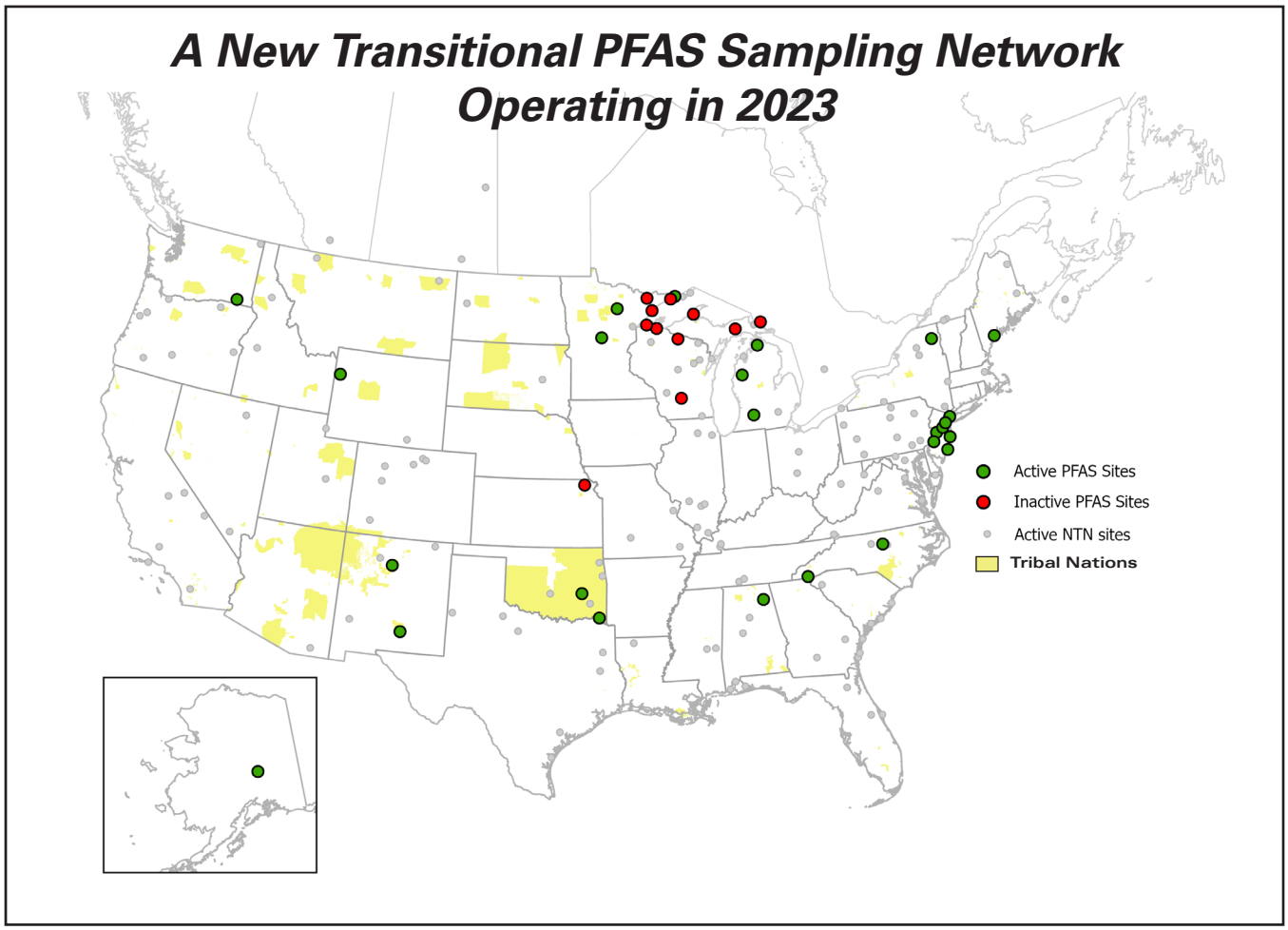
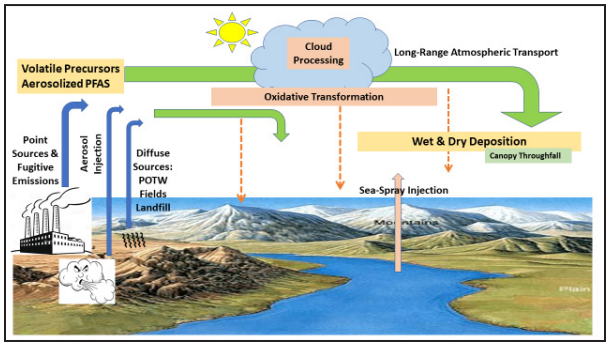
National Atmospheric Deposition Program

2023 Annual Summary



AK03	*AL99*	*ME96*	*MI09*	*MI26*	*MI53*	*MN16*	*MN23*	*MN97*
NC25	*NC30*	*NC96*	*NC97*	*NJ00*	*NJ30*	*NJ54*	*NJ39*	*NJ99*
Camden	*NM07*	*NM08*	*NY06*	*NY98*	*OK24*	*OK96*	*WA04*	*WY94*

On the Cover: At the Fall 2023 meeting, the PolyFluoroAlkyl Substances (PFAS) subnetwork advocates (representing US EPA, USGS, NPS, Native American tribes, several states and a private concern) proposed the transitional PFAS NTN-subnetwork for at least a one-year period beginning Jan 1, 2024.



The PFAS NTN-subnetwork (PFN) measures the concentration of 33 PFAS compounds in weekly NTN samples. The PFN has continued to grow with support from new partners (see map). Sites shown are locations of all sites collecting samples since 2020, and those continuing as of 1/1/2024, and several starting in early 2024 before publishing. See nadp.slh.wisc.edu/pfas-sub-network/, and more information on page 6.

When referencing maps or information in this report, please use the citation: National Atmospheric Deposition Program, 2024. National Atmospheric Deposition Program 2023 Annual Summary. Wisconsin State Laboratory of Hygiene, University of Wisconsin-Madison, WI.

Contents

2023 Highlights

The National Atmospheric Deposition Program provides high-quality, robust measurements that support informed decisions about environmental and public health issues as they relate to atmospheric deposition chemistry, and advance our understanding of atmospheric processing through the measurement of gaseous ammonia and mercury. NADP data is relevant to scientists, educators, policymakers, and the public. All data is available without charge on the NADP website (http://nadp.slh.wisc.edu).

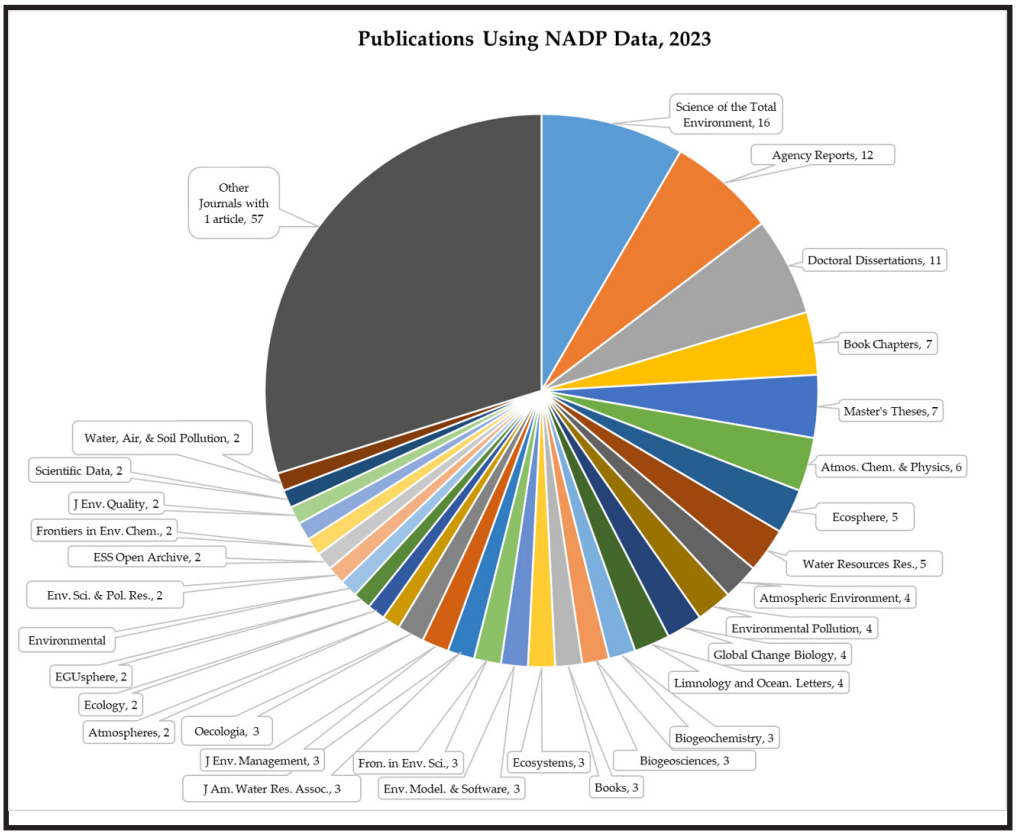
The NADP is composed of five networks, including the National Trends Network (NTN), the Mercury Deposition Network (MDN), the Atmospheric Mercury Network (AMNet), the Ammonia Monitoring Network (AMoN), and the Mercury Litterfall Network (MLN). The table nearby summarizes the number of measurements from each network in 2023.

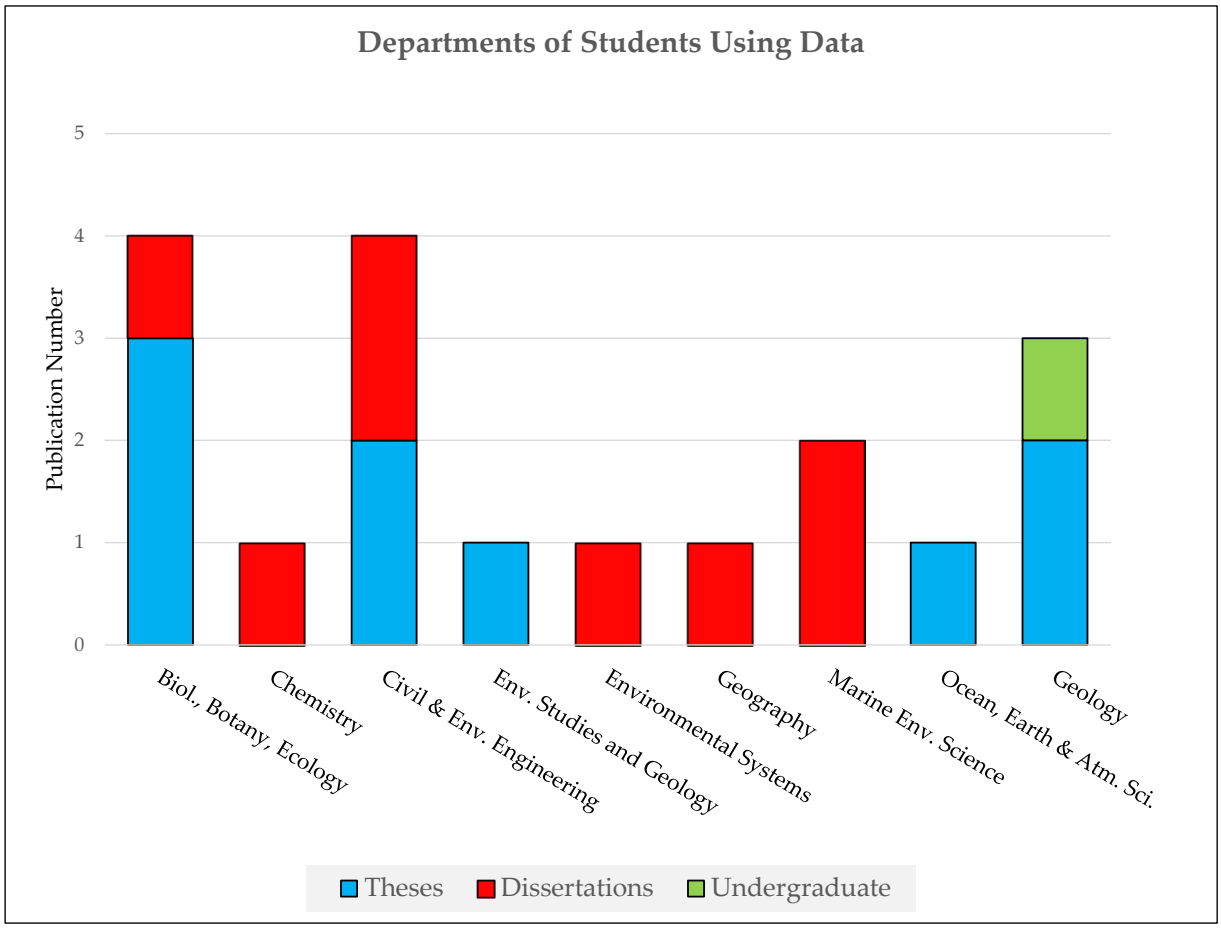
Summary of 2023 Network Measurements

Network	Measurements	Period	No. of sites
NTN	12,818	weekly	253
MDN	4,084	weekly	84
AMNet	43,056	hourly/ 2-hourly	11
AMoN	3,118	two week	92
MLN	25	seasonal	29

Highlights:

- During the 2023 calendar year, 191 articles and reports were identified as having used NADP data. See the figure below for where these data appeared. Within the publications, there were several non-journal publications, including:
  - 11 doctoral dissertations
  - 7 master's theses
  - 12 agency/institute reports





- You might notice that country north of the Border in our 2023 maps; that is Canada, now mapped in all NTN maps, and more consistent with the MDN maps.

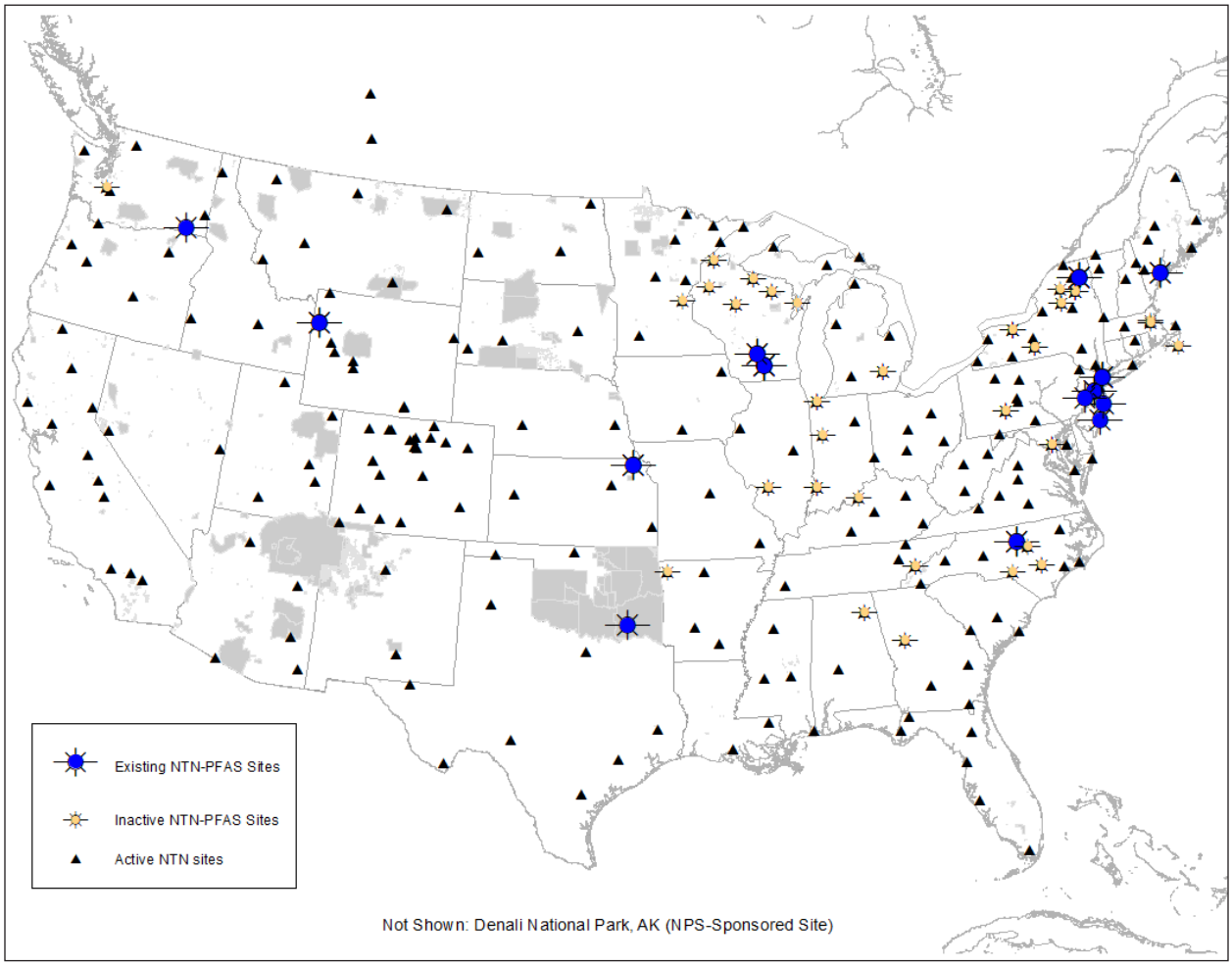
- NADP Officers beginning in October 2023
  - Chair: Mike Bell, NPS
  - Vice Chair: Melissa Puchalski, US EPA
  - Secretary: Catherine Collins, US EPA Reg. 8
  - Past Chair: Dr. John Walker, US EPA

- The 2023 Annual Fall Meeting and Scientific Symposium was held in Madison, WI from October 23 through 27, 2023. It was again a hybrid meeting, with 232 total attendees (https://nadp.slh.wisc.edu/nadp2023/).

  The Friday tour included a lecture of the Epic Solar installation, a short lecture at Devils Lake State Park (Dr. Bill Sonzogni, UW Madison), and a visit to the longterm NTN and MDN WI31 site operated by the Wisconsin Department of Natural Resources.

- At the Fall 2023 Meeting, the PFAS Subnetwork advocates (representing US EPA, USGS, NPS, several states and a private concern) proposed a motion to make the PFAS subnetwork an official Pilot Network of NADP for a one year period beginning Jan 1, 2024. This motion was approved by the Executive Committee.

  The PFAS subnetwork measures the concentration of 33 PFAS compounds (Per- and polyfluoroalkyl substances) in weekly NTN samples. Over the previous years, PFAS samples have been made at many sites, and these are illustrated in the map below. At the meeting, the advocates had 16 pilot sites planning to operate in network mode as of November 1 (EPA, NJ, NY, included below).



Current and Past Monitoring Site Locations

- "The 10th International Conference on Acid Deposition, ACID RAIN 2020 – The Future Environment and Role of Multiple Air Pollutants" meeting was held April 17-21, 2023 in Niigata City, Japan (it was delayed three years by COVID).

  The NADP was a sponsor for the event and attended (Schauer, Gay, Burns, et al.). There were 215 participants from 21 countries represented (www.acidrain2020.org).

- The East Palestine Ohio train accident occurred on February 3, 2023, and the chemical traces of the accident fires were identified in our samples. The spatial extent of this unusual chemistry was documented in a journal article (right). Basic results showed that the compounds (namely H^+ ion, Cl^- ion, Ca^{2+} ion, etc.) were present in extremely high concentrations at many sites from Wisconsin to North Carolina. The article received significant news coverage, and the NADP received important recognition.


IOP Publishing Environ. Res. Lett. 19 (2024) 074022 https://doi.org/10.1088/1748-9326/ad52ac

ENVIRONMENTAL RESEARCH
LETTERS

LETTER

OPEN ACCESS

Widespread Impacts to precipitation of the East Palestine Ohio train accident

David A Gay*, Katelan Blaydes, James J Schauer and Martin Shafer

National Atmospheric Deposition Program, Wisconsin State Laboratory of Hygiene, University of Wisconsin Madison, 465 Henry Mall, Madison, WI 53706, United States of America

- During the year, these operators received 20, 25, and 30 year awards (table below). Both Bill and Robert exemplify the dedicated operators we have in the NADP networks. Thanks go to both Robert and Bill, and all of our operators, for many, many hours of excellent work.

Award	Primary Operator	Years	siteID	Networks	Site Name	Funding Agency
30 year awards	Bill Gawley	1993-2023	ME98	NTN, MDN	Acadia National Park-McFarland Hill	National Park Service
	Robert Ziegler	1993-2023	PA15	NTN	Penn State Univ.	NOAA
25 year awards	Charles Welsh	1998-2023	GA99	NTN	Chula	USGS
	Linda Weeks Connor	1998-2023	MT96	NTN	Poplar River	Fort Peck Tribes
	Linda Madron	1998-2023	NM08	NTN	Mayhill	USGS
	John E. Bithorn	1998-2023	PR20	NTN, MDN, AMoN	El Verde	USDA-Forest Service/USGS
20 year awards	Denise Dickson	2003-2023	MI51	NTN, AMoN	Unionville	WSP-US EPA
	John Korfmacher	2003-2023	WY00	NTN	Snowy Range	USDA-Forest Service
	John Korfmacher	2003-2023	WY95	NTN, AMoN	Brooklyn Lake	USDA-Forest Service/WSP-US EPA

30 Year Site Operators - Robert Ziegler (left) and Bill Gawley (right)

NADP Background

The NADP was established in 1977 under State Agricultural Experiment Station (SAES) leadership to address the problem of atmospheric deposition, and its effects on agricultural crops, forests, rangelands, surface waters, and other natural and cultural resources. The NADP's primary charge was to provide data on the temporal trends and geographic distribution of the atmospheric deposition of acids, nutrients, and base cations by precipitation. In 1978, sites in the NADP precipitation chemistry network first began collecting weekly, wet-only deposition samples. Chemical analysis was performed at the Illinois State Water Survey's Central Analytical Laboratory (CAL), located at the University of Illinois Urbana-Champaign and the Program Coordinator was housed at Colorado State University.

Initially, the NADP was organized as SAES North Central Regional Project NC-141, which all four SAES regions further endorsed in 1982 as Interregional Project IR-7. A decade later, IR-7 was reclassified as the National Research Support Project No. 3 (NRSP-3), which it remains to this day. NRSP projects are multistate activities that support research on topics of concern to more than one state or region of the country. Multistate projects involve the SAES in partnership with the USDA National Institute of Food and Agriculture (NIFA) and other universities, institutions, and agencies.

In October 1981, the federally-supported National Acid Precipitation Assessment Program (NAPAP) was established to increase our understanding of the causes and effects of acidic precipitation. This program sought to establish a long-term precipitation chemistry network of sampling sites away from point source influences. Building on its experience in organizing and operating a national-scale network, the NADP agreed to coordinate operation of NAPAP's National Trends Network. Later, to benefit from identical siting criteria, operating procedures, and a shared analytical laboratory, NADP and NTN merged with the designation NADP/NTN. This merger brought substantial new federal agency participation into the program. Many NADP/NTN sites were supported by the USGS, NAPAP's lead federal agency for deposition monitoring.

In October 1992, the AIRMoN was formed from the Multistate Atmospheric Power Production Pollution Study (MAP3S), which was operated by the Department of Energy and NOAA. MAP3S measured wet deposition and estimated dry deposition (later discontinued) for the same analytes. AIRMoN sites collect samples daily when precipitation occured, and were analyzed for the same analytes as NTN samples.

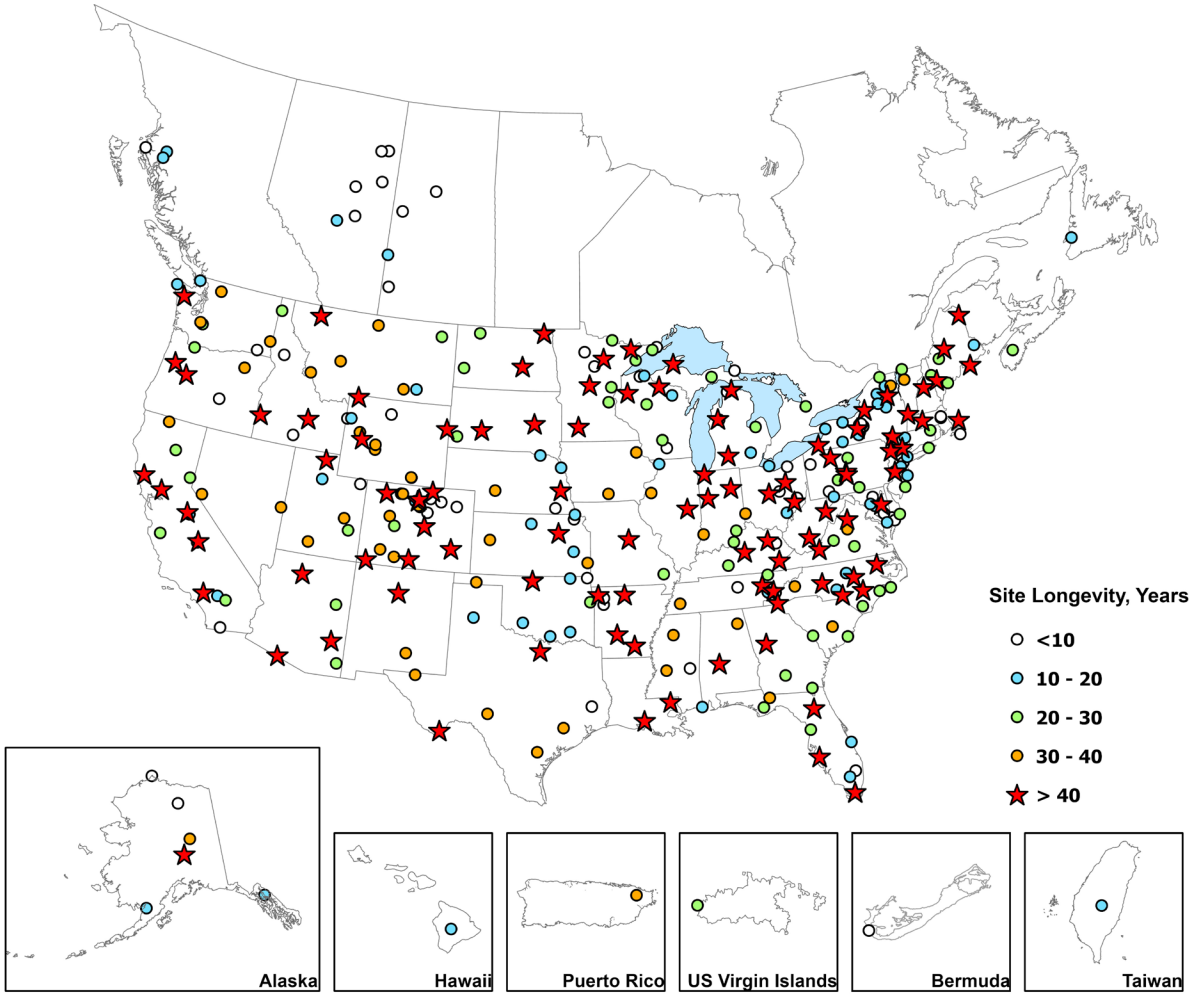
In January 1996, the NADP established the MDN, the third network in the organization. The MDN was formed to provide data on the wet deposition of mercury to surface waters, forested watersheds, and other receptors. MDN samples, like NTN samples, are weekly collections.

In October 2009, AMNet joined the NADP as its fourth network. AMNet measures the concentration of atmospheric mercury at high-time resolution using on-site, real-time analyzers.

In October 2010, AMoN joined the NADP. Atmospheric ammonia concentrations are measured every two weeks using passive samplers. The AMoN furthers the understanding of wet and dry deposition and ammonia partitioning in the atmosphere, allowing better assessment of ecosystem impacts and secondary air pollution formation.

Beginning in late 2017 and completed in mid-2018, the NADP PO and CAL moved from the University of Illinois at Urbana-Champaign to the University of Wisconsin–Madison. In June 2019 the HAL moved to the University of Wisconsin–Madison. Also in 2019, AIRMoN collected its last sample and the network was closed.

In the fall of 2021, the MLN joined the NADP. MLN measures concentrations of total mercury found in plant biomass litterfall. This measurement occurs in monthly samples over the autumn using passive collectors. The MLN provides information of additional mercury deposition in forested canopies.



Global distribution and longevity of NADP sites (years).

About the Maps

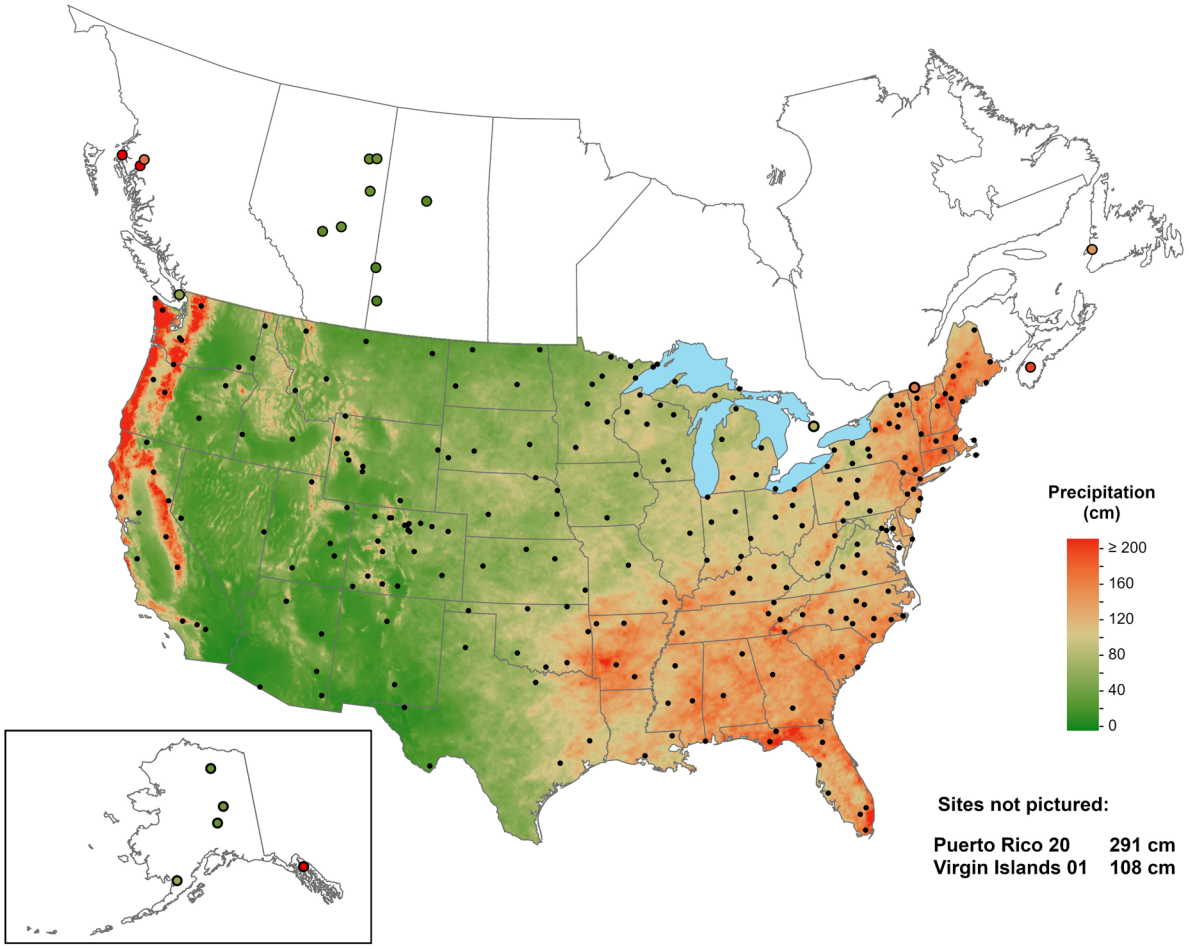
This map series is a principal product of the NADP. It summarizes the results of network operation for the most recent complete calendar year in graphical form. Additional maps, related geographic information, and reviewed analytical results are available on the NADP website.

To be included in a map product, site data must meet strict data completeness criteria (see the NADP website for details). Black dots mark site locations that met NADP completeness criteria in 2023. Open circles designate urban sites, defined as having at least 400 people per square kilometer (km^2) within a 15-km radius of the site. Sites (e.g., Canadian sites) that are too far removed from other observations to extend the contour surface also are represented as color- filled circles.

The map contour surface represents a gridded interpolation. Grid points within 500 km of each site are used in computations. Urban sites do not contribute to the contour surface. Colors represent interpolated values of concentration, deposition, or precipitation.

The precipitation surface is a modified version of the U.S. precipitation grid developed by the PRISM Climate Group ("Parameter-elevation Regressions on Independent Slopes Model," http:// prism.oregonstate.edu, data downloaded September 2024). These annual precipitation estimates incorporate point data, a digital elevation model, and expert knowledge of complex climatic extremes to produce continuous grid estimates. NADP precipitation observations are used to supplement the PRISM precipitation grids through an inverse distance weighting within a 20 km radius of each NADP site (see the NADP website for specific information). The resulting precipitation map is used to generate the deposition maps.

The precipitation figure on the next page has a continuous gradient of color from dark green (0 cm of precipitation) to yellow to dark red (greater than 200 cm of precipitation). Concentration and deposition maps follow this same format, with specified units on each map. All maps back to 1985 follow this schema and are available in multiple formats from the NADP website (https://nadp.slh.wisc.edu).



Total annual precipitation for 2023, using precipitation measurements from the NADP and PRISM (in cm).

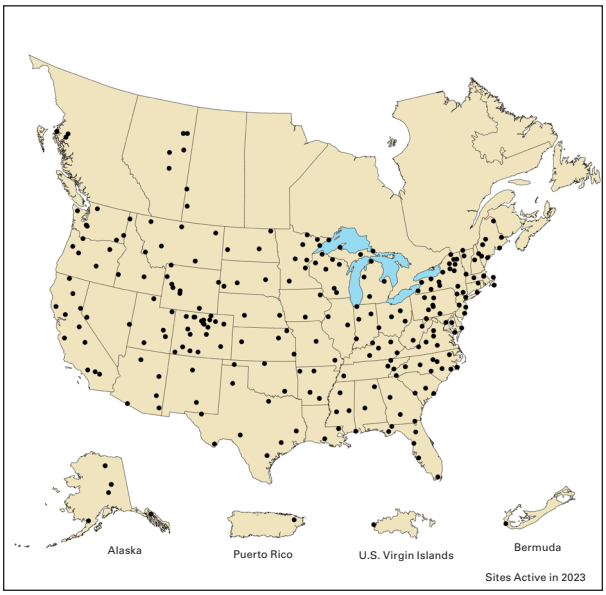
National Trends Network (NTN)

The NTN is the largest North American network that provides a long-term record of precipitation chemistry. Most sites are located away from urban areas and point sources of pollution, although urban sites do participate. Each site has a precipitation collector and precipitation gage. The automated collector ensures that sampling only occurs during precipitation events. Site operators follow standard operating procedures to help ensure NTN data comparability and representativeness across the network. Weekly samples are collected each Tuesday morning, using containers provided by the NADP.

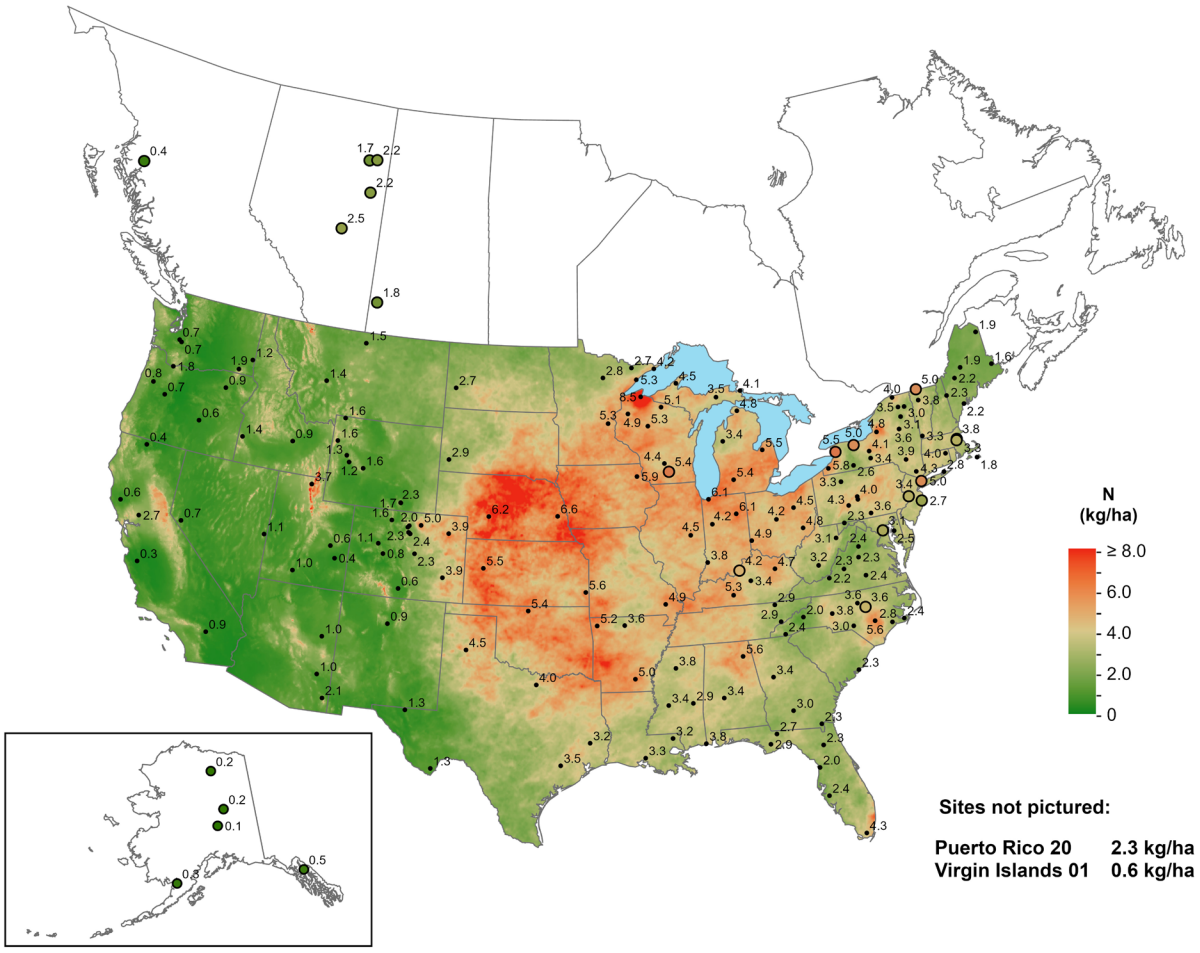
All samples are sent to the NADP laboratory for analysis of free acidity (H^+ as pH), specific conductance, calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^+), potassium (K^+), sulfate (SO_4^{2-}), nitrate (NO_3^-), chloride (Cl^-), and ammonium (NH_4^+) ions. The NADP quantifies orthophosphate for quality assurance purposes, as an indicator of potential field contamination. The CAL reviews field and laboratory data for accuracy and completeness and flags samples that were mishandled, compromised by equipment failure, or grossly contaminated. Data from the NTN are available on the NADP website (https://nadp.slh.wisc.edu/).

NTN Maps

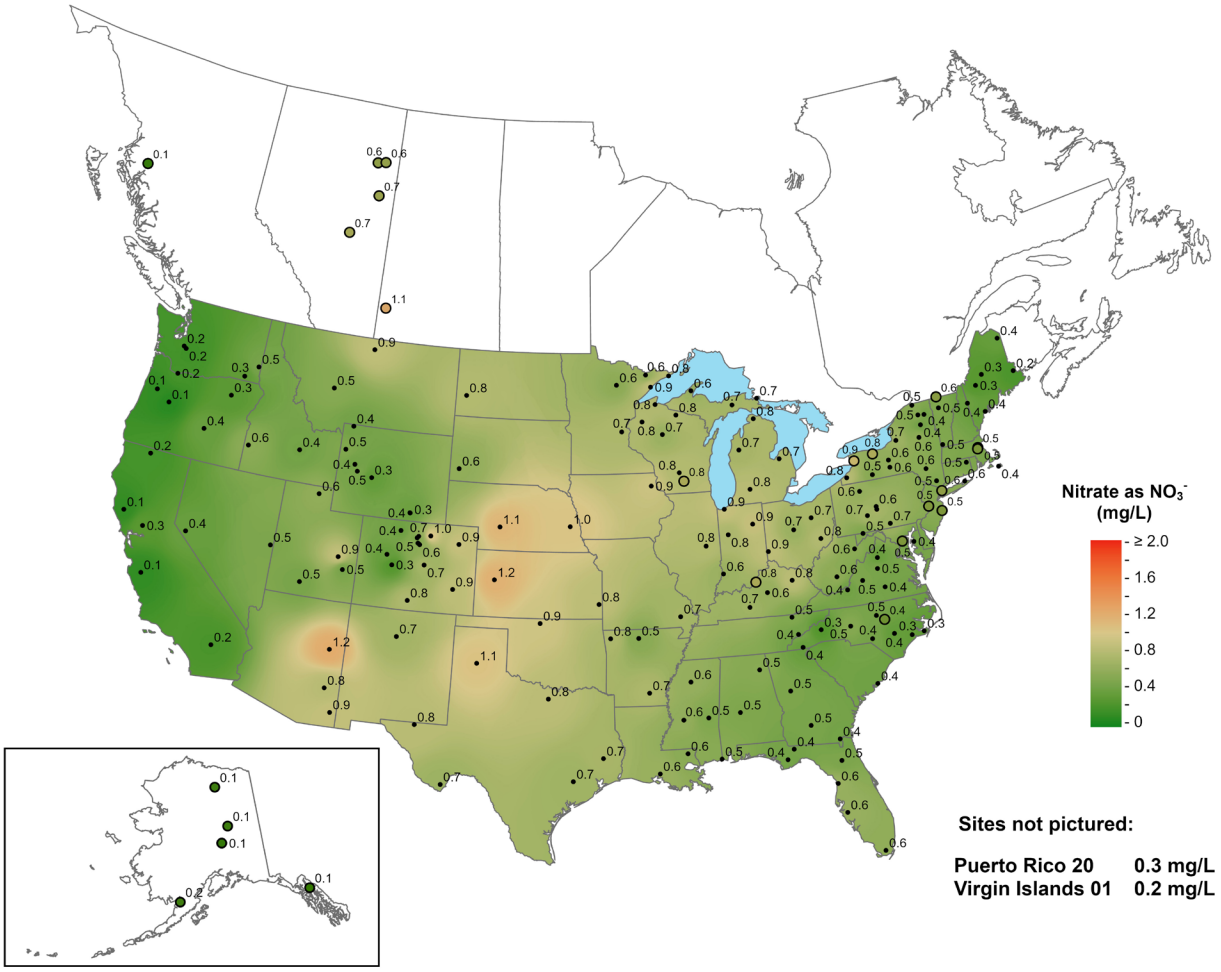
The maps on pages 13 through 33 show precipitation-weighted mean concentration and annual wet deposition for select acid anions, nutrients, and base cations. Substantial spatial heterogeneity across the nation is apparent for all measured species. In 2023, 185 of the 253 active sites met NADP completeness criteria. Concentration and deposition maps are included for SO_4^{2-}, NO_3^-, NH_4^+, pH, Ca^{2+}, Mg^{2+}, Cl^-, Na^+ and K^+.



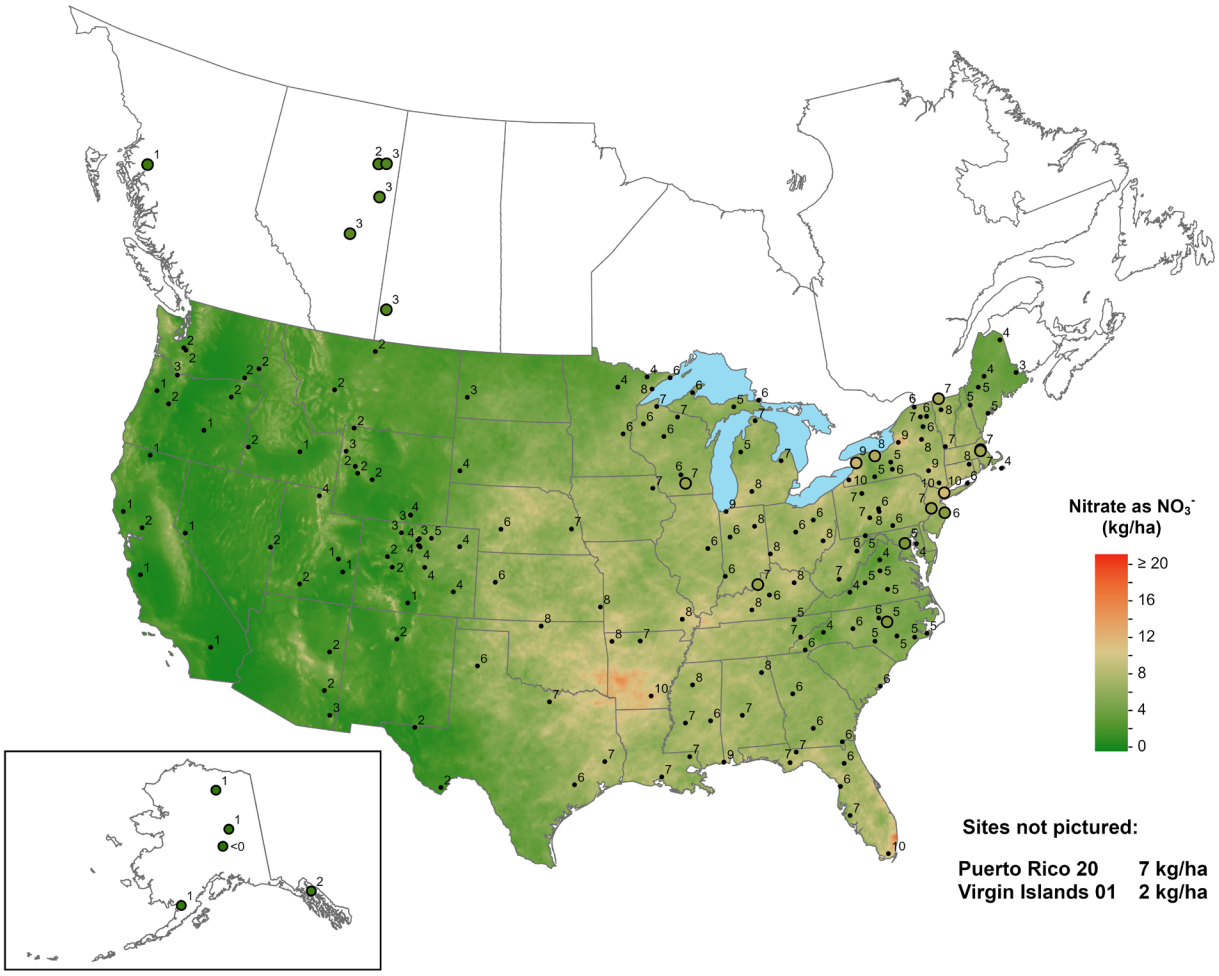
Annual maps for wet deposition of inorganic nitrogen (i.e., $NO_3^- + NH_4^+$) and sulfur + nitrogen (S + N) are also included. S + N (i.e., $SO_4^{2-} + NO_3^- + NH_4^+$) deposition is mapped as hydrogen ion equivalents per hectare (eq/ha).



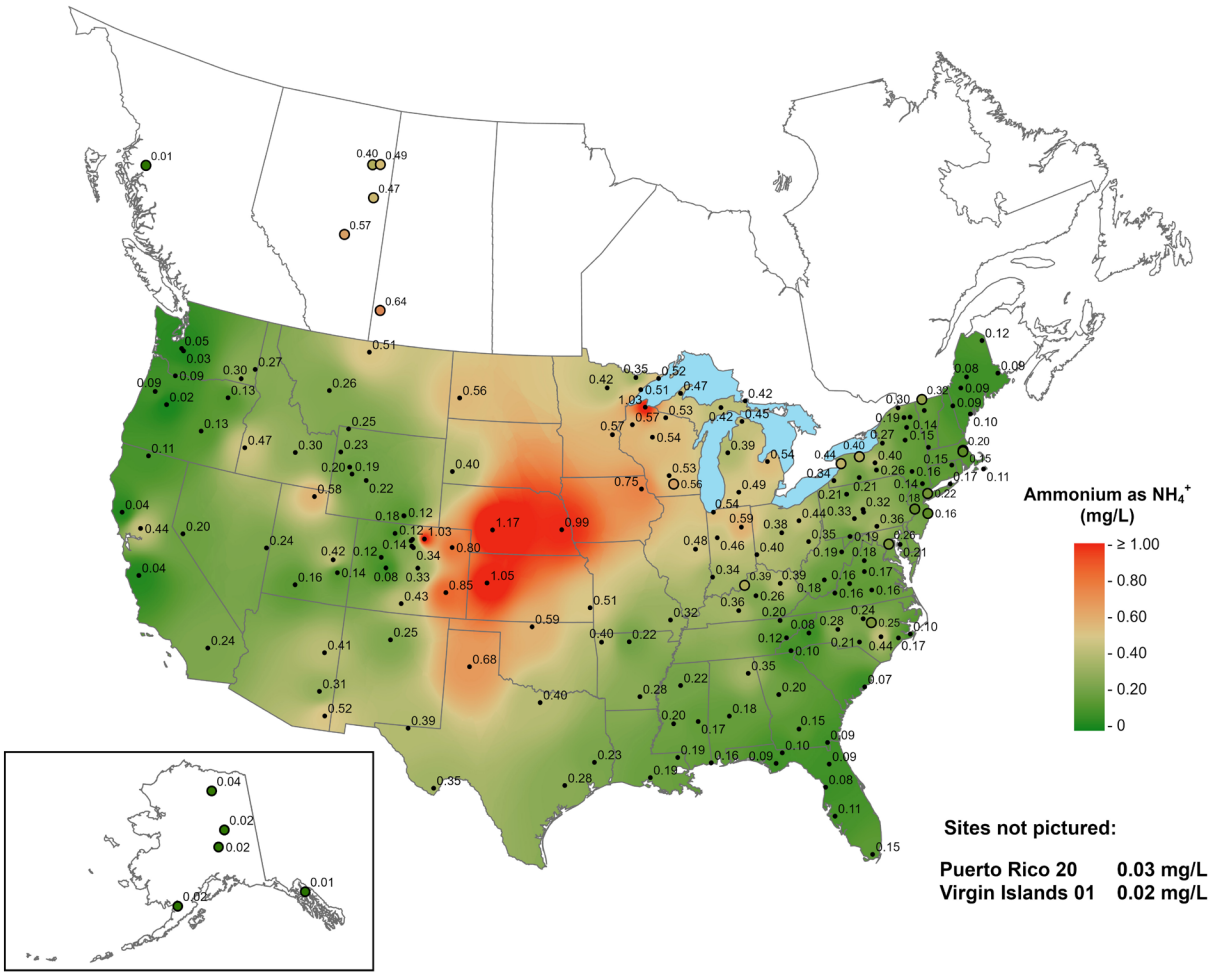
Inorganic nitrogen wet deposition from nitrate and ammonium, 2023.



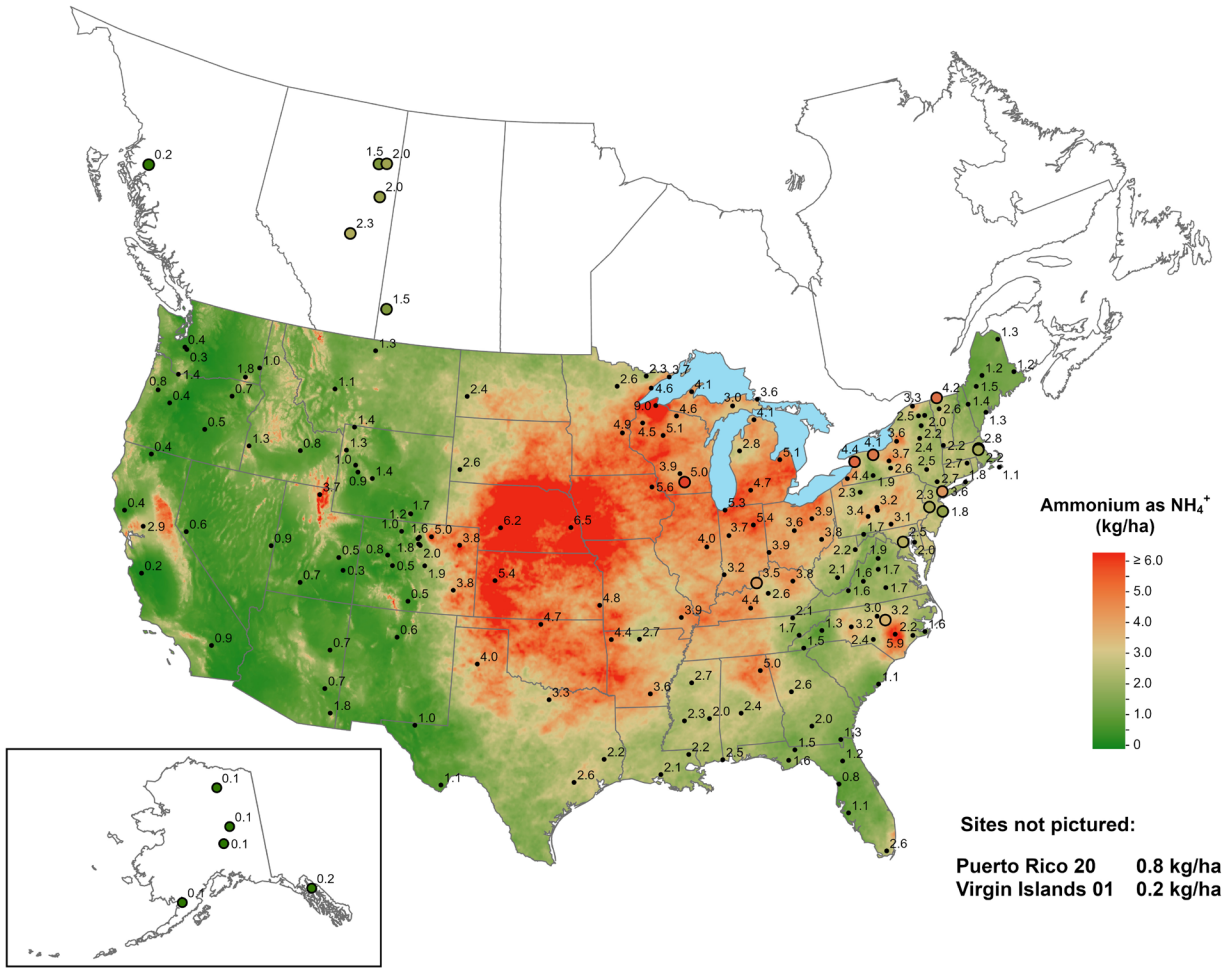
Nitrate ion concentration, 2023.



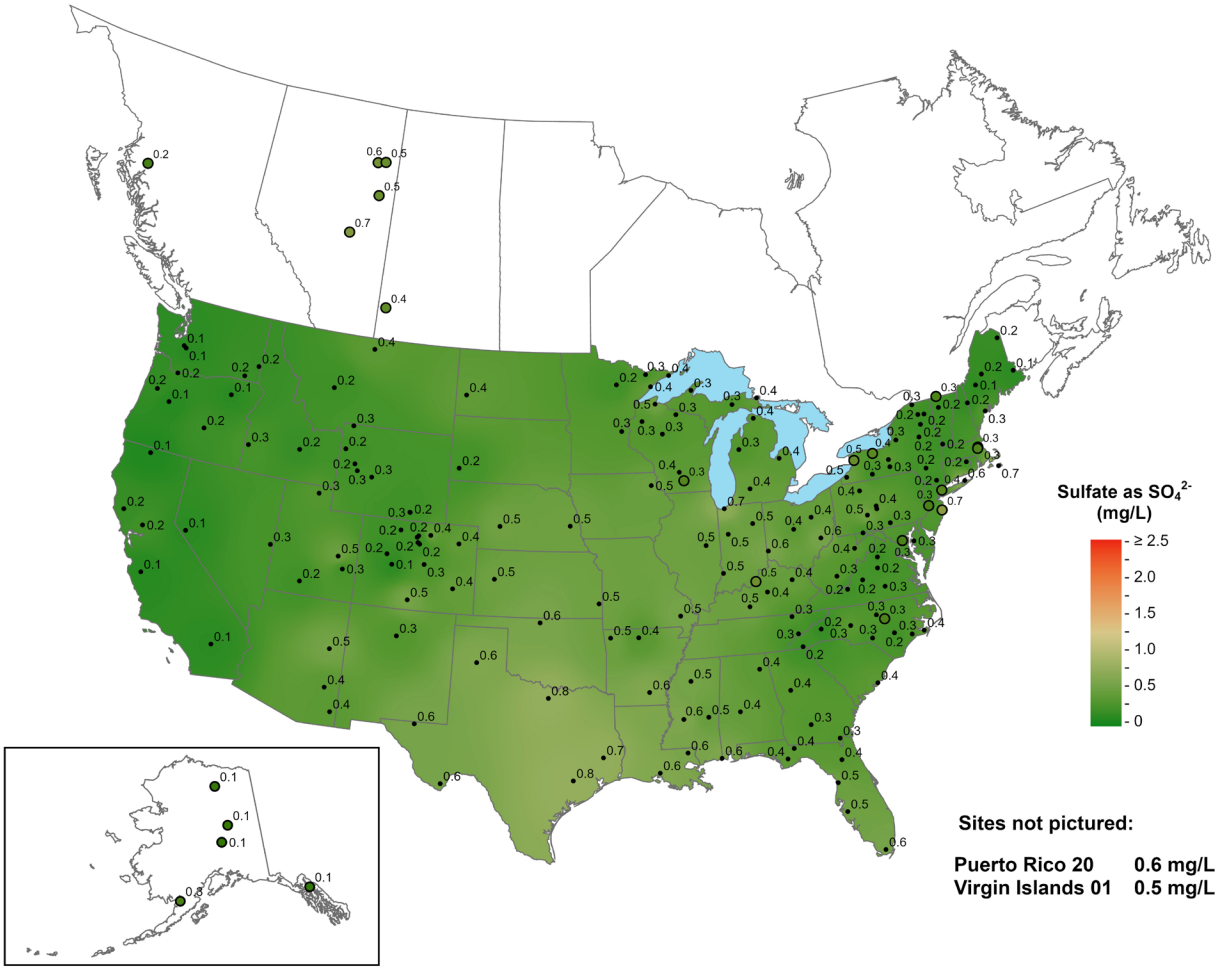
Nitrate ion wet deposition, 2023.



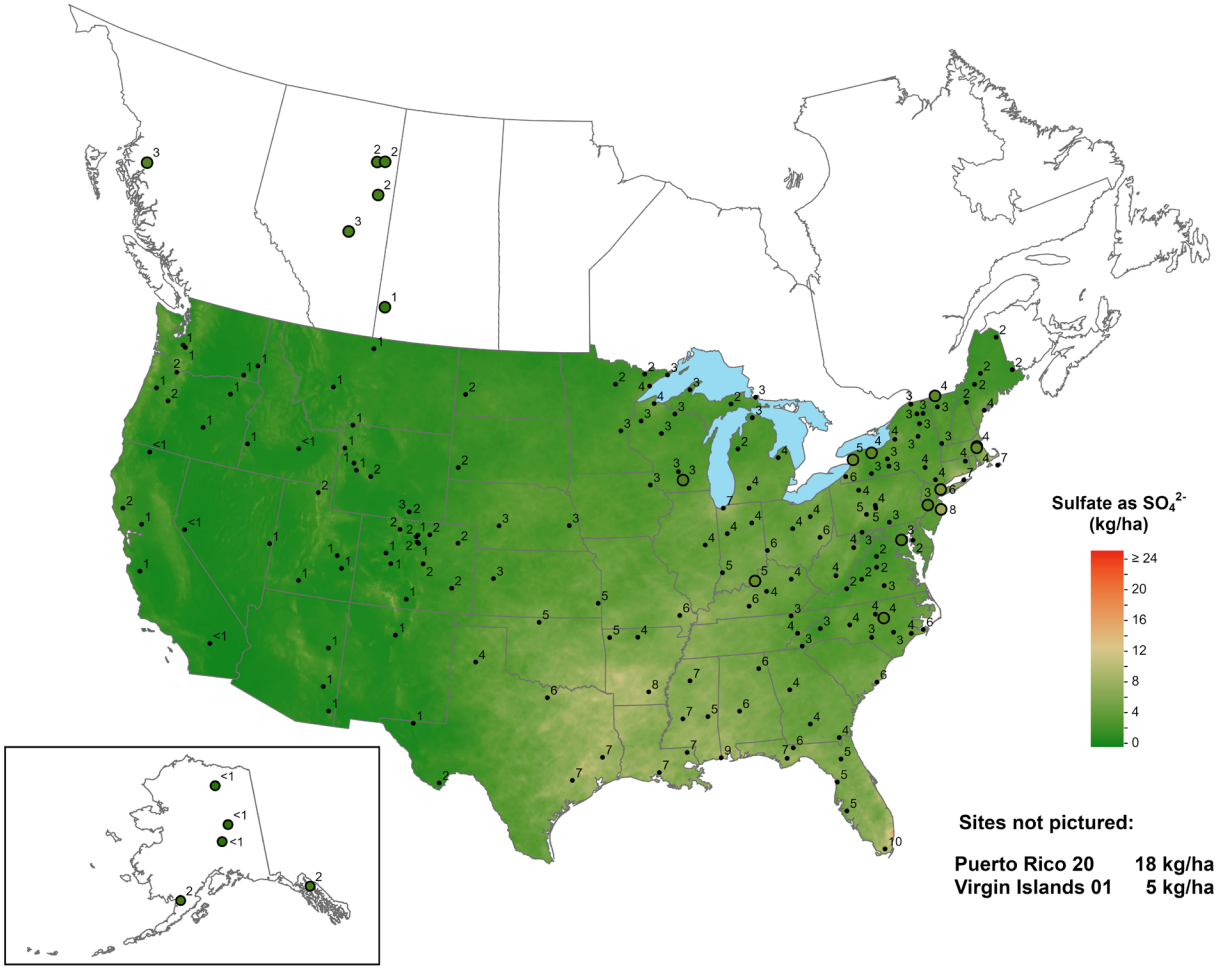
Ammonium ion concentration, 2023.



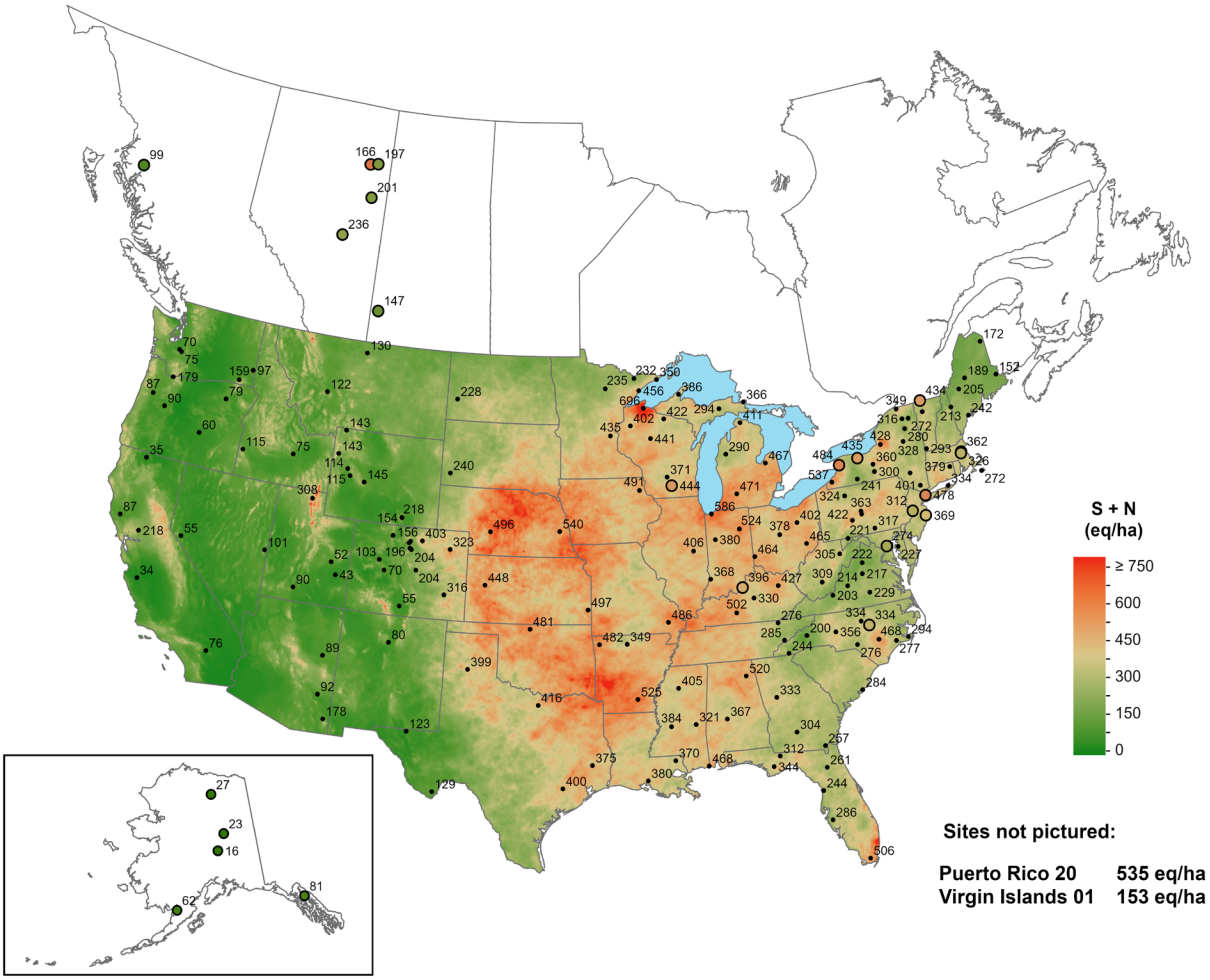
Ammonium ion wet deposition, 2023.



Sulfate ion concentration, 2023.

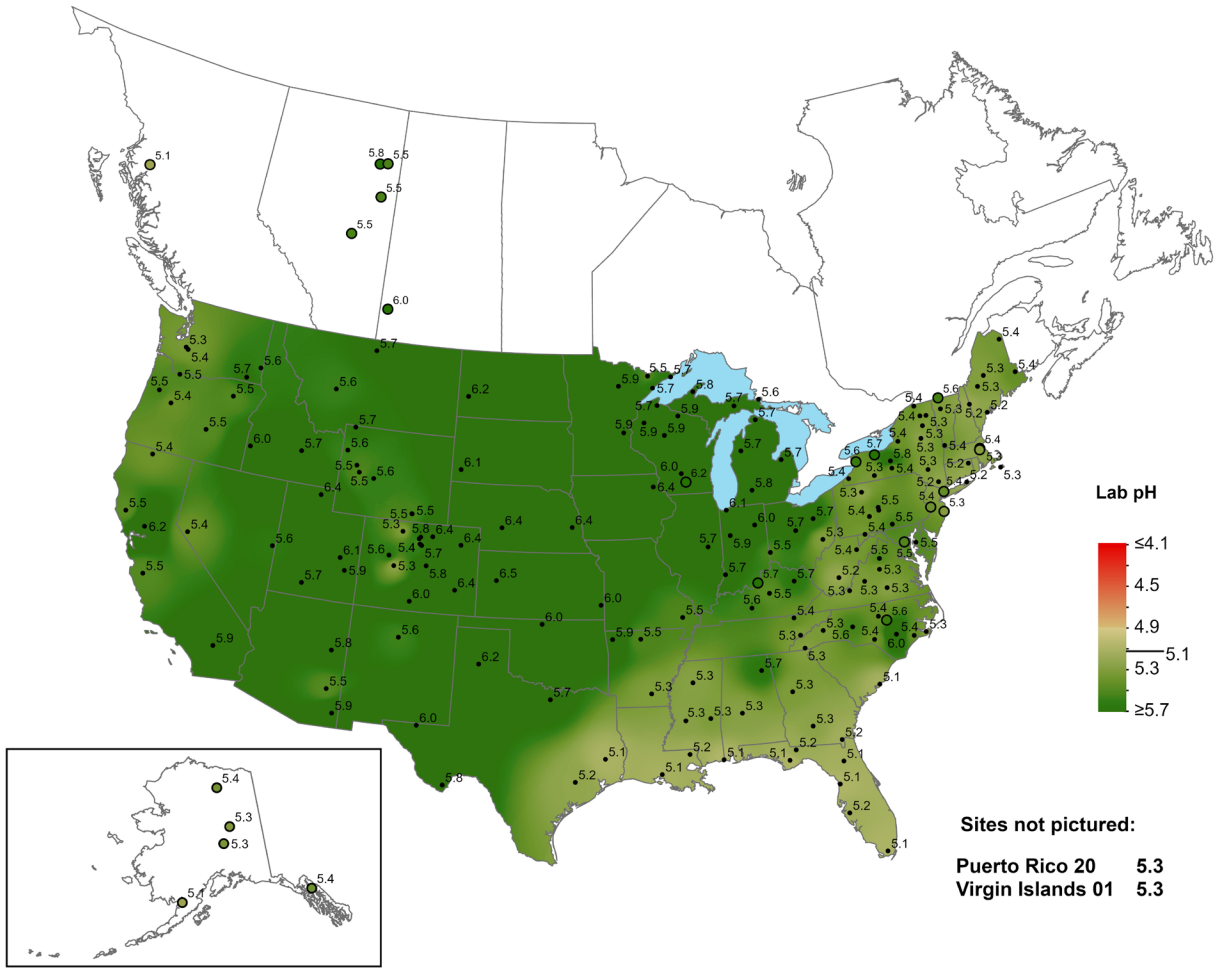


Sulfate ion wet deposition, 2023.

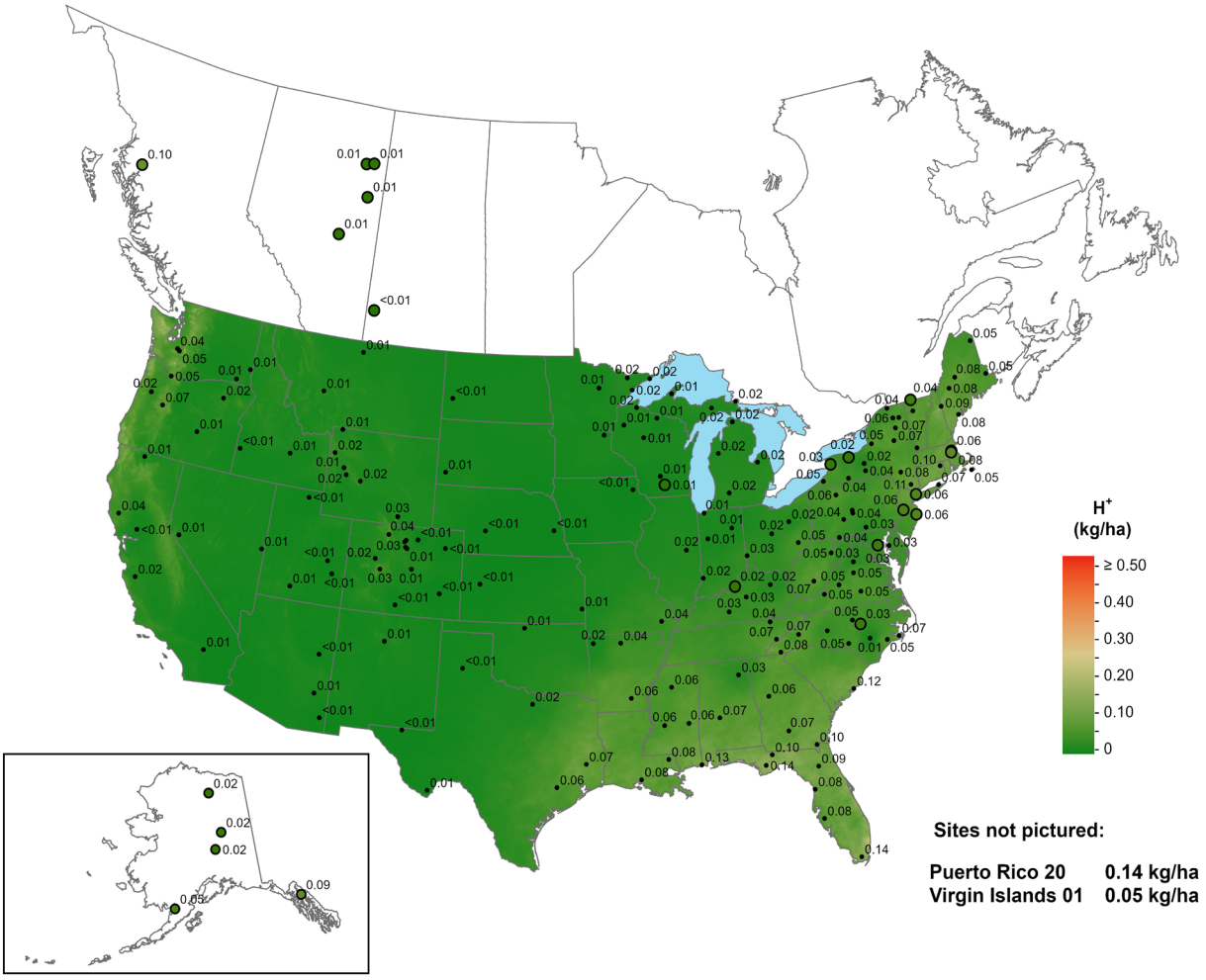


Sulfur plus nitrogen wet deposition from sulfate, nitrate and ammonium, 2023.

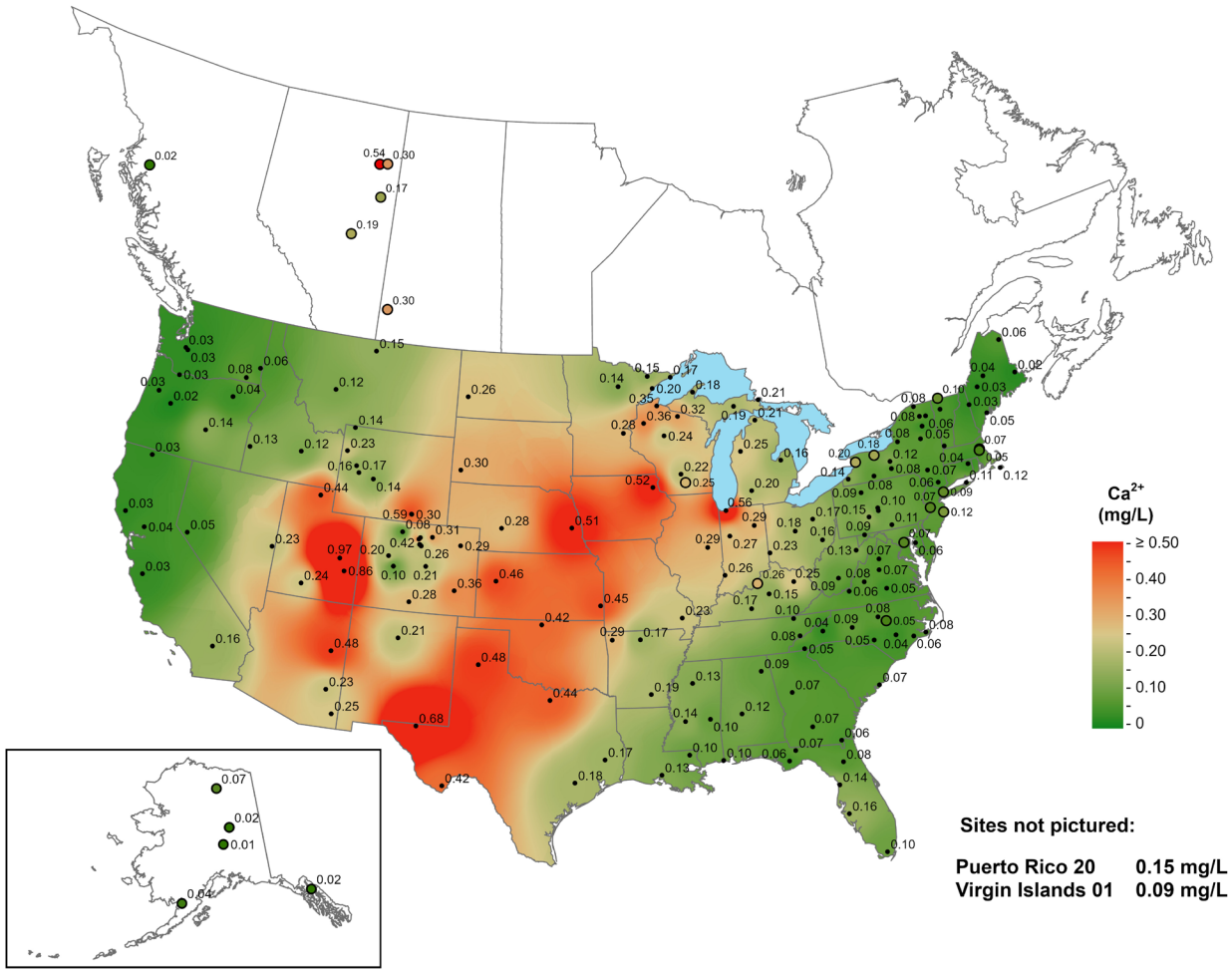
This page intentionally left blank.



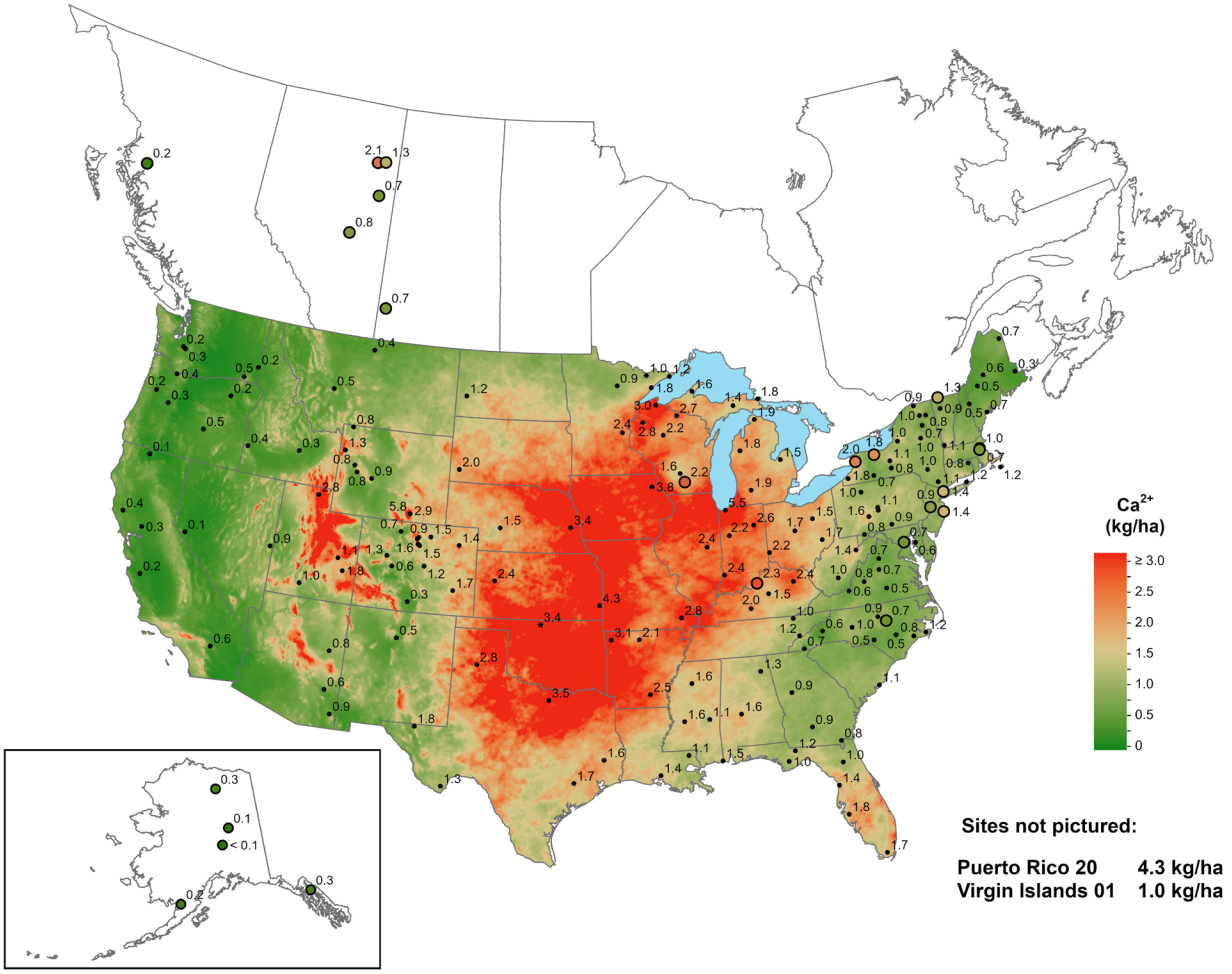
Hydrogen ion concentration as pH, 2023.
Typically, a precipitation pH of less than 5.1 is considered acidic precipitation.



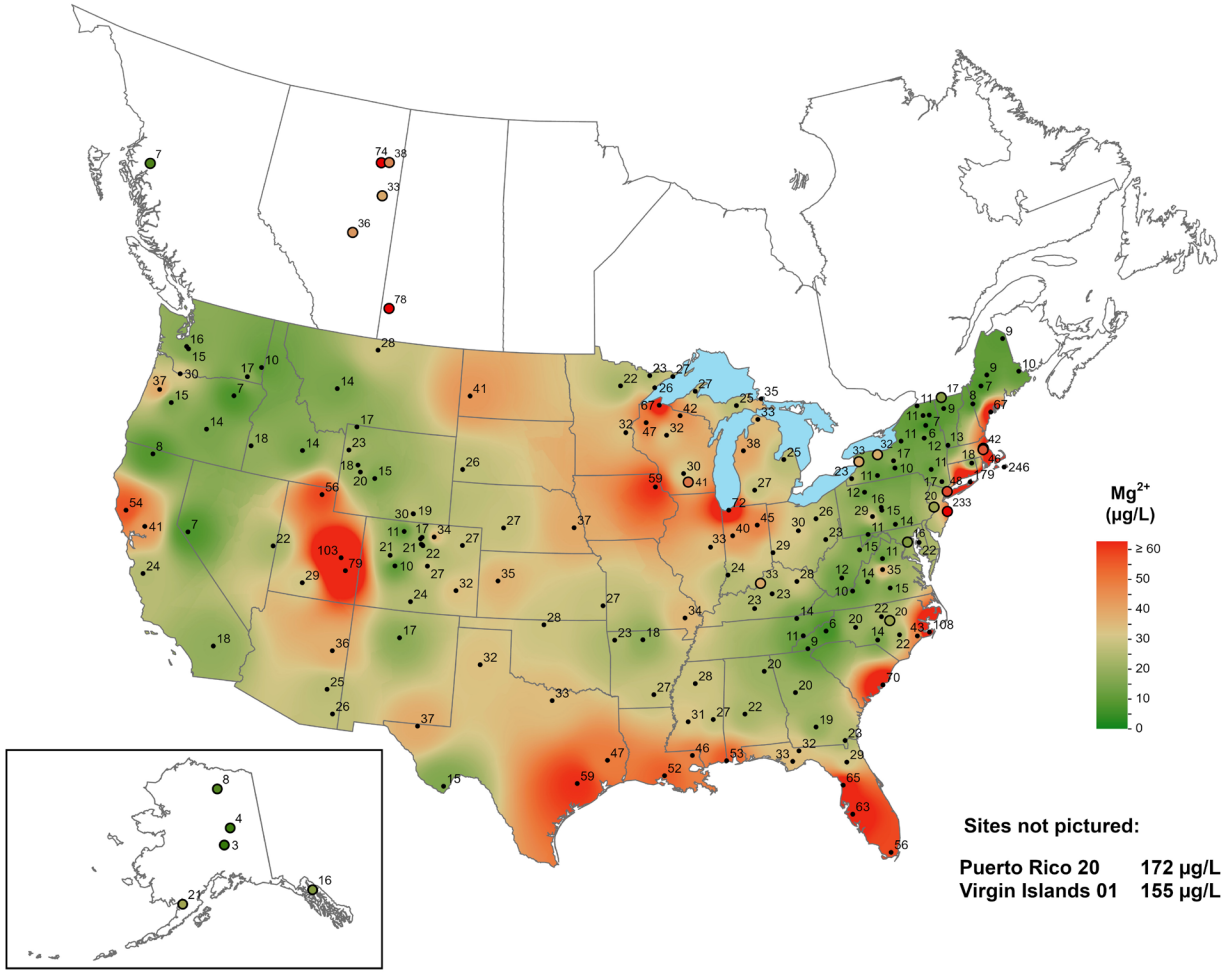
Hydrogen ion wet deposition, 2023



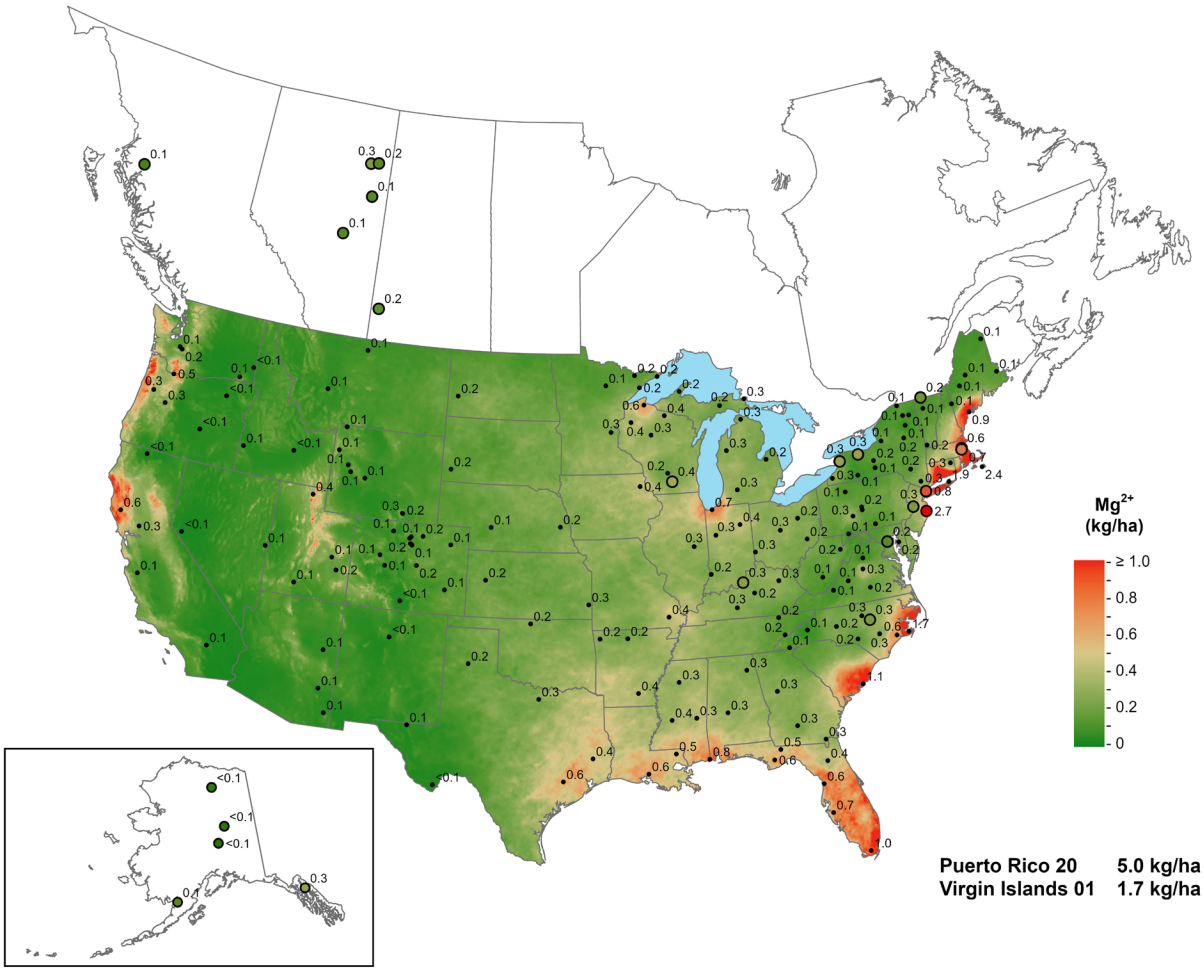
Calcium ion concentration, 2023.



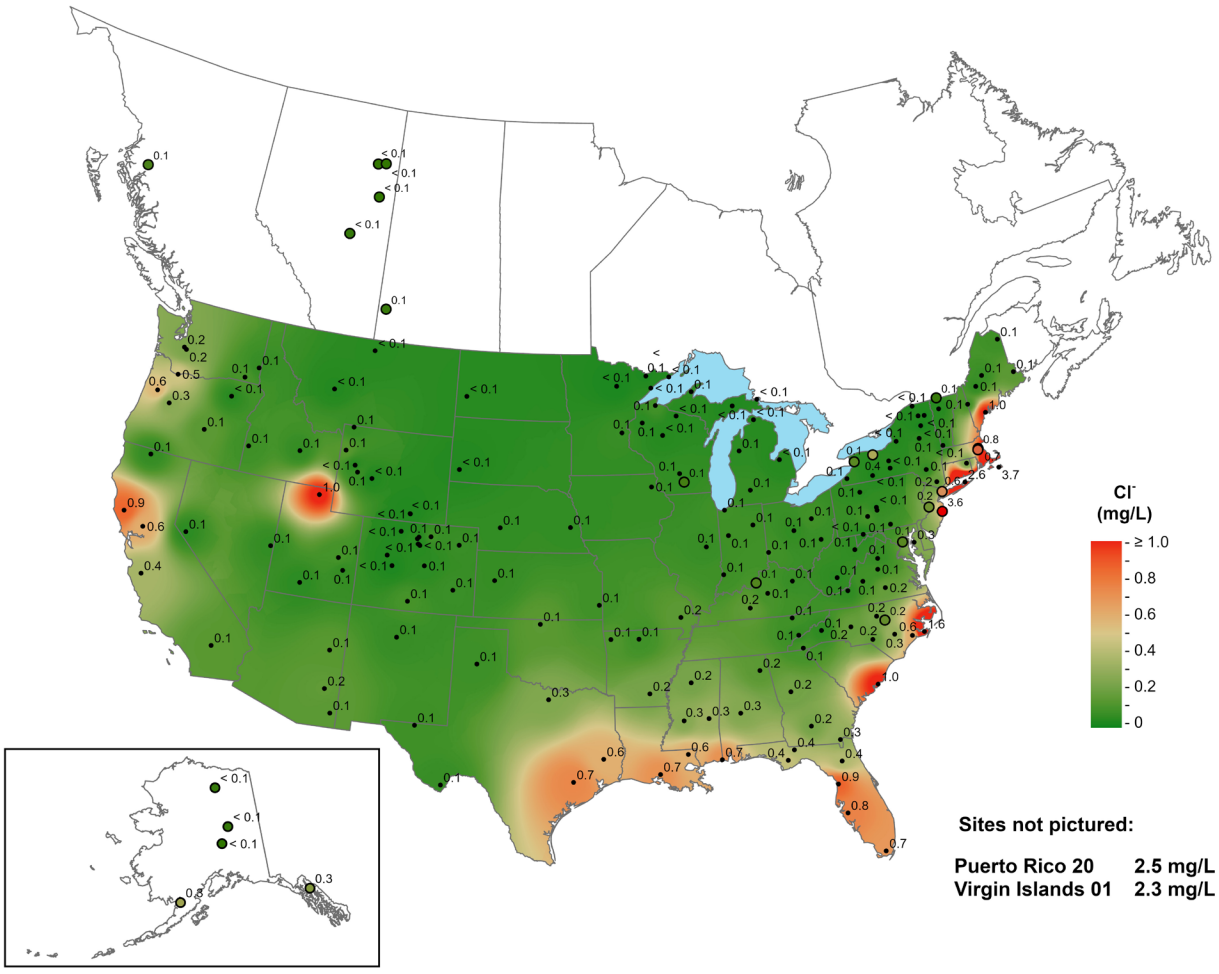
Calcium ion wet deposition, 2023.



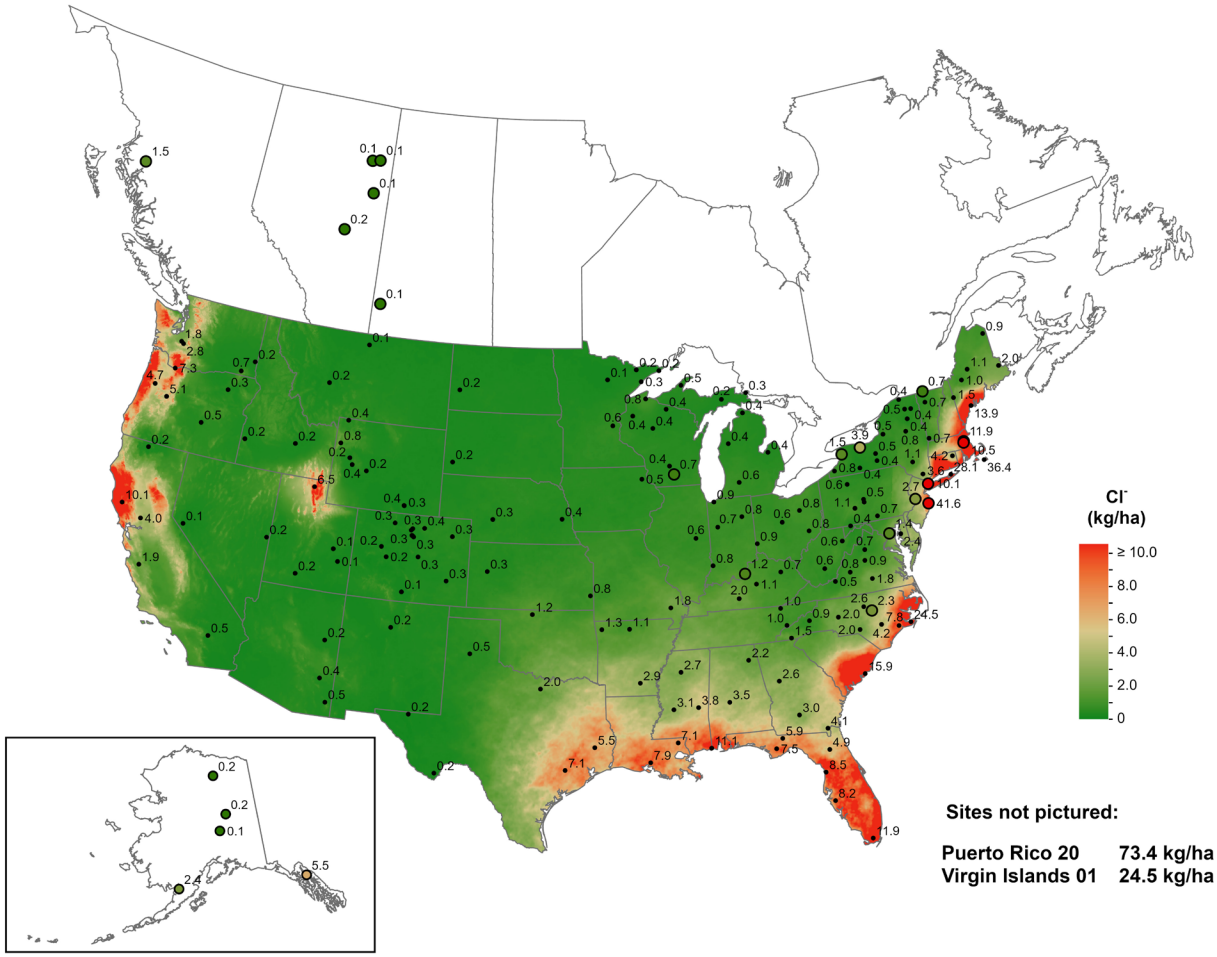
Magnesium ion concentration, 2023.



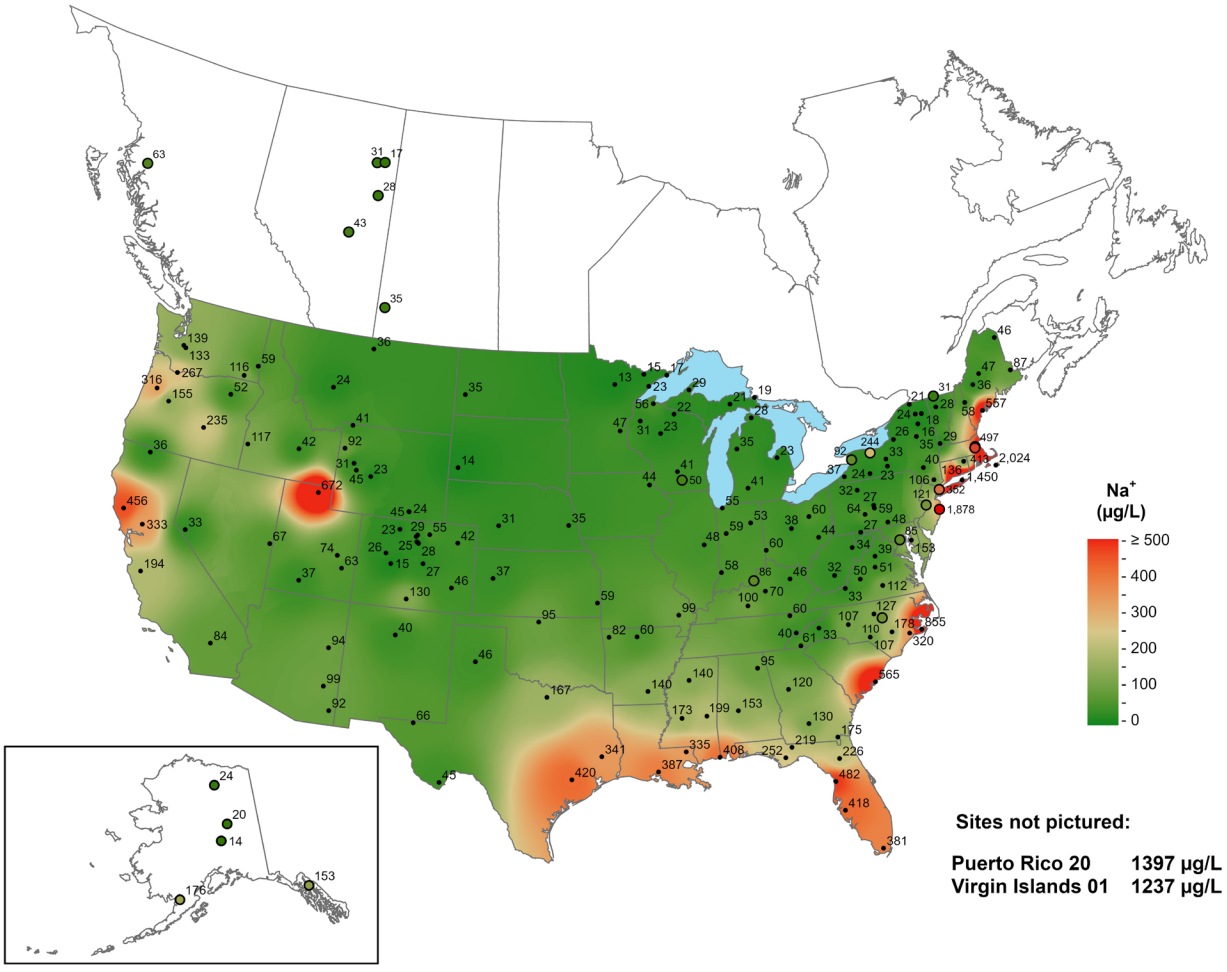
Magnesium ion wet deposition, 2023.



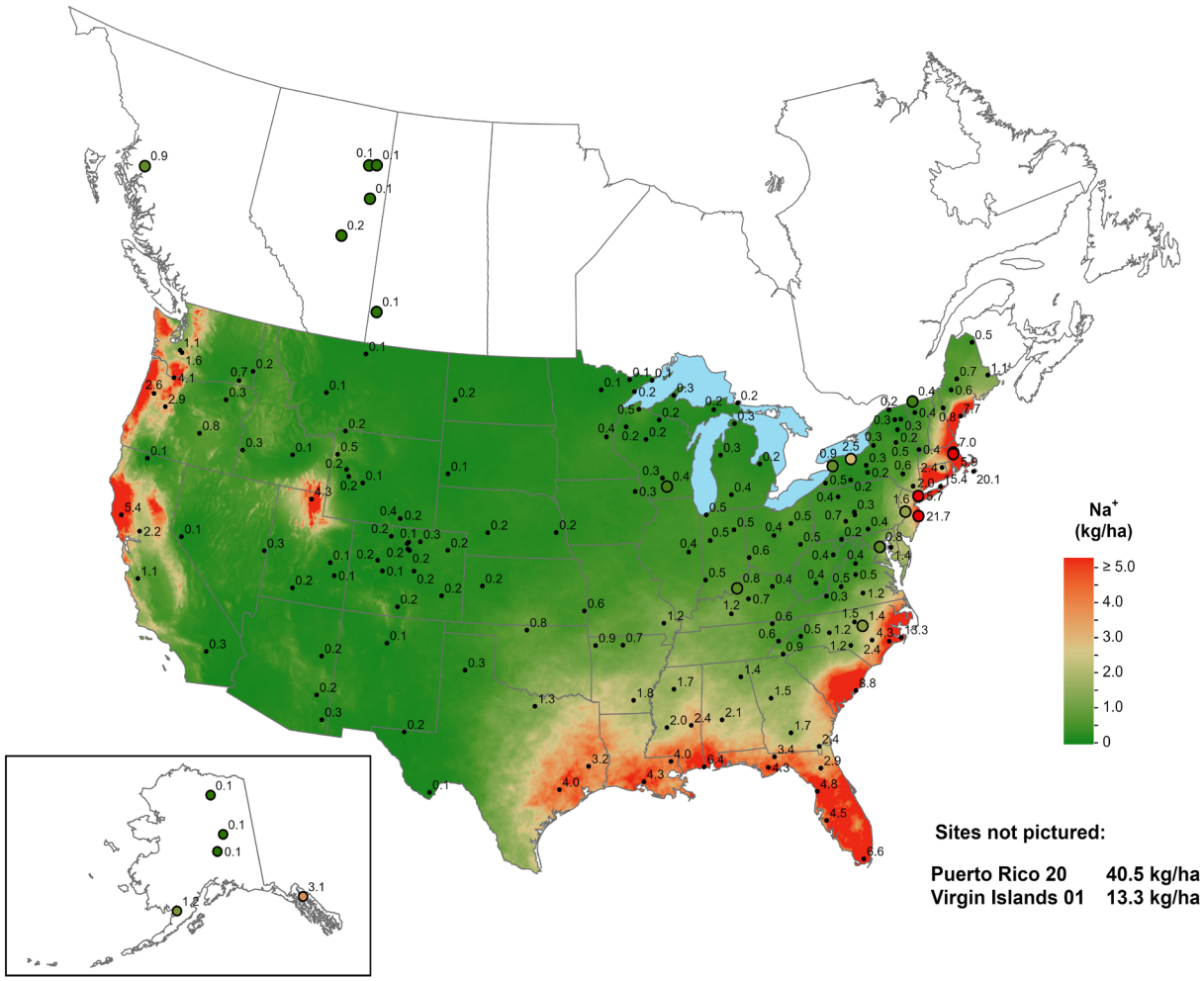
Chloride ion concentration, 2023.



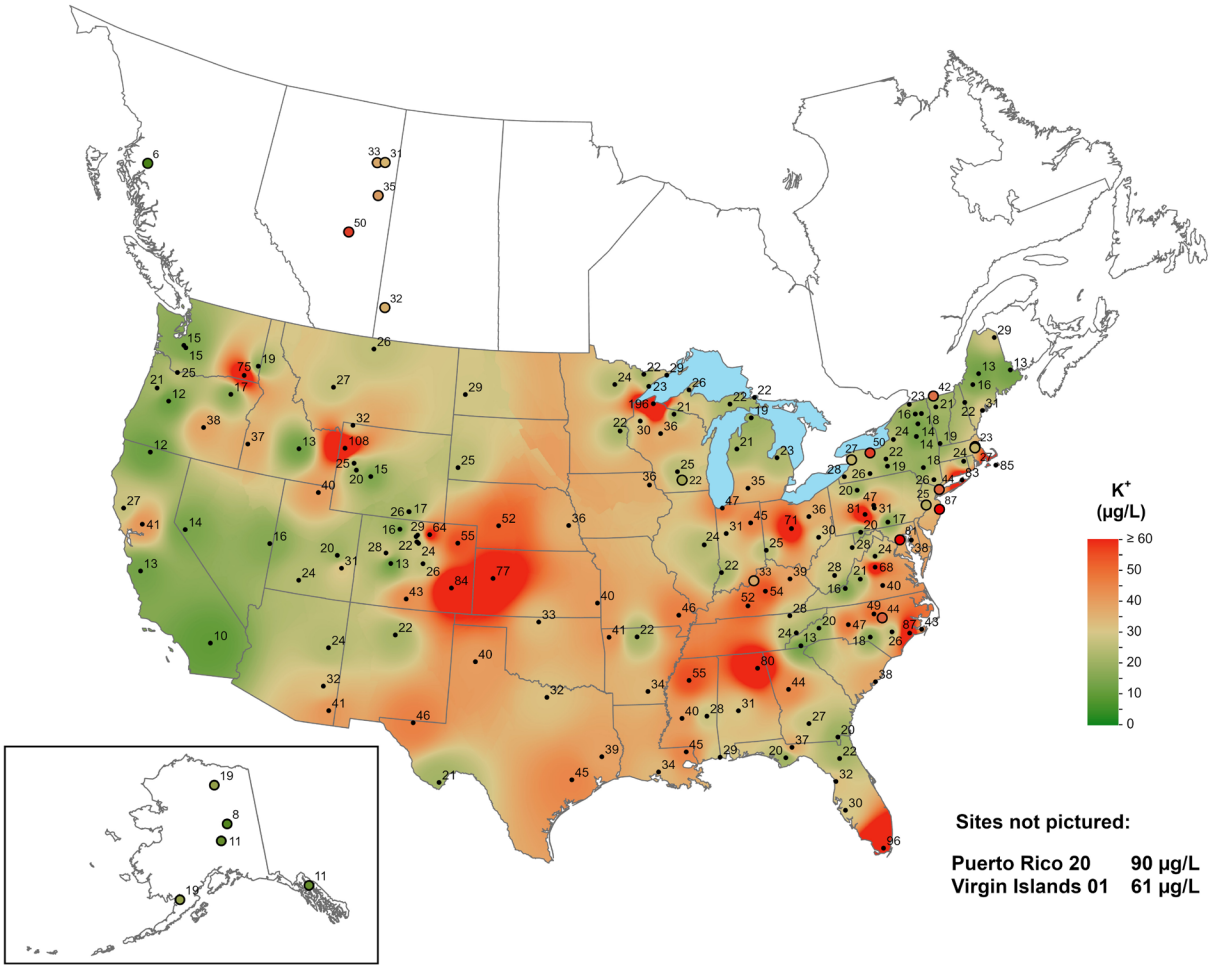
Chloride ion wet deposition, 2023.



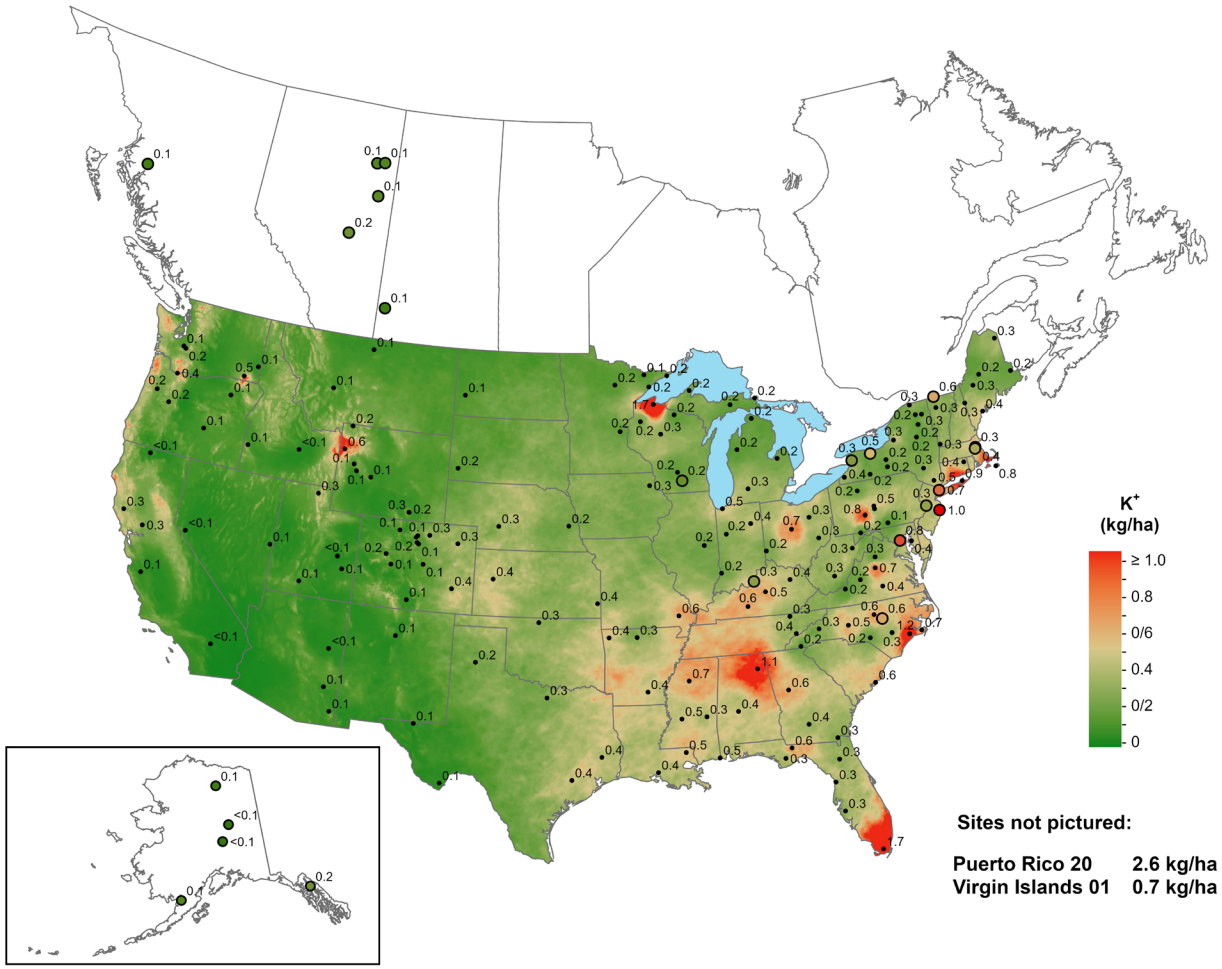
Sodium ion wet concentration, 2023.



Sodium ion wet deposition, 2023.



Potassium ion concentration, 2023.



Potassium ion wet deposition, 2023.

Mercury Deposition Network (MDN)

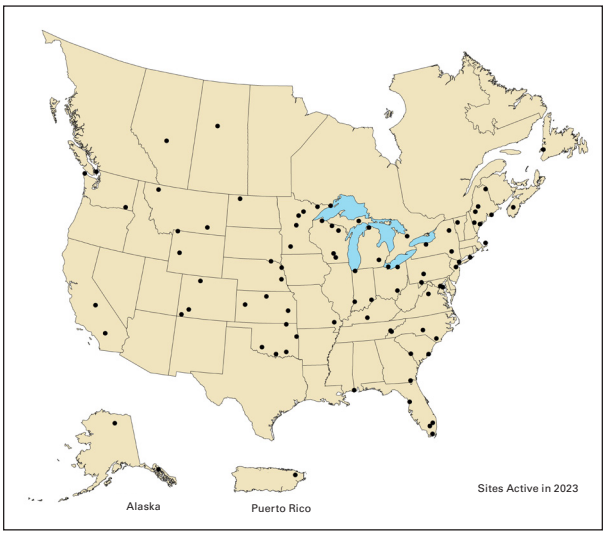
The MDN is the only network providing a long-term record for the concentration of mercury (Hg) in precipitation in North America. MDN sites follow standard procedures and use approved precipitation collectors and rain gages. The automated collector is similar to the NTN collector, but it is modified to preserve mercury. Site operators collect samples every Tuesday morning. Chemical analysis of the MDN samples is performed by the NADP laboratory.

All MDN samples are analyzed for total mercury concentration. The NADP reviews field and laboratory data for accuracy and completeness, and identifies samples that were mishandled, compromised by equipment failure, or grossly contaminated.

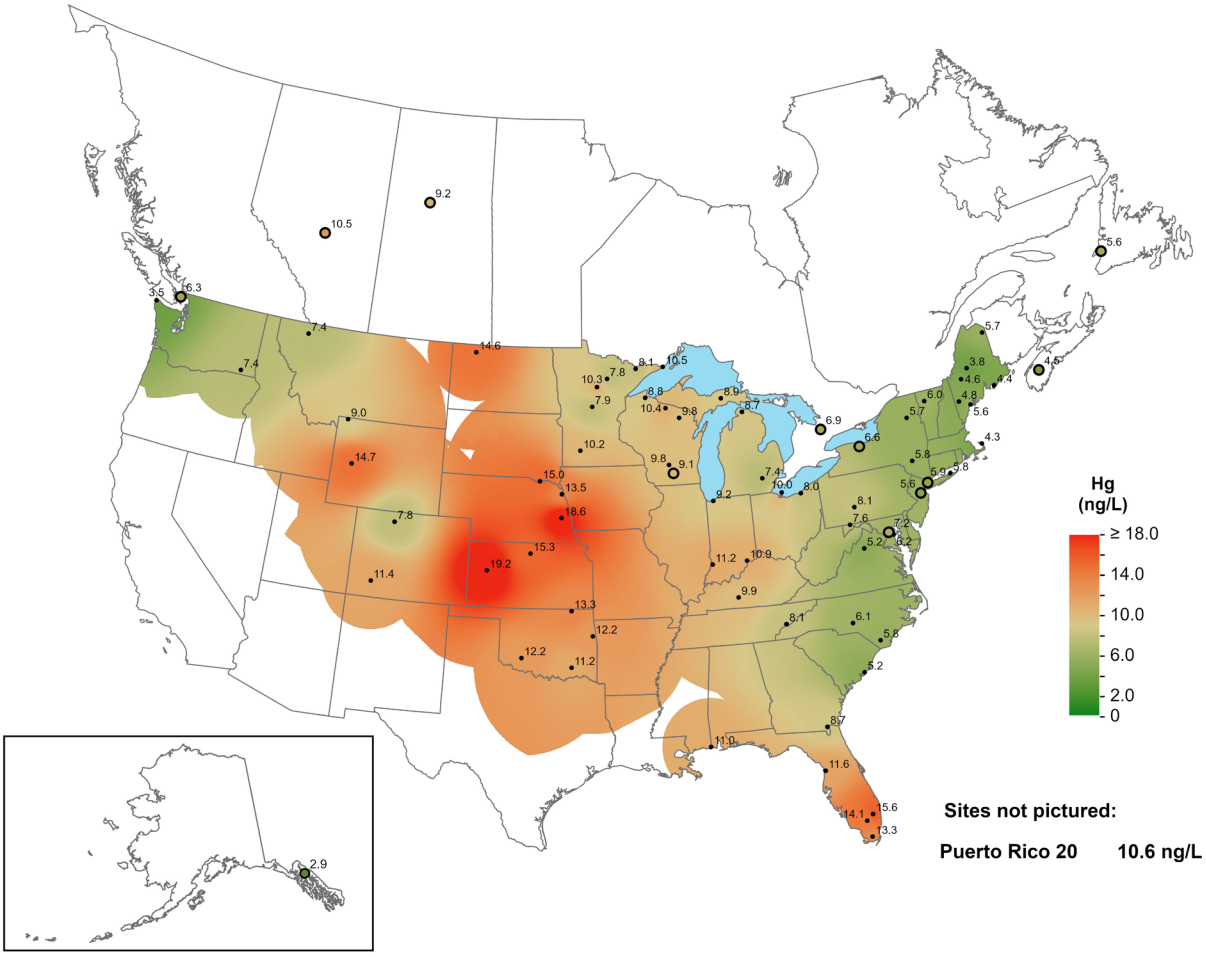
As of December 2023, there were 84 active MDN sites. Data from the MDN is available on the NADP website (http://nadp.slh.wisc.edu). Details about sample collection and analysis are available on the NADP website.

MDN Maps and Graphs

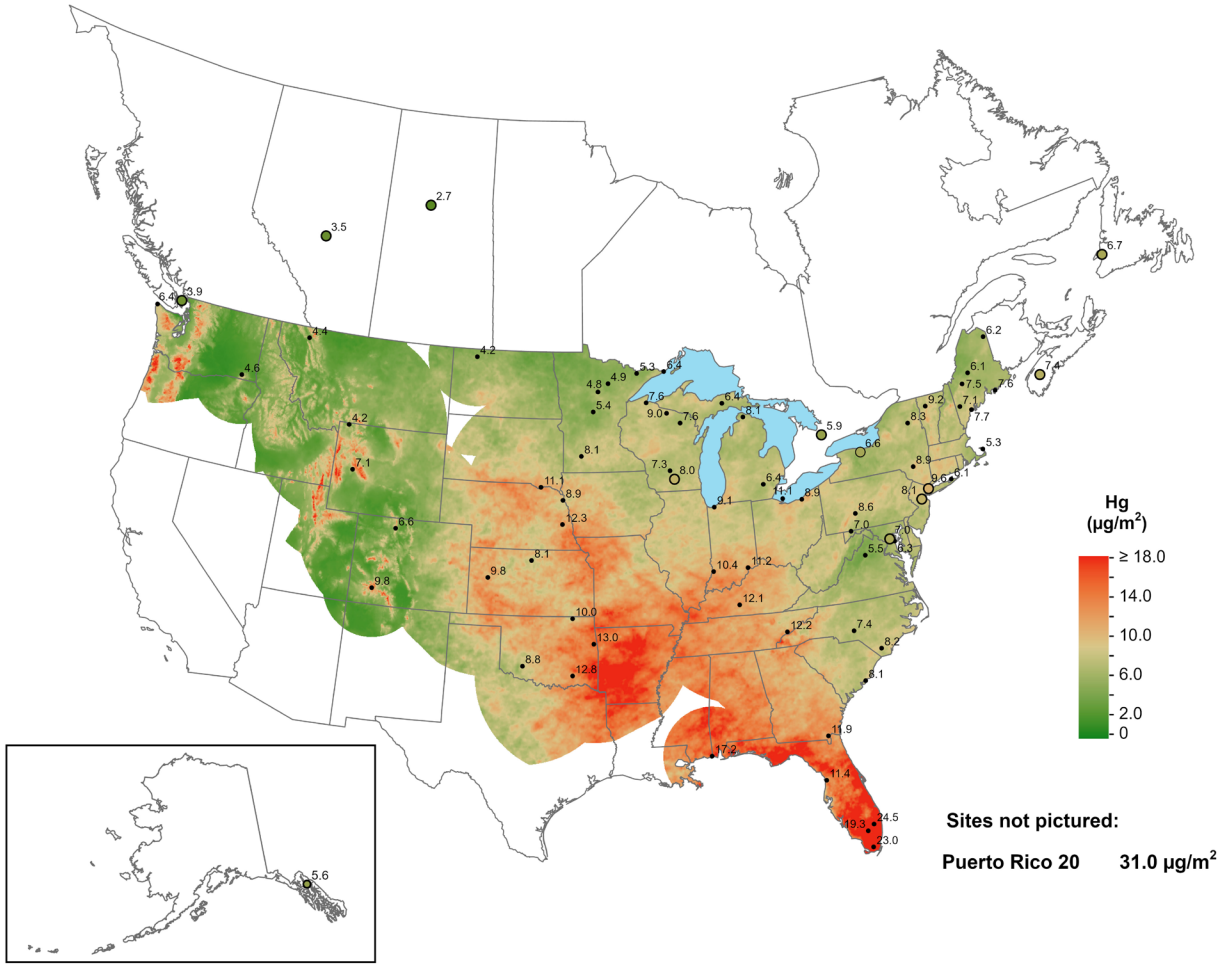
The maps on pages 35-36 show spatial variability in the precipitation-weighted mean concentration and wet deposition of total mercury across the United States.



Only sites meeting NADP completeness criteria are included. In 2023, 74 of 84 active sites met these criteria. Large variations in both mercury concentrations and wet-deposition are observed across the nation.



Total mercury concentration, 2023.



Total mercury wet deposition, 2023.

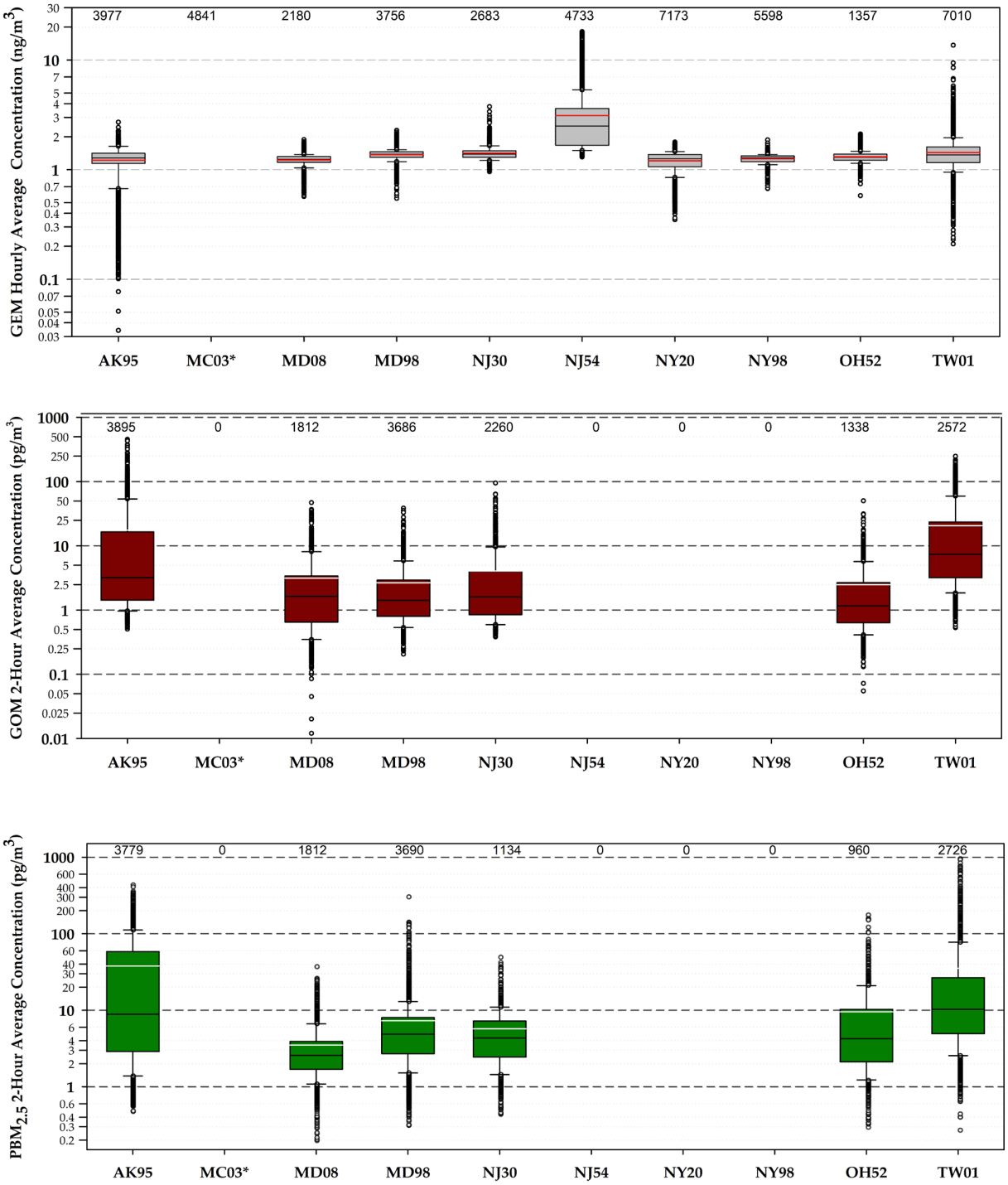
This page intentionally left blank.

Atmospheric Mercury Network (AMNet)

AMNet sites measure ambient atmospheric mercury using automated, continuous measurement systems in order to understand the impact of atmospheric mercury on deposition. Quality-assured measurements are made using NADP standardized methods.

AMNet measurements are made continuously (five minute and two-hour averages). Data is qualified and averaged to one-hour (gaseous elemental mercury, GEM) and two-hour values (gaseous oxidized mercury, GOM, and particulate bound mercury, $PBM_{2.5}$). As of December 2023, there were 11 AMNet sites. Data from the AMNet are available on the NADP website (https://nadp.slh.wisc.edu).

The figures on page 39 show the distribution of atmospheric mercury concentrations for each site. The top figure shows the distribution of GEM (shaded grey area) for all sites reporting data. GEM is reported in nanograms per cubic meter (ng/m^3). The middle figure shows the distribution of two-hour atmospheric concentrations of GOM (red shaded area) and the bottom figure shows $PBM_{2.5}$ (green shaded area) in picograms per cubic meter (pg/m^3). Concentrations are plotted logarithmically, and with different scale ranges, to highlight the range of measured values for each site.



Hourly GEM concentration in ng/m3 for each AMNet site (top) and 2-hour GOM and $PBM_{2.5}$ concentrations in pg/m3 for each speciating AMNet site (middle and bottom) in 2023. For each data set, the mean value is indicated as a red (GEM) or white bar (GOM and $PBM_{2.5}$) and the median is indicated as a black bar. Sites with no GOM and $PBM_{2.5}$ data shown did not monitor for speciated mercury. Values above each symbol is the number of valid concentrations observed during the year. *MC03 is undergoing further quality assurance review.

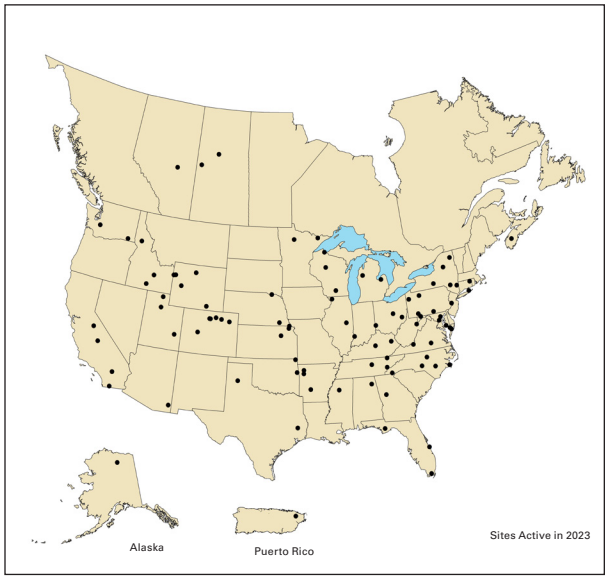
Ammonia Monitoring Network (AMoN)

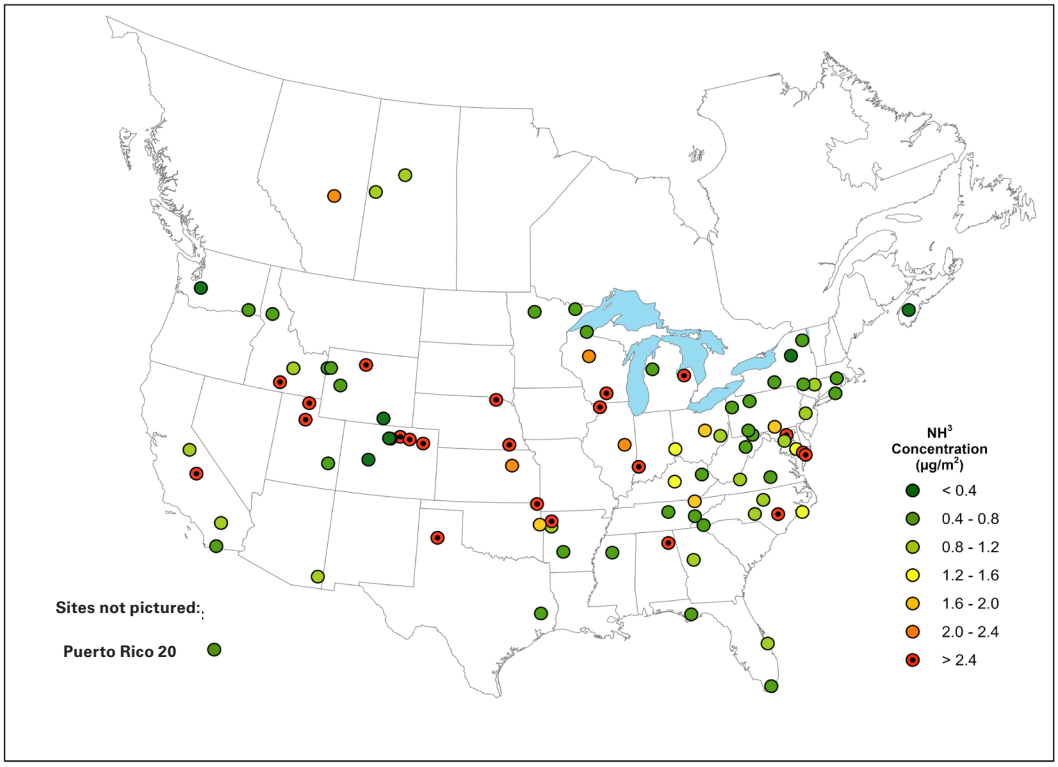
The AMoN measures atmospheric concentrations of ammonia (NH_3) gas. The network uses a passive diffusion-type sampler that provides cost-effective, accurate, and time-integrated measurements.

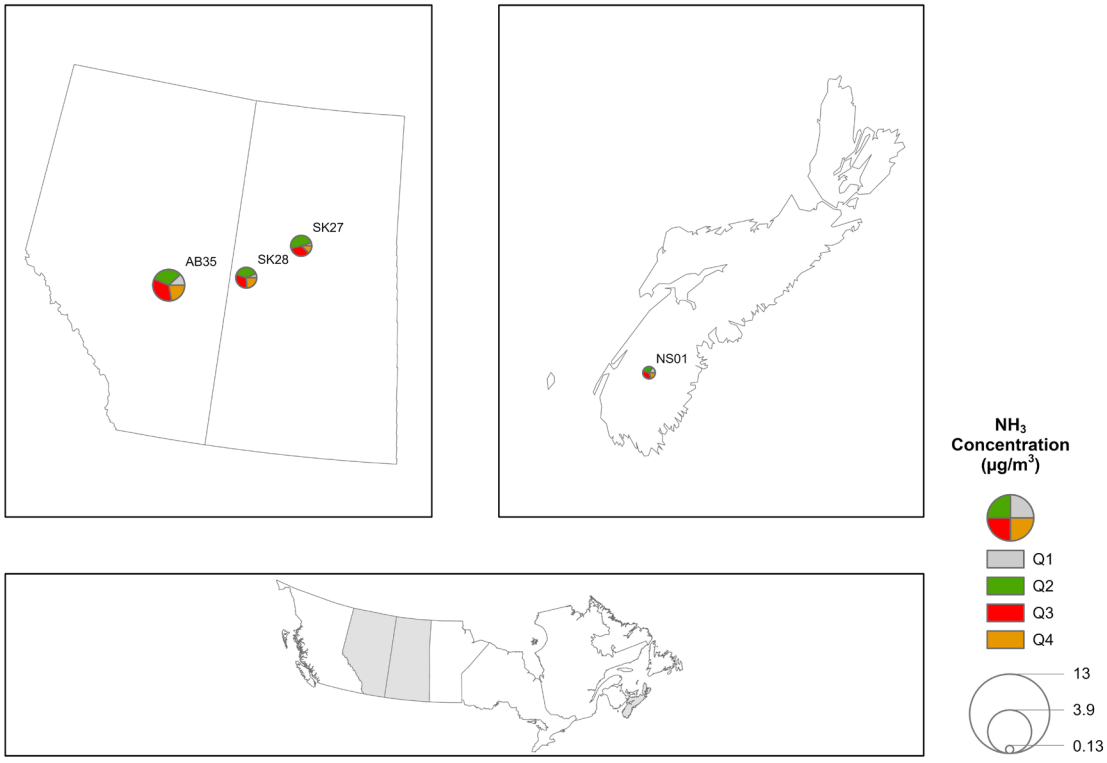
Sampling occurs over a two-week period, and all sites collect additional quality assurance samples on a rotating basis. This data is used to assess long-term NH_3 trends and changes in atmospheric chemistry, and to provide information for model development and verification.

As of December 2023, there were 92 AMoN sites. Data from the AMoN are available on the NADP website (https://nadp.slh.wisc.edu).

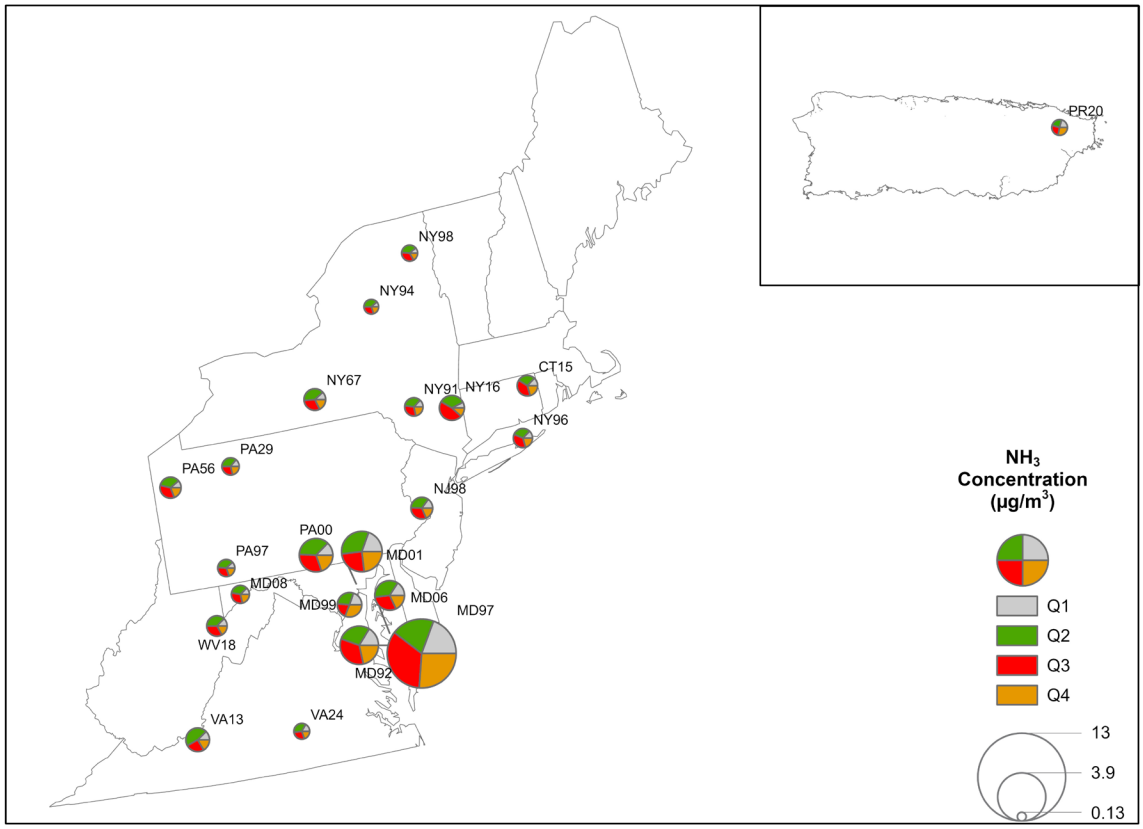
The figures on pages 41-44 show the distribution and seasonality of gaseous ammonia concentrations for each site meeting completeness criteria. In the first figure, circles represent annual average concentrations in micrograms per cubic meter (μg/m^3) at each site. In the following figures, the relative concentration for each site is shown for each calendar quarter. The size of the wedge is the relative percentage for the quarter. The area of the pie chart is proportional to the annual average for the site.

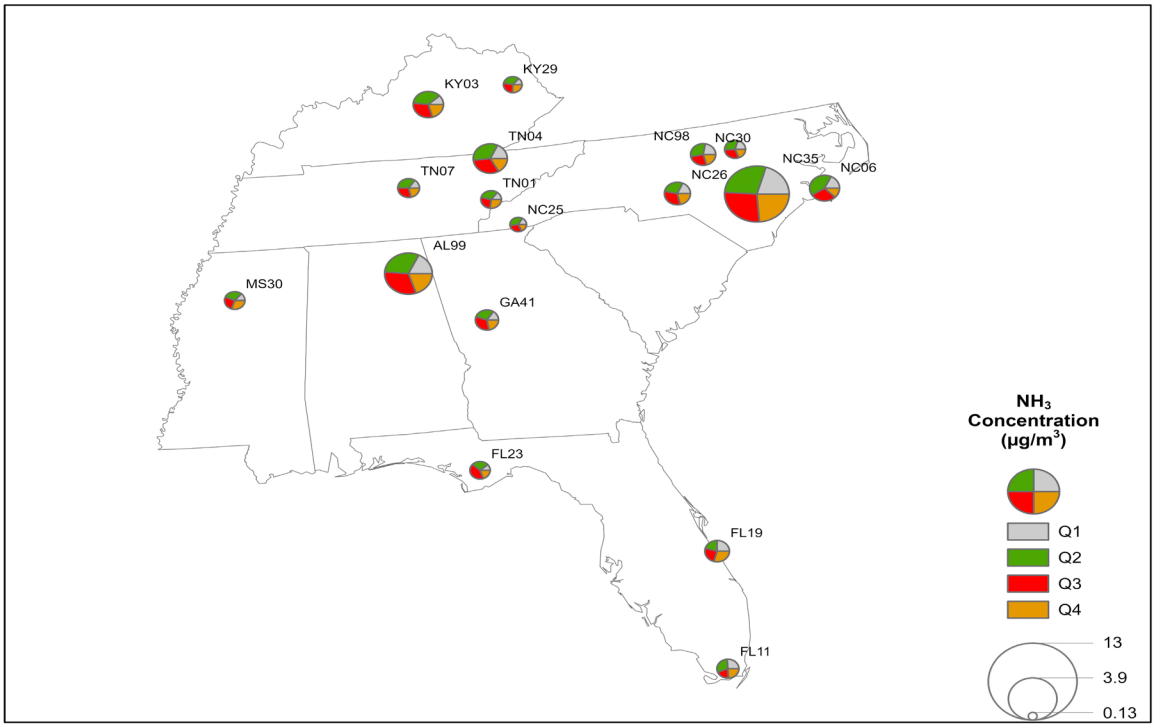




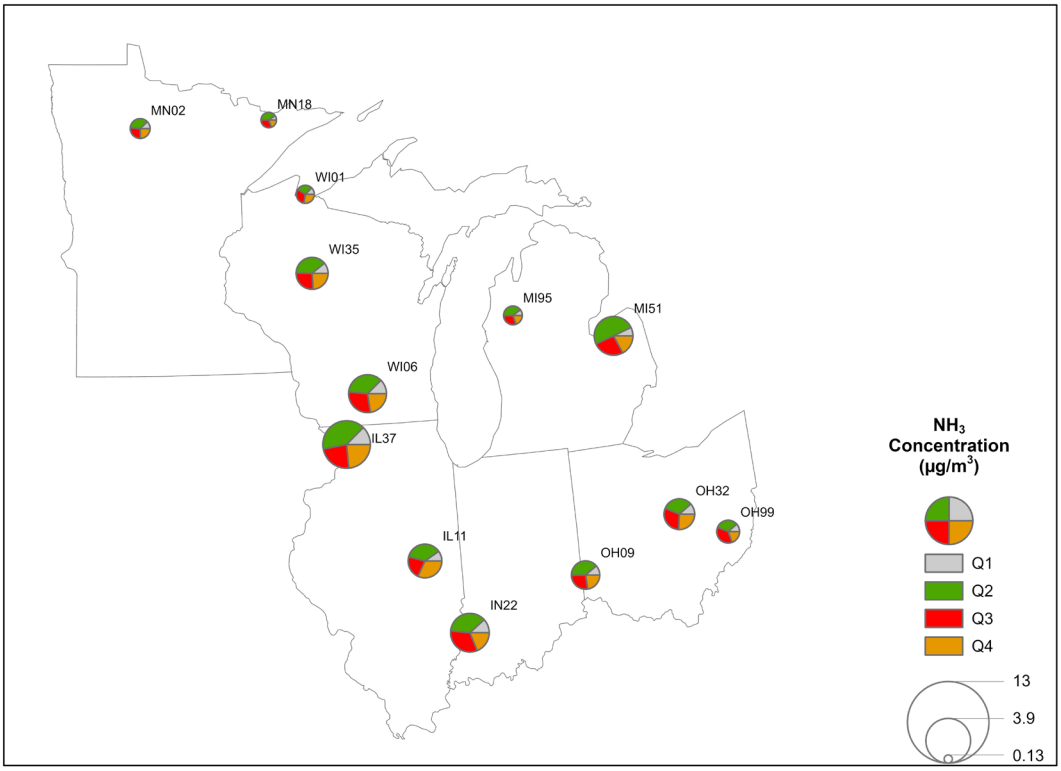


Average ammonia concentrations as measured by AMoN (first figure), and quarterly relative percentage (Q1 = January, February, March, etc.) for each AMoN site (in the subsequent figures), 2023. Size of the symbol in the bottom plot is relative to the annual concentration.

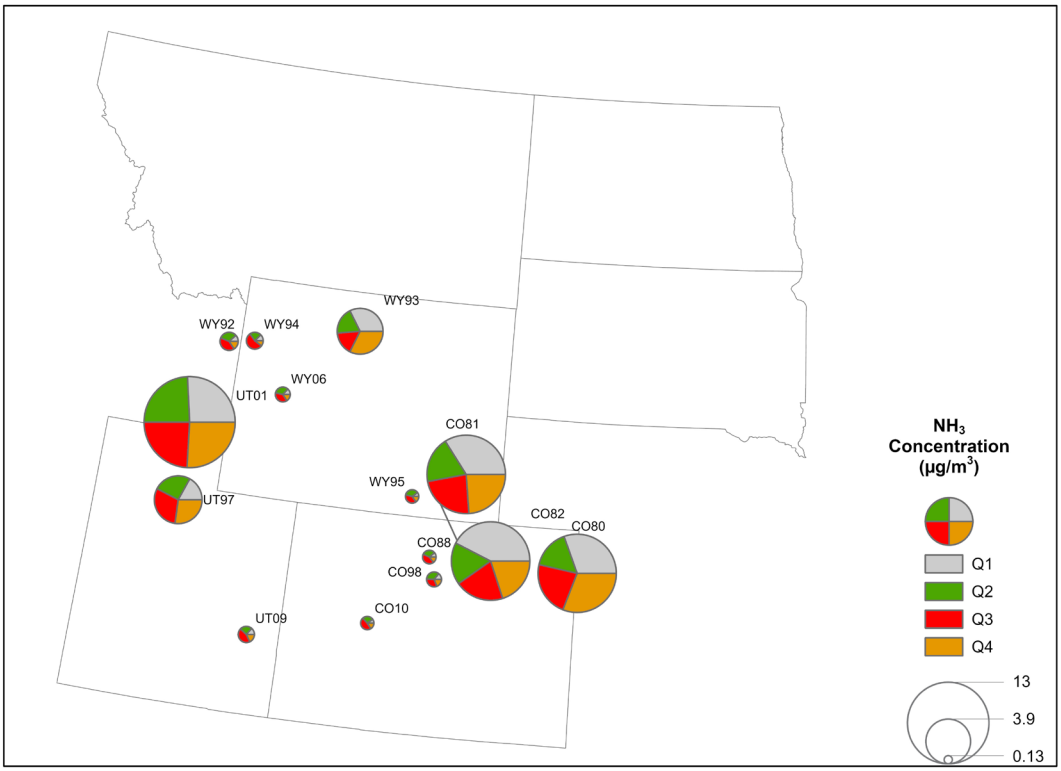


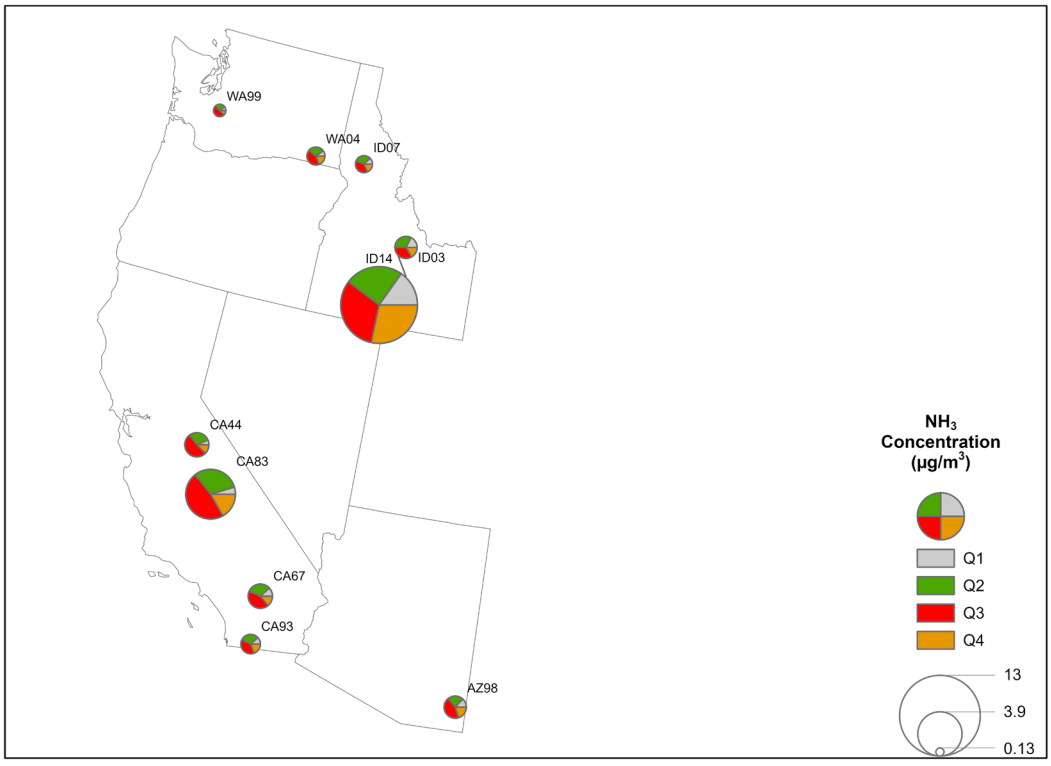


Quarterly relative percentage (Q1 = January, February, March, etc.) for each AMoN site (all figures), 2023. Size of the symbol in the bottom plot is relative to the annual concentration.



Quarterly relative percentage (Q1 = January, February, March, etc.) for each AMoN site (all figures), 2023. Size of the symbol in the bottom plot is relative to the annual concentration.





Quarterly relative percentage (Q1 = January, February, March, etc.) for each AMoN site (all figures), 2023. Size of the symbol in the bottom plot is relative to the annual concentration.

This page intentionally left blank.

Mercury Litterfall Network (MLN)

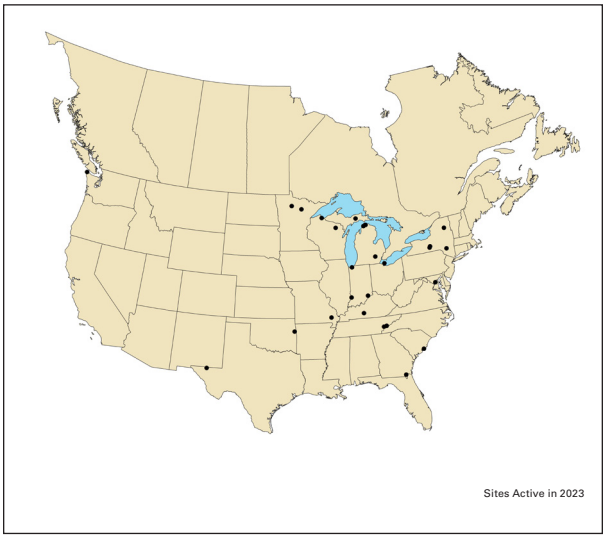
MLN sites measure concentrations of total mercury found in plant biomass litterfall associated with a forest overstory (leaves, twigs, debris, etc.) that fall to the forest floor. The network uses four passive collection samplers per site. The collectors are placed on the ground in randomized locations each year to estimate the deposition of biomass and associated total mercury.

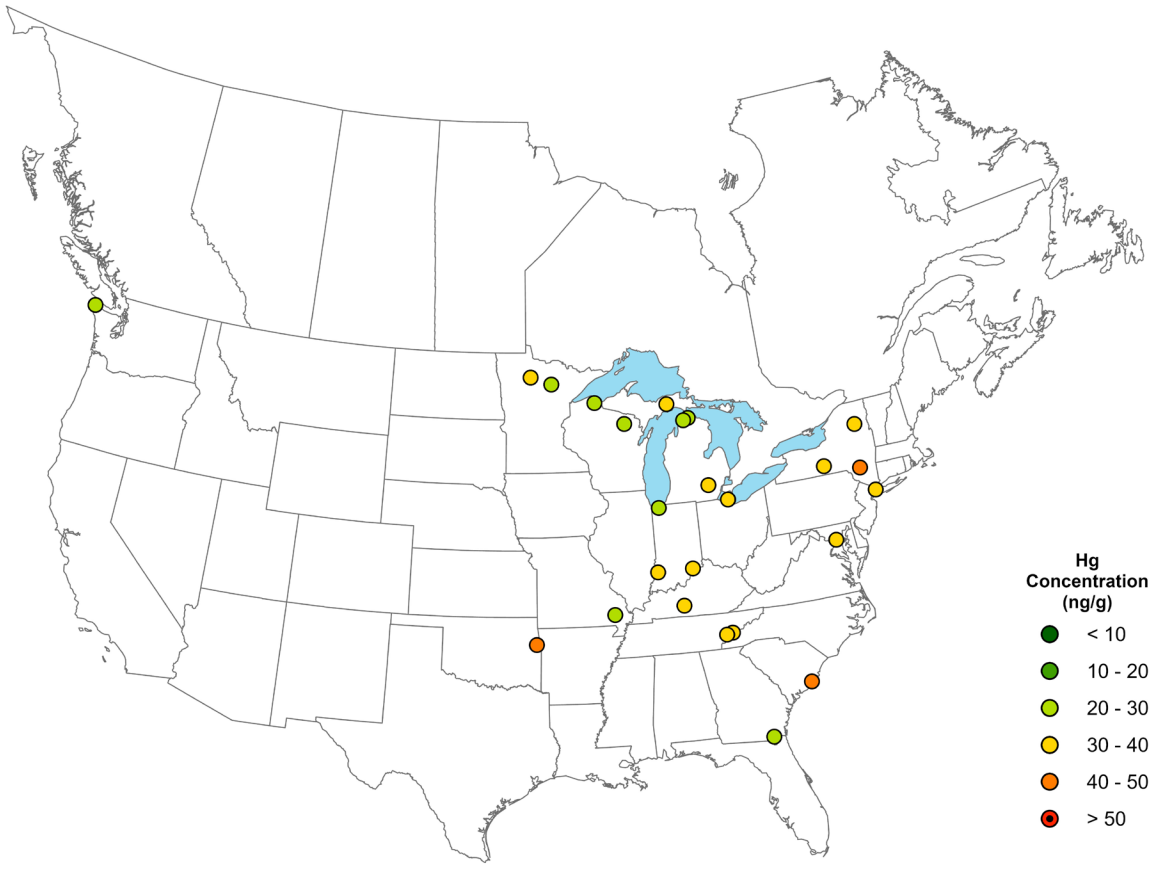
Sampling occurs over a several month period (generally September to December) with monthly biomass collections retrieved from each collector. These monthly collections are dried, composited by collector, and ground. Total mercury is measured in each of the four composites, and a weighted mean seasonal mercury concentration (ng Hg/gram biomass) is calculated. Using the seasonal mercury concentration and seasonal biomass deposition (g/m^2/season), a flux of mercury (µg Hg/m^2/season) to the forest floor is calculated.

This data is used to assess deposition in this manner, for further study and comparisons to traditional wet and dry deposition of mercury in MDN and other measures. These measurements can be used for trends over time, and to provide information for model development and verification.

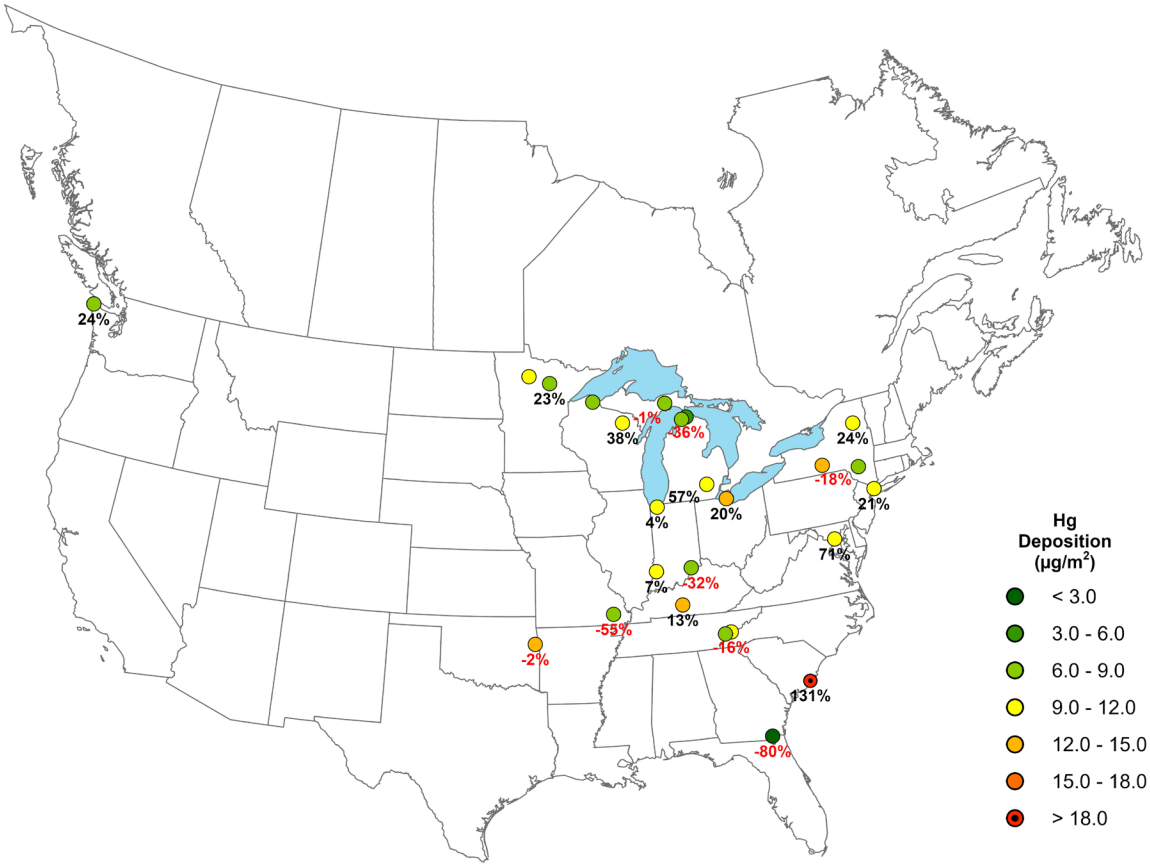
As of December 2023, there were 29 MLN sites. Data from the MLN are available on the NADP website (https://nadp.slh.wisc.edu).

The figures on page 47-48 show the total mercury concentration and deposition in biomass for the sampling season. The top figure shows the average concentration of total mercury per gram of biomass (ng Hg/g biomass) over the sampling season at each site. In the bottom figure, the total mercury deposition is shown as a function of the total biomass deposited at each site (µg Hg/m^2/season). The numerical value associated with each site is the percentage above (black, positive) or below (red, negative) total mercury deposition as compared to the wet deposition of total mercury at the same site.





Average total mercury concentration in biomass, 2023.



Average total mercury flux with biomass per season, 2023. Numerical values are percentages of mercury biomass flux more than (black) and less than (red) the colocated MDN wet deposition flux.

National Atmospheric Deposition Program

The NADP is the National Research Support Project-3: A Long-Term Monitoring Program in Support of Research on the Effects of Atmospheric Chemical Deposition. More than 250 sponsors support the NADP, including private companies and other non-governmental organizations, universities, local and state government agencies, State Agricultural Experiment Stations, national laboratories, Native American organizations, Canadian government agencies, the U.S. Geological Survey, the U.S. Environmental Protection Agency, the National Park Service, the National Oceanic and Atmospheric Administration, the U.S. Fish & Wildlife Service, the Bureau of Land Management, the U.S. Department of Agriculture - Forest Service, the U.S. Department of Agriculture - Agricultural Research Service, and the U.S. Department of Agriculture - National Institute of Food and Agriculture under agreement no. 2022-39133-38451. Any opinions, findings, and conclusions or recommendations expressed in this publication are those of the authors and do not necessarily reflect the views of the program sponsors or the University of Wisconsin-Madison.

Madison, WI: October 2024

http://nadp.slh.wisc.edu

All NADP data and information, including color contour maps in this publication, are available free of charge from the NADP website: https://nadp.slh.wisc.edu. Alternatively, contact: NADP Program Office, Wisconsin State Laboratory of Hygiene, 465 Henry Mall, Madison, WI 53706, Tel: (608) 263-9162, E-mail: nadp@slh.wisc.edu.

The NADP Program Office is located at the Wisconsin State Laboratory of Hygiene (WSLH), at the University of Wisconsin–Madison.