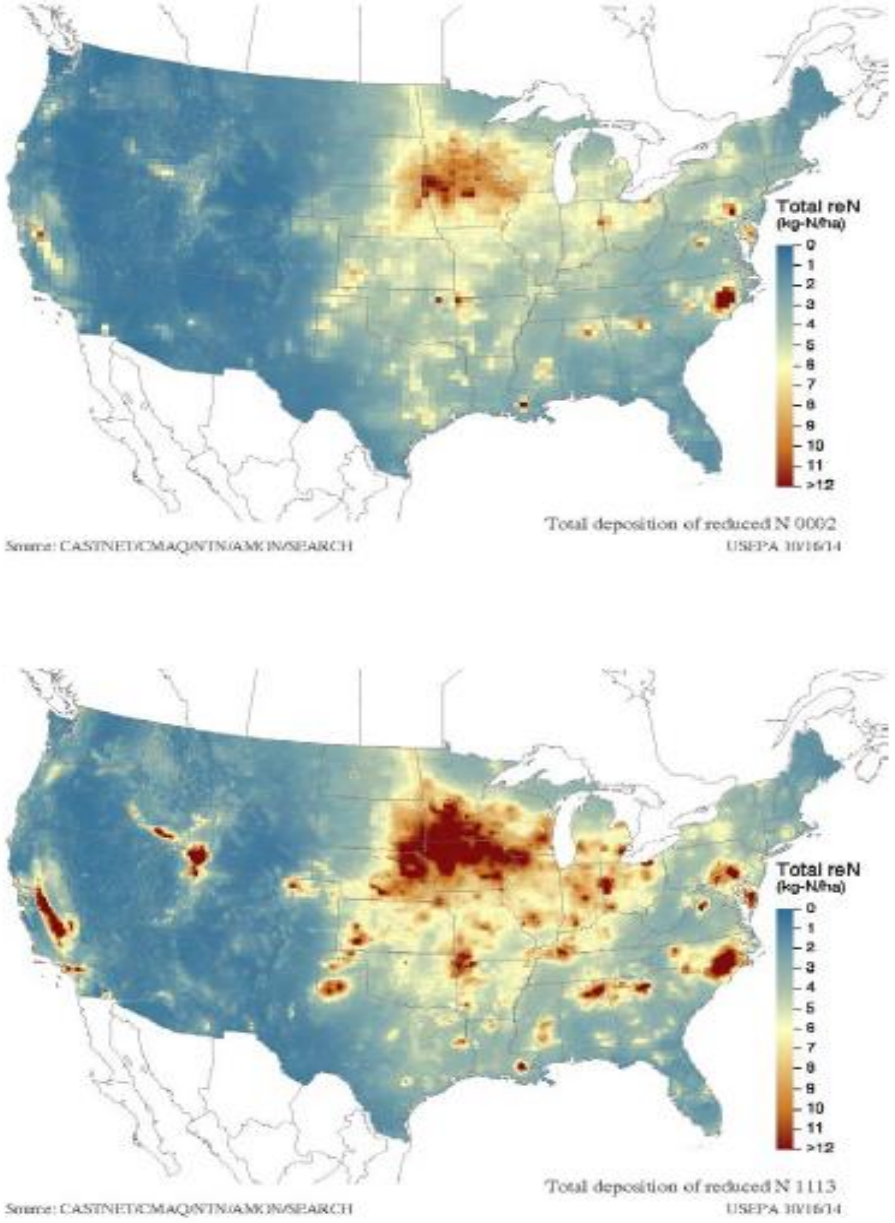



**Figure 2.** Temporal patterns (1986–2009) in annual (1) nitrate-N yields (kg ha$^{-1}$, pink lines/squares), (2) areal N deposition (kg ha$^{-1}$, blue lines/diamonds), (3) nitrate-N concentrations (mg N L$^{-1}$, red lines/circles), and (4) runoff (m, gray bars) for the nine study; letters correspond to watersheds identified in Figure 1. Time series illustrated with solid symbols produced statistically significant linear trends (see details in Table S2, Supporting Information).

Source: Eshleman et al. 2013. Surface Water Quality is Improving due to Declining Atmospheric N Deposition. *Environmental Science and Technology 47:12193-12200.*

**Source: Integrated Science Assessment for Oxides of Nitrogen, Oxides of Sulfur, and Particulate Matter—Ecological Criteria (First External Review Draft) EPA/600/R-16/372 February 2017 www.epa.gov/ncea/isa**




reN = reduced nitrogen.
Source: CASTNET/CMAQ/NTN/AMON/SEARCH.

**Figure A-14** Wet plus dry deposition of reduced (inorganic) nitrogen over 3-year periods. Top: 2000–2002; Bottom: 2011–2013.

# Overview:

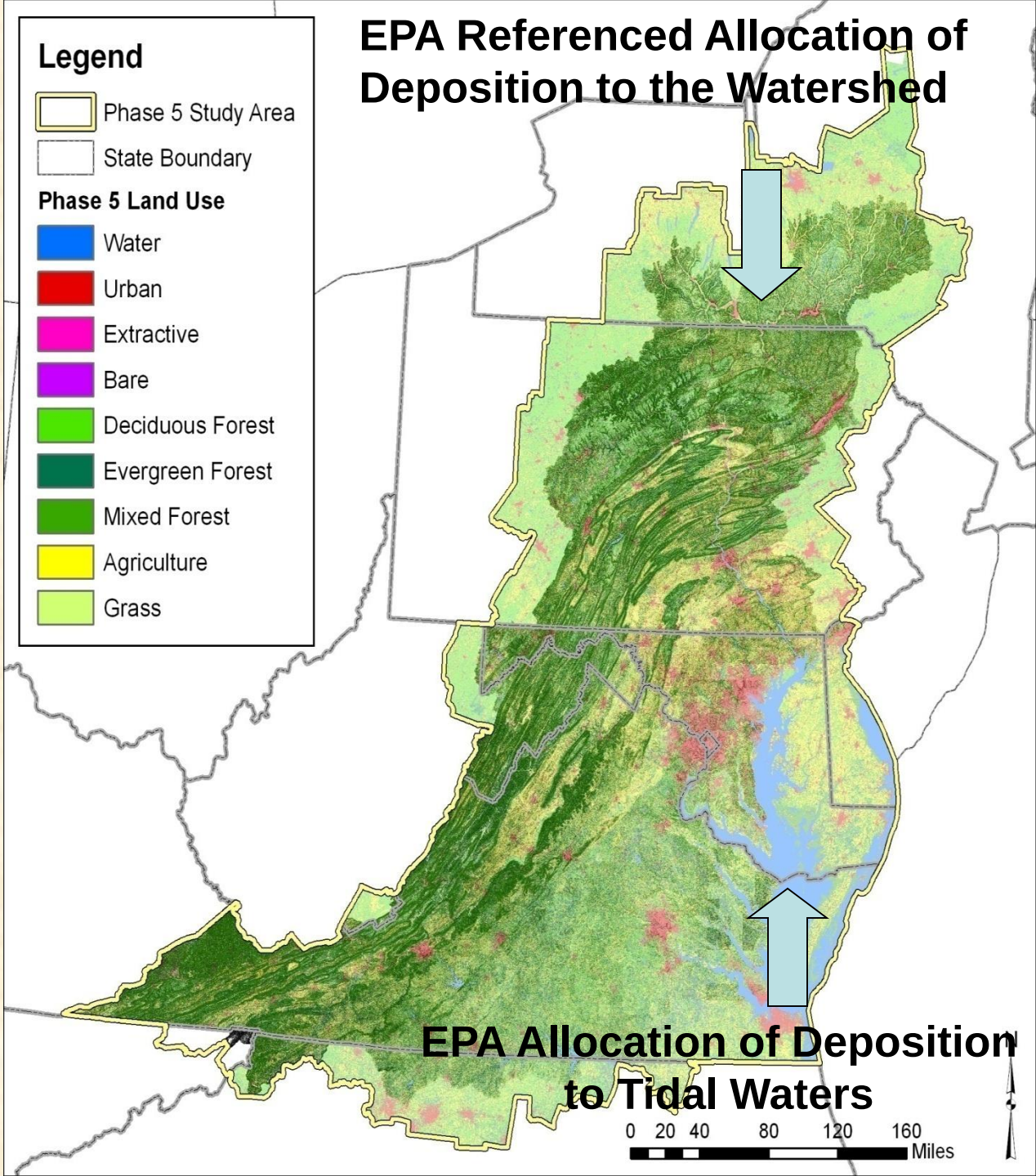
• For the Chesapeake Bay Restoration the EPA has developed a specific Chesapeake TMDL air load allocation **of 15.7 million pounds** for the tidal waters of the Chesapeake Bay (and also to account for air deposition of nitrogen in the load allocations to the watershed).

• The TMDL air allocation reflects the modeled nitrogen deposition to the Bay, taking into account the reduction in air emissions expected from sources regulated under existing or planned federal Clean Air Act (CAA)-authorized programs.

• By including air deposition in the TMDL load allocations, the TMDL accounts for the emission reductions achieved by Bay states as well as those achieved by other states within and beyond the airshed.

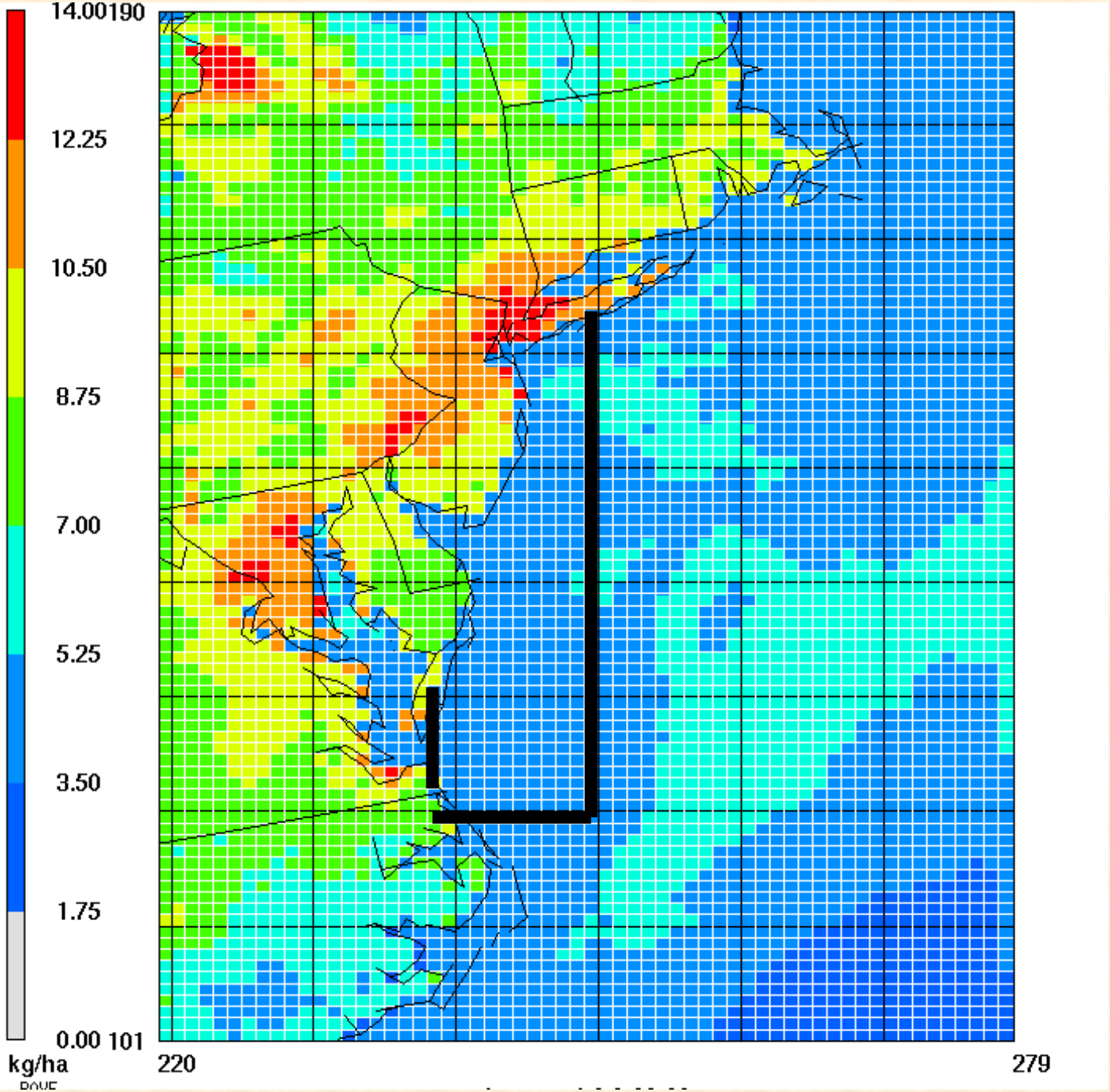
• This is the first time EPA has included air loads in a TMDL based watershed restoration.

The EPA air allocation are the load reductions up to and including the 2020 Air Allocation Scenario. The EPA Air Allocation is 15.7 million pounds to the tidal waters of the Chesapeake Bay. The 2020 Air Allocation loads are already factored into the State WIPs through the "referenced allocation" in the watershed.

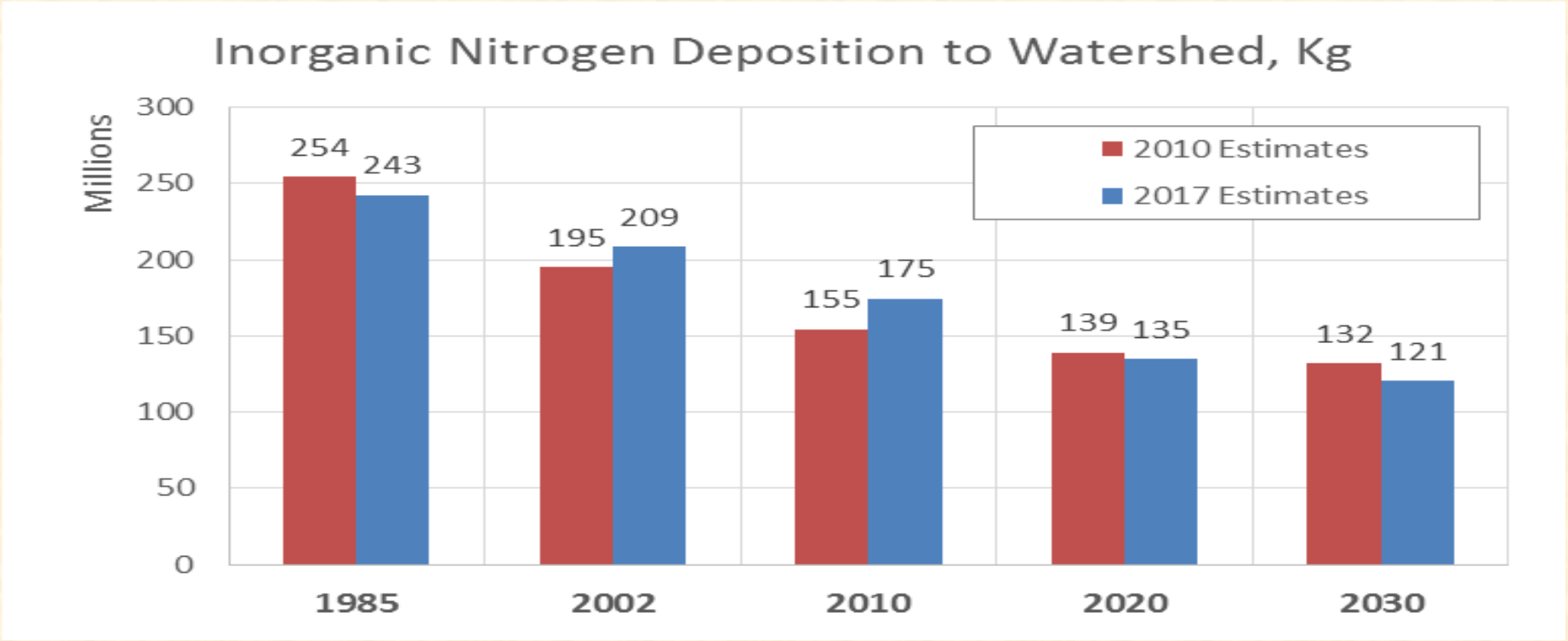


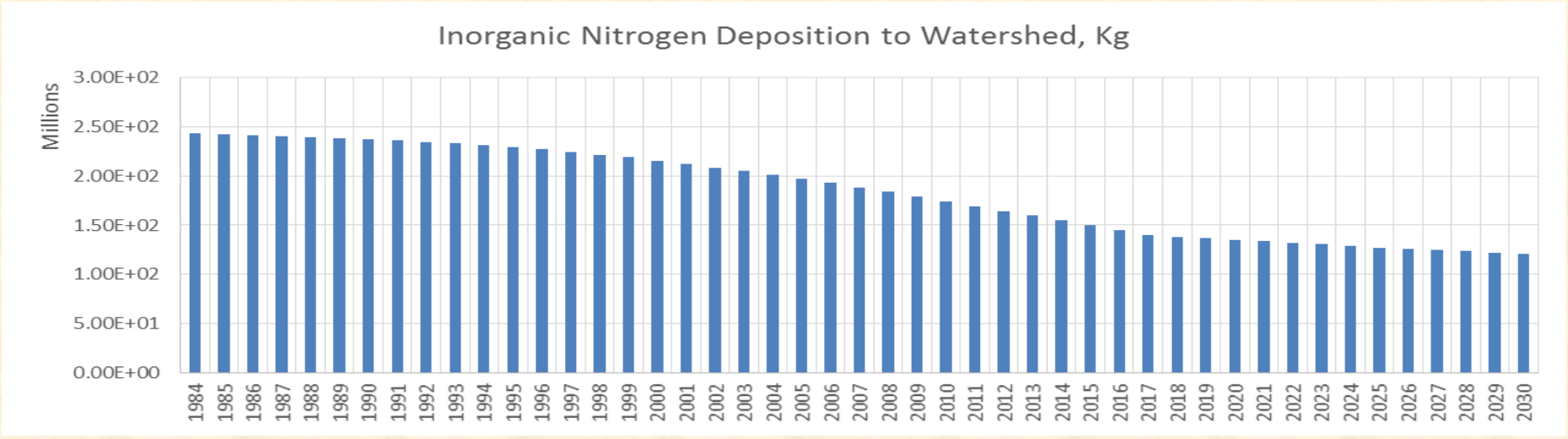
**Boundaries of the coastal ocean region used to adjust the ocean boundary conditions in the WQSTM.**

Emission reductions resulting in reduced loads to the coastal ocean are also estimated as an adjustment to the ocean boundary loads in the CBP models.

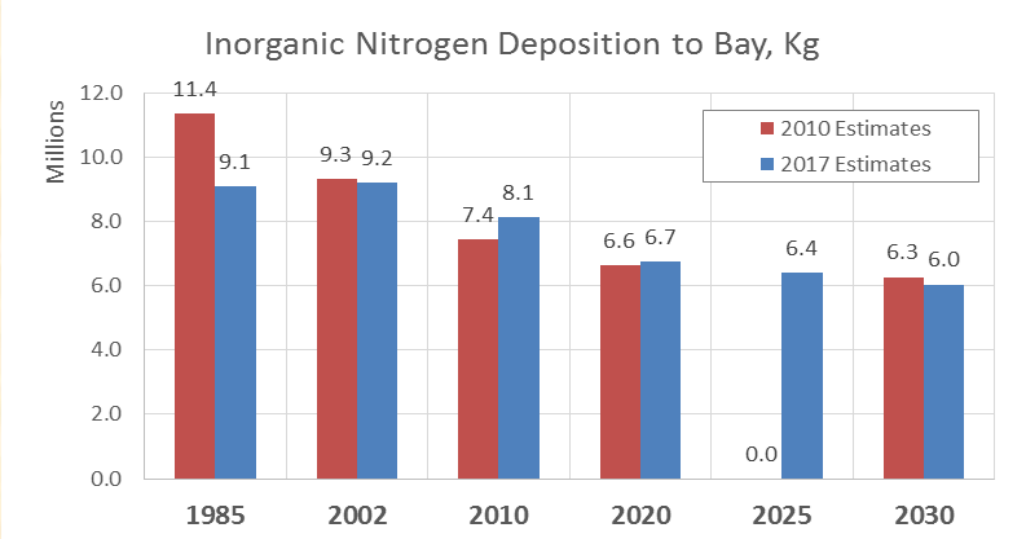


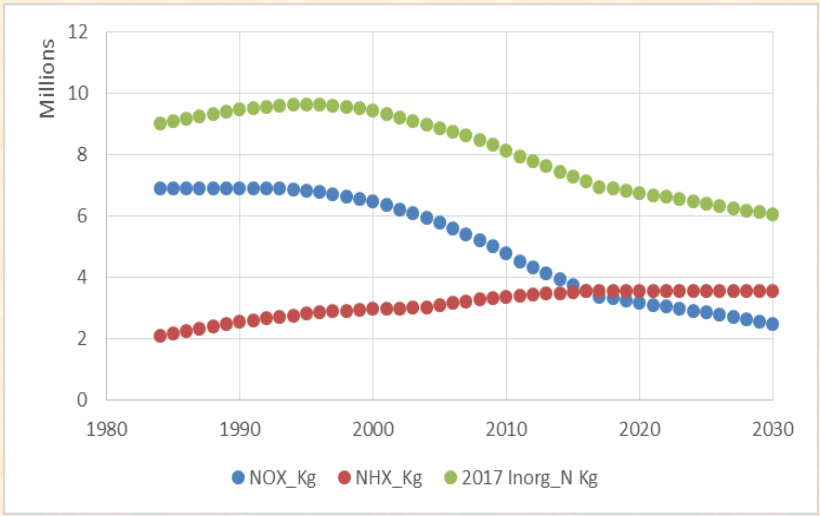
# Watershed Loads of Atmospheric Deposition of Nitrogen



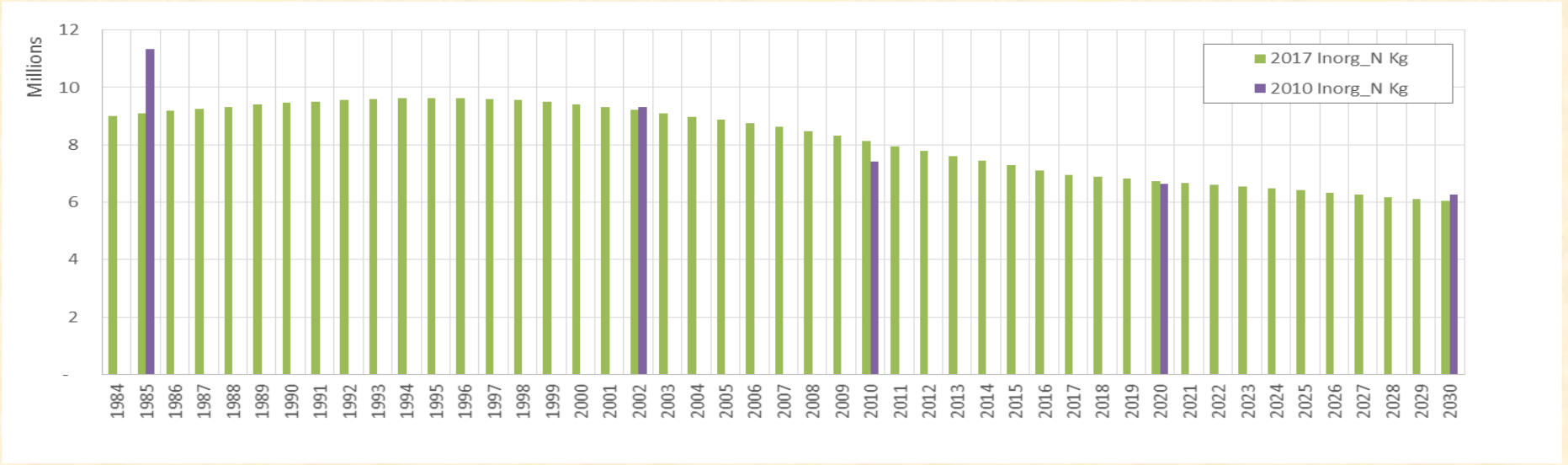



# Tidal Bay Loads of Atmospheric Deposition of Nitrogen




**The EPA Air Allocation is 15.7 million pounds (TN) to the tidal waters of the Chesapeake Bay. The Phase 6 estimate of TN deposition to tidal waters is 15.6 million pounds in 2025 and 14.8 million pounds in 2030.**



# CMAQ Scenarios of 2002, 2011, 2018, 2025, and 2050

- **New rules in Place or About to be in Play Along with Other Elements That Influence Atmospheric Deposition of Nitrogen in the Chesapeake Watershed**
- **2015 ozone standard of 70** ppb announced October 1, 2015 (2010 TMDL was an 80 ppb ozone standard – an estimated additional reduction of 1.8 million pounds TN to tidal waters of the Chesapeake)
  http://www3.epa.gov/ozonepollution/actions.html
- **Clean Power Plan** – announced August 3, 2015
  http://www2.epa.gov/cleanpowerplan/regulatory-actions
- **Mercury and Air Toxics Standards** (MATS)
  http://www3.epa.gov/mats/
- **Tier 3 Vehicle Emission and Fuel Standards Program** – To be implemented in 2017
  http://www3.epa.gov/otaq/tier3.htm

# CMAQ Scenarios of 2002, 2011, 2018, 2025, and 2050

- **CAFE Rule** http://www3.epa.gov/otaq/climate/regs-light-duty.htm

- **RICE and related Stationary Internal Combustion Engine Rules** http://www3.epa.gov/ttn/atw/icengines/

- **Cross-State Air Pollution Rule (CSAPR)** http://www3.epa.gov/crossstaterule/

- **Cement Rule** http://www3.epa.gov/airquality/cement/basic.html

- **Rules on Nonroad Engines, Equipment, and Vehicles** of all types http://www3.epa.gov/nonroad/

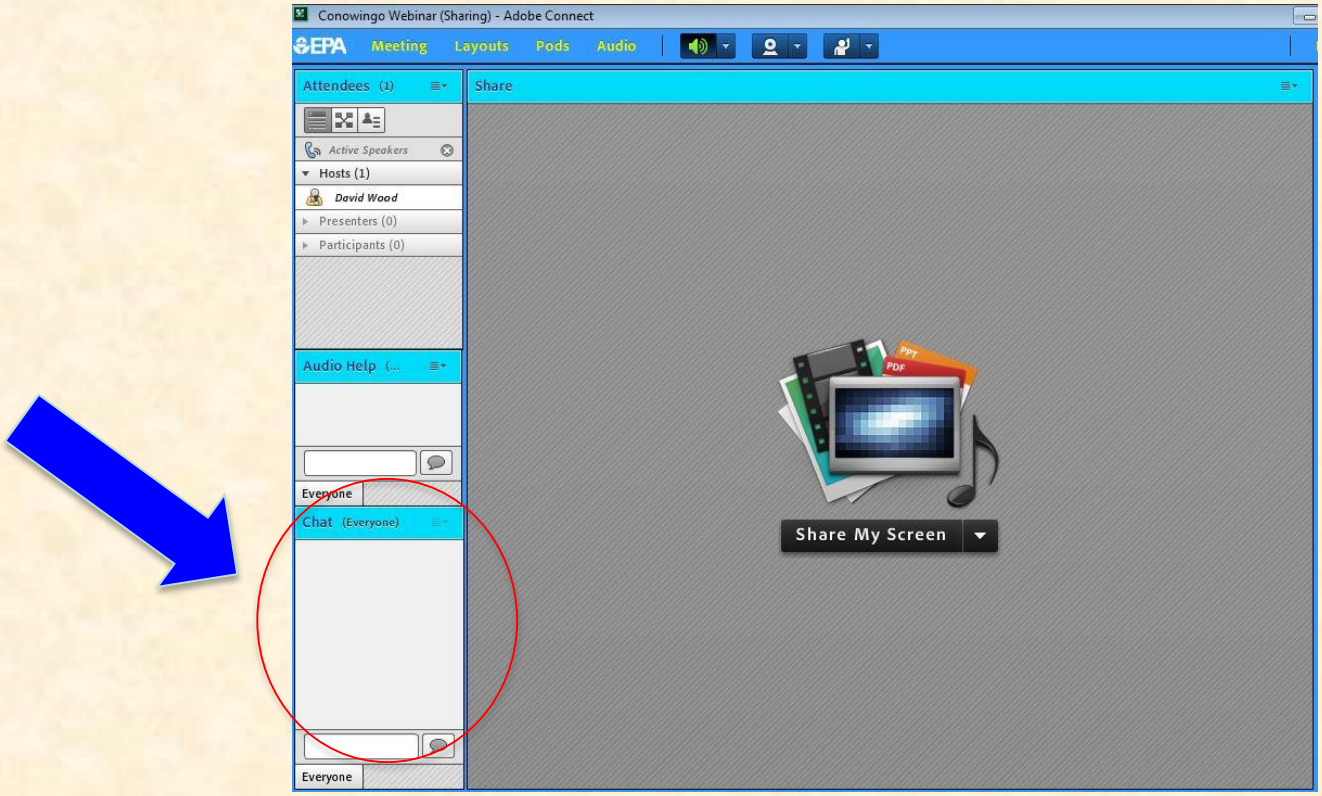
# CMAQ Scenarios of 2002, 2011, 2018, 2025, and 2050

- **Large Marine Diesel Rule - Category 3 (C3) have Tier 3 standards that begin in 2016.**
http://www3.epa.gov/otaq/oceanvessels.htm

- **Consent decrees and industrial facilities closures**

# Reminder:

- To Ask a Question
  - Submit your question in the chat box, located in the bottom left of the screen.



# Current and Estimated Future Atmospheric Nitrogen Loads to the Chesapeake

**Jesse Bash**

U.S. EPA National Exposure Research Laboratory, Research Triangle Park, NC

# Climate and the Bay

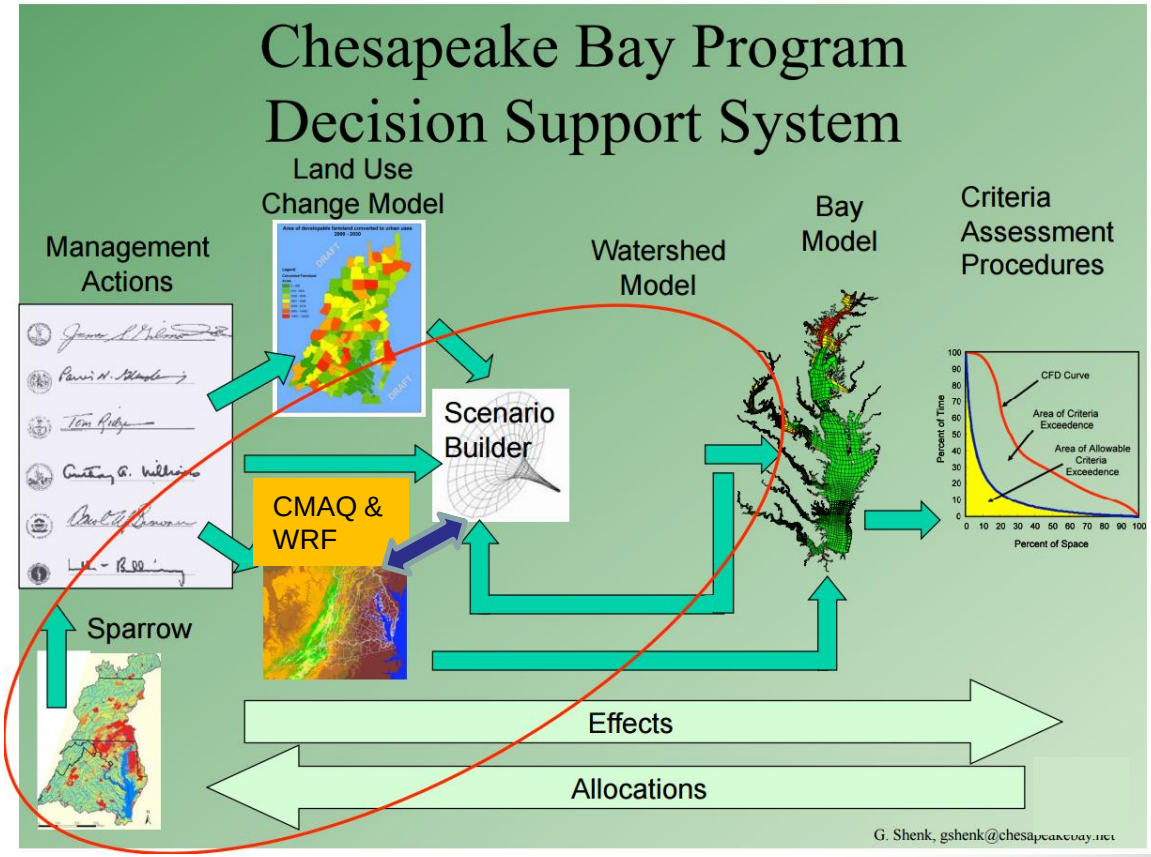
"Changes in climate systems are expected to alter key variables and processes within the Watershed and should be examined in concurrence with land use changes that will interact with and potentially exacerbate climate impacts."

*Scientific and Technical Advisory Committee (STAC)*

Key scientific question: How do changes in climate, land use, and emissions impact regional meteorological drivers and nutrient deposition loading important to the Chesapeake Bay's water quality and ecosystem health?

# Linked Ecosystem Modeling System

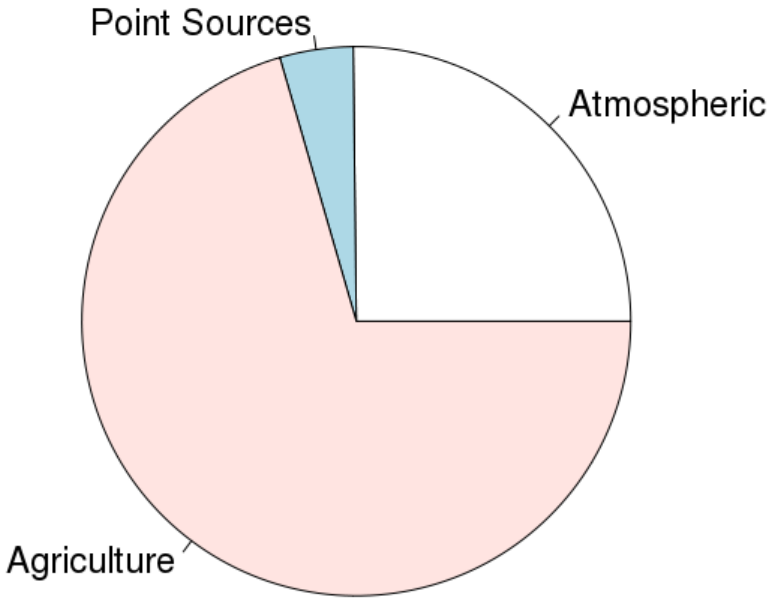
- The Chesapeake Bay modeling system connects management decisions with land use, air quality, water quality and ecosystem services/health
- NERL's Community Multiscale Air Quality (CMAQ) model is an integral part of this system
- This linked modeling system is used to assess the water quality and ecosystem health of the Chesapeake Bay
- CMAQ and the Weather Research and Forecasting (WRF) models were modified to have more consistent physical parameterizations



# Nitrogen Loading

- Atmospheric nitrogen loading is the second largest source of nitrogen in the watershed
  - Point and Agriculture loading presented here are direct loading to the watershed
- Modeling results indicate that a 23% reduction in atmospheric nitrogen loading has been achieved through air quality regulations from 2002 to 2012
- The composition of atmospheric reactive nitrogen deposition is shifting from oxidized (fossil fuel combustion) to reduced (largely agricultural)
  - Controls of emissions differ:
    - Fossil fuel combustion emissions are regulated under Clean Air Act
    - Agricultural best management practices are largely voluntary
  - Ecosystem impacts differ

**Nitrogen Loading to the Chesapeake Bay Watershed**




Data from: Linker *et al.* 2013 JAWRA

# Modeling the N Cycle in CMAQ

- **Bidirectional exchange**
  - Coupled Agro-ecosystem model to the chemical transport model
    - Environmental Policy Integrated Climate (EPIC) model
  - Couples agricultural cropping management and soil geochemical processes with CMAQ
  - Dynamic $NH_3$ emissions from fertilizer application
    - Dependent on fertilizer composition, meteorology, soil conditions, crop, application method, etc.
- **Temporal Animal Feeding Operations (AFO) $NH_3$ emissions:**
  - Applies physical constraints for hourly emissions estimates from annual totals submitted by the States
- **Oxidized N emissions are taken from the nearest available National Emissions Inventory (NEI) adjusted for the year-specific meteorology, vehicle miles traveled and continuous emissions monitoring data**

# Simulation Periods

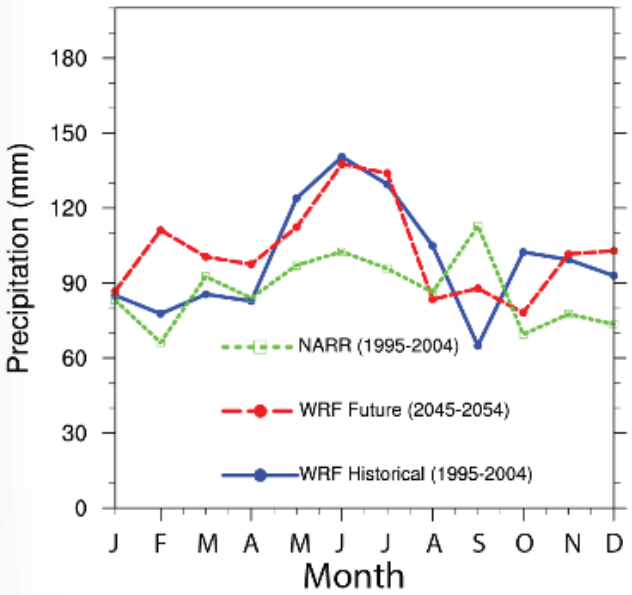
- **Retrospective (2002-2012)**
  - **Utilizes projections from the nearest national emissions inventory with continuous emissions monitoring data for all other pollutants**
- **Near Term Projections (2017-2028)**
  - **Projected emissions including emission reductions**
  - **Meteorology held constant at 2011 values**
- **Long Term Projections (2045-2054)**
  - **Driven by Community Earth System Model (CESM) historical (1995-2004) and future (2045-2054) simulations under the global RCP 4.5 emissions scenario.**
  - **Regional simulations use the 2011 NEI emissions for the historical period**
  - **Projected regional emissions including emission reductions and projected economic growth consistent with RCP 4.5 scenario**
  - **Dynamically downscaled meteorology using the regional Weather Research Forecasting (WRF) Model**
    - **Takes large scale meteorological forcing from CESM and utilizes physics and land use information from a regional scale meteorological model**
    - **Hourly estimates of temperature, precipitation, radiation, wind speed, surface fluxes, etc.**

# Modifications for Long Term Projections

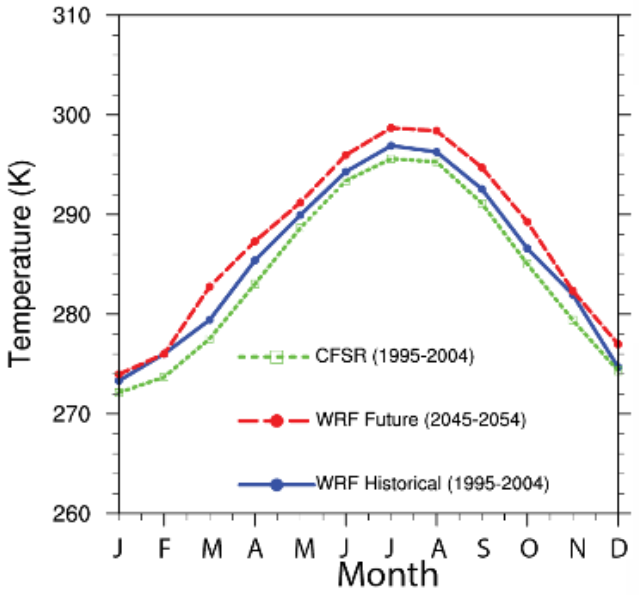
- WRF used for dynamic downscaling of climate simulations requires modifications to be more consistent with the input data expected by the CMAQ model
- Vegetation properties updated in WRF based on satellite data:
  - Updating model properties rather that using satellite data allows the model to incorporate land use changes
- Soil hydraulic properties updated using observations
- WRF-Noah modified to output variables needed by CMAQ for atmospheric chemistry simulations
- More details found in our 2017 WRF User's Workshop presentation: (http://www2.mmm.ucar.edu/wrf/users/workshops/WS2017/oral_presentations/5.2.pdf); also in upcoming manuscript: *Campbell et al.* (2017).

# Climate Reanalysis Evaluation

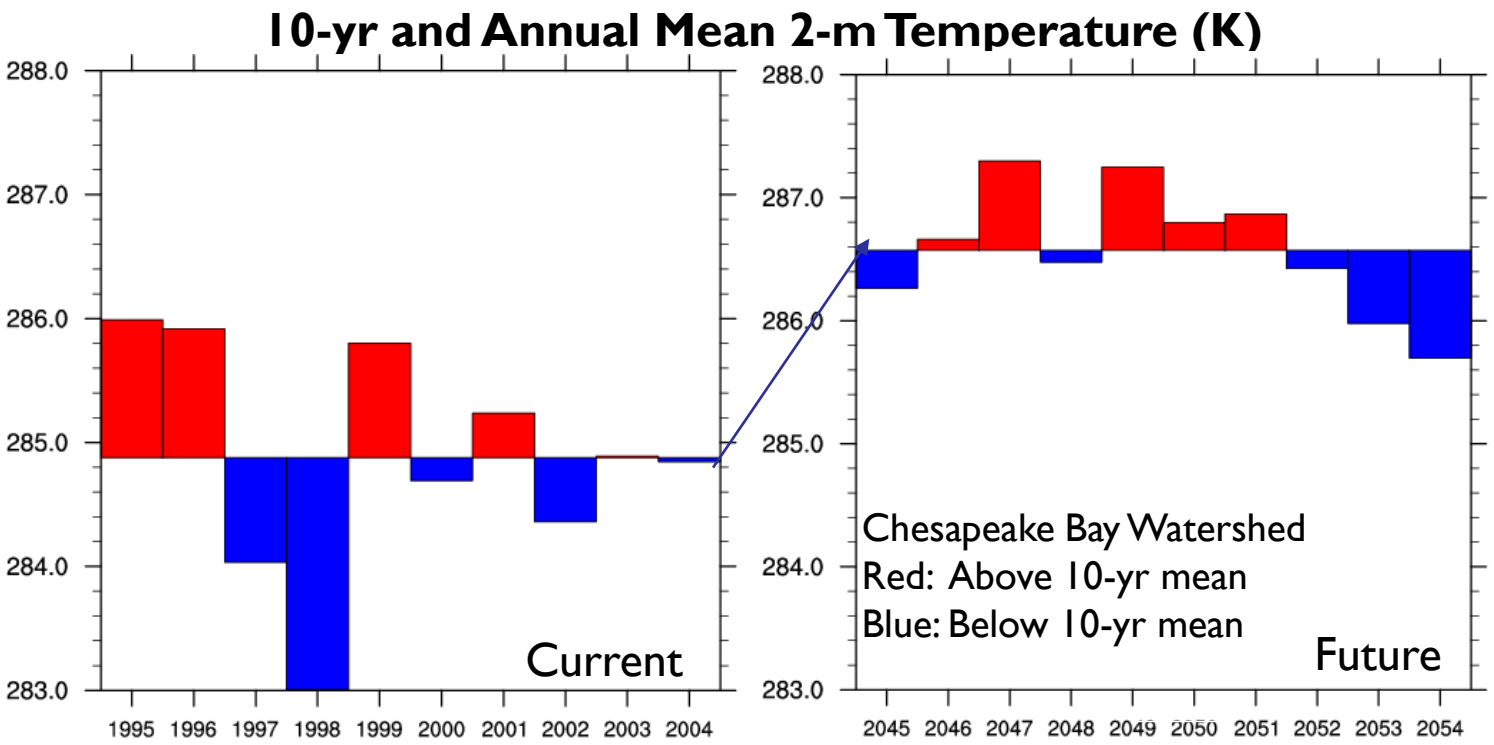
## 10-year Mean Monthly Precipitation




## 10-year Mean Monthly Temperature

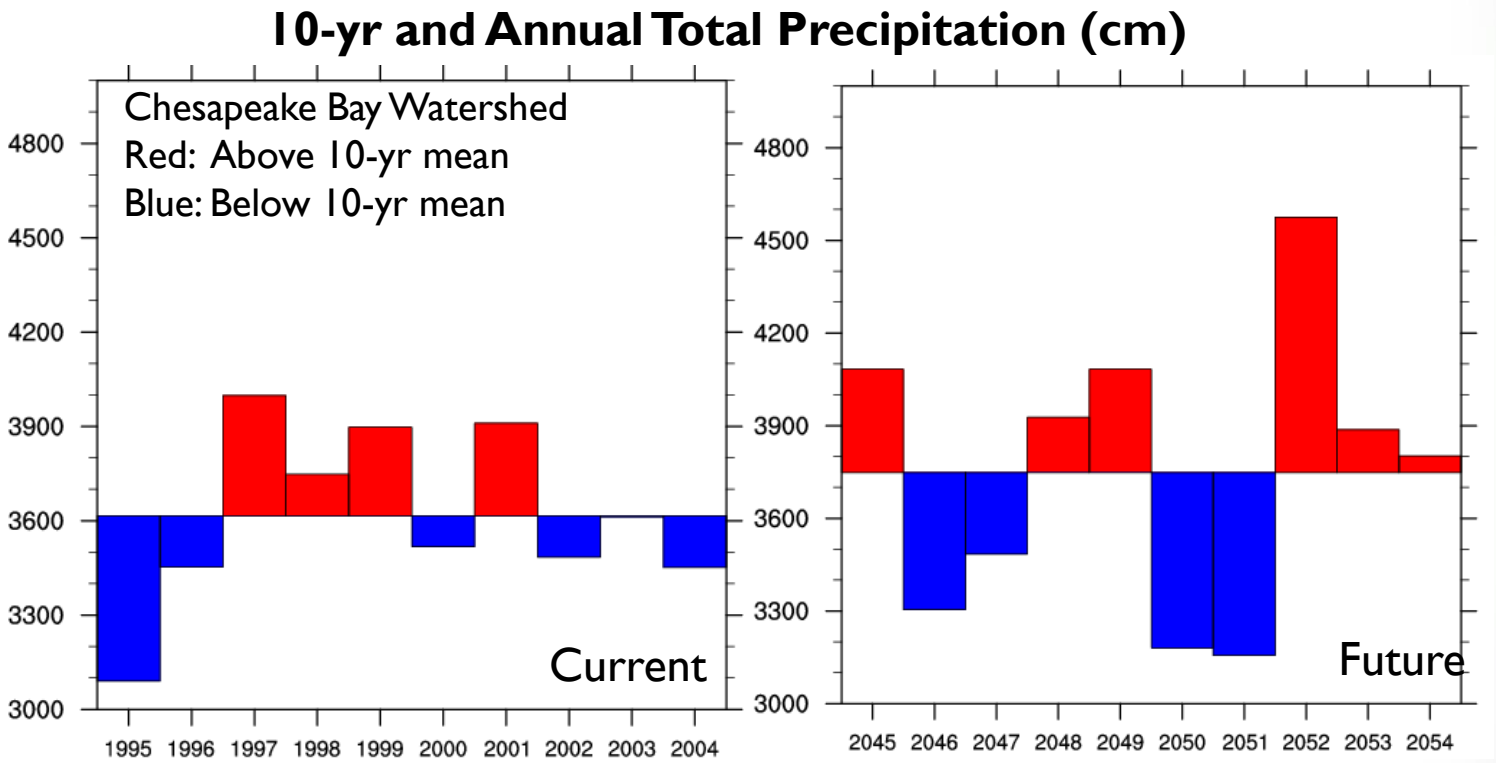


# Climate Changes (2 Meter Temperature)




**Mean: 1.7 K increase**

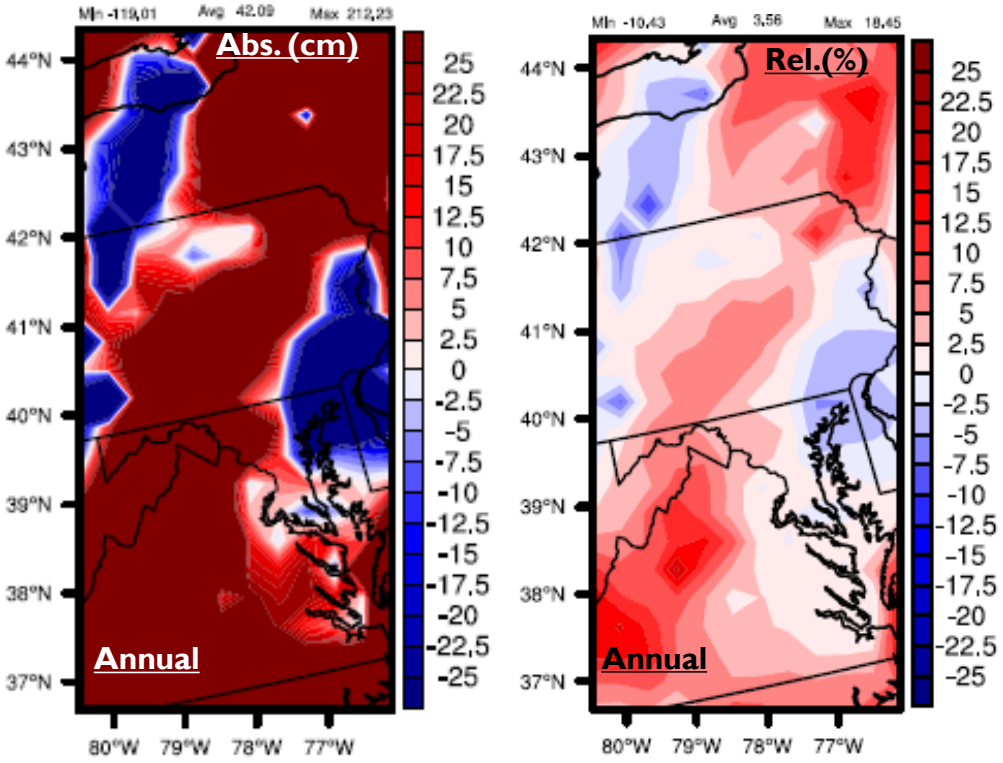
# Climate Change (Precipitation)



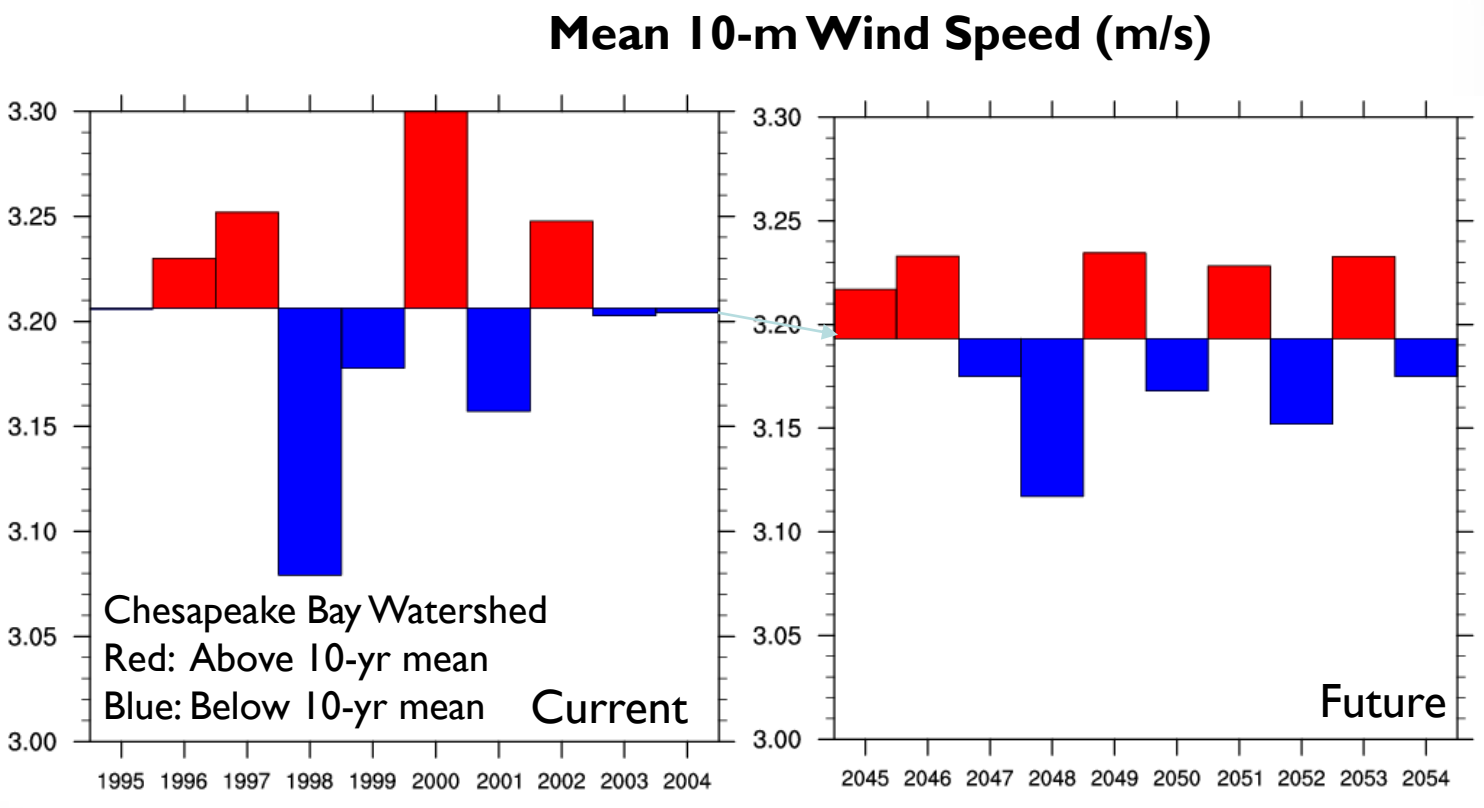

**Mean: +42.1 cm (+3.6%)**

# Climate Changes (Precipitation)

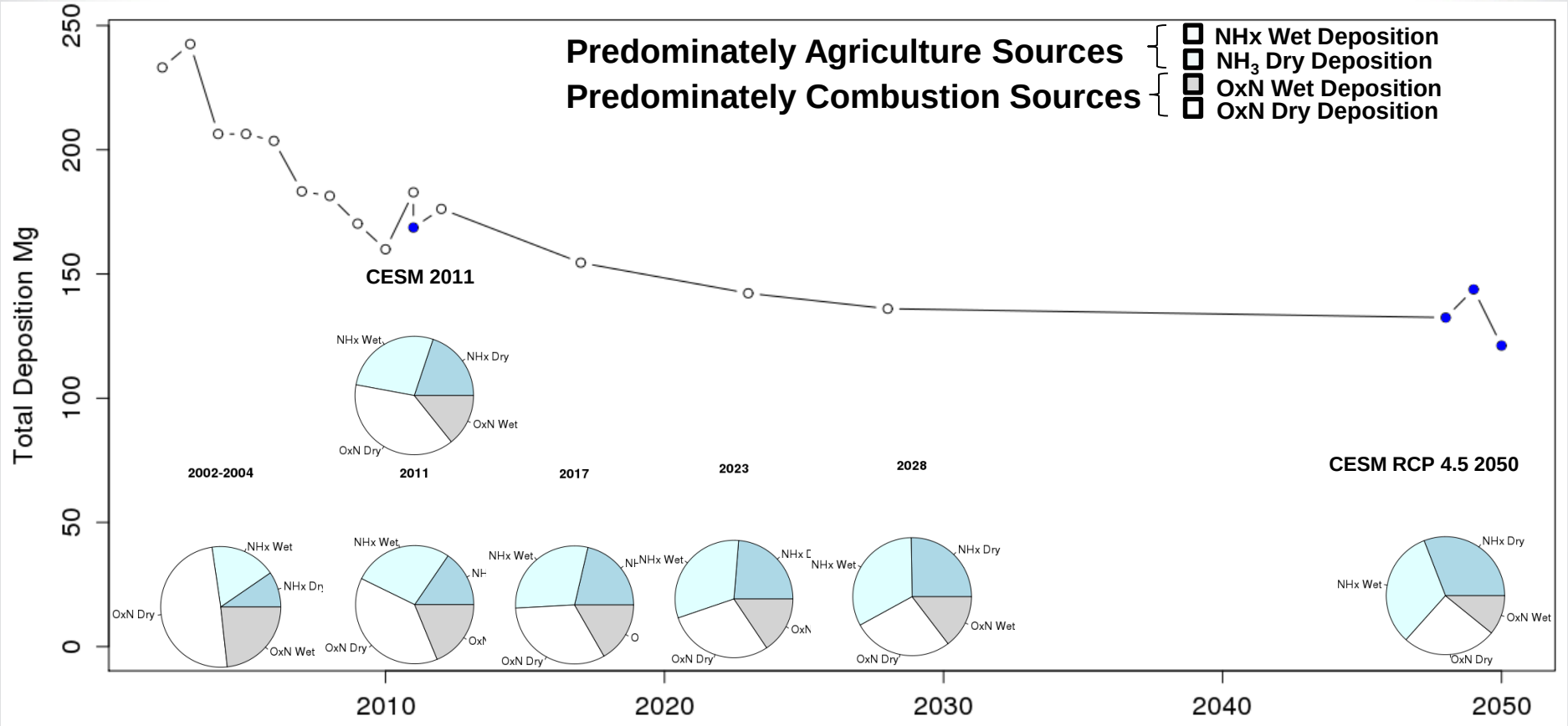
## 10-yr Annual Total Precipitation



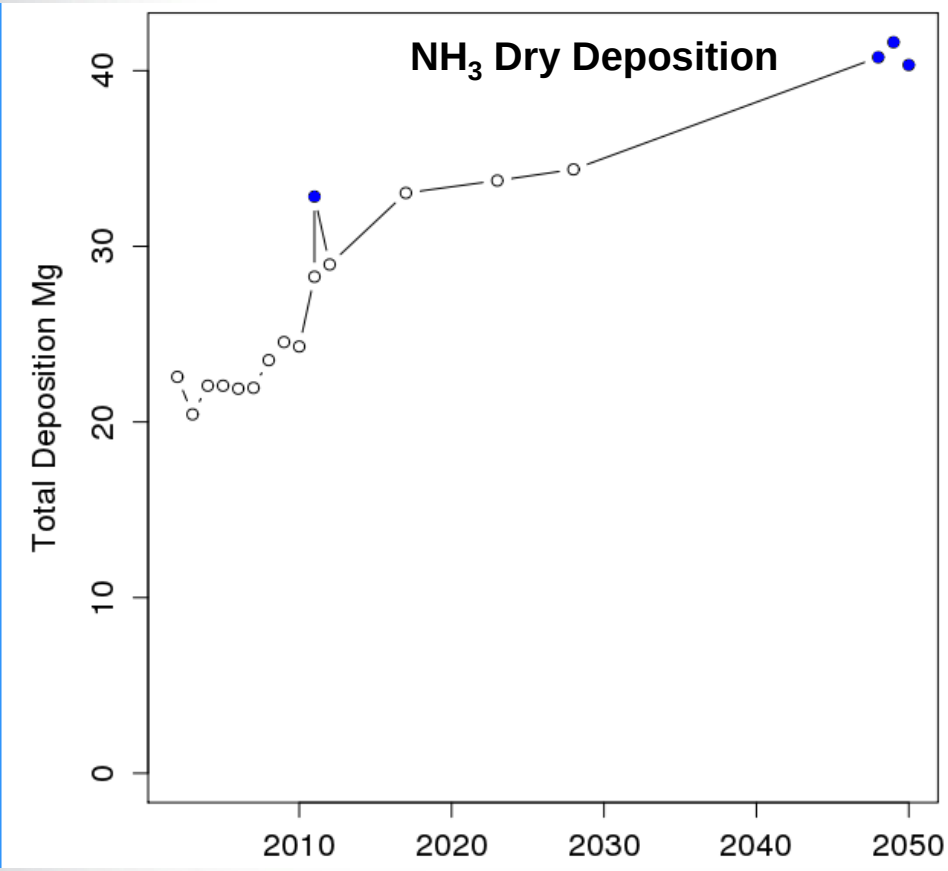
# Climate Changes (Wind Speed)



# Total N Deposition



# $NH_3$ Dry Deposition




| Year | Total N Deposition | NH3 Dry Deposition |
|---|---|---|
| 2002-2004 | 0% | 0% |
| 2017 | -32% | 80% |
| 2028 | -40% | 92% |
| 2048-2050 | -42% | 122% |

- Significant decrease in total N deposition
  - Largely due to NOx reductions
- Increase in $NH_3$ deposition
  - Aerosol chemistry and NOx/SOx reductions
  - Relatively constant $NH_3$ emissions
  - Differences in deposition in $NH_3$ and $NH_4^+$ deposition

# Summary

- WRF-CMAQ in a climate configuration Performs well against historical meteorology and deposition observations
  - Summer precipitation biases exist in historical simulations
- The climate influence on atmospheric nitrogen deposition is much smaller than the reduction due to emissions reductions
- Atmospheric nitrogen deposition to the Chesapeake Bay is forecast to decrease with emission reductions
  - Reduced nitrogen species (largely agricultural sources) in deposition are increasing
  - Oxidized nitrogen species (largely combustion sources) in deposition are decreasing
- Increases in temperature, precipitation and wind speed will likely alter the nitrogen cycling in the Bay

# Conclusions:

- Model integration makes a more complete analysis of issues:

  Improving environmental management and understanding by taking into account cross-media fate and transport among different media.

  More complete economic analysis of benefits and costs.

  Improved understanding of all impacts of actions and policies.

- The 2017 Midpoint Assessment is supported by state-of-the-science scenarios of atmospheric deposition for 2017, 2025, 2030, and 2050.

# Conclusions:

- Atmospheric nitrogen deposition is the highest input of nitrogen loads to the Chesapeake, nevertheless nitrogen load reductions from the sector are higher than all others.
- The Phase 6 estimate of TN deposition to tidal waters is 15.6 million pounds in 2025 and 14.8 million pounds in 2030. The EPA Air Allocation is 15.7 million pounds (TN).
- Expanded capacities of CMAQ have considerably improved estimates of ammonia deposition.
- Long term projections of CMAQ estimate that increases in temperature, precipitation, and wind speed will likely alter the nitrogen cycling in the Bay

# Questions and Answers Session

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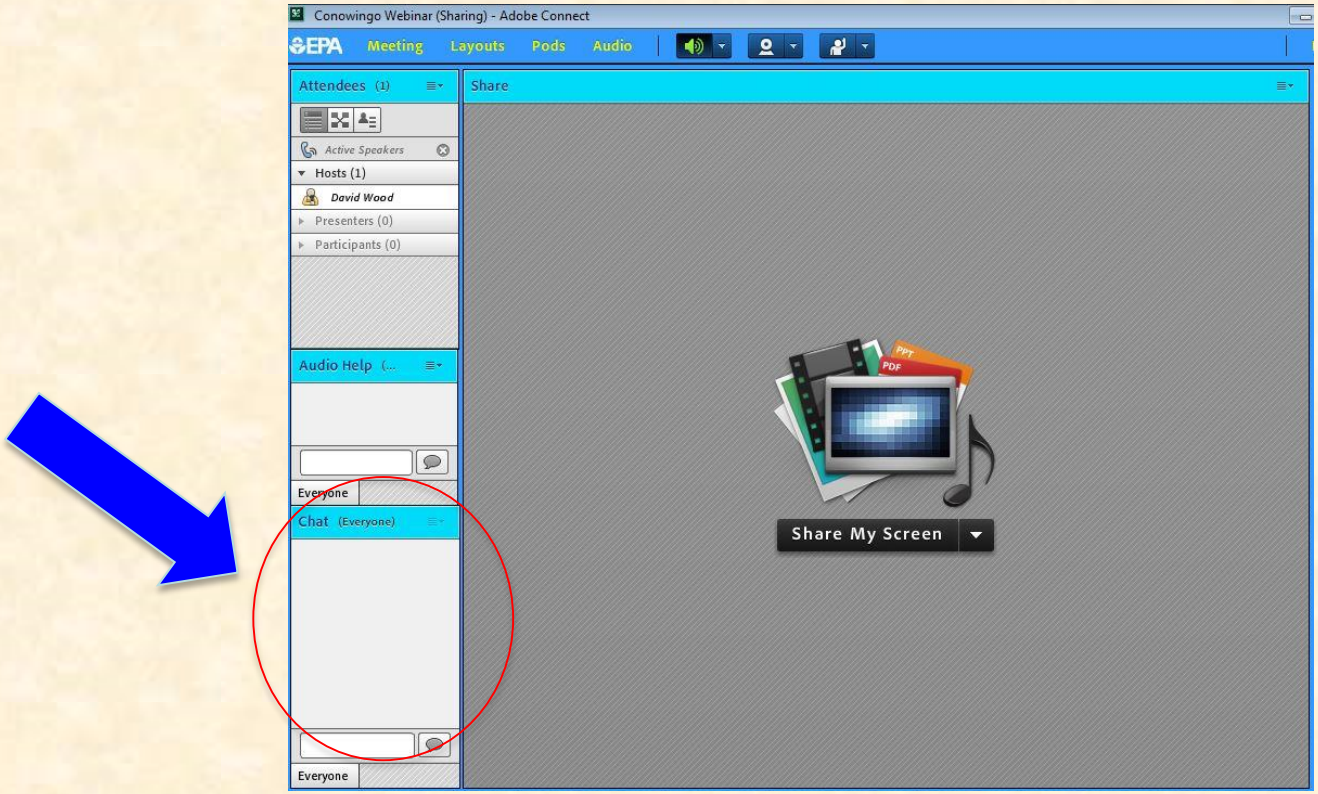

# Access to Atmospheric Deposition of Nitrogen in the Chesapeake Webinar Recording

A recording of this webinar along with the presentation will be posted to the following page on the Chesapeake Bay Program Partnership's website:

**Atmospheric Deposition of Nitrogen in the Chesapeake Infill Webinar Calendar Page:**
http://www.chesapeakebay.net/calendar/event/XXXXX

# Additional Resources:

This is an interactive visualization of air-water management in the Chesapeake Bay Program: http://gis.chesapeakebay.net/air/

And this is a video that can be looped: http://www.chesapeakebay.net/videos/clip/bay_101_air_pollution

Chesapeake Bay Program
*Science, Restoration, Partnership*