Introduction to Nitrogen Deposition for Agriculture

Long-term measurements to support deposition and critical load assessments in the U.S.

David A. Gay

NADP Program Office,
University of Wisconsin Madison,
dgay2@wisc.edu, (217) 898-1444

National Atmospheric Deposition Program

1

Talk Summary

1. Source of NH_3 emissions to the atmosphere
2. NH_3 is not directly regulated, but contributes to air quality issues (including Deposition of N)
3. NADP/CASTNET measurement shows that reduced nitrogen is now the major N deposit.
4. Impacts to the Environment and Agriculture's Response

National Atmospheric Deposition Program

2

Section 1.

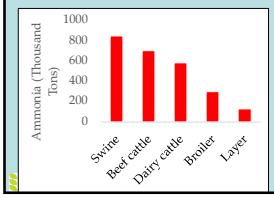
Sources of Ammonia to the Atmosphere & Ammonia Regulation

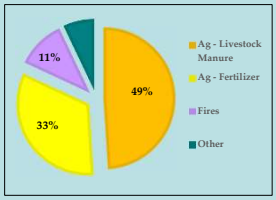
National Atmospheric Deposition Program

3

U.S. Ammonia Emissions

- 80% of all US NH_3 emissions come from agriculture.
- The majority is associated with livestock production.
- 2.8–3.2 Teragrams NH3–N/year *(1,000,000,000,000 g)*





- Breakdown of NH_3 emissions by source category (2020 EPA NEI)

https://www.epa.gov/air-emissions-inventories/2020-national-emissions-inventory-nei-data

4

Overall

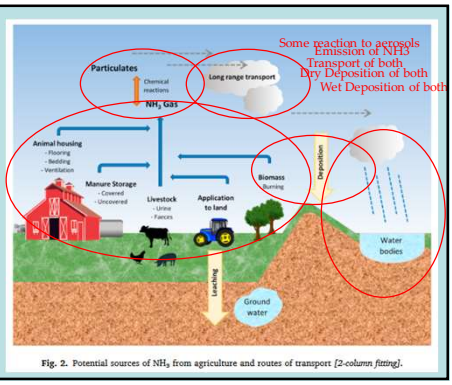
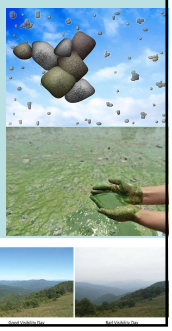


Fig. 2. Potential sources of NH_3 from agriculture and routes of transport *[2-column fitting]*.

5

Air Policies Relevant to Ammonia

- NH_3 is not directly regulated under the Clean Air Act
- However, it contributes to particulate matter formation and N deposition
- Therefore, it is relevant to many air quality issue and policies
  - National Ambient Air Quality Standards (NAAQS)-
    - Primary NAAQS protect human health
    - NH_4^+ is a component of $PM_{2.5}$ forming particulate matter
    - State Implementation Plans for PM nonattainment areas required to consider NH_3 as a precursor
    - Secondary NAAQS protect public welfare, including ecosystem health
    - Review of standard considers all forms of Nr in assessment of ecosystem effects (deposition)
  - The Regional Haze Rule
    - Aerosols/particulates reducing visibility
    - require agencies to work together to improve visibility in 156 national parks and wilderness areas.



National Atmospheric Deposition Program

6

Section 2.

Measurement of Ammonia/Ammonium

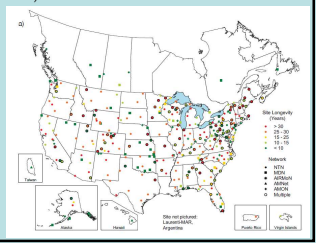
NADP and wet nitrogen deposition
CASTNET and dry deposition
AMON and gaseous concentrations

National Atmospheric Deposition Program

7

What Is the National Atmospheric Deposition Program?

- A Cooperative Research Support Project @Un Wisconsin (USDA)
  - Five Networks
  - measure wet deposition of pollutants ("precipitation")
  - measure gaseous concentrations for dry deposition estimation
  - pollution flux out of the atmosphere & into the biosphere
  - over North America
    - Plus Hawaii, Bermuda, Taiwan, Puerto Rico, US Virgin Islands
  - ~ 600,000 precipitation samples
    - Started in 1978, 44th year
  - ~49,000 Ammonia gas concentrations



National Atmospheric Deposition Program

8

NADP: Two Monitoring Networks Important for NH_3

- National Trends Network

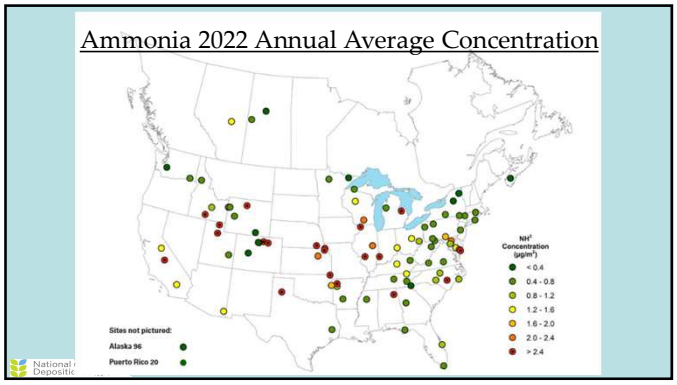
- Wet deposition fluxes of NO_3^- and NH_4^+
- ~ 260 sites, weekly samples

- Ammonia Monitoring Network

- Gaseous NH_3 in the atmosphere
- 80 sites, 2 week average concentrations

National Atmospheric Deposition Program

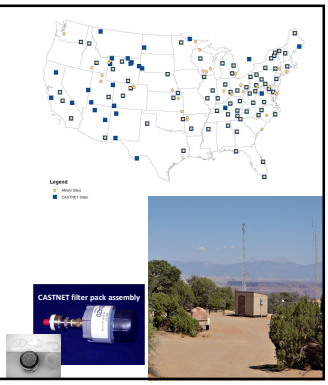
9



10

Clean Air Status and Trends Network (CASTNET)

- **CASTNET** was established in 1988 to measure pollutants causing aquatic and terrestrial acidification
  - Ambient air concentrations used to model dry deposition
  - Most sites are co-located with NADP's **National Trends Network** (NTN) to provide wet deposition fluxes
  - NADP's **Ammonia Monitoring Network** (AMoN) added to most CASTNET sites in 2011
- Sites are located away from known emissions sources to provide regionally representative measurements (Rural)
- Data are used to provide:
  - Long-term trends in air quality
  - Maps of dry and total deposition
  - NAAQS compliance



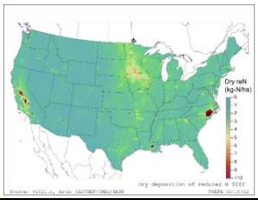
National Atmospheric Deposition Program

11

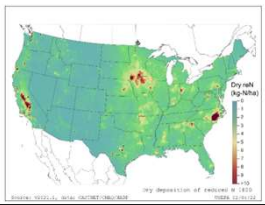
Estimates of NH_3 Dry Deposition

- Estimate of Dry deposition of NH_3 (Kg-N / ha yr)
- Significant increase over ~20 years, particularly in Midwest

2000-2002



2018-2020



12

Section 3.

NADP data shows that reduced nitrogen is now the major contributor to nitrogen deposition

National Atmospheric Deposition Program

13

N Deposition: Oxidized to Reduced

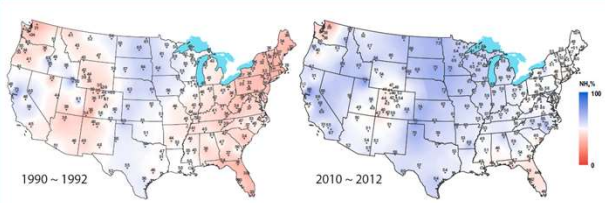


Fig. 1. Comparisons of the 3-y average NH_4^+ percentage of wet inorganic nitrogen deposition across the United States in 1990–1992 (*Left*) and 2010–2012 (*Right*). To help visualize spatial patterns, isopleths were produced by interpolating NH_4^+ mole percentages at individual monitoring sites using a cubic inverse-distance weighting of sites within 500 km of each observation station. The black dots on the map represent locations of sites with 3-y data available for each time period. The NH_4^+ percentage on a molar basis [$(NH_4^+\%) = (NH_4^+)/(NO_3^- + NH_4^+) \times 100\%$] is noted at each site.

Increasing importance of deposition of reduce nitrogen in the United States

Yi Li[a], Bret A. Schichtel[b], John T. Walker[c], Donna B. Schwede[d], Xi Chen[e], Christopher M. B. Lehmann[e], Melissa A. Puchalski[f], David A. Gay[g], and Jeffrey L. Collett Jr.[a,1]

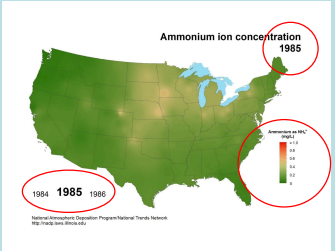
Journal of Geophysical Research: Atmospheres 125, e2019JD031684. https://doi.org/10.1029/2019JD031684

National Atmospheric Deposition Program

14

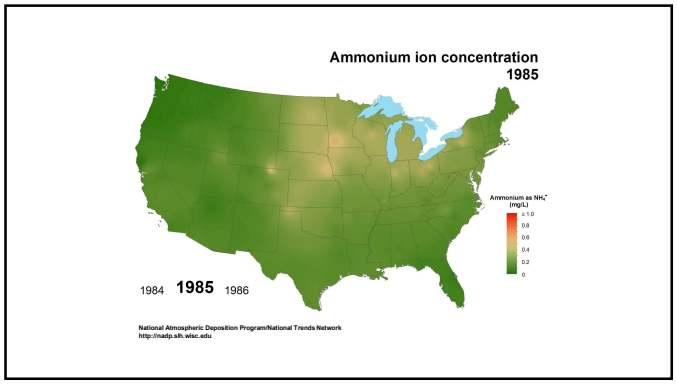
NADP Data is also showing this: Ammonium Wet Deposition Over Time

- Map series
- Wet deposition of NH3

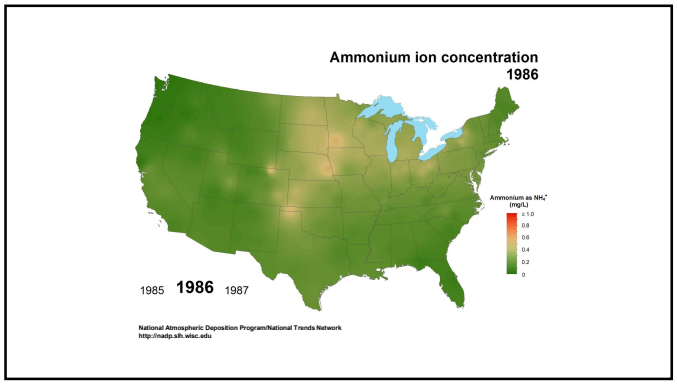


National Atmospheric Deposition Program

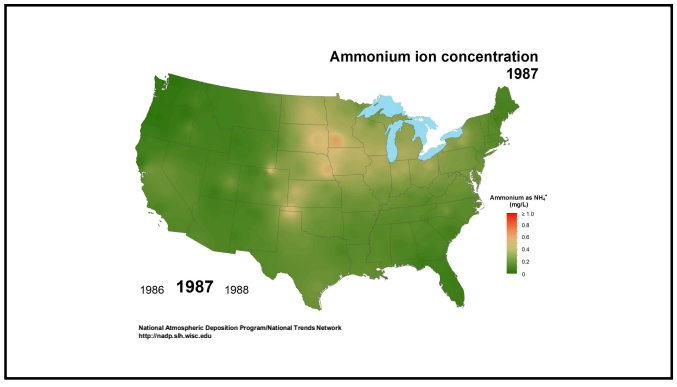
15


Ammonium ion concentration
1985
Ammonium as NH4+ (mg/L)
≥ 1.0
0.8
0.6
0.4
0.2
0
1984 1985 1986
National Atmospheric Deposition Program/National Trends Network
http://nadp.sih.wisc.edu

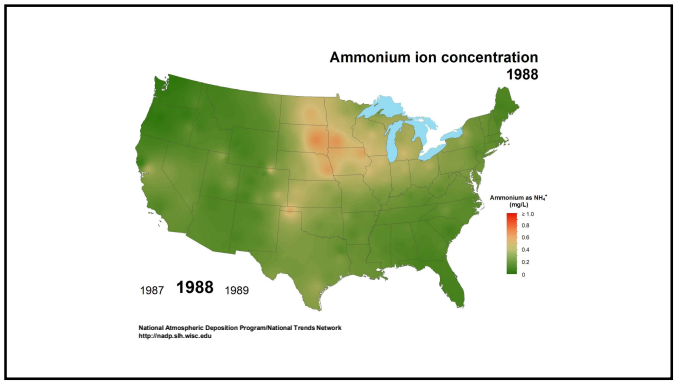
16


Ammonium ion concentration
1986
Ammonium as NH4+ (mg/L)
≥ 1.0
0.8
0.6
0.4
0.2
0
1985 1986 1987
National Atmospheric Deposition Program/National Trends Network
http://nadp.sih.wisc.edu

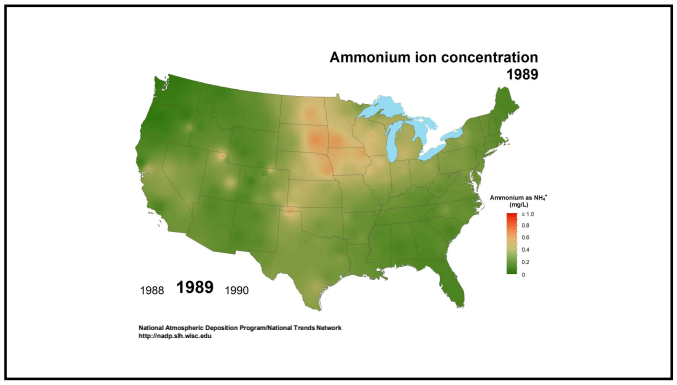
17


Ammonium ion concentration
1987
Ammonium as NH4+ (mg/L)
≥ 1.0
0.8
0.6
0.4
0.2
0
1986 1987 1988
National Atmospheric Deposition Program/National Trends Network
http://nadp.sih.wisc.edu

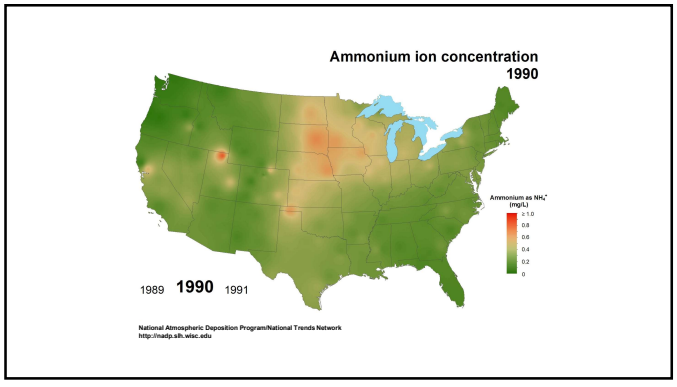
18


Ammonium ion concentration
1988
Ammonium as NH4+ (mg/L)
≥ 1.0
0.8
0.6
0.4
0.2
0
1987 1988 1989
National Atmospheric Deposition Program/National Trends Network
http://nadp.sih.wisc.edu

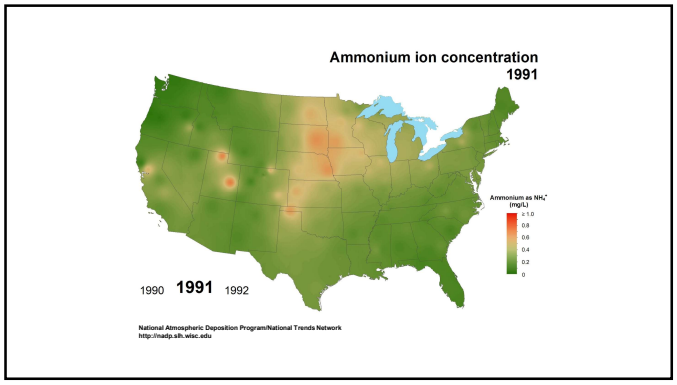
19


Ammonium ion concentration
1989
Ammonium as NH4+ (mg/L)
≥ 1.0
0.8
0.6
0.4
0.2
0
1988 1989 1990
National Atmospheric Deposition Program/National Trends Network
http://nadp.sih.wisc.edu

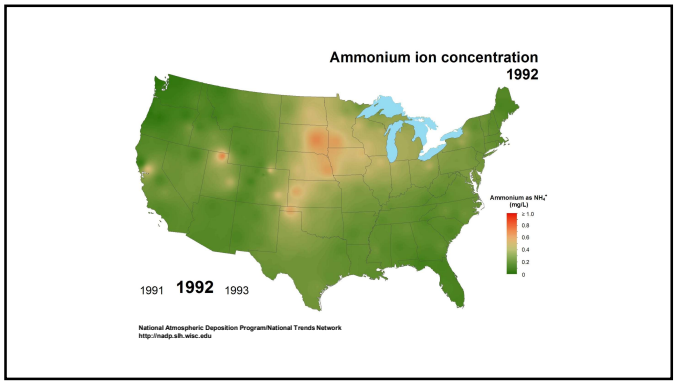
20


Ammonium ion concentration
1990
Ammonium as NH4+ (mg/L)
≥ 1.0
0.8
0.6
0.4
0.2
0
1989 1990 1991
National Atmospheric Deposition Program/National Trends Network
http://nadp.sih.wisc.edu

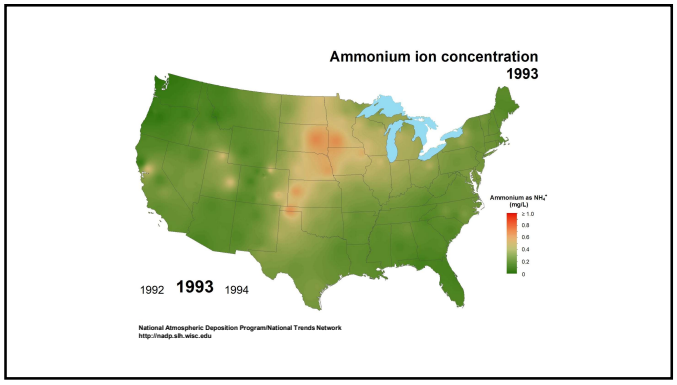
21


Ammonium ion concentration
1991
Ammonium as NH4+ (mg/L)
≥ 1.0
0.8
0.6
0.4
0.2
0
1990 1991 1992
National Atmospheric Deposition Program/National Trends Network
http://nadp.sih.wisc.edu

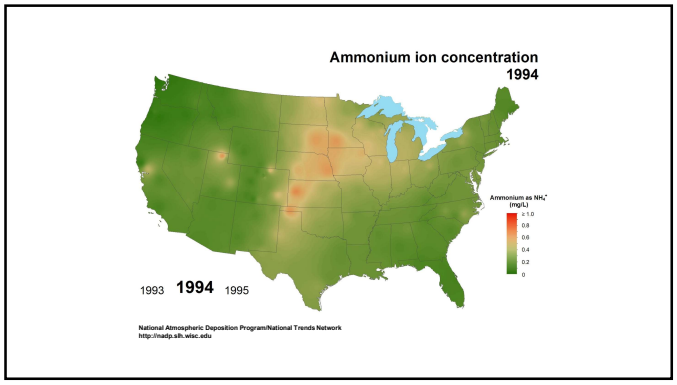
22


Ammonium ion concentration
1992
Ammonium as NH4+ (mg/L)
≥ 1.0
0.8
0.6
0.4
0.2
0
1991 1992 1993
National Atmospheric Deposition Program/National Trends Network
http://nadp.sih.wisc.edu

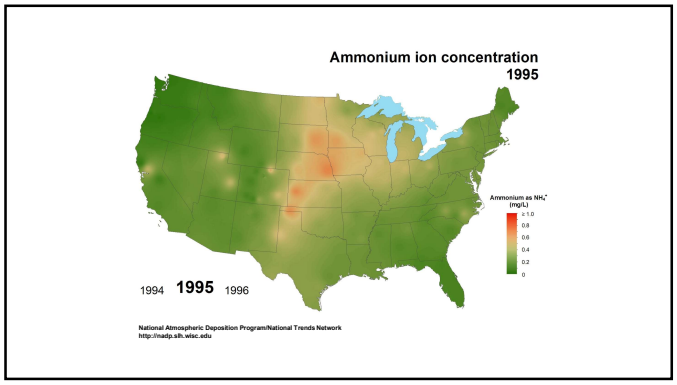
23


Ammonium ion concentration
1993
Ammonium as NH4+ (mg/L)
≥ 1.0
0.8
0.6
0.4
0.2
0
1992 1993 1994
National Atmospheric Deposition Program/National Trends Network
http://nadp.sih.wisc.edu

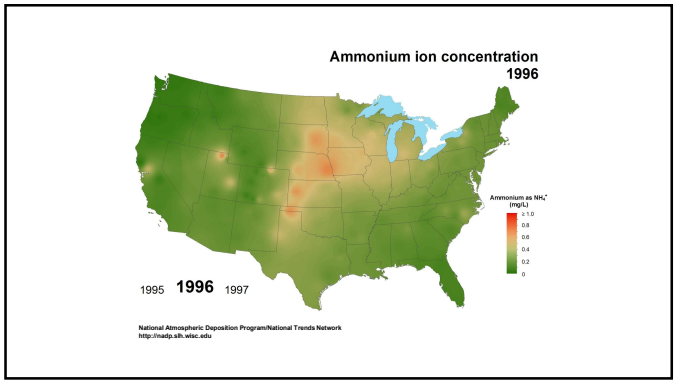
24


Ammonium ion concentration
1994
Ammonium as NH4+ (mg/L)
≥ 1.0
0.8
0.6
0.4
0.2
0
1993 1994 1995
National Atmospheric Deposition Program/National Trends Network
http://nadp.sih.wisc.edu

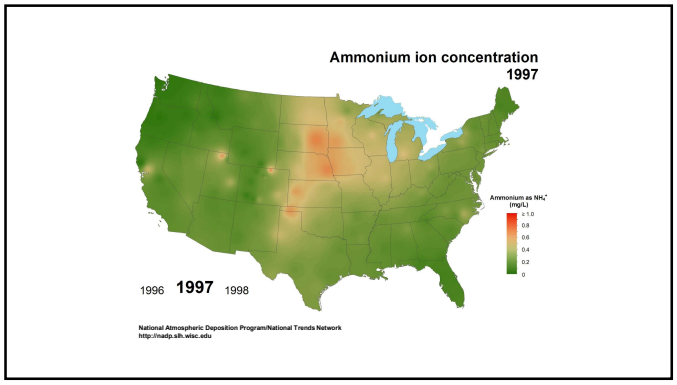
25


Ammonium ion concentration
1995
Ammonium as NH4+ (mg/L)
≥ 1.0
0.8
0.6
0.4
0.2
0
1994 1995 1996
National Atmospheric Deposition Program/National Trends Network
http://nadp.sih.wisc.edu

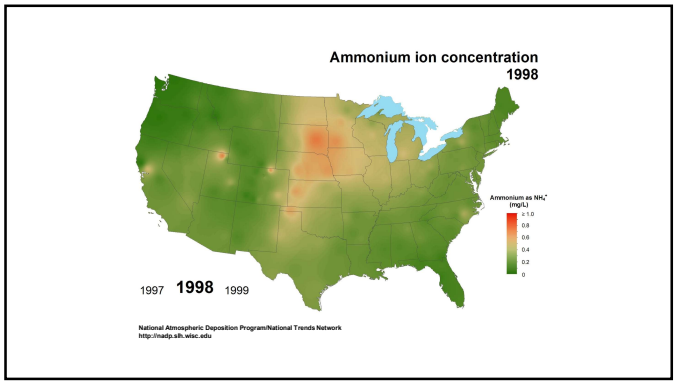
26


Ammonium ion concentration
1996
Ammonium as NH4+ (mg/L)
≥ 1.0
0.8
0.6
0.4
0.2
0
1995 1996 1997
National Atmospheric Deposition Program/National Trends Network
http://nadp.sih.wisc.edu

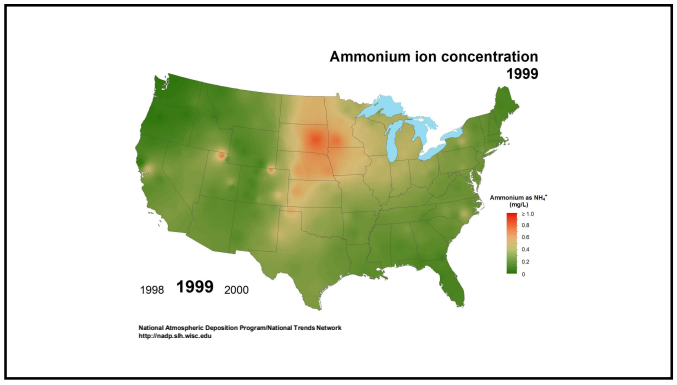
27


Ammonium ion concentration
1997
Ammonium as NH4+ (mg/L)
≥ 1.0
0.8
0.6
0.4
0.2
0
1996 1997 1998
National Atmospheric Deposition Program/National Trends Network
http://nadp.sih.wisc.edu

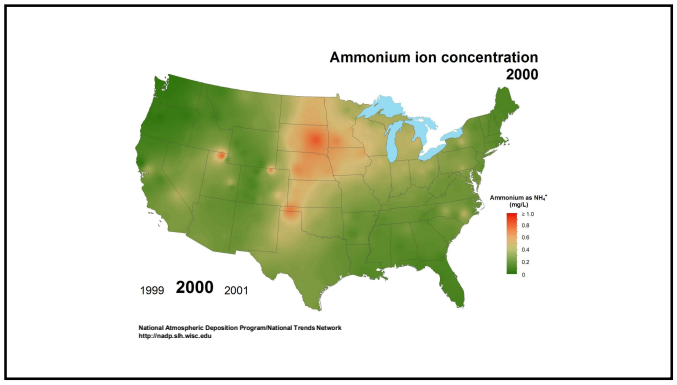
28


Ammonium ion concentration
1998
Ammonium as NH4+ (mg/L)
≥ 1.0
0.8
0.6
0.4
0.2
0
1997 1998 1999
National Atmospheric Deposition Program/National Trends Network
http://nadp.sih.wisc.edu

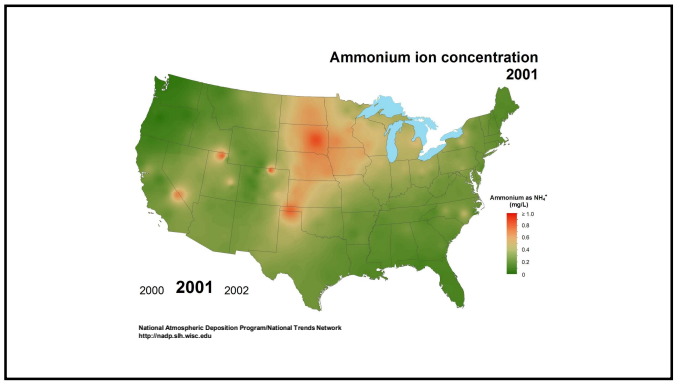
29


Ammonium ion concentration
1999
Ammonium as NH4+ (mg/L)
≥ 1.0
0.8
0.6
0.4
0.2
0
1998 1999 2000
National Atmospheric Deposition Program/National Trends Network
http://nadp.sih.wisc.edu

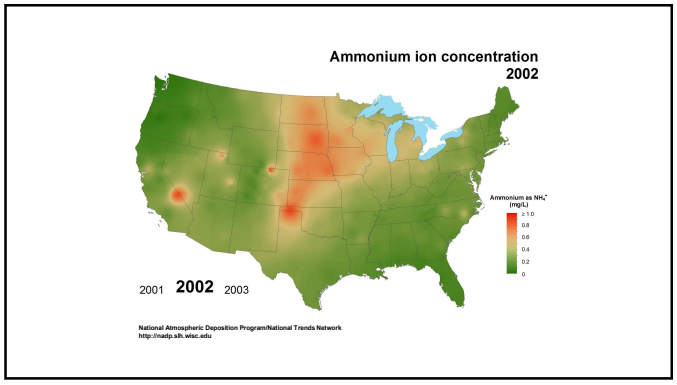
30


Ammonium ion concentration
2000
Ammonium as NH4+ (mg/L)
≥ 1.0
0.8
0.6
0.4
0.2
0
1999 2000 2001
National Atmospheric Deposition Program/National Trends Network
http://nadp.sih.wisc.edu

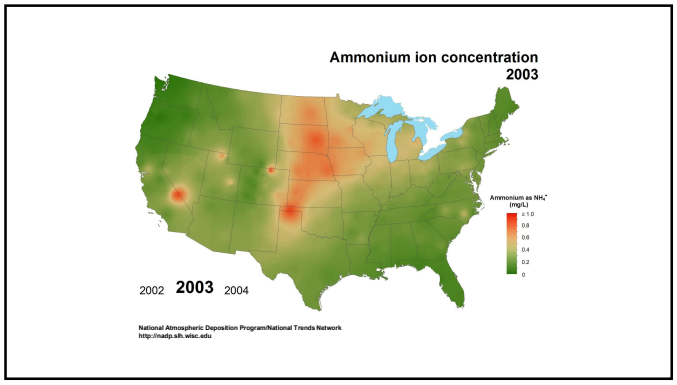
31


Ammonium ion concentration
2001
Ammonium as NH4+ (mg/L)
≥ 1.0
0.8
0.6
0.4
0.2
0
2000 2001 2002
National Atmospheric Deposition Program/National Trends Network
http://nadp.sih.wisc.edu

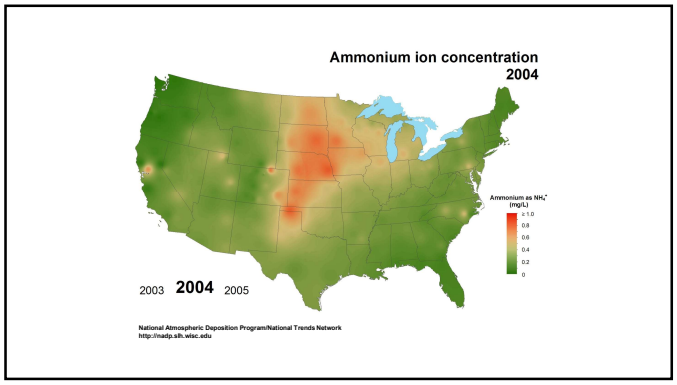
32


Ammonium ion concentration
2002
Ammonium as NH4+ (mg/L)
≥ 1.0
0.8
0.6
0.4
0.2
0
2001 2002 2003
National Atmospheric Deposition Program/National Trends Network
http://nadp.sih.wisc.edu

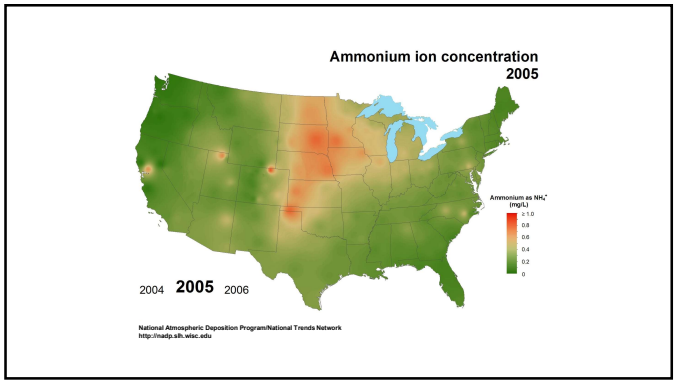
33


Ammonium ion concentration
2003
Ammonium as NH4+ (mg/L)
≥ 1.0
0.8
0.6
0.4
0.2
0
2002 2003 2004
National Atmospheric Deposition Program/National Trends Network
http://nadp.sih.wisc.edu

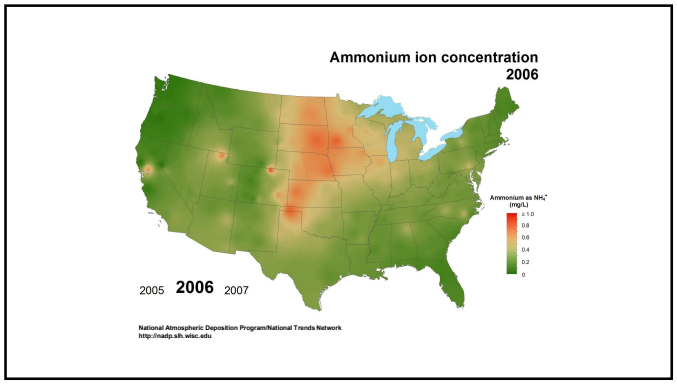
34


Ammonium ion concentration
2004
Ammonium as NH4+ (mg/L)
≥ 1.0
0.8
0.6
0.4
0.2
0
2003 2004 2005
National Atmospheric Deposition Program/National Trends Network
http://nadp.sih.wisc.edu

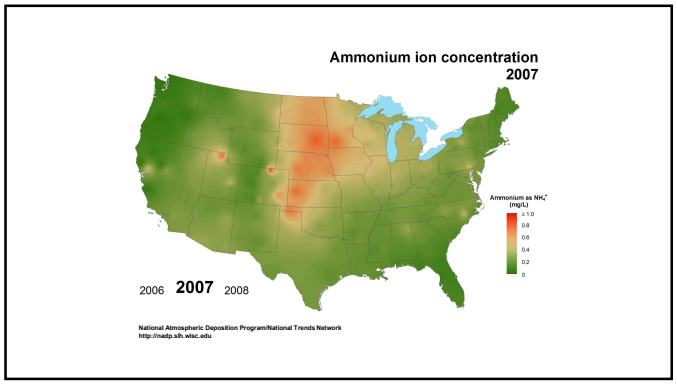
35


Ammonium ion concentration
2005
Ammonium as NH4+ (mg/L)
≥ 1.0
0.8
0.6
0.4
0.2
0
2004 2005 2006
National Atmospheric Deposition Program/National Trends Network
http://nadp.sih.wisc.edu

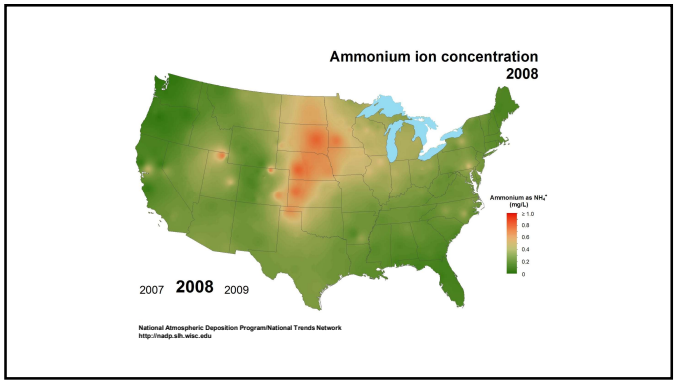
36


Ammonium ion concentration
2006
Ammonium as NH4+ (mg/L)
≥ 1.0
0.8
0.6
0.4
0.2
0
2005 2006 2007
National Atmospheric Deposition Program/National Trends Network
http://nadp.sih.wisc.edu

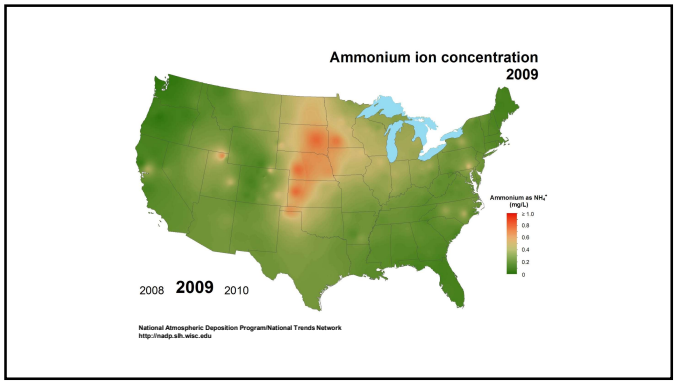
37


Ammonium ion concentration
2007
Ammonium as NH4+ (mg/L)
≥ 1.0
0.8
0.6
0.4
0.2
0
2006 2007 2008
National Atmospheric Deposition Program/National Trends Network
http://nadp.sih.wisc.edu

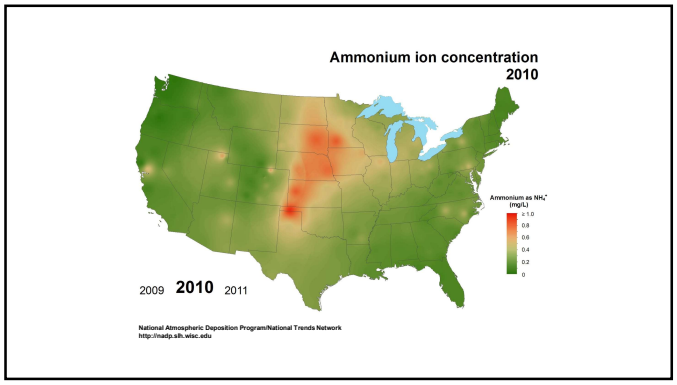
38


Ammonium ion concentration
2008
Ammonium as NH4+ (mg/L)
≥ 1.0
0.8
0.6
0.4
0.2
0
2007 2008 2009
National Atmospheric Deposition Program/National Trends Network
http://nadp.sih.wisc.edu

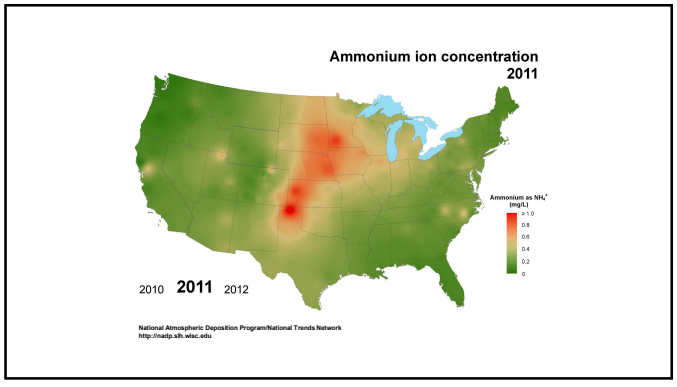
39


Ammonium ion concentration
2009
Ammonium as NH4+ (mg/L)
≥ 1.0
0.8
0.6
0.4
0.2
0
2008 2009 2010
National Atmospheric Deposition Program/National Trends Network
http://nadp.sih.wisc.edu

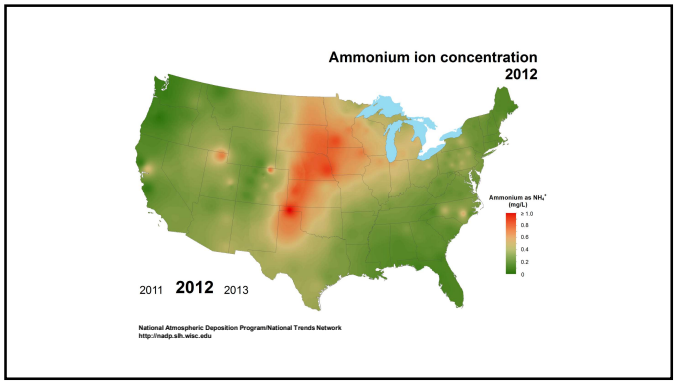
40


Ammonium ion concentration
2010
Ammonium as NH4+ (mg/L)
≥ 1.0
0.8
0.6
0.4
0.2
0
2009 2010 2011
National Atmospheric Deposition Program/National Trends Network
http://nadp.sih.wisc.edu

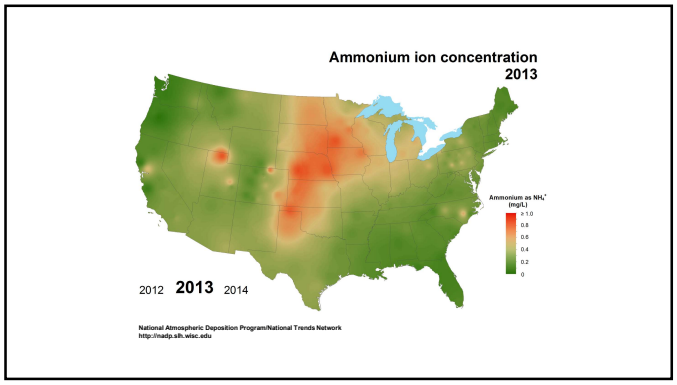
41


Ammonium ion concentration
2011
Ammonium as NH4+ (mg/L)
≥ 1.0
0.8
0.6
0.4
0.2
0
2010 2011 2012
National Atmospheric Deposition Program/National Trends Network
http://nadp.sih.wisc.edu

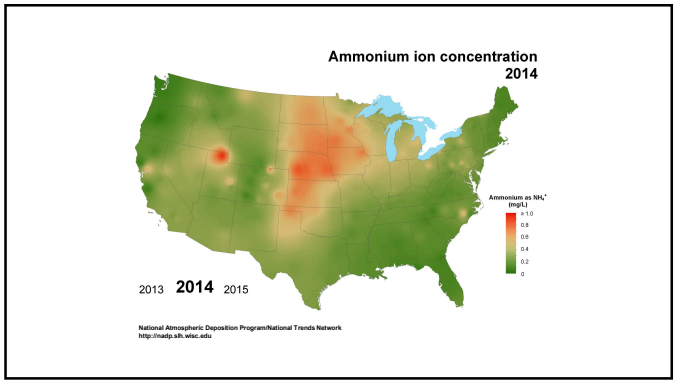
42


Ammonium ion concentration
2012
Ammonium as NH4+ (mg/L)
≥ 1.0
0.8
0.6
0.4
0.2
0
2011 2012 2013
National Atmospheric Deposition Program/National Trends Network
http://nadp.sih.wisc.edu

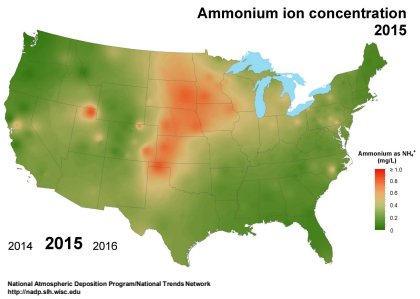
43


Ammonium ion concentration
2013
Ammonium as NH4+ (mg/L)
≥ 1.0
0.8
0.6
0.4
0.2
0
2012 2013 2014
National Atmospheric Deposition Program/National Trends Network
http://nadp.sih.wisc.edu

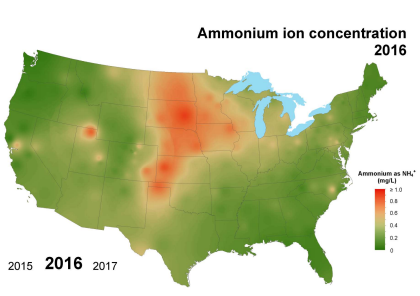
44


Ammonium ion concentration
2014
Ammonium as NH4+ (mg/L)
≥ 1.0
0.8
0.6
0.4
0.2
0
2013 2014 2015
National Atmospheric Deposition Program/National Trends Network
http://nadp.sih.wisc.edu

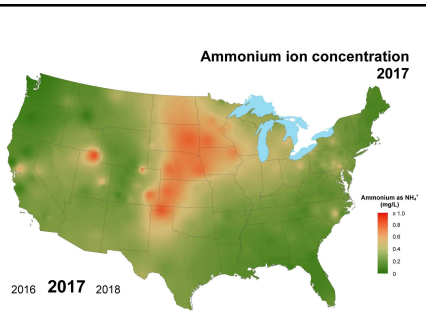
45


Ammonium ion concentration
2015
Ammonium as NH4+ (mg/L)
2014 2015 2016
National Atmospheric Deposition Program/National Trends Network
http://nadp.sih.wisc.edu

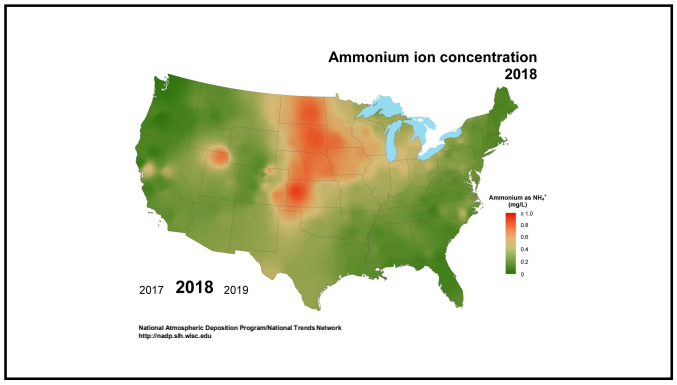
46


Ammonium ion concentration
2016
Ammonium as NH4+ (mg/L)
2015 2016 2017
National Atmospheric Deposition Program/National Trends Network
http://nadp.sih.wisc.edu

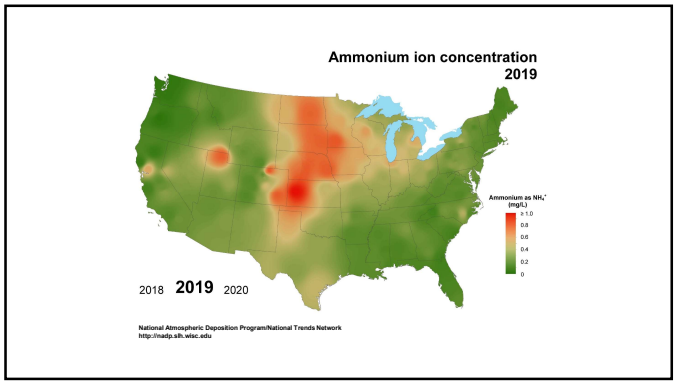
47


Ammonium ion concentration
2017
Ammonium as NH4+ (mg/L)
2016 2017 2018
National Atmospheric Deposition Program/National Trends Network
http://nadp.sih.wisc.edu

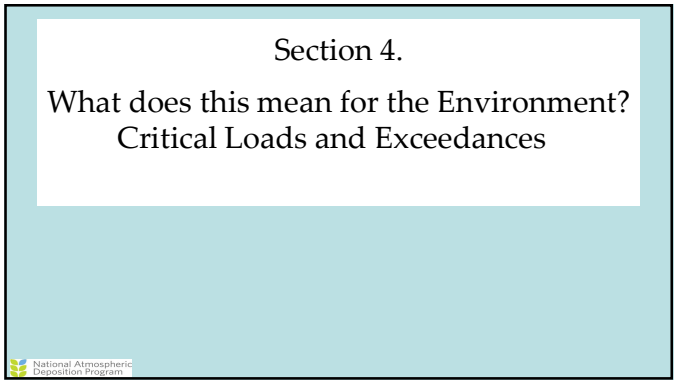
48


Ammonium ion concentration
2018
Ammonium as NH4+ (mg/L)
≥ 1.0
0.8
0.6
0.4
0.2
0
2017 2018 2019
National Atmospheric Deposition Program/National Trends Network
http://nadp.sih.wisc.edu

49


Ammonium ion concentration
2019
Ammonium as NH4+ (mg/L)
≥ 1.0
0.8
0.6
0.4
0.2
0
2018 2019 2020
National Atmospheric Deposition Program/National Trends Network
http://nadp.sih.wisc.edu

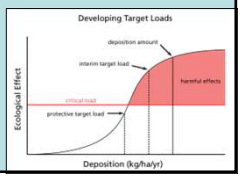
50


Section 4.
What does this mean for the Environment?
Critical Loads and Exceedances
National Atmospheric Deposition Program

51

Critical Loads Evaluation of NH_3?

- International and U.S. federal land managers use the concept of critical loads (CLs) to assess and manage effects of atmospheric deposition.
- A CL is a level of atmospheric deposition *below which adverse effects to ecosystems are not expected* to occur given current understanding
- Nitrogen CL (atmospheric deposition) have been determined and are being utilized to identify areas where decreases in AD or other management actions are needed to maintain healthy ecosystems



National Atmospheric Deposition Program

52

Estimates of Critical Load Exceedances, Tree Growth & Survival

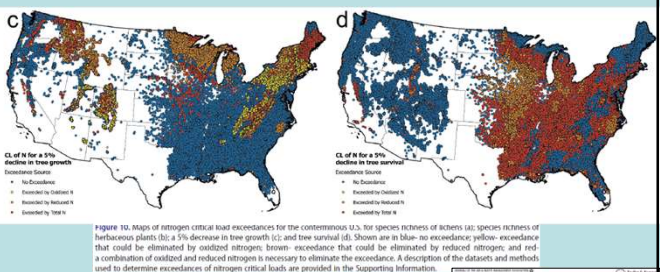


Figure 10. Maps of nitrogen critical load exceedances for the conterminous U.S. for species richness of lichens (a); species richness of herbaceous plants (b); a 5% decrease in tree growth (c); and tree survival (d). Shown are in blue- no exceedance; yellow- exceedance that could be eliminated by oxidized nitrogen; brown- exceedance that could be eliminated by reduced nitrogen; and red- a combination of oxidized and reduced nitrogen is necessary to eliminate the exceedance. A description of the datasets and methods used to determine exceedances of nitrogen critical loads are provided in the Supporting Information.

Atmospheric reduced nitrogen: Sources, transformations, effects, and management

National Atmospheric Deposition Program

53

And On Coastal Waters (Eutrophication)

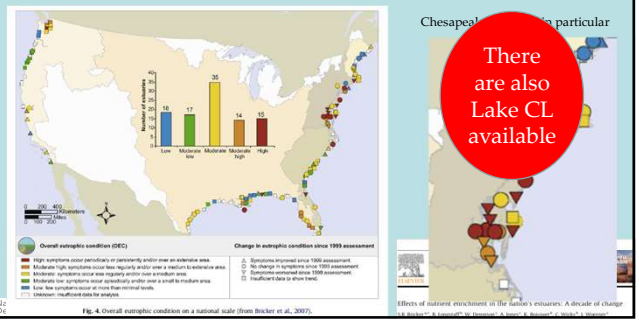


Fig. 4. Overall eutrophic condition on a national scale (from Bricker et al., 2007).

Effects of nutrient enrichment in the nation's estuaries: A decade of change

54

Section 5.

Best management practices
(more in Presentation 3)

National Atmospheric Deposition Program

55

Summary of Agricultural Management Practices

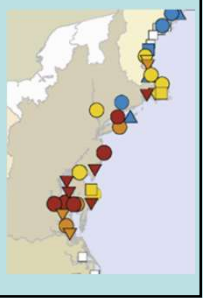
- Congress & USDA establish national priorities of "Air quality"(7 CFR §1466.4)
  - "Emissions of Airborne Reactive Nitrogen" specifically listed as a resource concern by NRCS
  - NRCS Conservation Practice Standard (CPS) 590 covers nutrient management for croplands, including decreasing fertilizer application rates, use of nitrification inhibitors and slow-release fertilizers, and replacing synthetic fertilizer with livestock manure (NRCS 2023b).
  - NRCS also has conservation practice standards for reducing ammonia from livestock operations that include air filtration and scrubbing (CPS 371), feed management (CPS 592), amendments for treatment of agricultural waste (591), and waste treatment (CPS 629)
- The USDA currently administers incentive programs covering a broad range of environmental concerns,
- Environmental Quality Incentives Program ("EQIP", 7 CFR Part 1466) is the main working lands program with potential to address NH3 emissions.
  - Payments to eligible farmers/ranchers for investment in equipment and management practices to mitigate air and water pollution and/or improve soil, water, and wildlife conservation.
  - $1.2 billion was obligated in 2022 (USDA 2023) and has been increasing.

National Atmospheric Deposition Program

56

In Summary

- Nitrogen emission to the atmosphere is very important to many areas
- It is driven by very significant increases of Ammonia
- This is primarily due to Agricultural Sources
  - Multiple agricultural sources (swine, dairy, fertilizer, etc.)
- We are seeing more ammonia, both in wet and dry deposition and air concentrations
- And it is having an effect on
  - air quality and visibility
  - forest, agricultural and water environments through deposition
- Agriculture has a role to play in the solution
  - Improve best management practices
  - And control N releases



57

NADP Total Deposition Science Committee Ag. Stakeholders Webinar Series

Webinar series to start on **Wednesday October 9th at 2:00pm ET, 1:00pm CT, 12pm MT, 11am PT**

- Consist of 3 webinars that expand upon topics discussed in this webinar. Webinars are approximately an hour in length and will be held approximately every 1-2 months with a common topic for each webinar.

Webinar # 1: *Impact of Atmospheric Nitrogen Deposition on Water Quality*

- Presentation 1: Overview of the Role of Agriculture in Impacting Nitrogen Deposition: Sources, Impacts and Management - **David Gay** (University of Wisconsin Madison)
- Presentation 2: Cleaner Air, Cleaner Water? Impacts of Atmospheric Nitrogen Deposition on Water Resources in the United States - **Robert Sabo** (EPA - Office of Research and Development (ORD))
  - Scientist at EPA-ORD since December 2019
  - Research lead for ORD's National Nutrient Inventory Research Portfolio, a multi-agency effort developing novel tools, models and datasets designed to track the evolution of point and nonpoint sources of nutrient pollution to waterways across the U.S. and how changing environmental conditions impact waterbodies

- More information including how to **register for the Ag. Stakeholder webinars** will be provided on the NADP website at https://nadp.slh.wisc.edu/ and https://nadp.slh.wisc.edu/committees/tdep/

58

58

Introduction to Nitrogen Deposition for Agriculture

Long-term measurements to support deposition and critical load assessments in the U.S.

David A. Gay

NADP Program Office,
University of Wisconsin Madison,
dgay2@wisc.edu, (217) 898-1444

National Atmospheric Deposition Program

59