Current and estimated future atmospheric nitrogen loads to the Chesapeake Bay Watershed

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Outline

Background of historic and future simulations	• Data availability for future meteorology
Trends in CMAQ dry and wet deposition	• Retrospective Simulations 2002-2012 • Near term projections 2017-2028 • Future projections 2048-2050
Wet and dry deposition regression	• NHx and NOx deposition to the Bay and Watershed
Projected Changes in Meteorology	• Changes in projected 1995-2004 and 2045-2054 meteorological fields

Nitrogen Cycling in the Environment

- Nitrogen (N) is an essential nutrient for all life
- A single molecule of reactive N, created through natural or man-made processes, can cycle through various environmental systems—the atmosphere, terrestrial ecosystem, and aquatic ecosystems—where it can be transformed or temporarily stored
  - Reactive N
    - Naturally produced via enzymatic reactions, forest fires and lightning
    - Anthropogenically produced via fossil fuel combustion and synthesis of fertilizers
  - The anthropogenic contribution to this cycle is now larger than natural sources in the United States and globally
- Atmospheric reactive N is largely composed of Ammonia (NH_3) and Nitrogen Oxides (NO_x)
  - NH_3 is the most abundant atmospheric base and emissions remain largely uncontrolled, with only voluntary measures
- NH_3 is an ambient aerosols precursor and is a significant component (~50%) of reactive N deposition
  - Contributes to biodiversity loss, soil acidification, surface water eutrophication, and harmful algal blooms
  - Contributes to adverse respiratory and cardiac responses

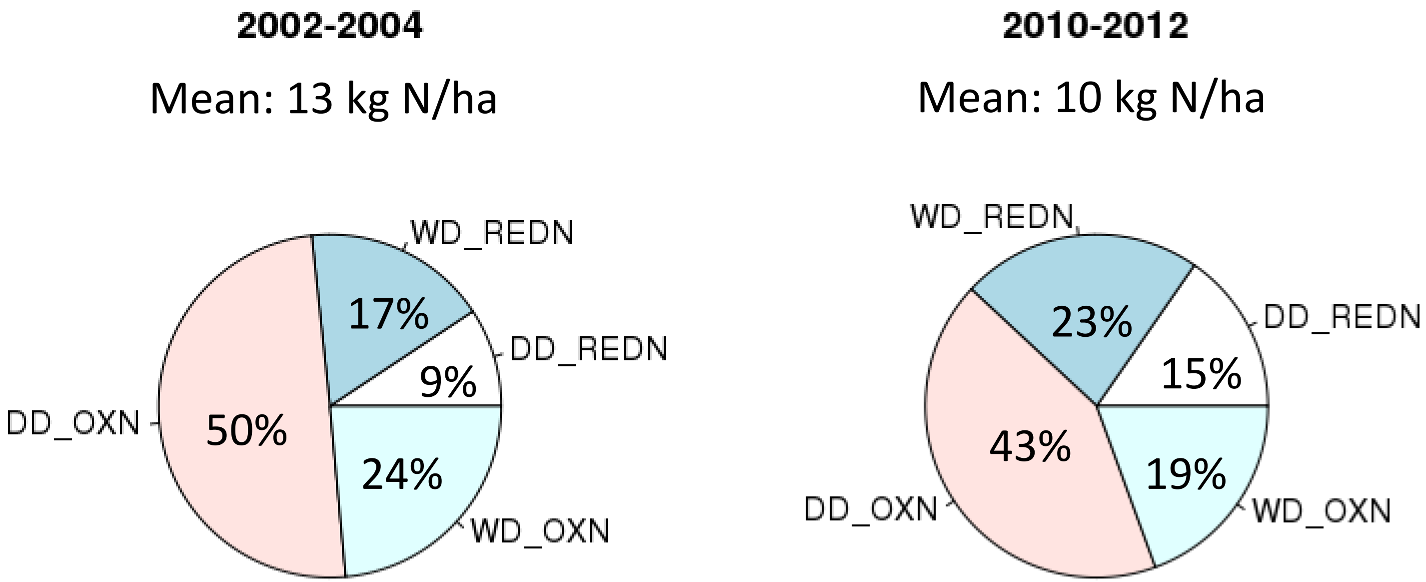
Modeling the N Cycle in CMAQ

- **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, weather, 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 NEI adjusted for the year-specific meteorology, vehicle miles traveled and continuous emissions monitoring data**

Simulation Periods

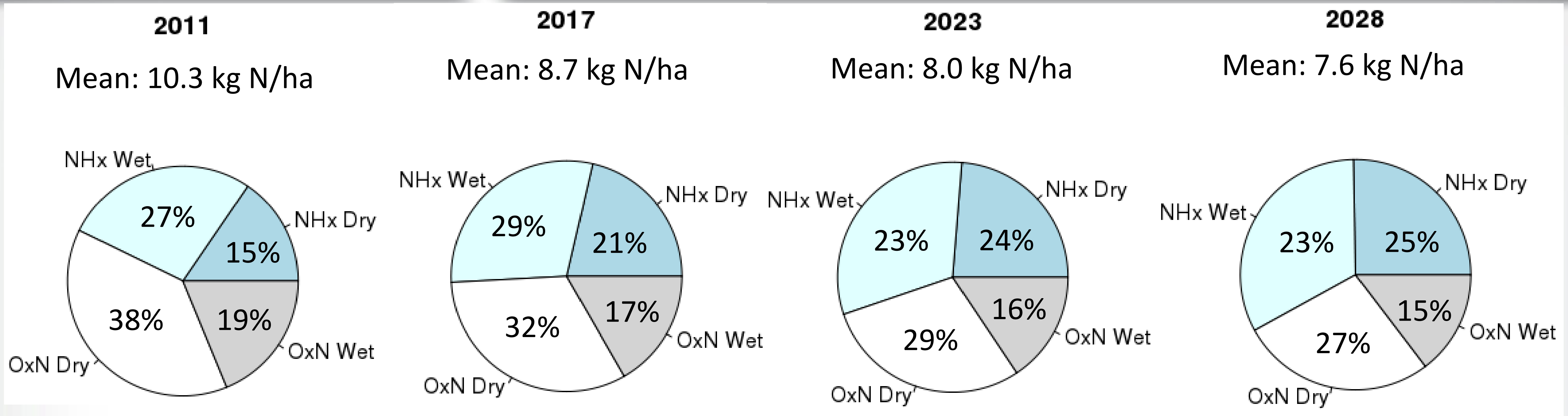
- **Retrospective (2002-2012)**
  - **Utilizes projections from the nearest national emissions inventory with continuous emissions monitoring data for all other pollutants**
- **Near Term Projections (2017-2028)**
  - **Projected emissions including emission reductions**
  - **Meteorology held constant 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 National Emission Inventory (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.**

Chesapeake Bay Watershed N Deposition Budget



- Overall N deposition has decreased due to NOx reductions
- Ratio of oxidized to reduced N deposition is changing
- Oxidized N deposition is decreasing
  - Controls on combustion sources
- Reduced N deposition is increasing
  - Increasing gas phase NH_3

Near Term Projections

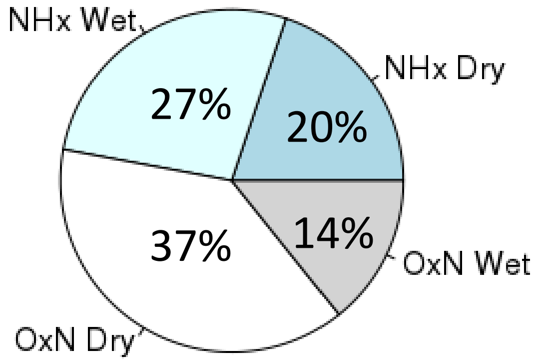


- Oxidized N deposition continues to decline in response to NOx-SOx reductions
- Reduced N wet deposition declines but not at the same rate as oxidized N deposition
- Reduced N dry deposition increases due to lower atmospheric particulate matter loading
  - Less NH_4^+ aerosols and more ambient NH_3
  - NH_3 dry deposits much faster than NH_4^+

RCP 4.5 Long Term Projections

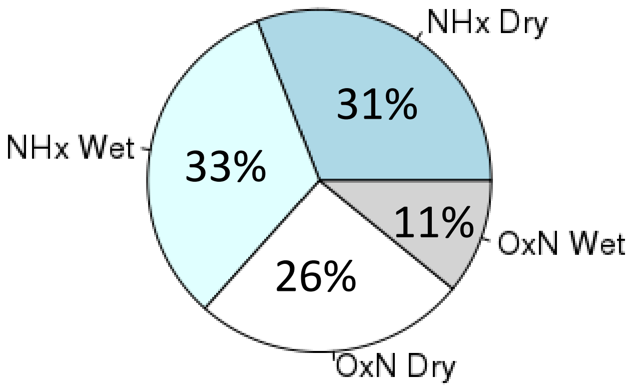
GCM 2011

Mean: 9.7 kg N/ha



GCM RCP 4.5 2050

Mean: 7.6 kg N/ha



- Overall N deposition projected to decrease due to further NOx reductions
- Ratio of oxidized to reduced N deposition projected to decrease
- Oxidized N deposition is projected to further decrease
  - Due to controls on combustion sources
- Reduced N deposition projected to increase further
  - Due to changes in atmospheric composition and a lack of controls on NH_3 emissions
- These simulations did not include lightning generated NOx

Climate and the N Deposition Budget

	2010-2012	GCM Historical	2028	RCP 4.5 2050*
Dry NHx	15%	19%	25%	31%
Wet NHx	23%	27%	23%	33%
Dry OxN	43%	39%	27%	26%
Wet OxN	19%	15%	15%	11%
Total (kg N/ha)	10	9.6	7.6	7.6

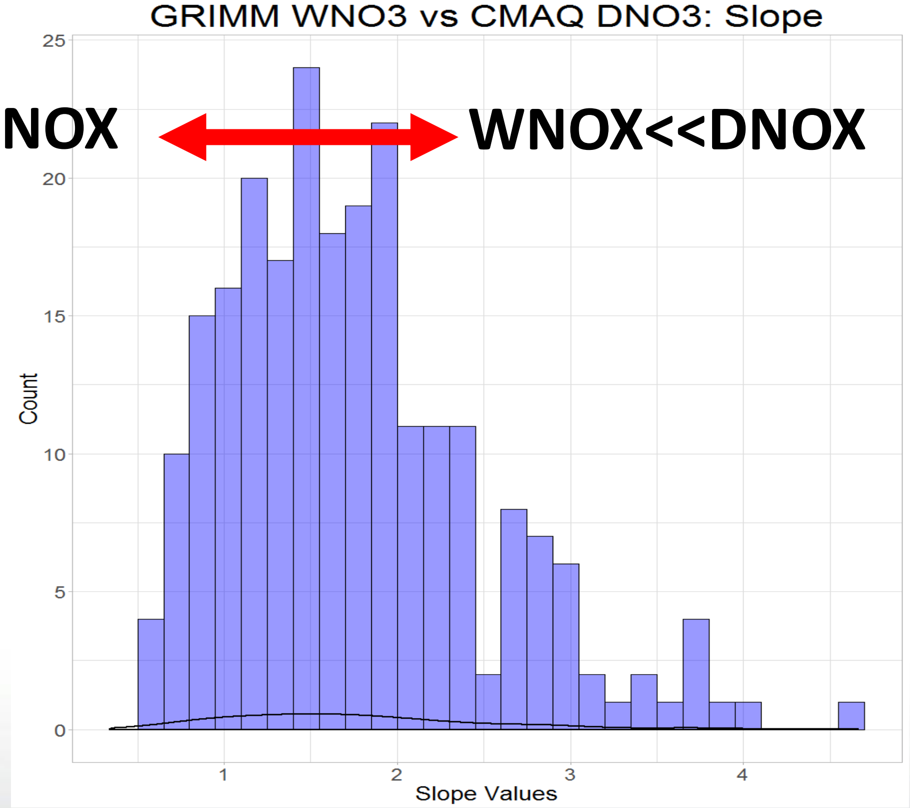
- Downscaled CESM and retrospective simulations are quite consistent given the differences in the model configurations and driving meteorological data
- Projects near constant deposition from 2028 to 2050 with changes in NOx/NHx composition
    - NOx emission cuts plateau
    - Increases in temperature drive higher NH_3 emissions
    - RCP 4.5 simulations did not include lightning generated NOx
        - Likely underestimates total N deposition
- Likely underestimating organic N deposition (better in more recent atmospheric chemistry mechanisms)

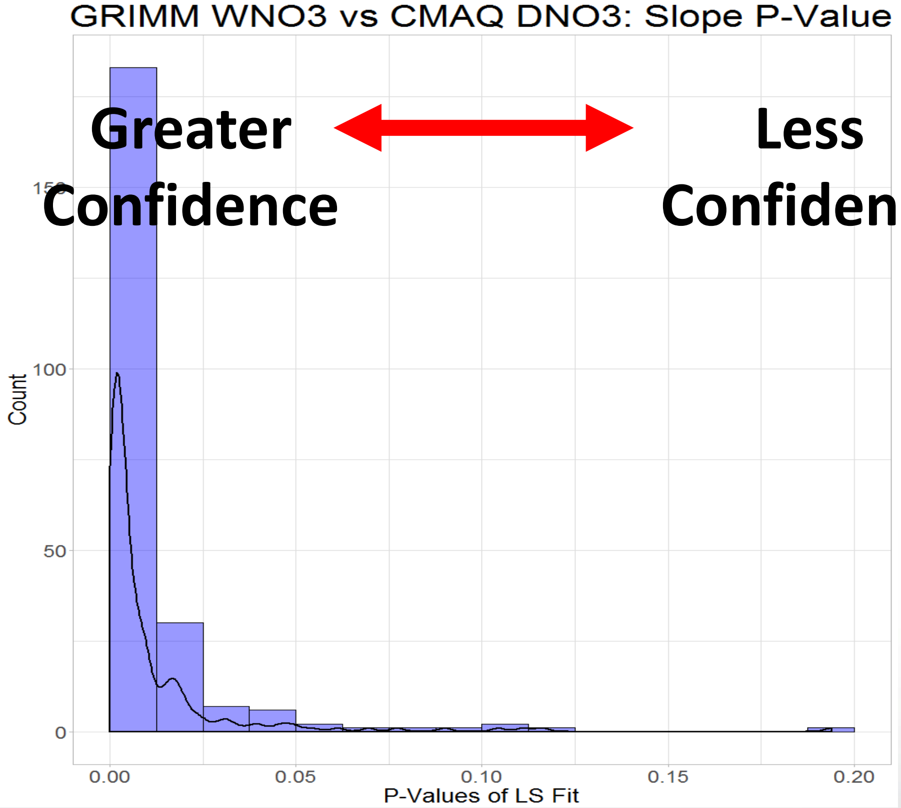
Atmospheric deposition regression for the Chesapeake Bay Watershed Model

Kyle Hinson

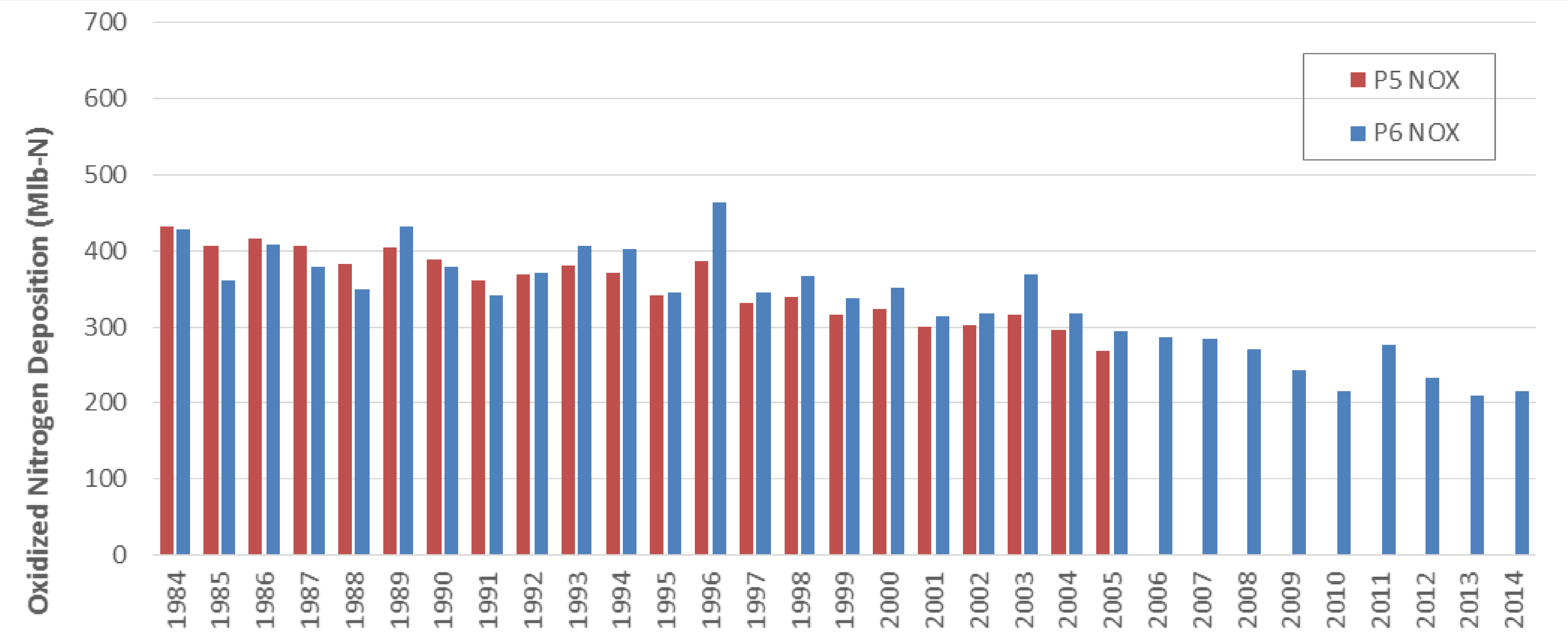
Dry Deposition Regressions

- **NOx dry deposition dataset was developed by utilizing the relationship between CMAQ NOx dry deposition and a time series of NOx wet deposition provided by Jeff Grimm**
- **NHx dry deposition was held constant throughout the watershed prior to 2002 at a level of deposition equal to the average of the data provided by CMAQ from 2002-2004**

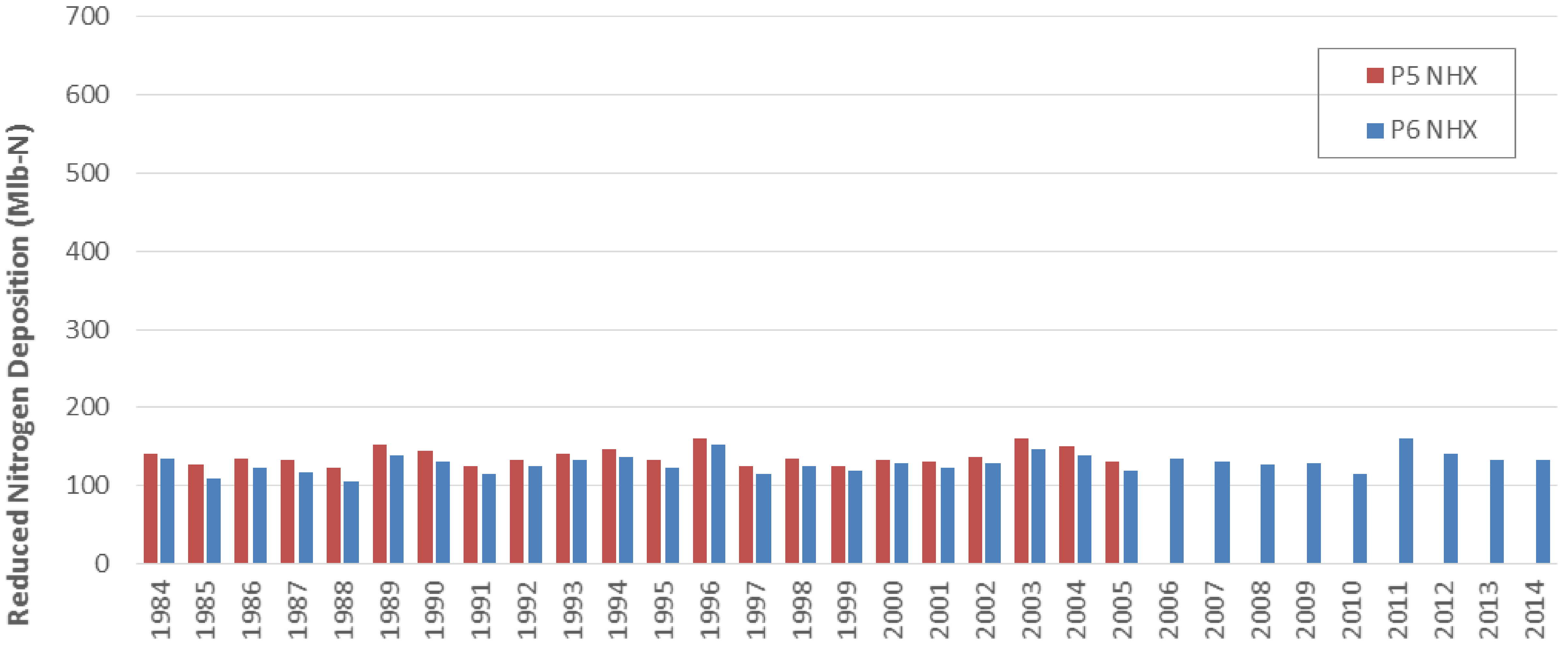




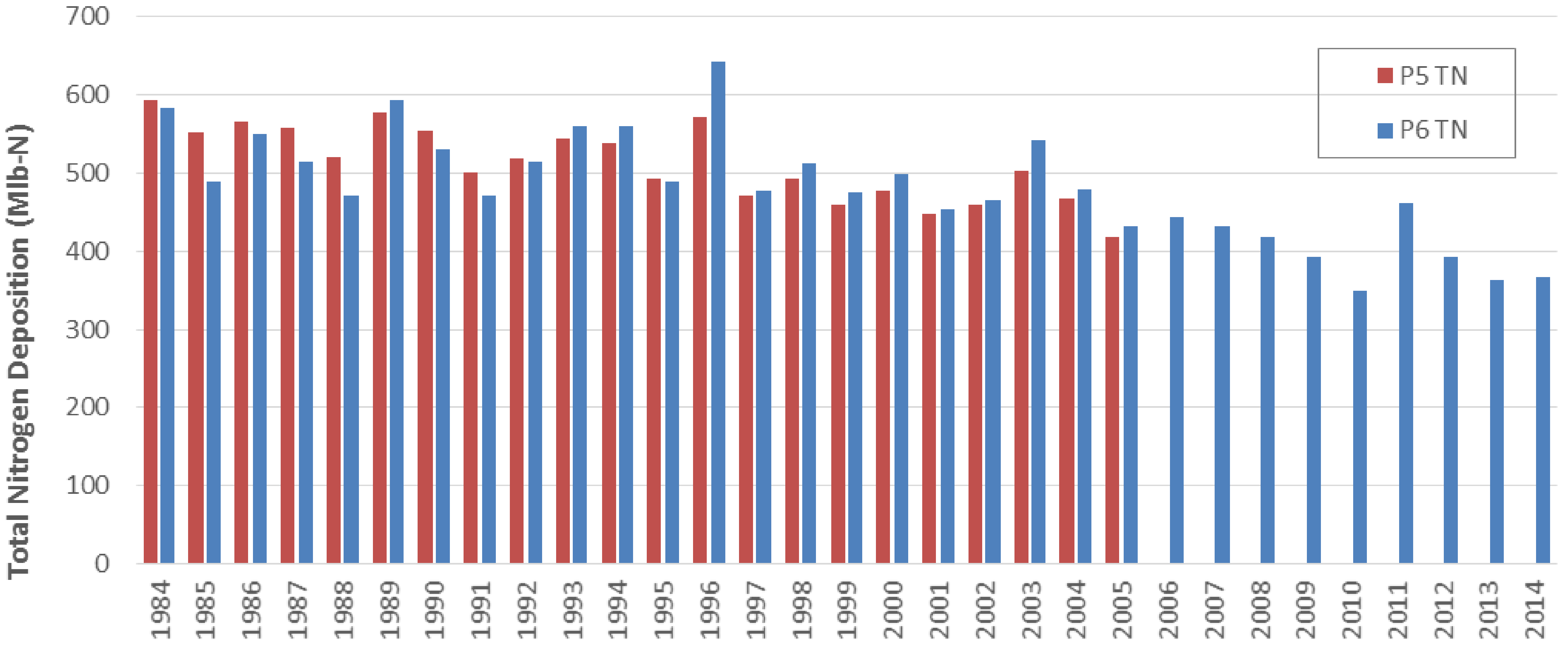
Watershed Deposition



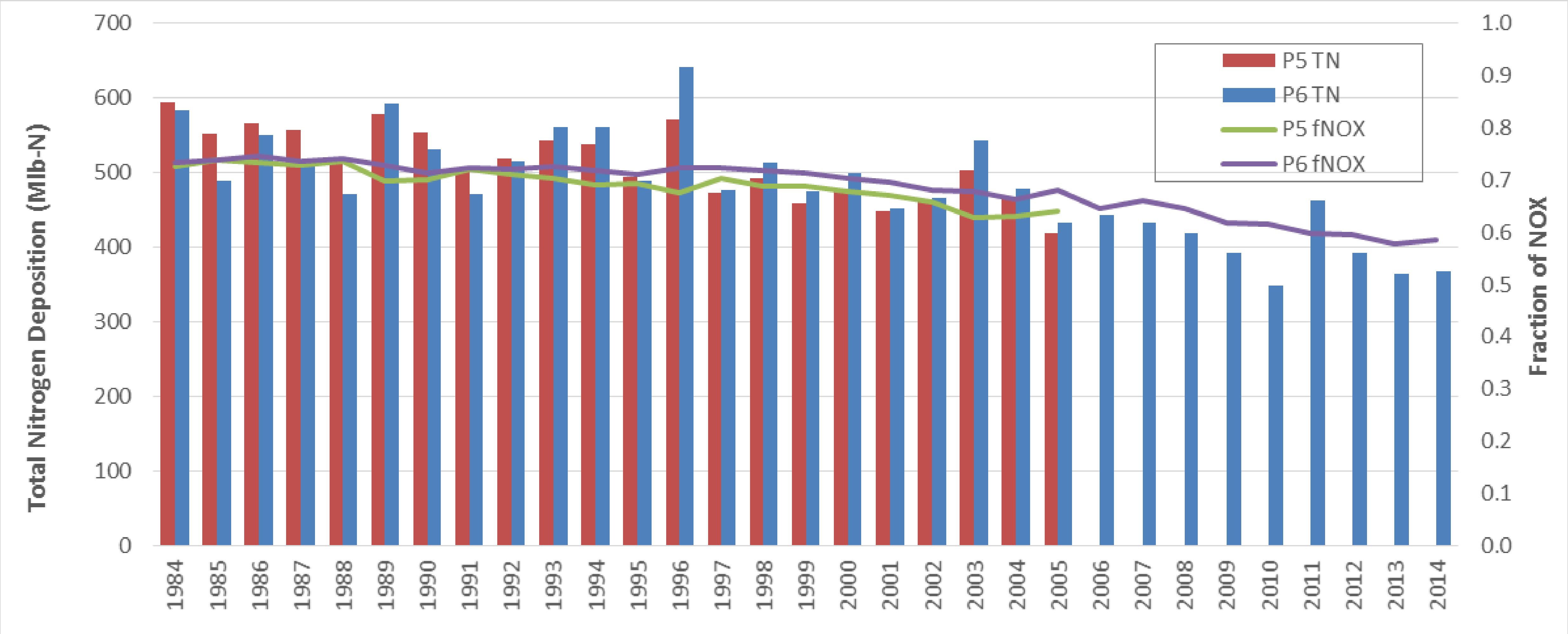
Watershed Deposition



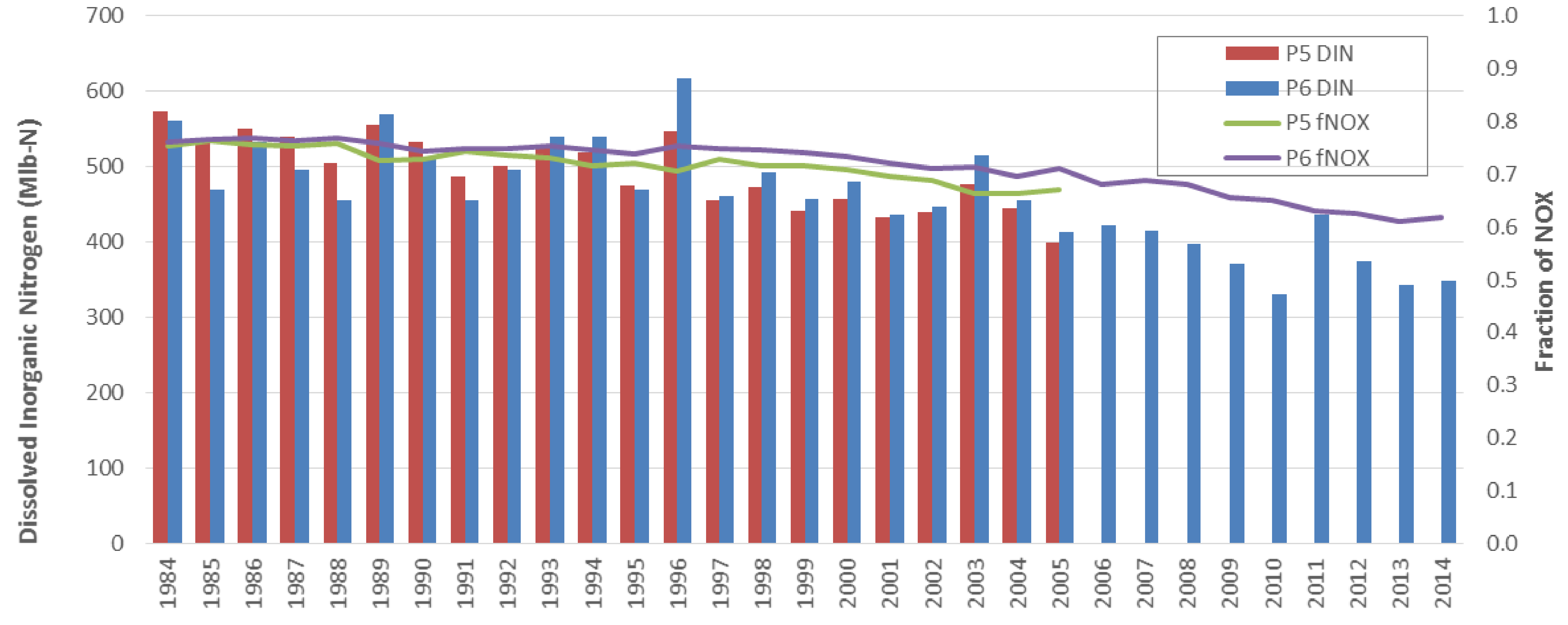
Watershed Deposition



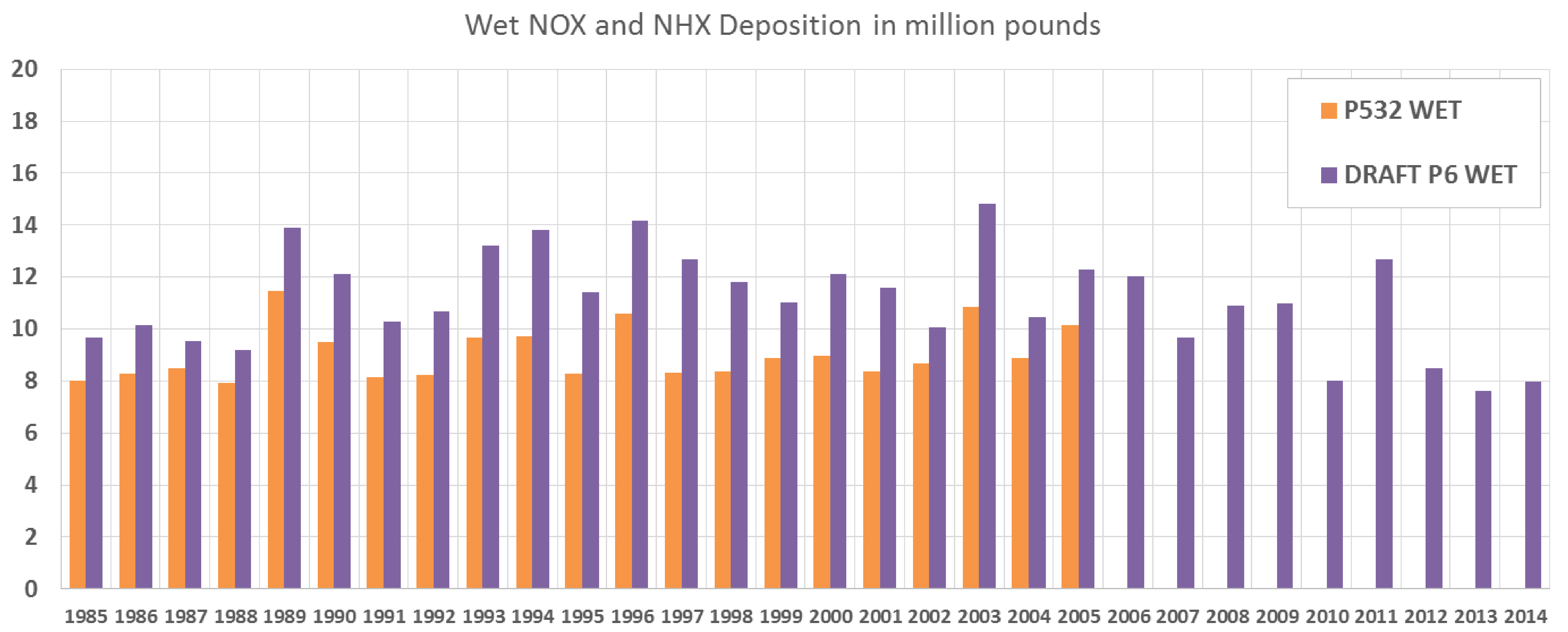
Watershed Dry Deposition



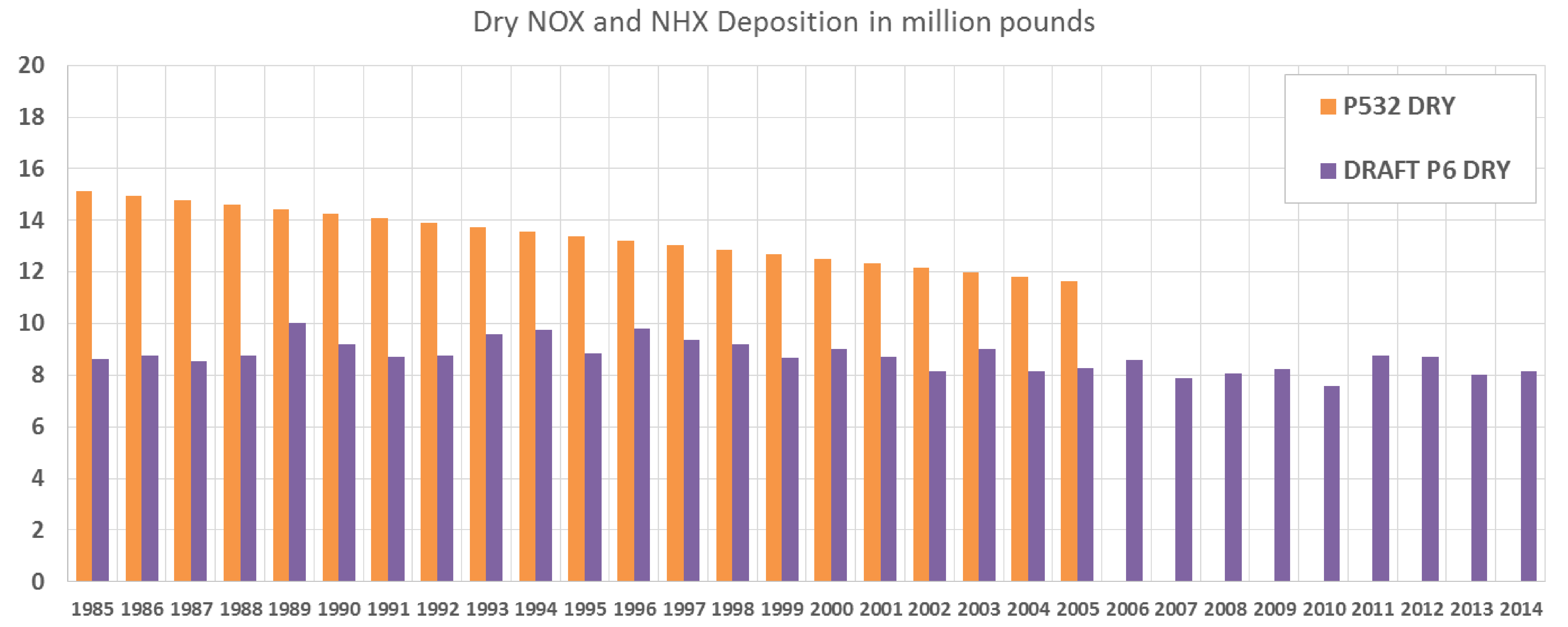
Watershed Dry Deposition



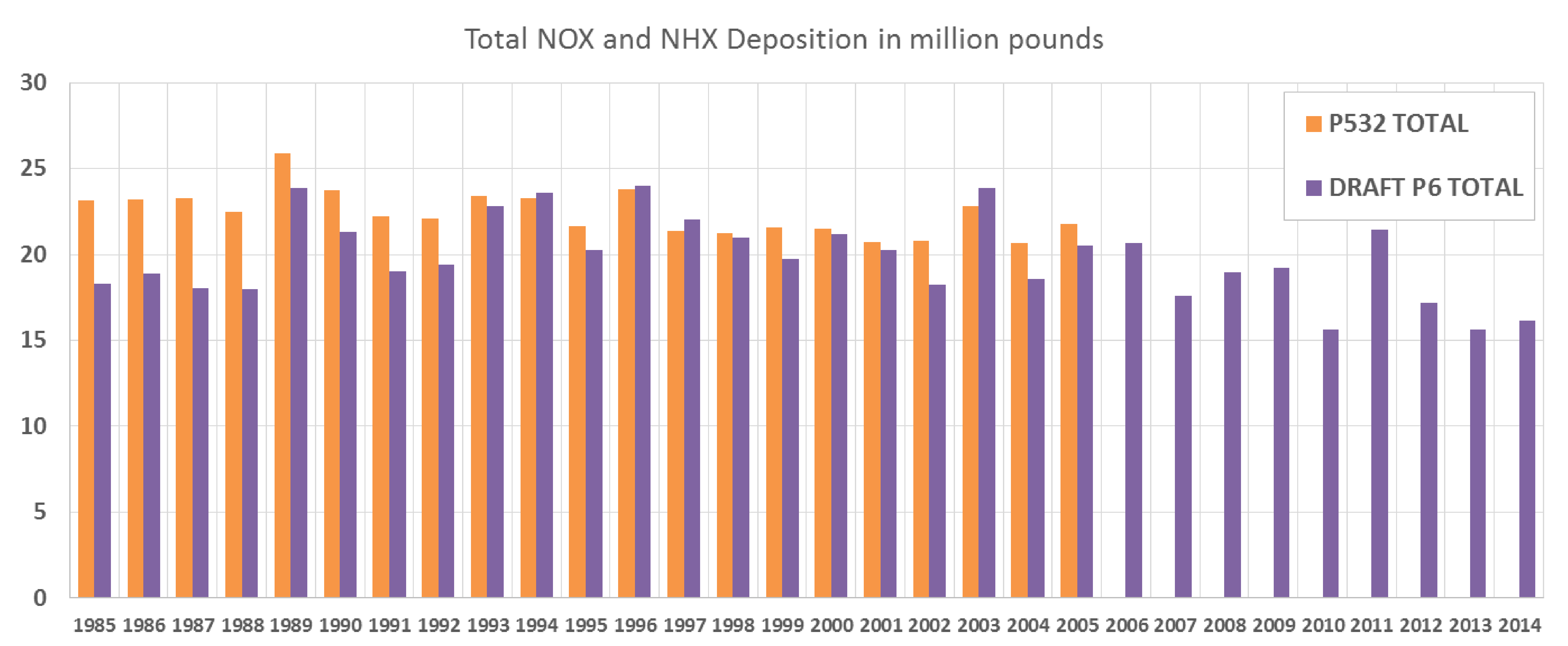
Bay Deposition



Bay Deposition

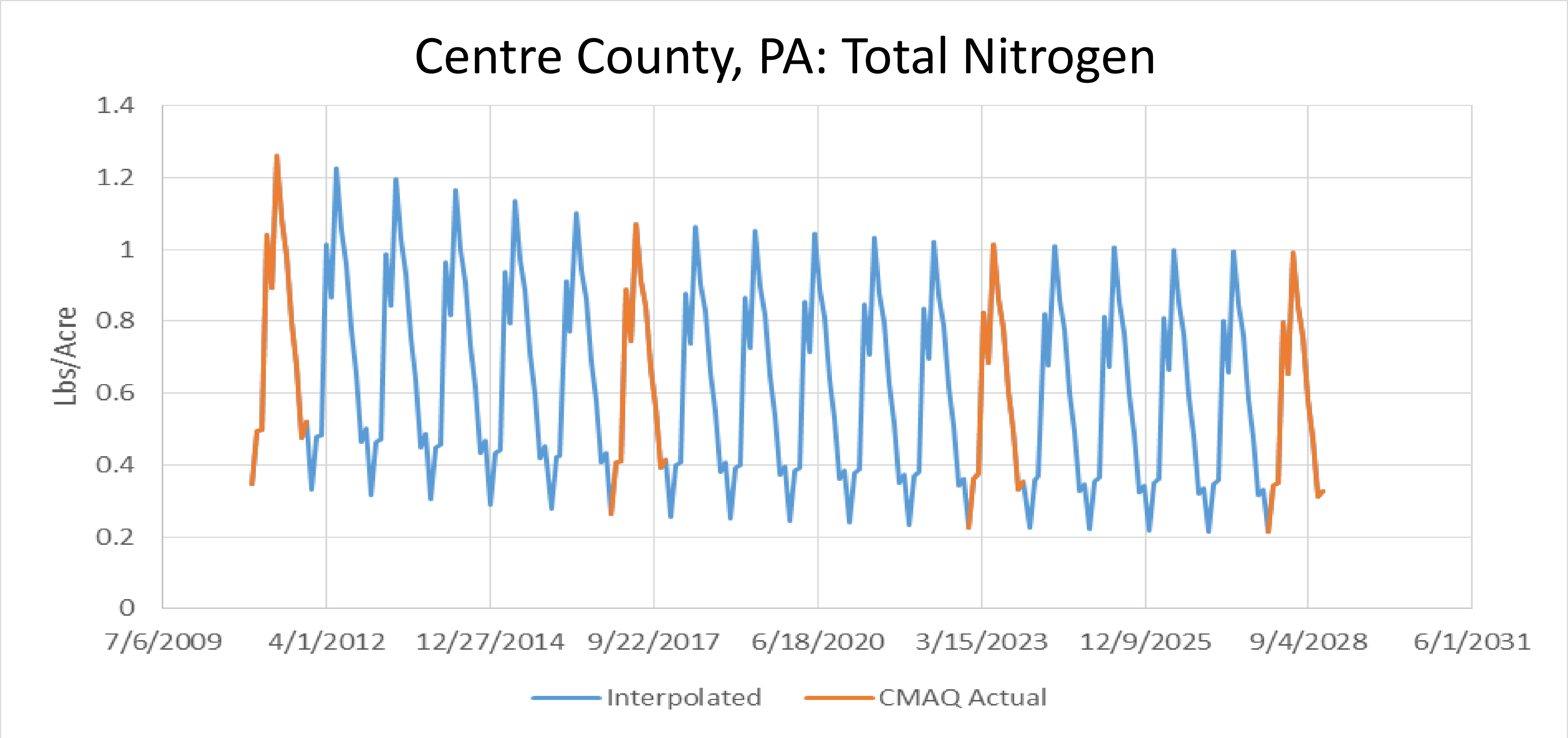


Bay Deposition

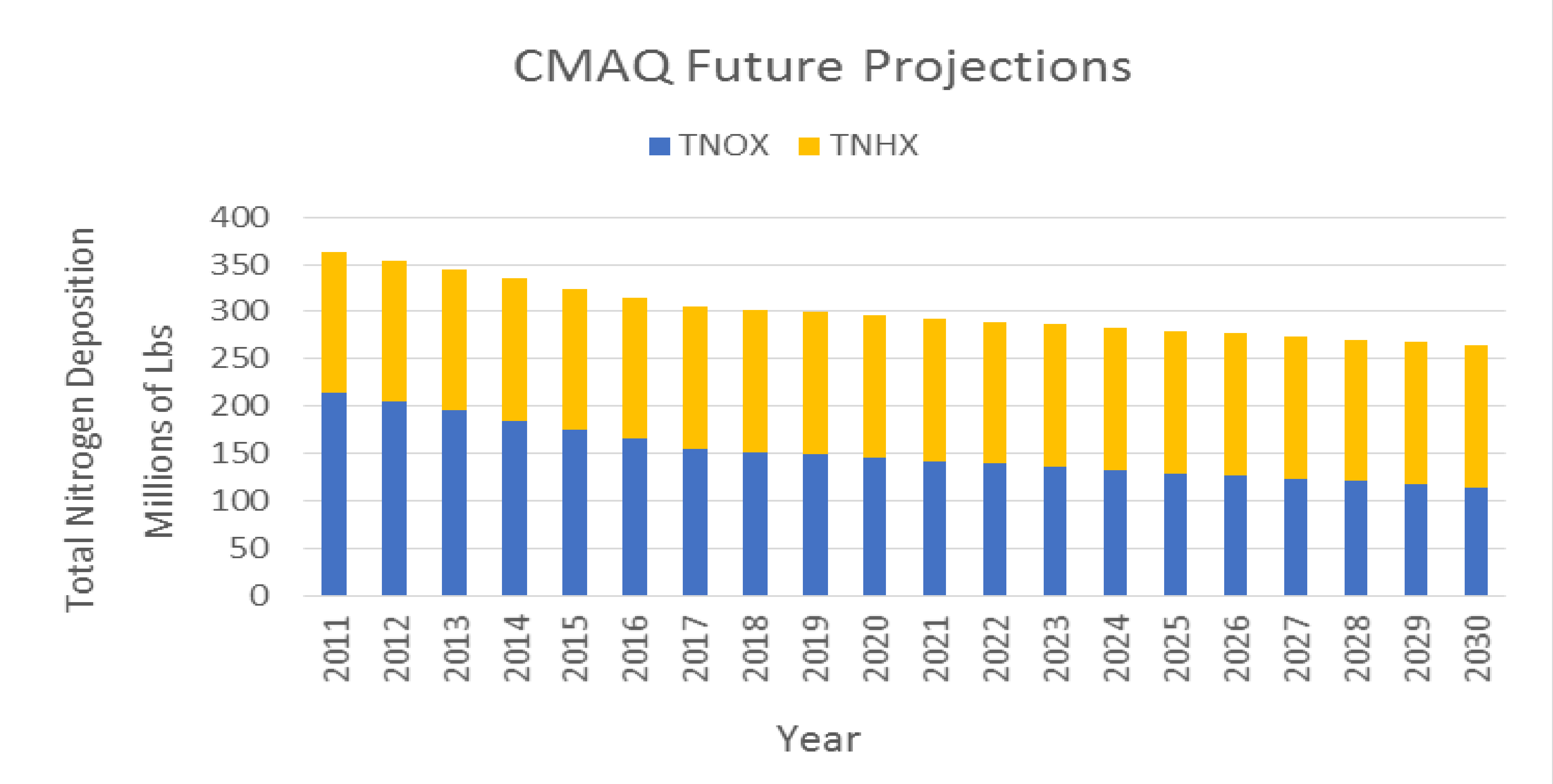


Future Deposition

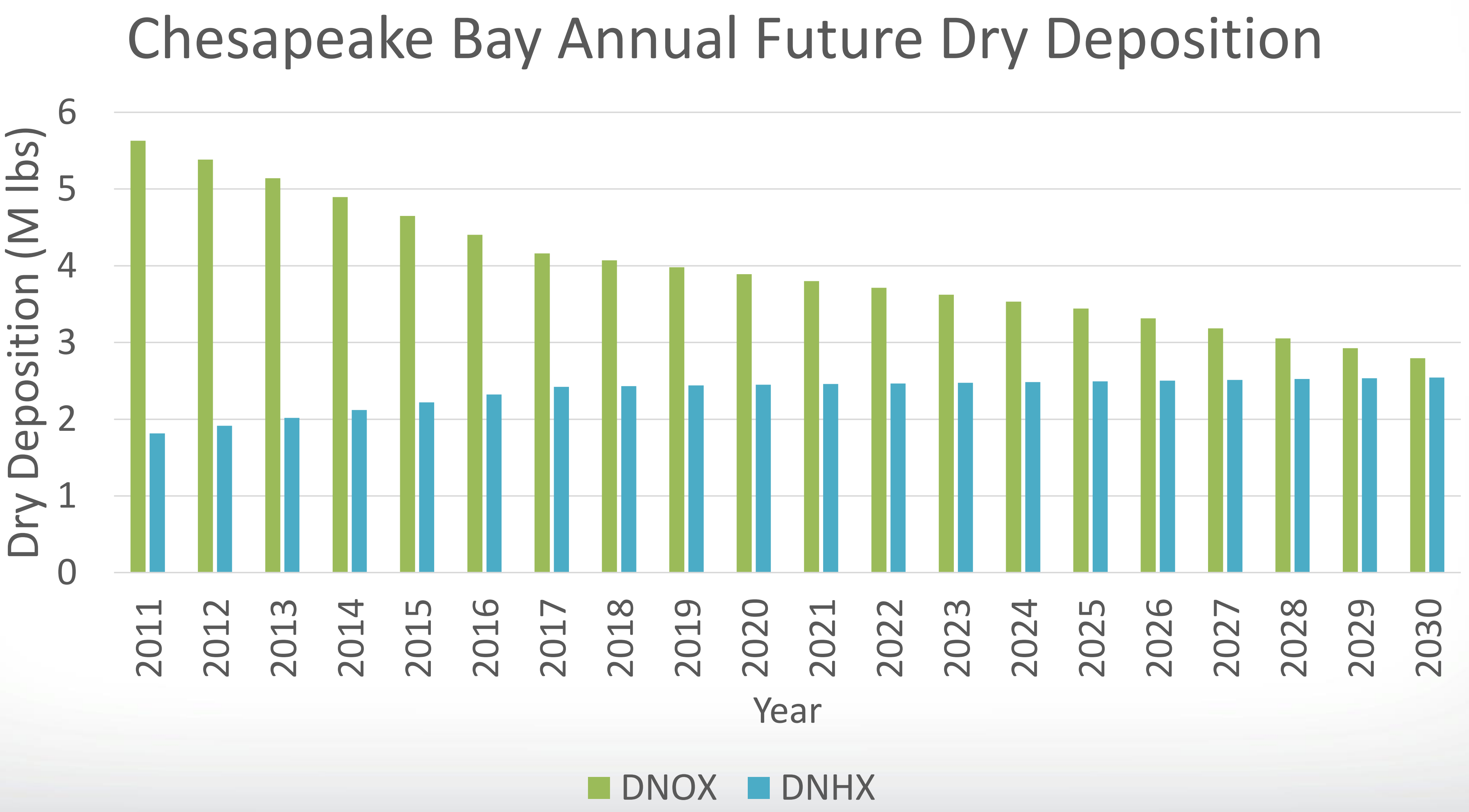
- **Future deposition data was provided by CMAQ for future years, and a time series was developed by interpolating between those years.**



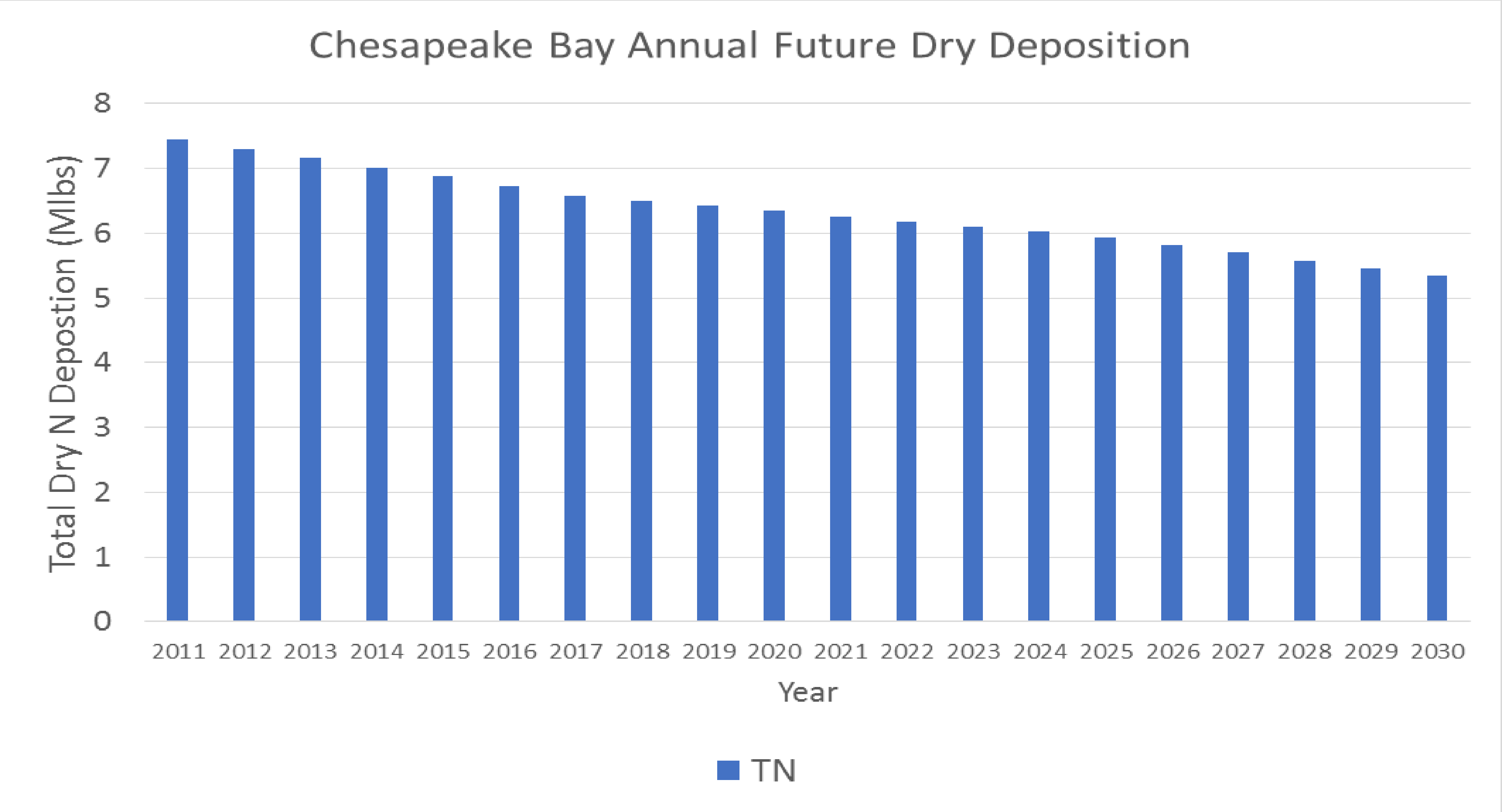
Watershed Future Deposition



Bay Future Deposition



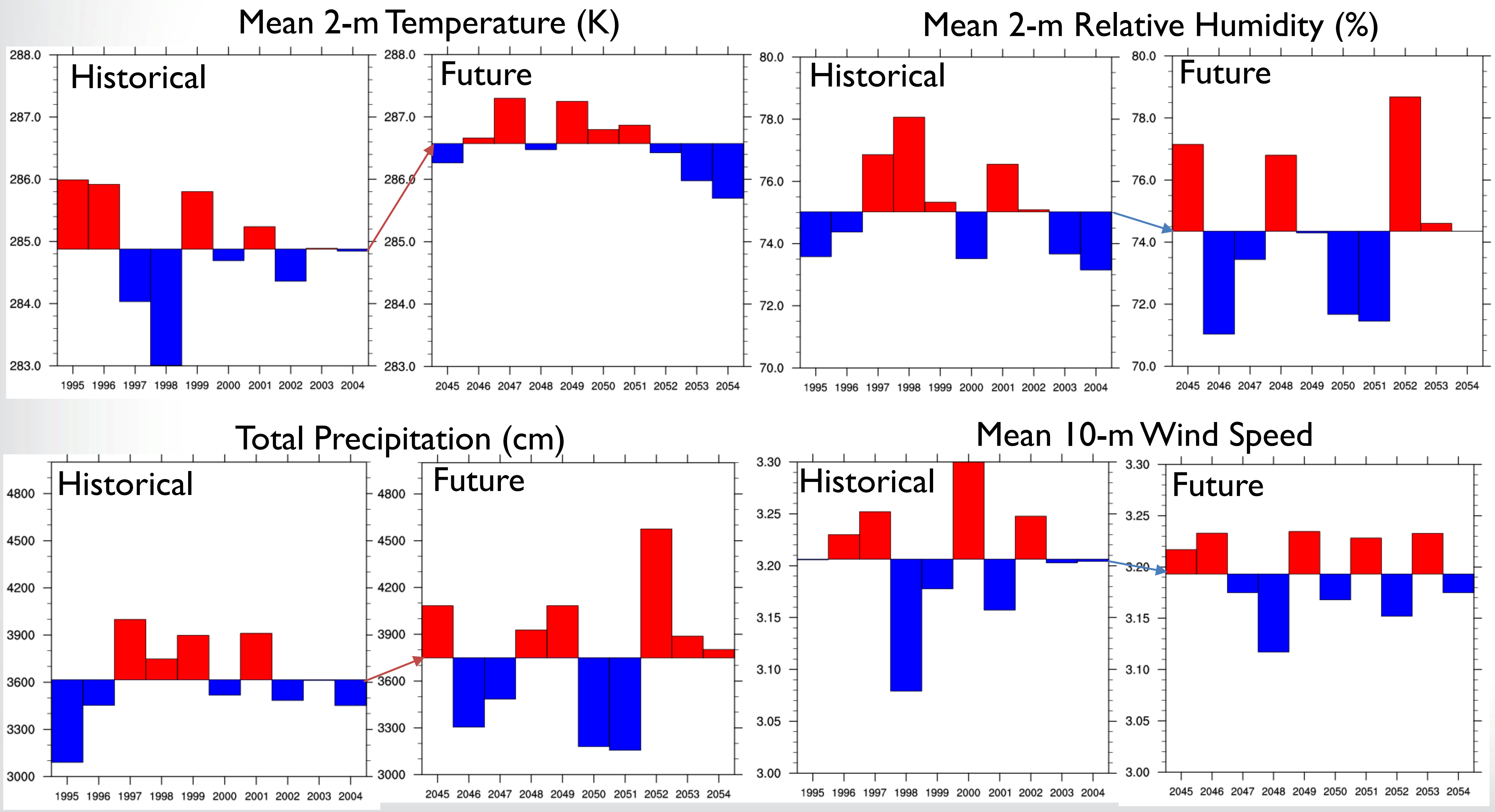
Bay Future Deposition



Meteorological Changes for the RCP 4.5 scenario over the Chesapeake Bay

Patrick Campbell

Annual average changes vs. 10-yr mean



Chesapeake Bay Watershed

RCP4.5 Scenario

Historical: 1995 – 2004

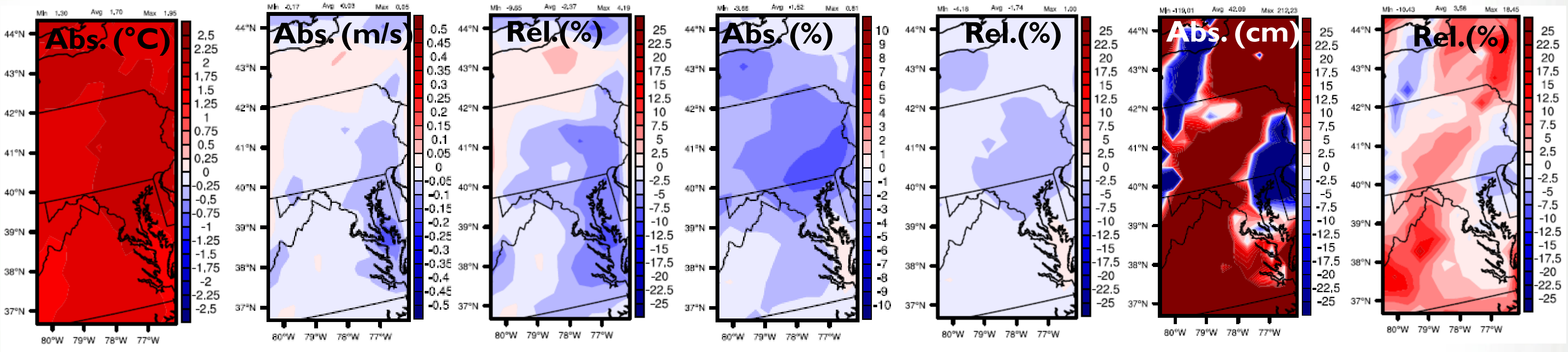
Future: 2045 – 2054

Red: Above 10-yr mean
Blue: Below 10-yr mean

Annual absolute and relative changes

<u>Annual</u> absolute and relative percent changes in 10-yr average 2-m temperature (T2), 10-m wind speed (WSPD10), 2-m relative humidity (RH), and total precipitation (PRECIP) for the RCP4.5 future (2045-2054) - historical (1995-2004) period

2 Meter Temp. | **10 Meter Wind Speed** | **Relative Humidity** | **Precipitation**



2 Meter Temp.
Min: +1.3 °C
Max: +2.0 °C
Mean: +1.7

10 Meter Wind Speed
Min: -0.2 m/s (-9.7%)
Max: +0.1m/s (+4.2%)
Mean: -0.03 m/s (-2.4%)

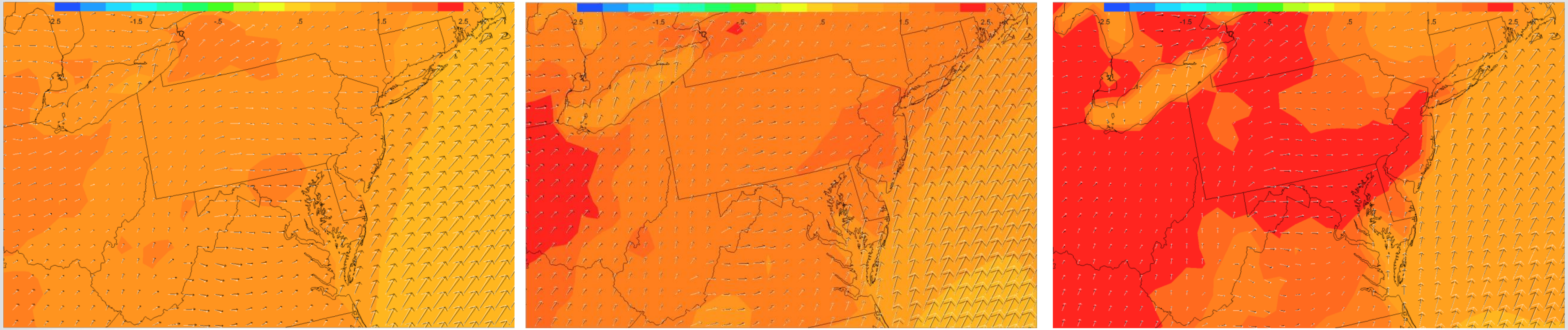
Relative Humidity
Min: -3.7% (-4.2%)
Max: +0.8% (+1.0%)
Mean: -1.5% (-1.7%)

Precipitation
Min: -119.0 cm (-10.4%)
Max: +212.2 cm (+18.5%)
Mean: +42.1 cm (+3.6%)

Temperatures & wind vectors

<u>Summer</u> months absolute changes in 10-yr average T2 (color scale: °C) and 10-yr average wind vectors (range -5 to +5 m/s) for RCP4.5 historical (1995-2004; black) and future period (2045-2054; white)

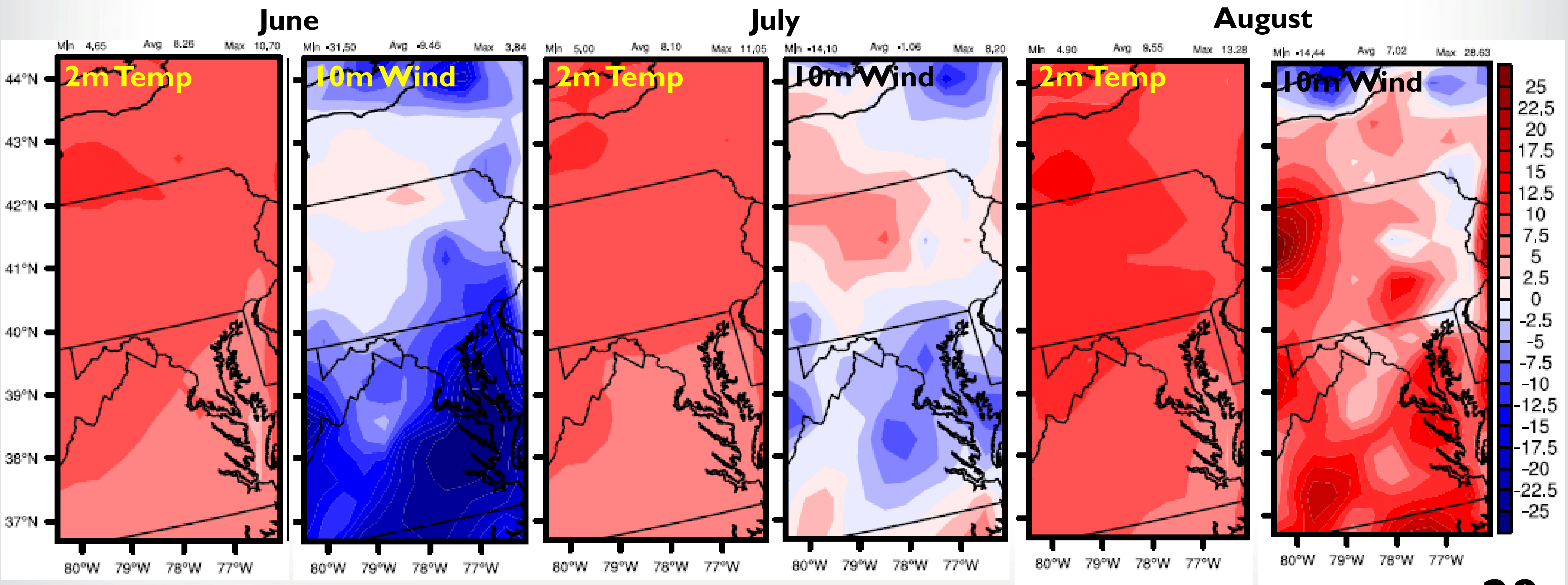
June July August



10-yr Mean Absolute Changes for all Months and Annual													
	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Ann
2m Temp (°C)	+2.3	+0.8	-0.04	+3.3	+1.9	+1.3	+1.7	+1.8	+2.1	+2.2	+2.7	+0.5	+1.7
10m Wind (m/s)	+0.1	-0.2	-0.1	-0.1	-0.1	+0.2	-0.1	-0.02	+0.1	-0.2	+0.04	0.0	-0.03

Relative temperature and wind speed changes

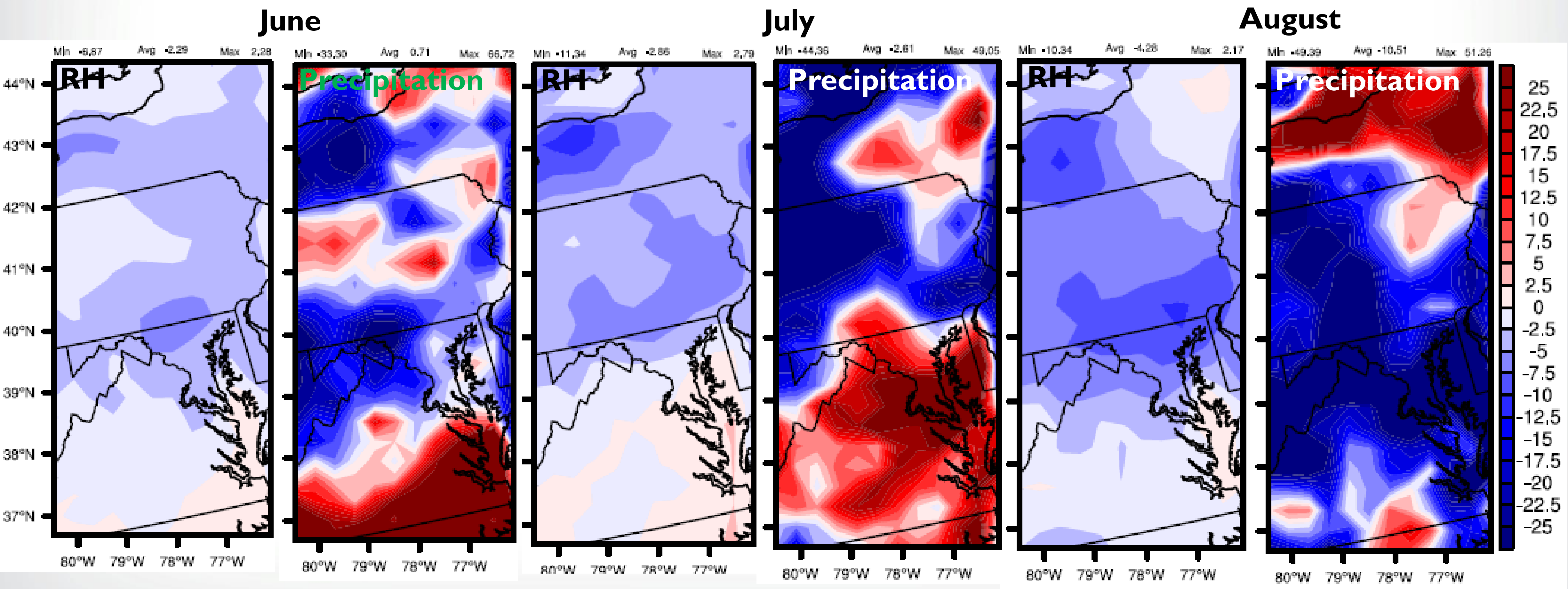
<u>Summer</u> months relative percent (color scale: %) changes in 10-yr T2 and WSPD10



Mean: +8.3% | Mean: -9.5% | Mean: +8.1% | Mean: -1.1% | Mean: +9.6% | Mean: +7.0%

Relative humidity and precipitation changes

Summer months relative percent (color scale: %) changes in 10-yr average RH and total PRECIP



Mean: -2.3% **Mean:** +0.7% **Mean:** -2.9% **Mean:** -2.6% **Mean:** -4.3% **Mean:** -10.5%

Summary

- Oxidized N deposition is decreasing due to atmospheric emission regulations
  - Reductions are projected to decrease as large reductions have already been implemented and NOx emission controls become more difficult
- Wet Reduced N deposition is decreasing but at a slower rate than oxidized N
  - Reduction in precipitation scavenging of aerosol NH_4^+ deposition offset by increases in NH_3
- Dry Reduced N deposition is increasing due to NOx-SOx cuts and likely due to a climate penalty
  - Driven by increased ambient NH_3 as aerosol ammonium nitrate and ammonium sulfate decrease due to NOx-SOx cuts
  - Increased temperatures will result in an increase in NH_3 emissions
- A method to estimate deposition trends has been developed for the Chesapeake Bay Model where modeled atmospheric deposition is missing
- A data rich projected hourly meteorology for 2045-2054 RCP 4.5 has been developed
  - Estimates show an increase in annual average air temperature and precipitation and a decrease in wind speed for the Chesapeake Bay
  - There are interannual and monthly variability in the projected changes