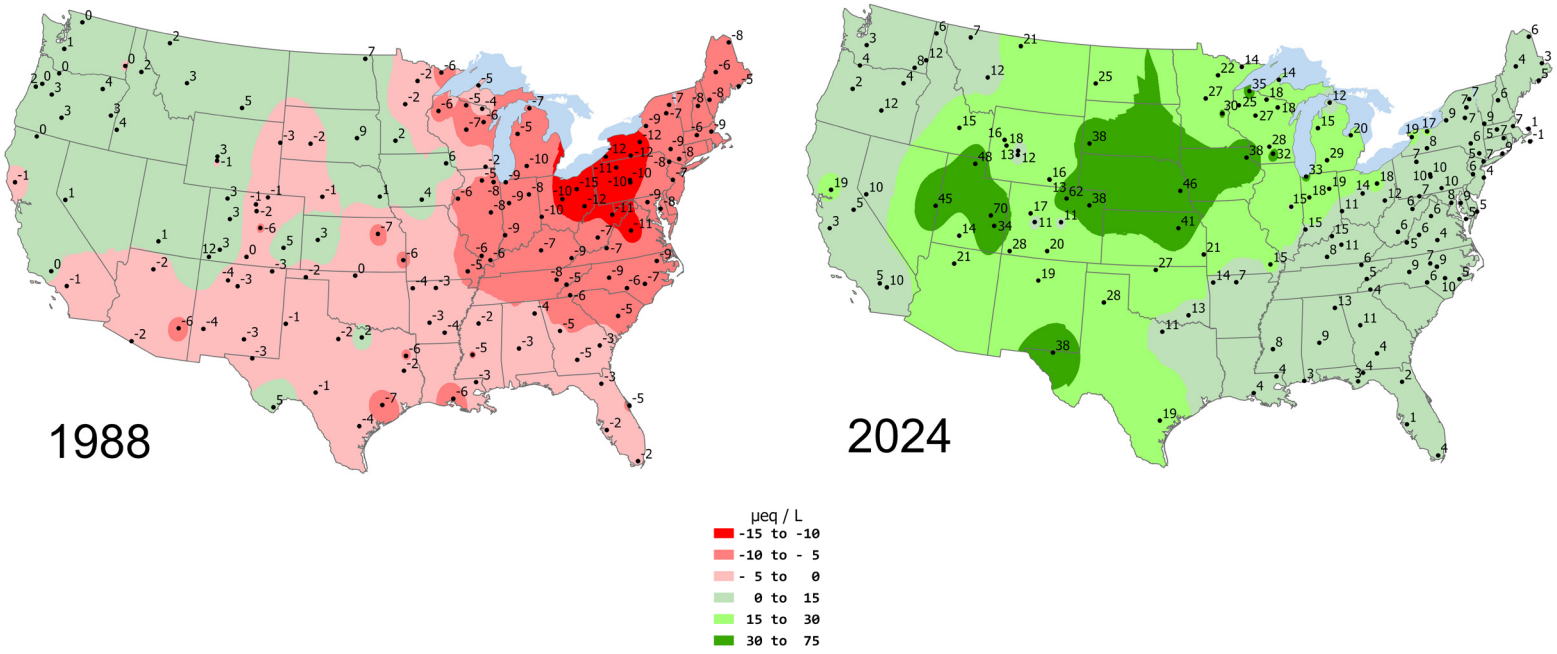
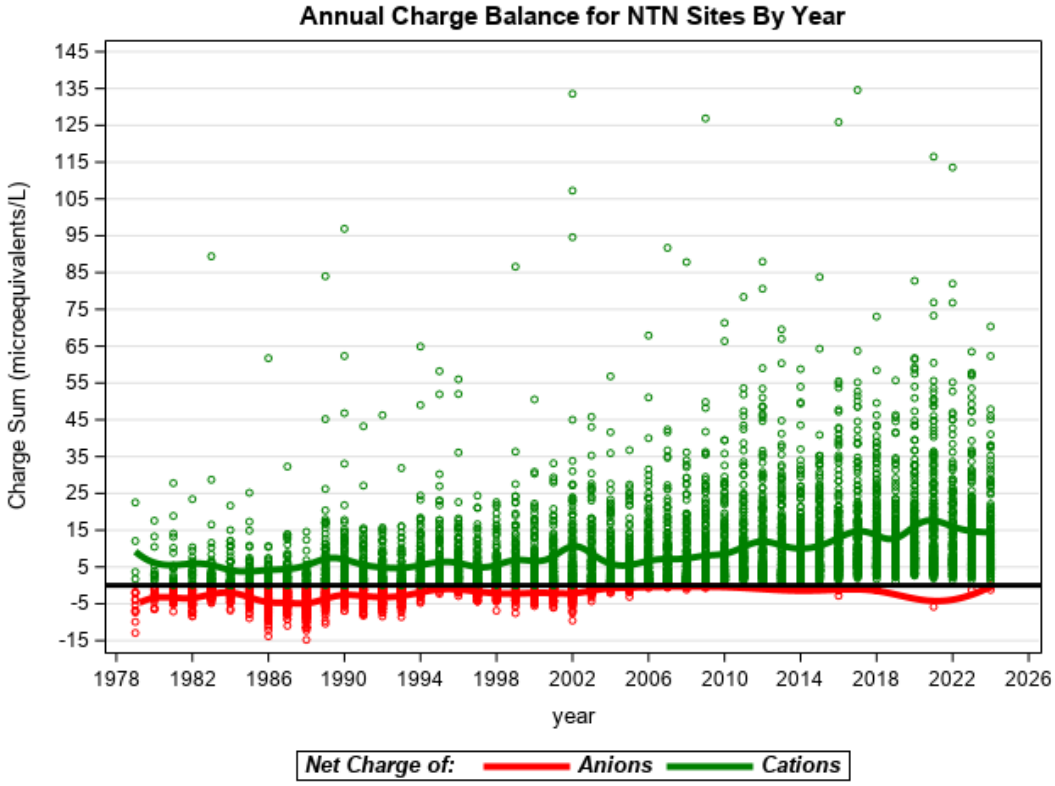
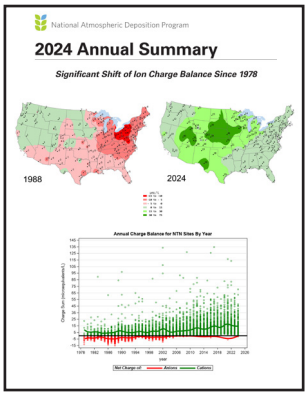
National Atmospheric Deposition Program

2024 Annual Summary

Significant Shift of Ion Charge Balance Since 1978







On the Cover: The cover graphics show the ion charge balance for NTN sites of the precipitation-weighted average annual concentration for all years and sites. The two maps show the spatial distribution of the ion charge balance for 1988 and 2024. The charge balance is the sum of analyte ion charges, in microequivalents per liter, of the cations {hydrogen (H^+), calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^+), potassium (K^+), and ammonium (NH_4^+)} minus the anions {sulfate (SO_4^{2-}), nitrate (NO_3^-), and chloride (Cl^-)}. An equivalent is the amount of an analyte that can react with one unit of a hydrogen ion (H^+) or one unit of hydroxide ion (OH^-). A microequivalent represents one-millionth of an equivalent. Microequivalents per liter is a unit of concentration measuring the amount of an ion's reactive power in a solution.

The plot clearly shows that early in the NTN record, there was a relatively equal number of sites with small cation surpluses and anion surpluses. This charge balance has clearly shifted to a more recent cation dominance at effectively all sites, with the balance becoming more strongly positive. Spatially, the 1988 map show cation dominance in much of the western U.S., and a stronger anion dominance in the eastern U.S. The 2024 map clearly shows a change where all sites are cation dominant, and now most strongly in the western plains and mountains. This ion balance shift is in part due to the strong reductions in both sulfate and nitrate anions (less negative, much in the East), and the rise of ammonium cation deposition more recently (more positive, mostly in the West). There are likely many contributors to these observations, including the bicarbonate anion, and organic acids (mono and di acids).

When referencing maps or information in this report, please use the citation: National Atmospheric Deposition Program, 2025. National Atmospheric Deposition Program 2024 Annual Summary. Wisconsin State Laboratory of Hygiene, University of Wisconsin-Madison, WI.

Contents

2024 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 2024.

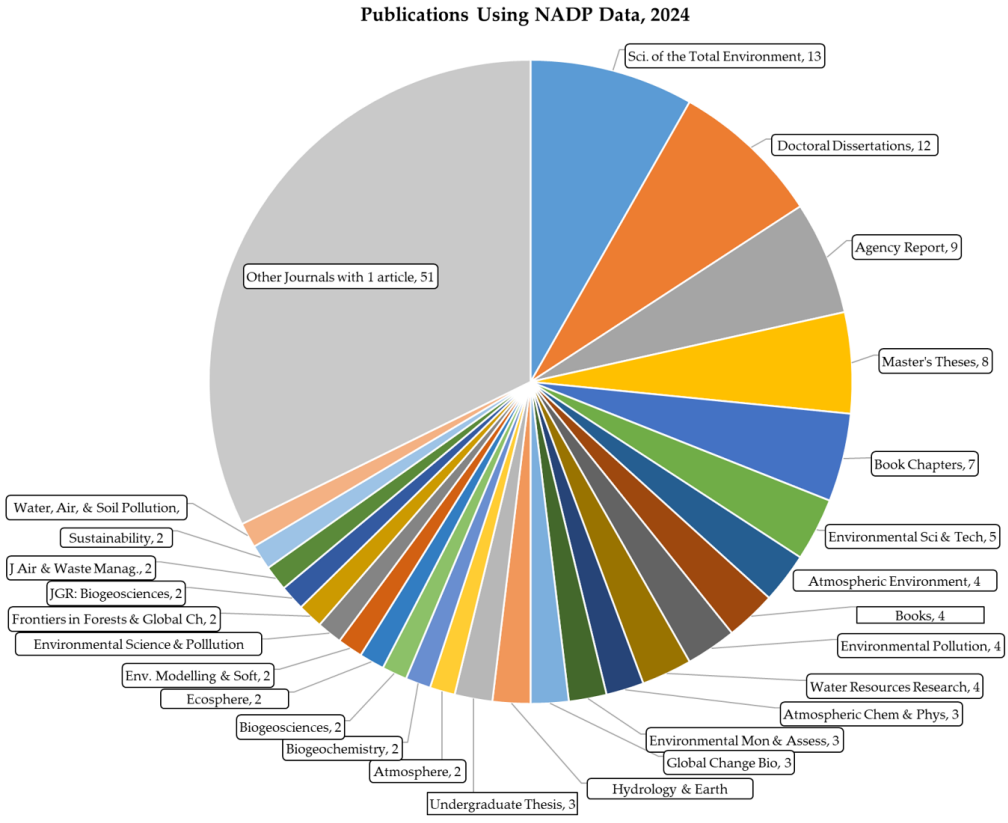
Summary of 2024 Network Measurements

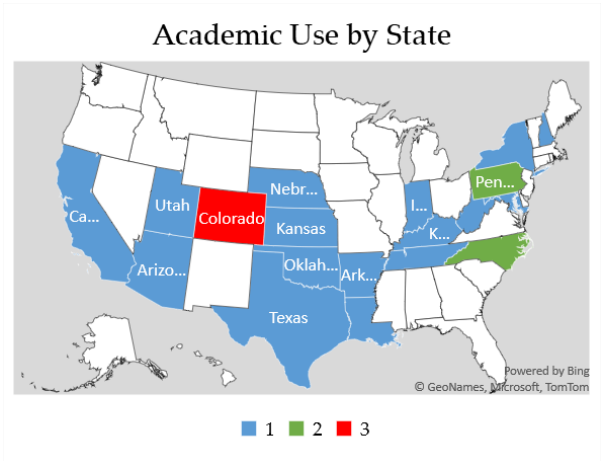
Network	Measurements	Period	No. of sites
NTN	12,295	weekly	241
MDN	4,086	weekly	78
AMNet	43,151	hourly/ 2-hourly	8
AMoN	3,144	two week	103
MLN	25	seasonal	26

Highlights:

- The year 2024 is the 47th year of continuous operation of the National Atmospheric Deposition Program, which began in 1978. Very few networks can claim anything approaching this length.
- NADP Officers beginning in October 2024
    - Chair: Ms. Melissa Puchalski, US EPA
    - Vice Chair: Mr. Michael McHale, USGS
    - Secretary: Dr. David Felix, University of North Carolina Wilmington
    - Past Chair: Dr. Michael Bell, NPS
- During the 2024 calendar year, 161 articles and reports were identified as having used NADP data. See the figures on the next page for the distribution of publication journals. Within the publications, there were several non-journal publications, including:
    - 12 doctoral dissertations
    - 8 master's theses
    - 3 undergraduate works
    - 9 agency/institute reports
    - 7 book chapters

  Additionally, we now have a searchable database for the historic publications, which is available on the website (nadp.slh.wisc.edu/pubs).


Publications Using NADP Data, 2024
Sci. of the Total Environment, 13
Doctoral Dissertations, 12
Agency Report, 9
Master's Theses, 8
Book Chapters, 7
Environmental Sci & Tech, 5
Atmospheric Environment, 4
Books, 4
Environmental Pollution, 4
Water Resources Research, 4
Atmospheric Chem & Phys, 3
Environmental Mon & Assess, 3
Global Change Bio, 3
Hydrology & Earth
Undergraduate Thesis, 3
Atmosphere, 2
Biogeochemistry, 2
Biogeosciences, 2
Ecosphere, 2
Env. Modelling & Soft, 2
Environmental Science & Polllution
Frontiers in Forests & Global Ch, 2
JGR: Biogeosciences, 2
J Air & Waste Manag., 2
Sustainability, 2
Water, Air, & Soil Pollution,
Other Journals with 1 article, 51


Academic Use by State
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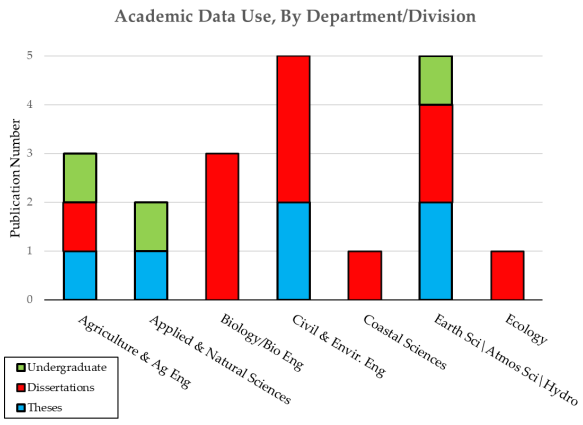
Academic Data Use, By Department/Division
Publication Number
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Agriculture & Ag Eng
Applied & Natural Sciences
Biology/Bio Eng
Civil & Envir. Eng
Coastal Sciences
Earth Sci\Atmos Sci\Hydro
Ecology
Undergraduate
Dissertations
Theses

- The 2024 Fall Meeting and Science Symposium was held as a live meeting in the Duluth MN Canal District. It was one of our larger meetings with 158 participants, including a larger number of students and tribal members. https://nadp.slh.wisc.edu/nadp2024/.

  During the meeting, we had a presentation from Dr. Randy Kolka, about MN16, which has two of the oldest continuously operating sites in NADP very near Duluth: NTN (July 5, 1978) and MDN (February 27, 1996).

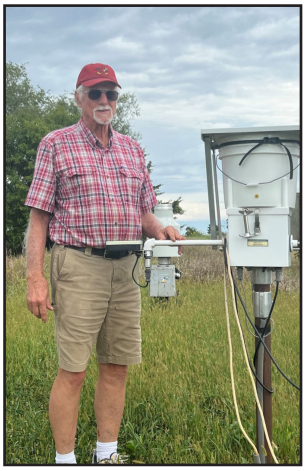
- Mary Lou Trainer, 77, of Quaker City, Ohio passed away this year. She was the longtime operator of AMON OH99, and will be missed.

- Significant QA development with passive Hg sampling during the year, leading to a test network starting on January 1, 2025. Eight sites will be running, and an NADP acceptance proposal (12-point plan) is in development.

- During the year, the Province of Alberta's Ministry of Environment and Protected Areas started 7 new NTN sites within the Province. This covers a large area of North America that was previously unmonitored in the NTN, and provides Alberta with a significant increase in NTN sites and a very large provincial network for making informed environmental decisions.

- During the year, we have two operator milestones and two excellent operators. Hoss Parks (below left) recently received the NADP Operator Recognition Award and has recieved his 30 year operator award this year. This puts Hoss into the rarified group of about 15 operators that have reached the 30 year mark. But Jim Secor (below right) is the clear leader (as of now) for operators who have reached the unprecedented 40 year mark; our first operator that we know of to have done this. That is a job well done. To both Jim and Hoss, and to all of our operators - both new and well seasoned - we say THANKS for the dedicated service to the network. Nothing can replace a good and reliable operator...

Francis "Hoss" Parks

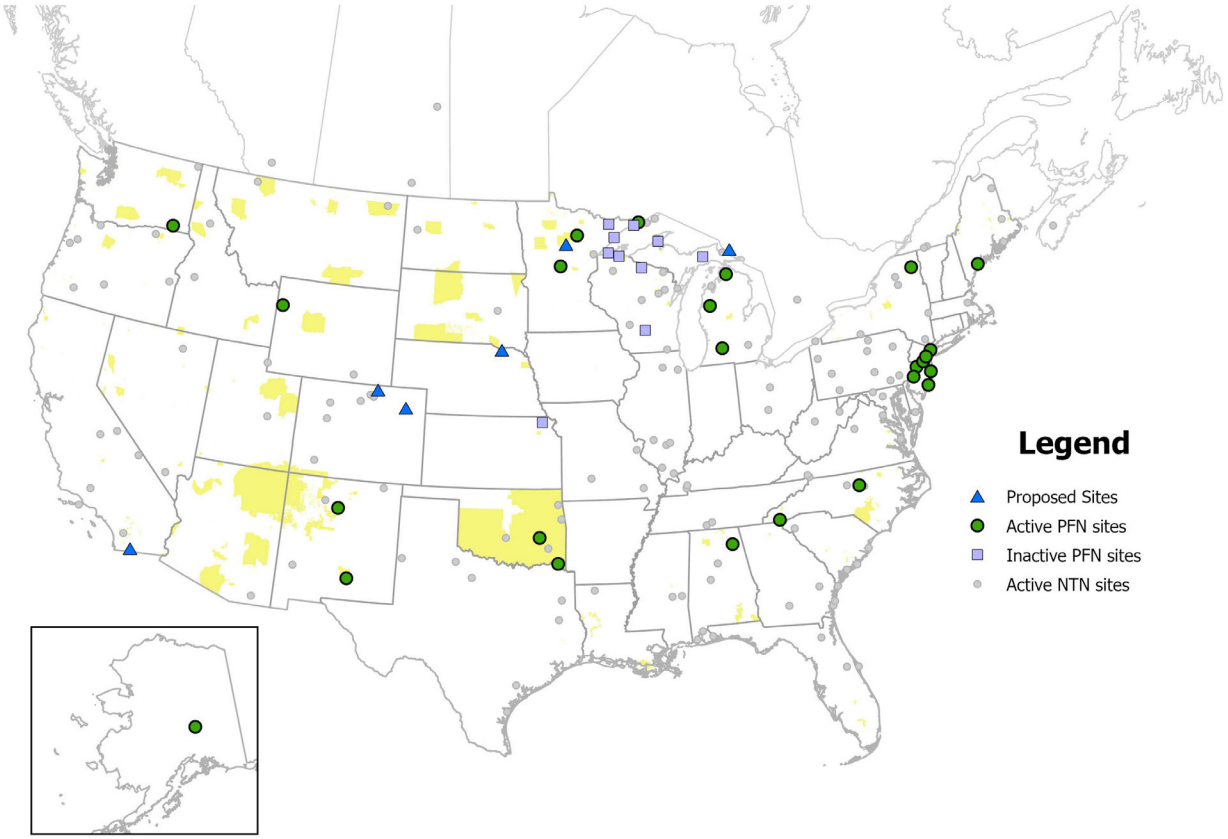


Jim Secor

Award	Operator	Years	Site	Network	Site Name	Funding Agency
40 Year Award	Jim Secor	1985 - 2025	IA23	NTN	McNay Research Center, Iowa State University	U.S. Geological Survey
30 Year Award	Francis "Hoss" Parks	1995 - 2025	MD15	NTN	Smith Island	National Oceanic & Atmospheric Administration

- The PFAS NTN Subnetwork continued to grow. The PFN is currently a provisional (transition) network, with final approval to be requested in the fall of 2025. As of the end of the year, 16 sites are operating regularly in the network with several others expecting to be added (see below). Work is ongoing to extend the number of PFAS compounds analyzed from 33 to ~40.

- Remaining to do: an updated QAPP and final methods/SOPs for sample handling, etc., QAAG for review and approval, NTN field flags coding, a user interface for the NADP/PFN webpage to allow data users to download PFAS concentrations and fluxes, site maps, site information, sponsors, etc., and establish a PFAS science committee that would be charged with advancing research.



Current PFAS Site Map.

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 occurred, and were analyzed for the same analytes as NTN samples.

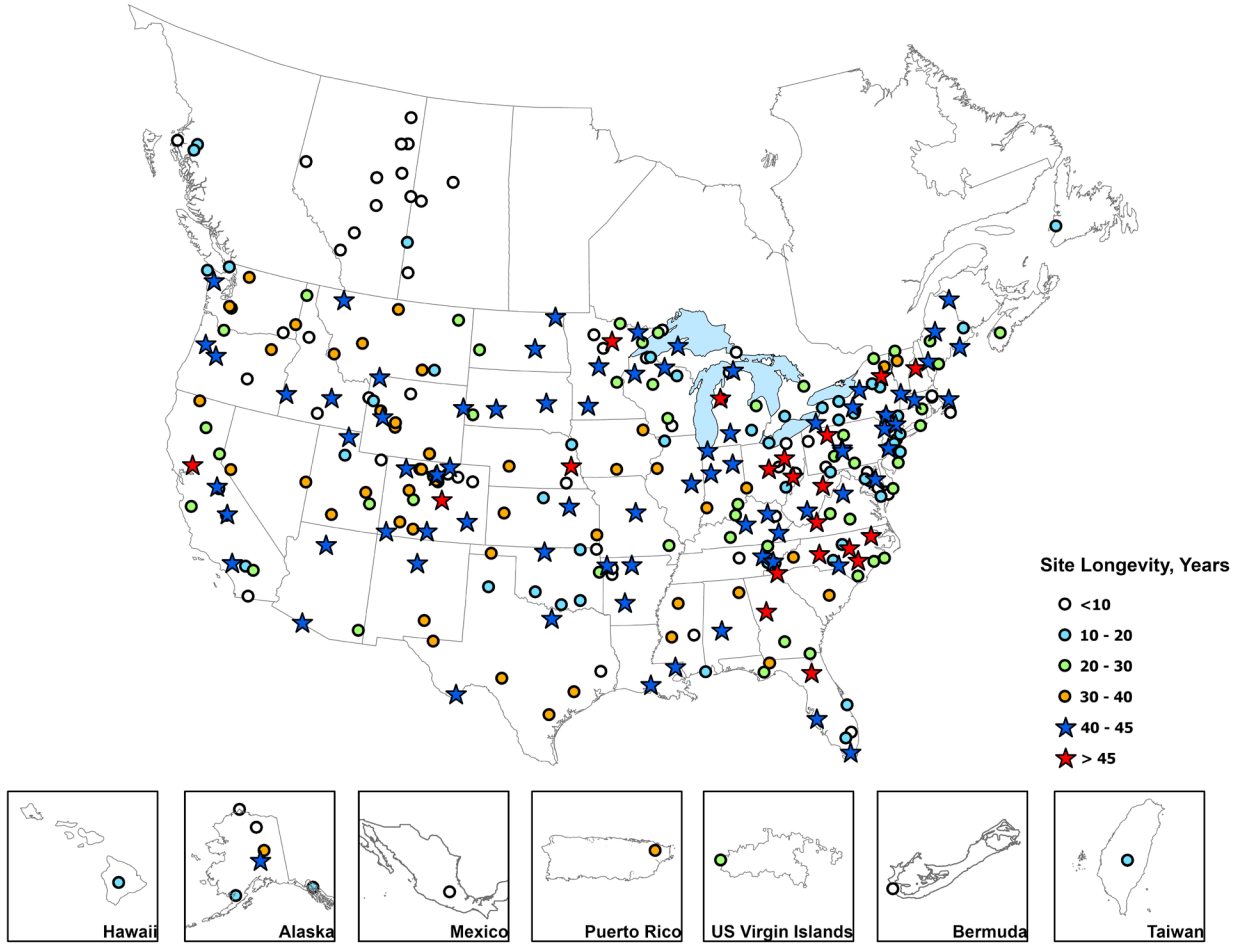
In January 1996, the NADP established the MDN, the third network in the organization. The MDN was formed to provide data on the wet deposition of mercury to surface waters, forested watersheds, and other receptors. MDN samples, like NTN samples, are weekly collections.

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

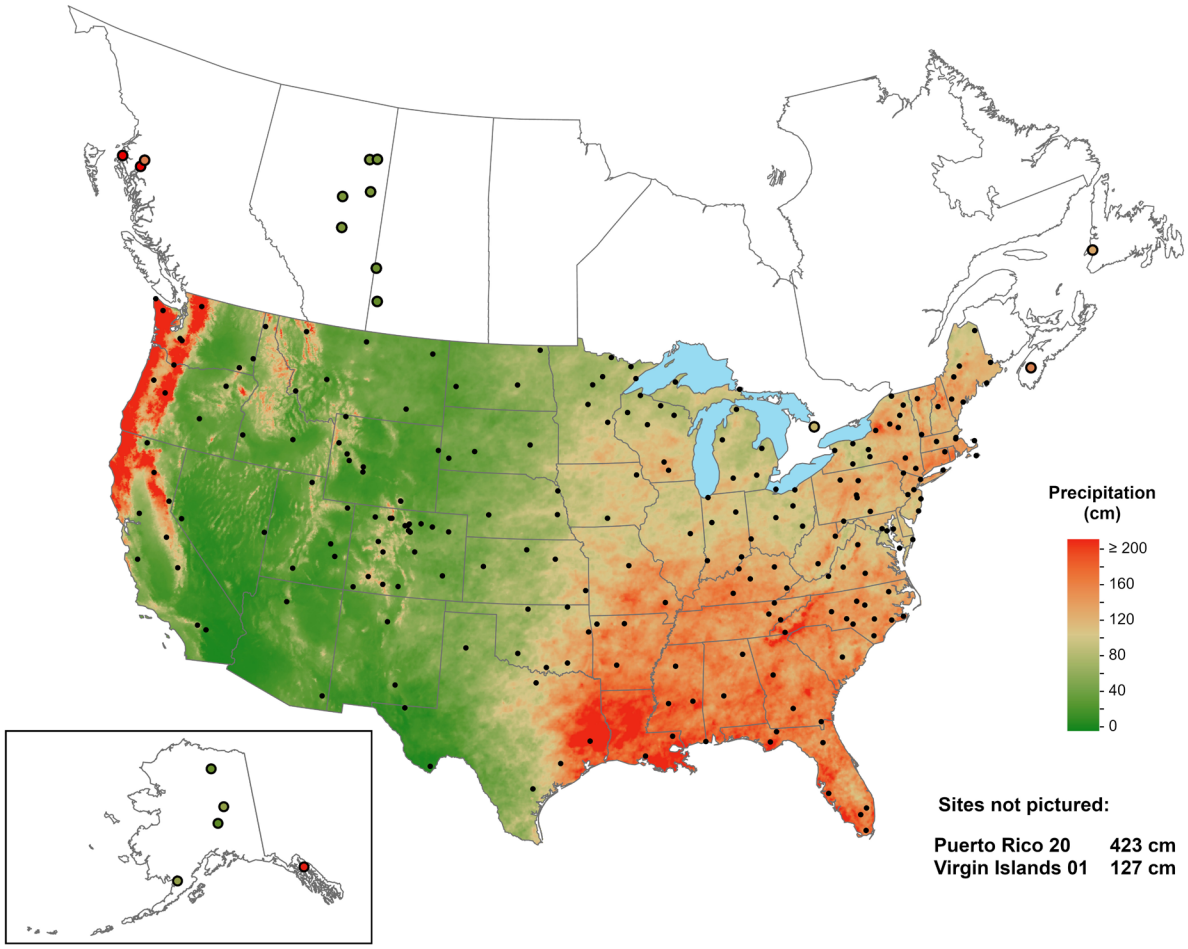
This map series is a principal product of the NADP. It summarizes the results of network operation for the most recent complete calendar year in graphical form. Additional maps, related geographic information, and reviewed analytical results are available on the NADP website.

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 2024. Open circles primarily designate urban sites, defined as having at least 400 people per square kilometer (km2) within a 15-km radius of the site. Specially designated industrial sites, and sites that are too far removed from other observations to extend the contour surface (e.g., Canadian sites) 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. Open circle sites do not contribute to the contour surface. Colors represent interpolated values of concentration, deposition, or precipitation.

The CONUS 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 2025). 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 2024, using precipitation measurements from the NADP and PRISM (in cm).

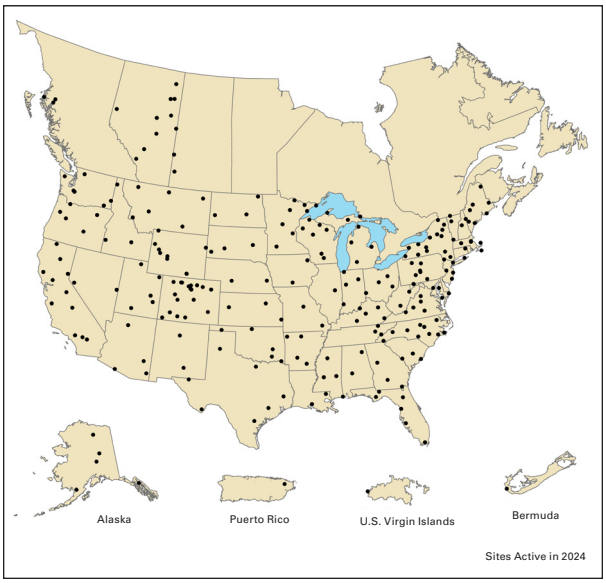
National Trends Network (NTN)

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.

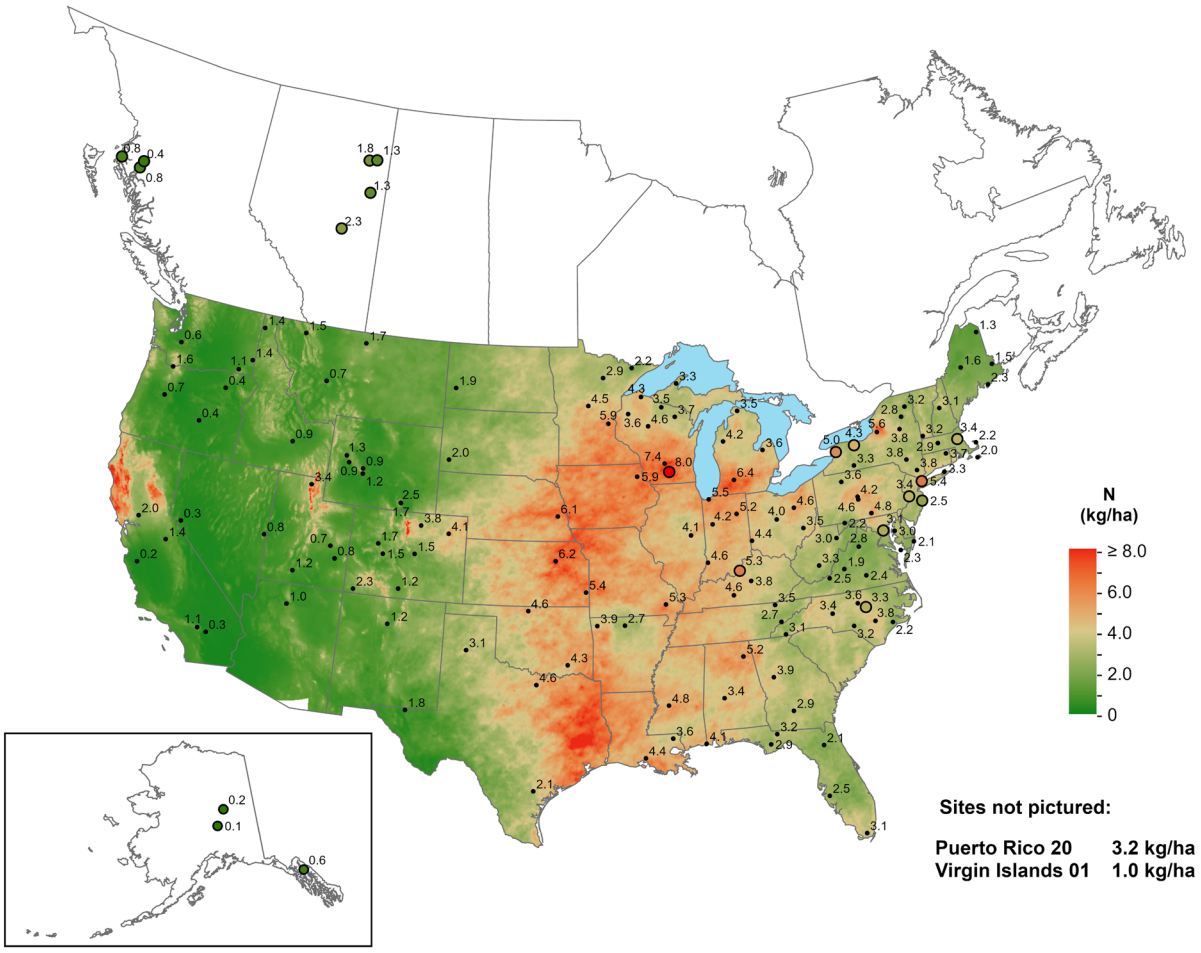
All samples are sent to the NADP laboratory for analysis of free acidity (H^+ as pH), specific conductance, calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^+), potassium (K^+), sulfate (SO_4^{2-}), nitrate (NO_3^-), chloride (Cl^-), and ammonium (NH_4^+) ions. The NADP quantifies orthophosphate for quality assurance purposes, as an indicator of potential field contamination. The laboratory 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

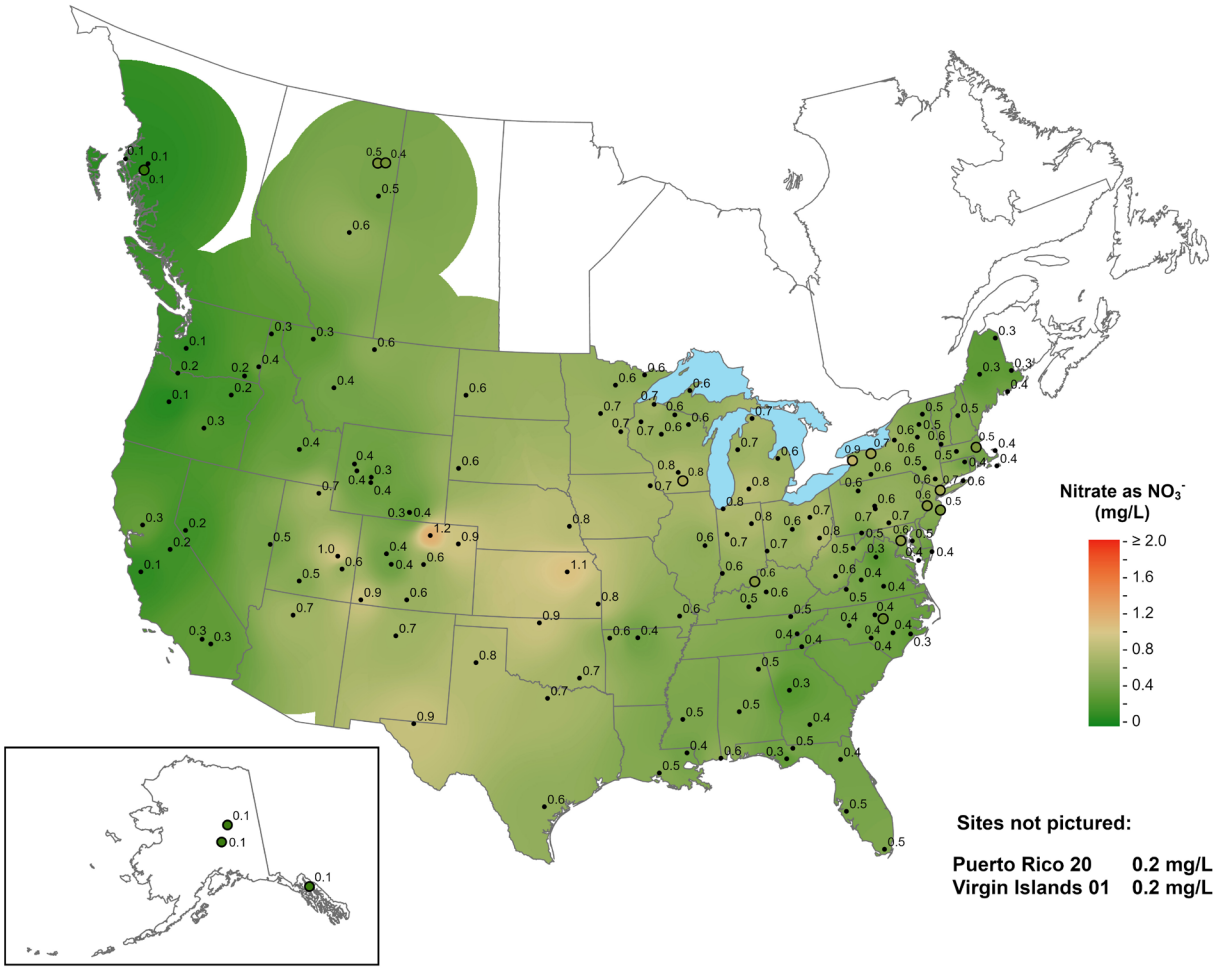
The maps on pages 13 through 33 show precipitation-weighted mean concentration and annual wet deposition for select acid anions, nutrients, and base cations. Substantial spatial heterogeneity across the nation is apparent for all measured species. In 2024, 154 of the 254 active sites met NADP completeness criteria. Canadian sites BC22, AB32, and AB36 are located in immediate vicinity of heavy industry. Concentration and deposition maps are included for SO_4^{2-}, NO_3^-, NH_4^+, pH, Ca^{2+}, Mg^{2+}, Cl^-, Na^+ and K^+.



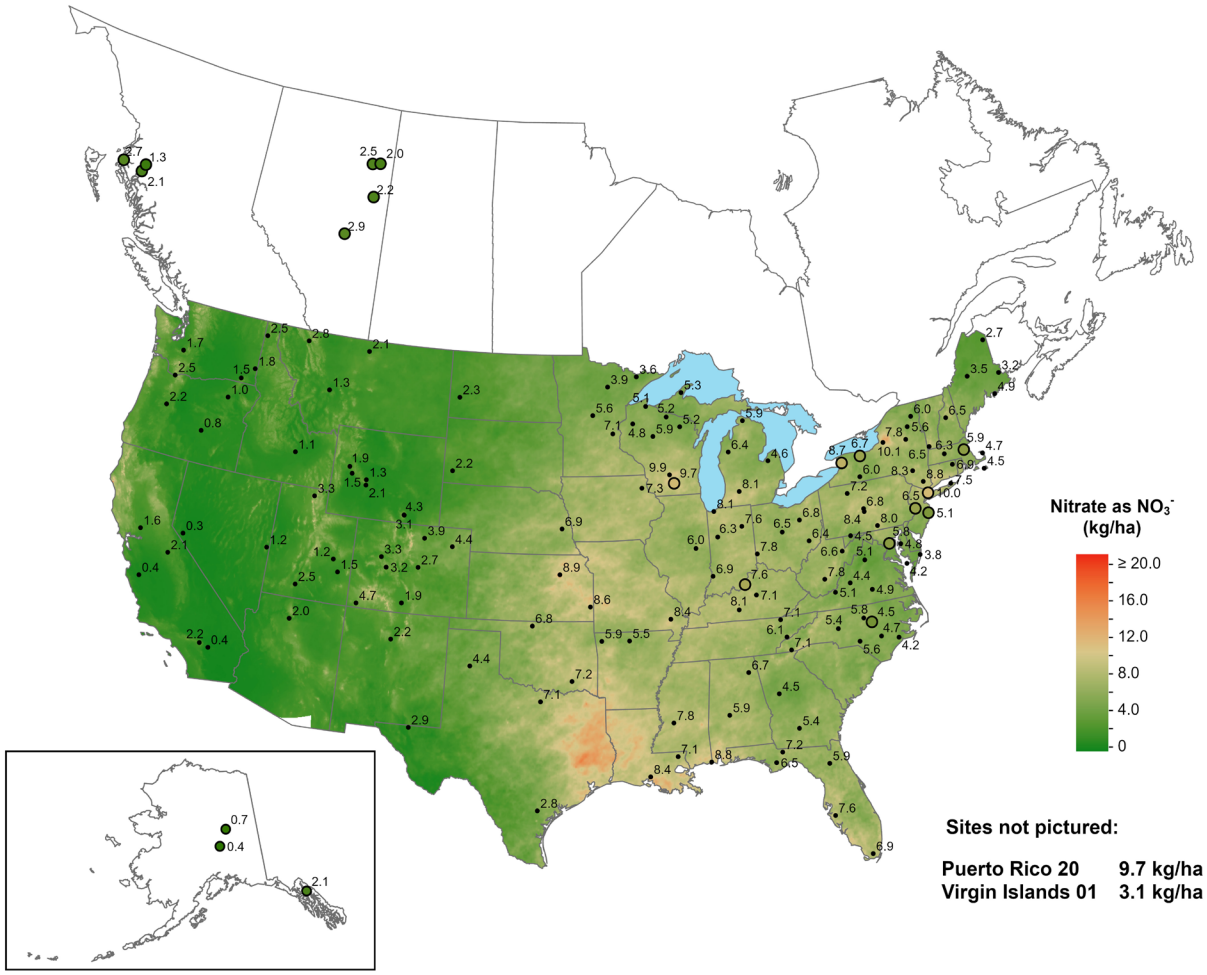
Annual maps for wet deposition of inorganic nitrogen (i.e., $NO_3^- + NH_4^+$) and sulfur + nitrogen (S + N) are also included. S + N (i.e., $SO_4^{2-} + NO_3^- + NH_4^+$) deposition is mapped as hydrogen ion equivalents per hectare (eq/ha).



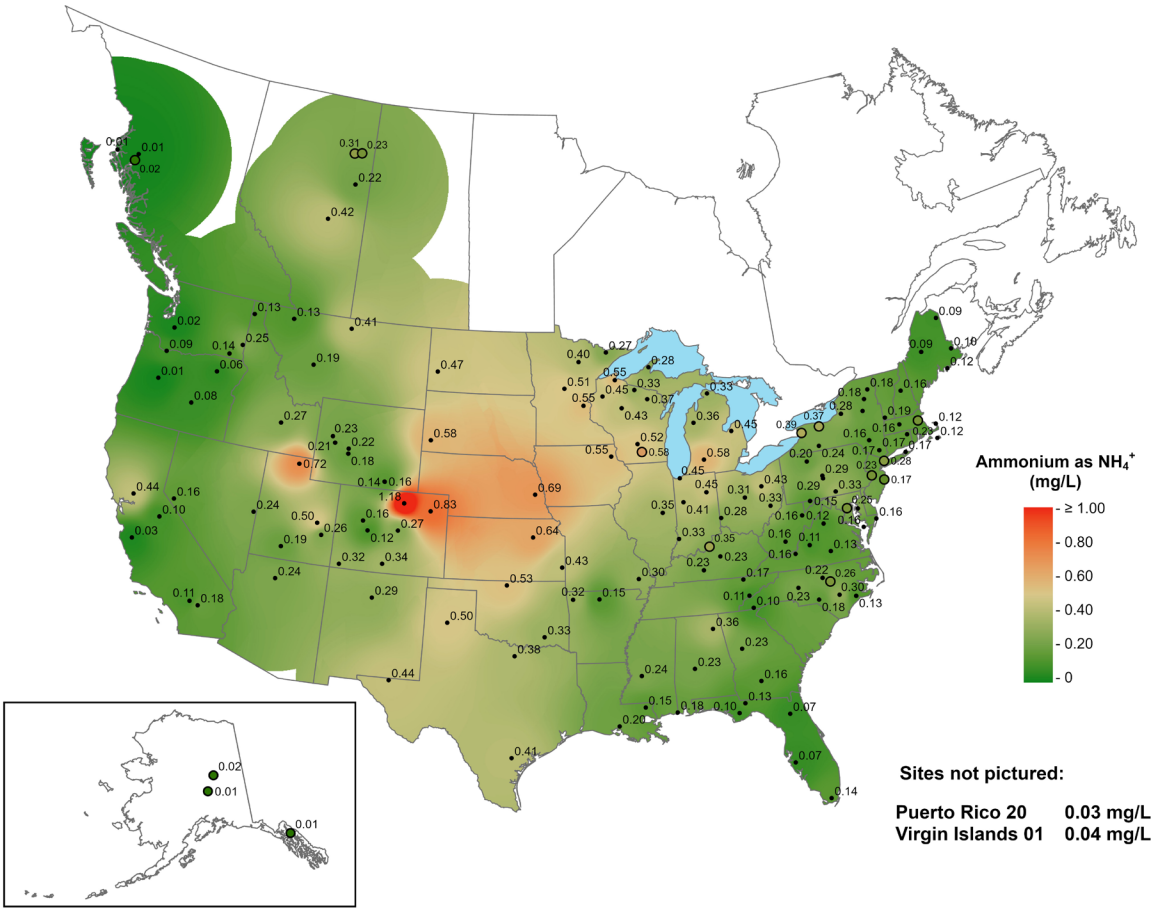
Inorganic nitrogen wet deposition from nitrate and ammonium, 2024.



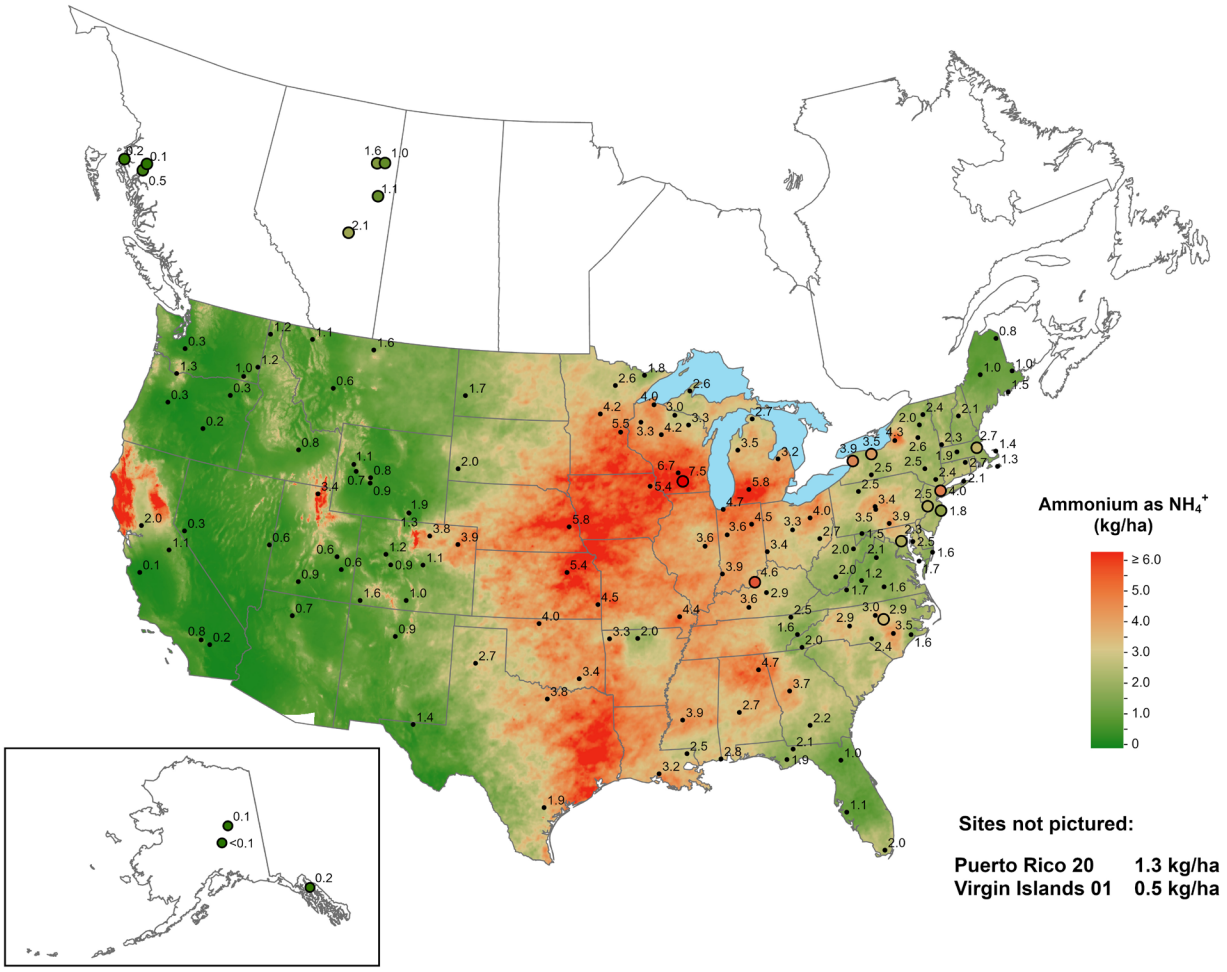
Nitrate ion concentration, 2024.



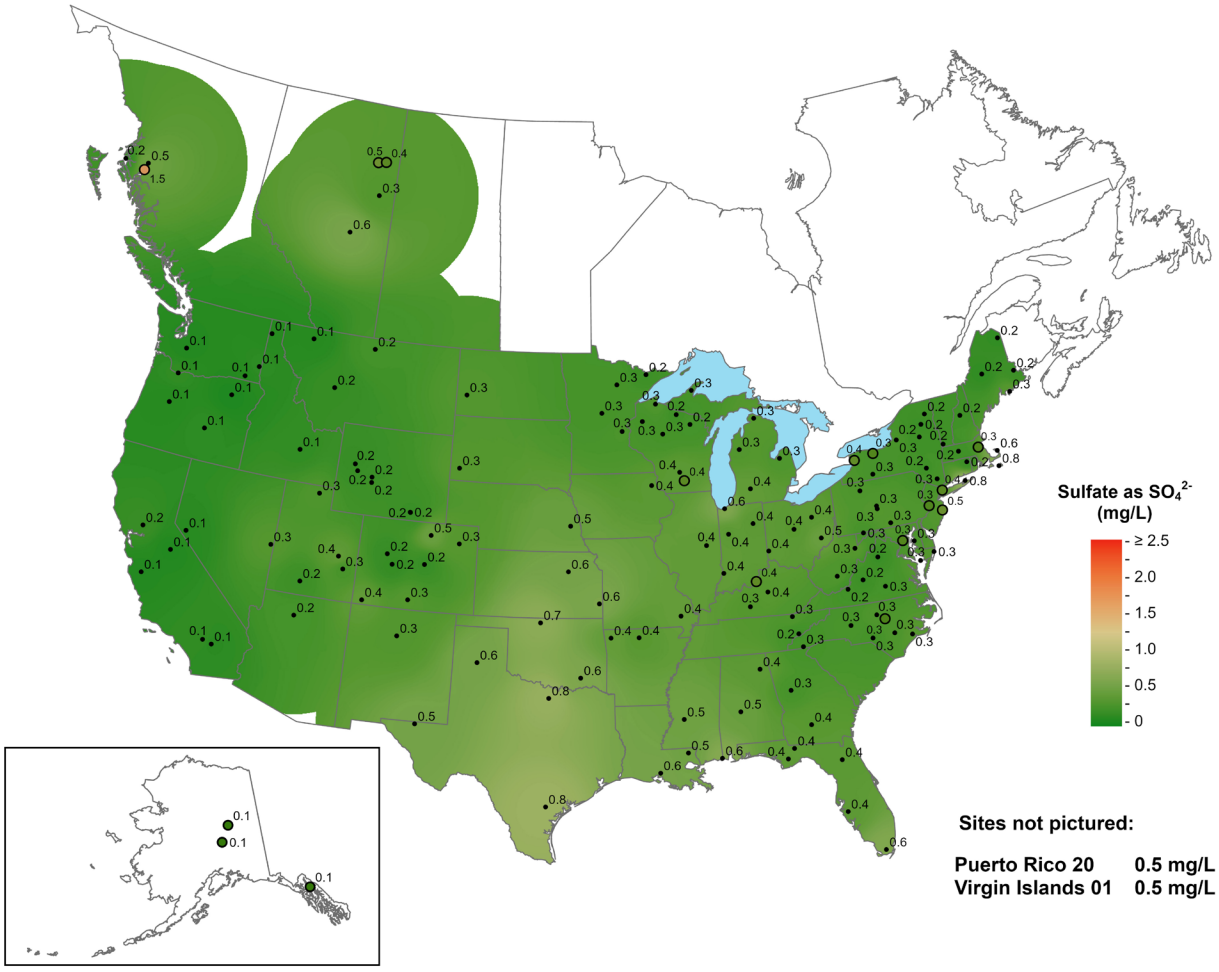
Nitrate ion wet deposition, 2024.



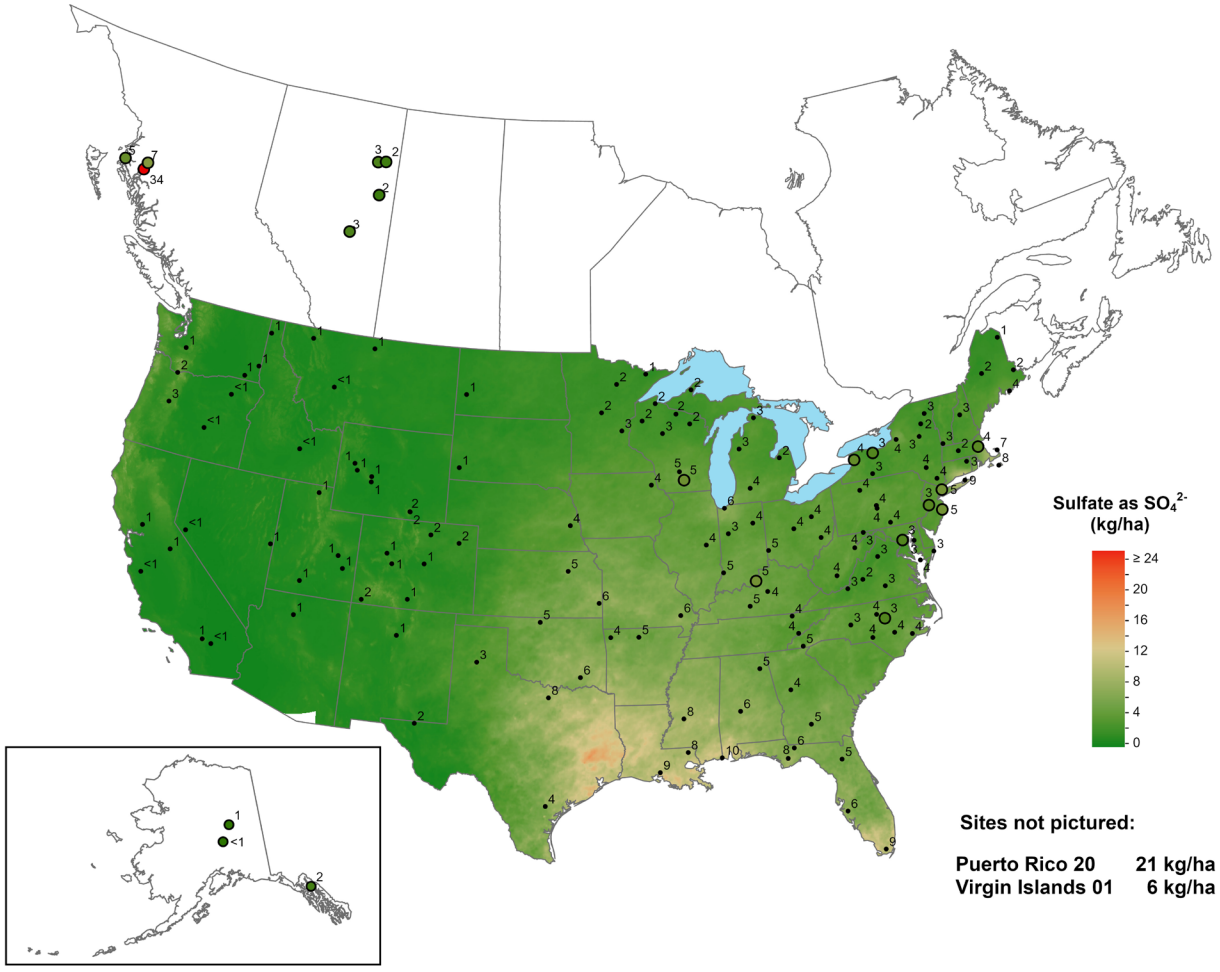
Ammonium ion concentration, 2024.



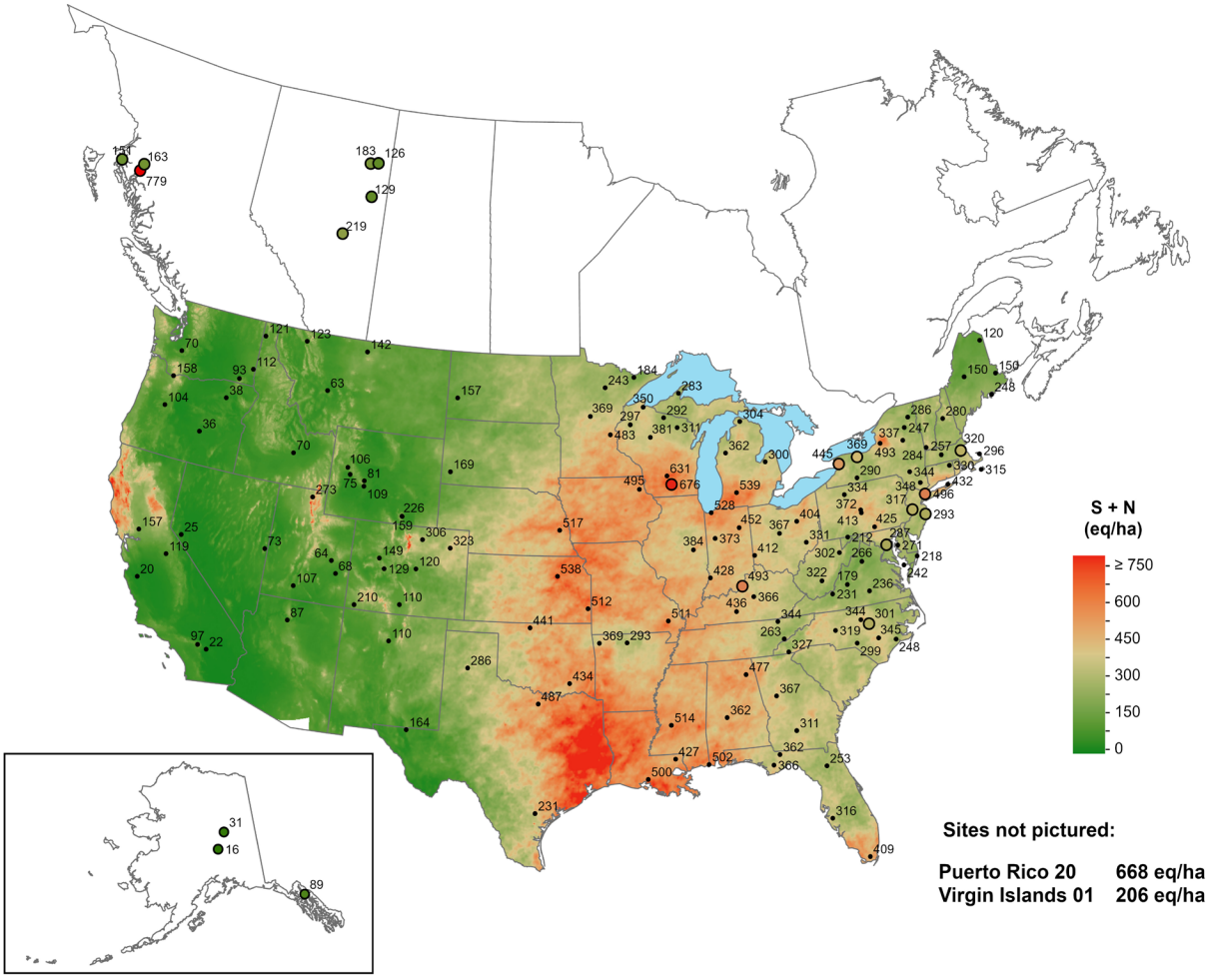
Ammonium ion wet deposition, 2024.



Sulfate ion concentration, 2024.



Sulfate ion wet deposition, 2024.



Sulfur plus nitrogen wet deposition from sulfate, nitrate and ammonium, 2024.

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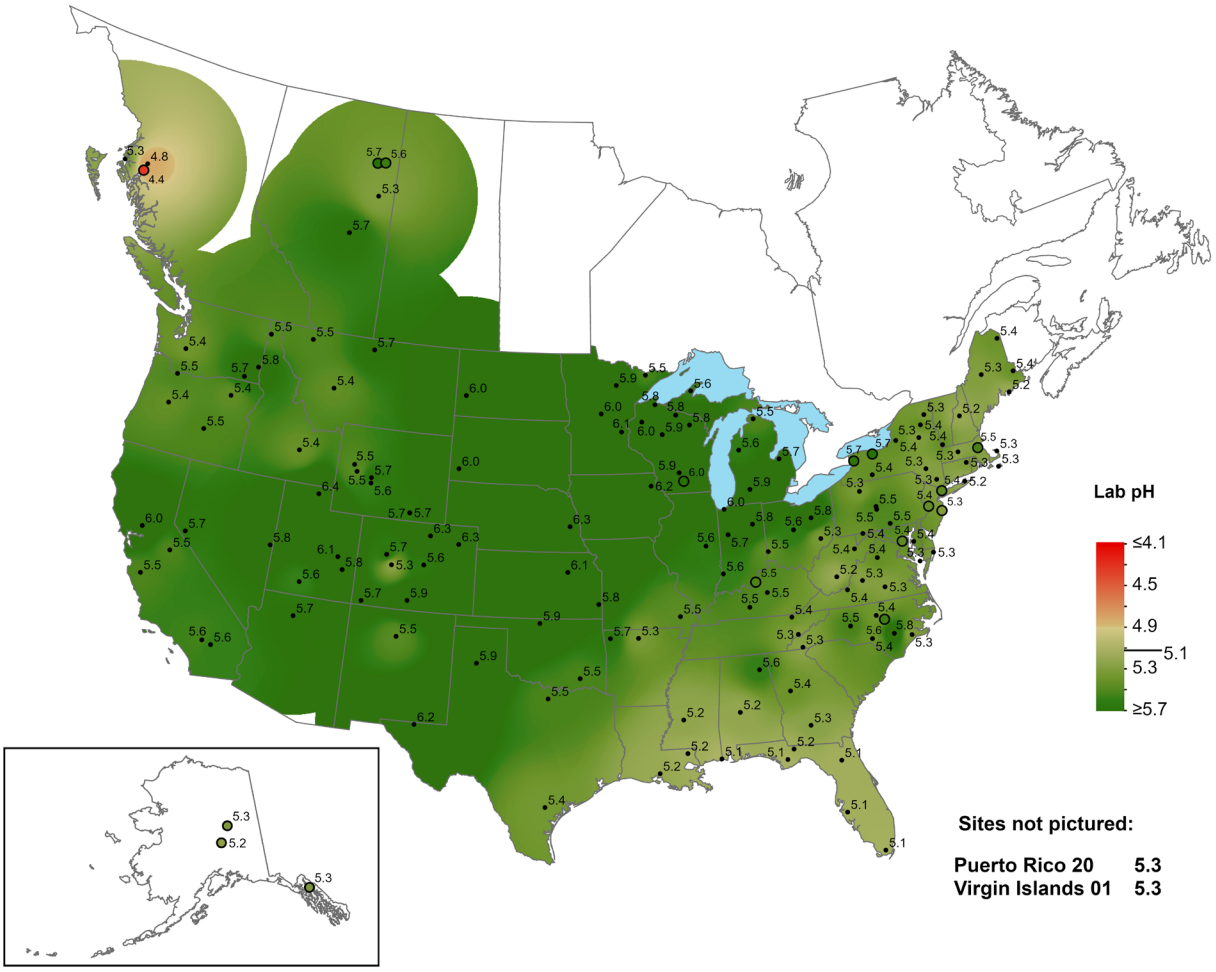
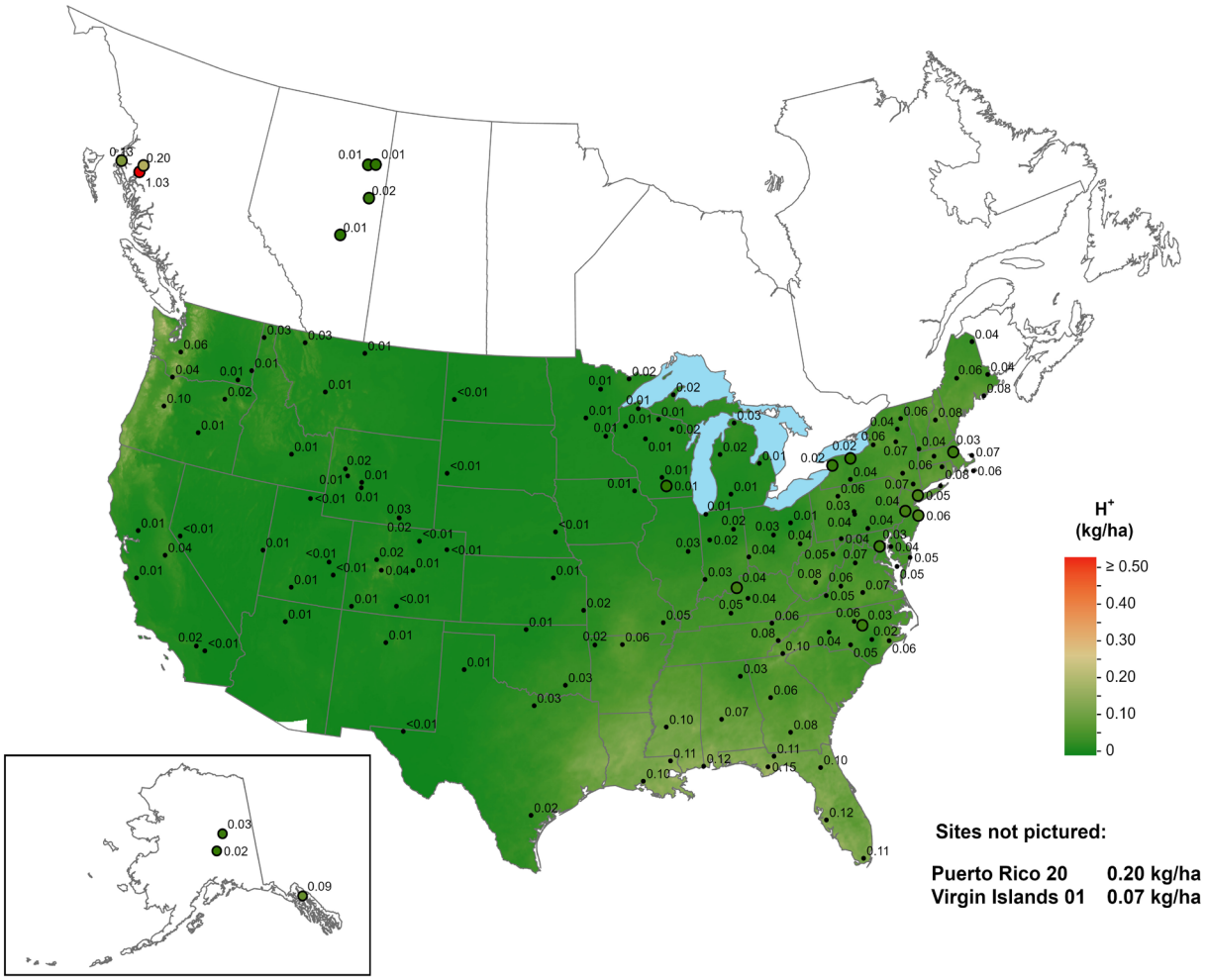
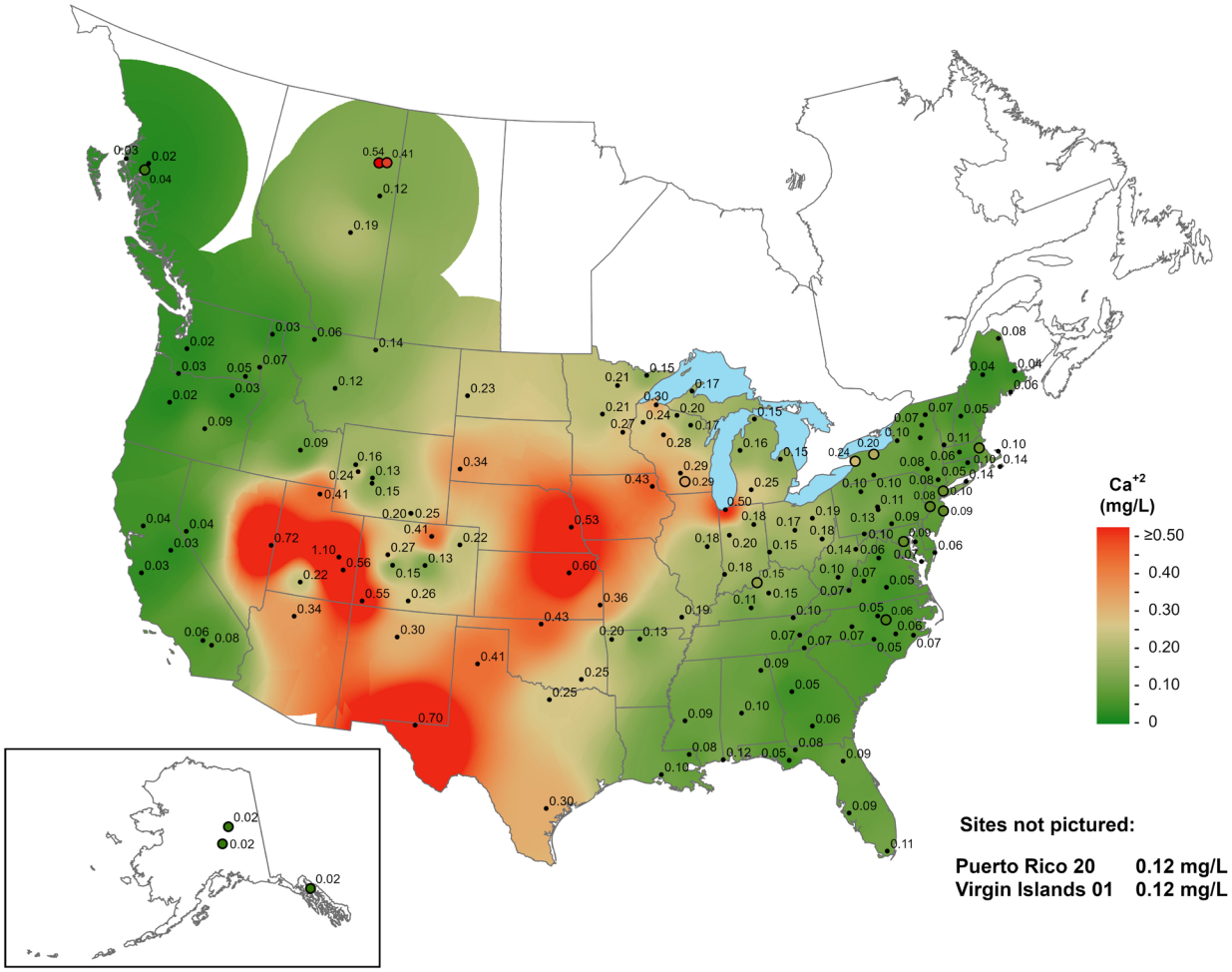


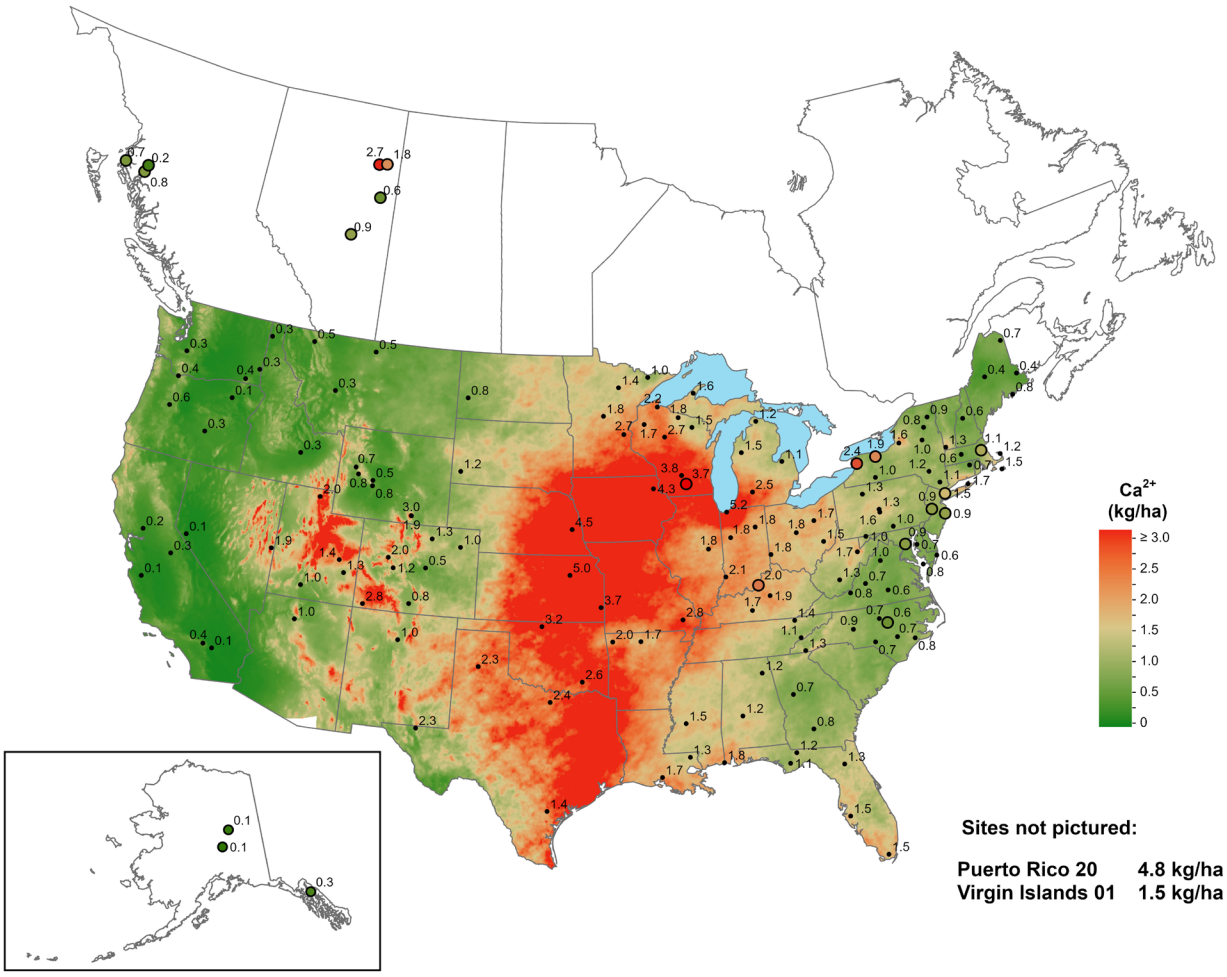
Hydrogen ion concentration as pH, 2024.
Typically, a precipitation pH of less than 5.1 is considered acidic precipitation.



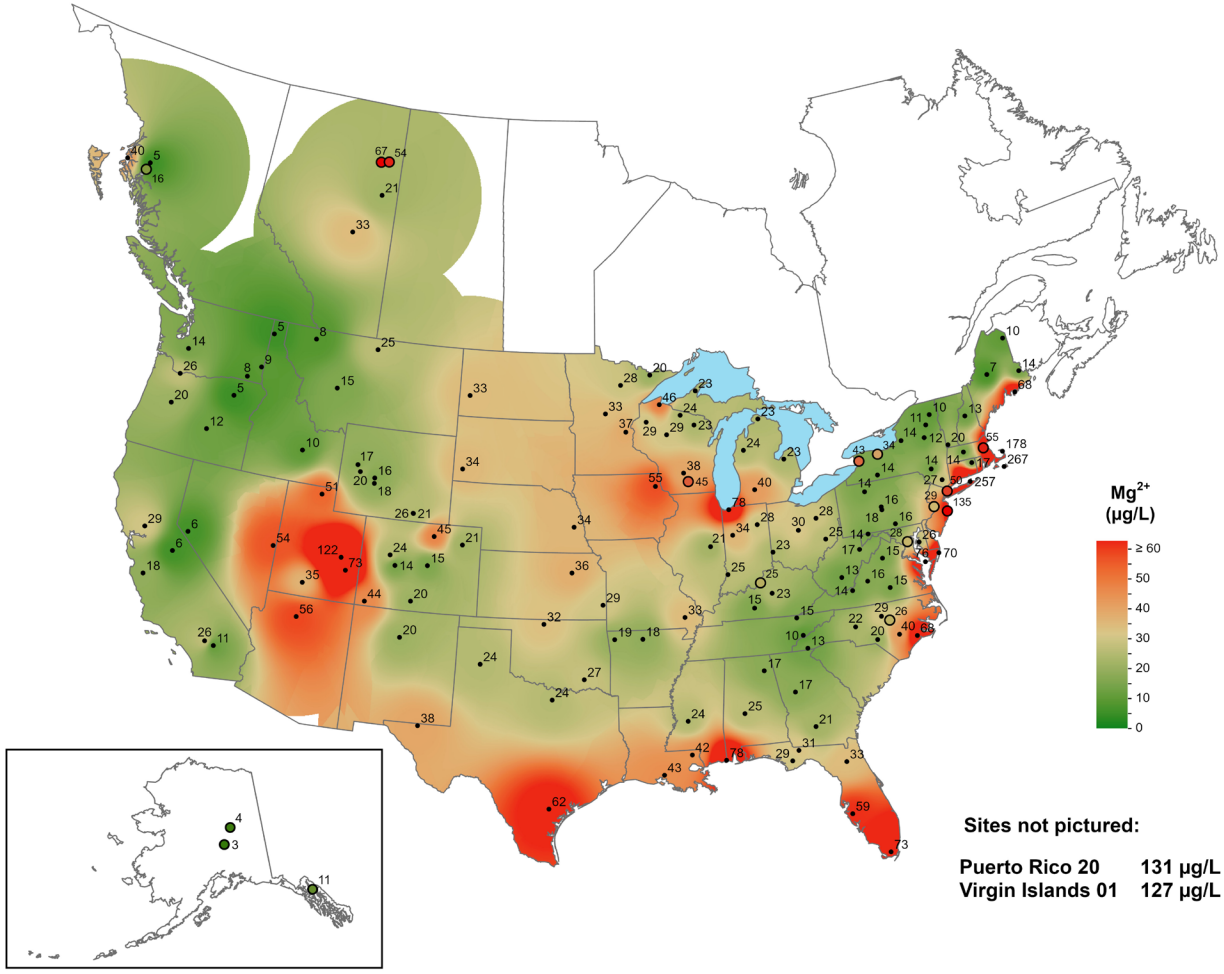
Hydrogen ion wet deposition, 2024.



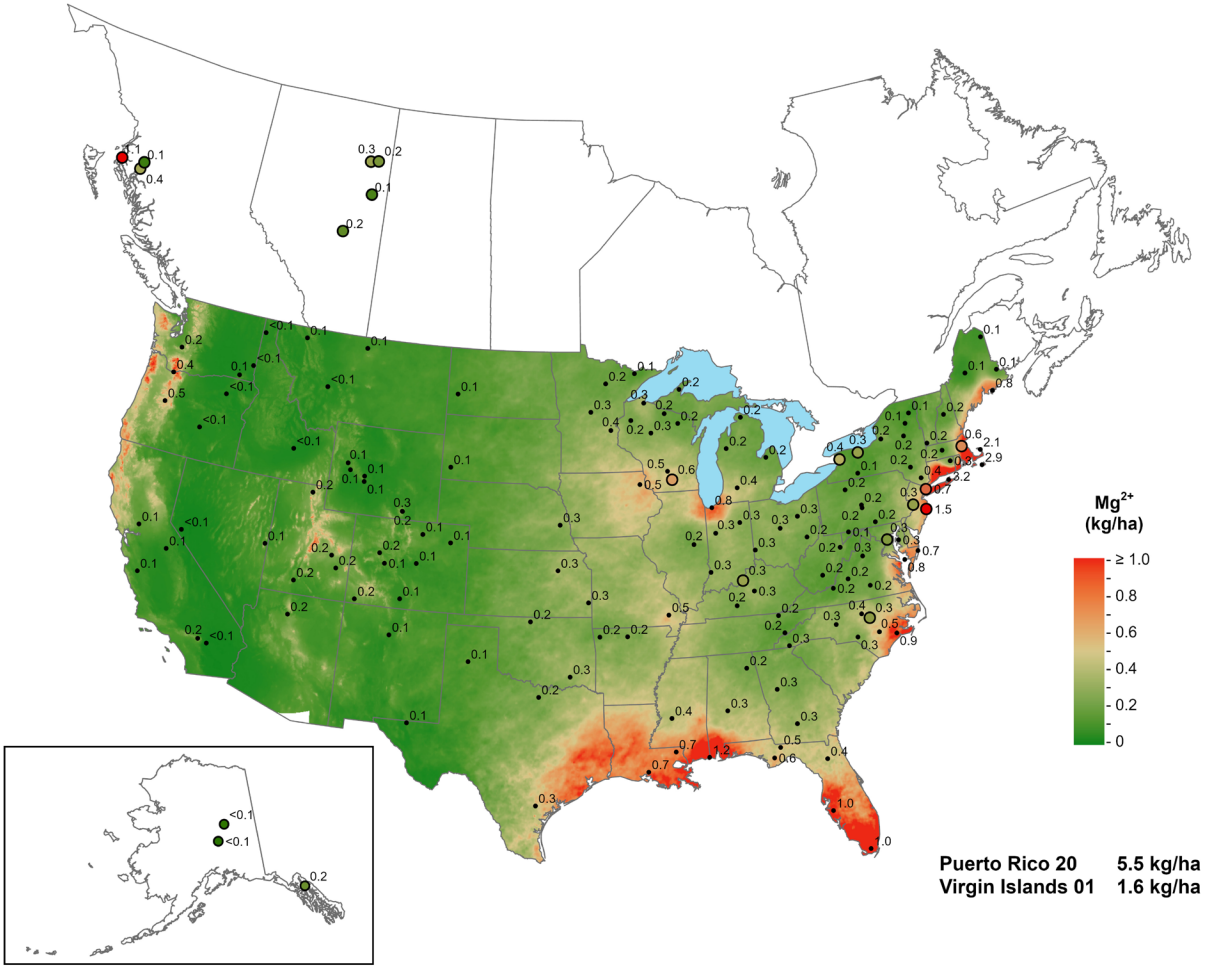
Calcium ion concentration, 2024.



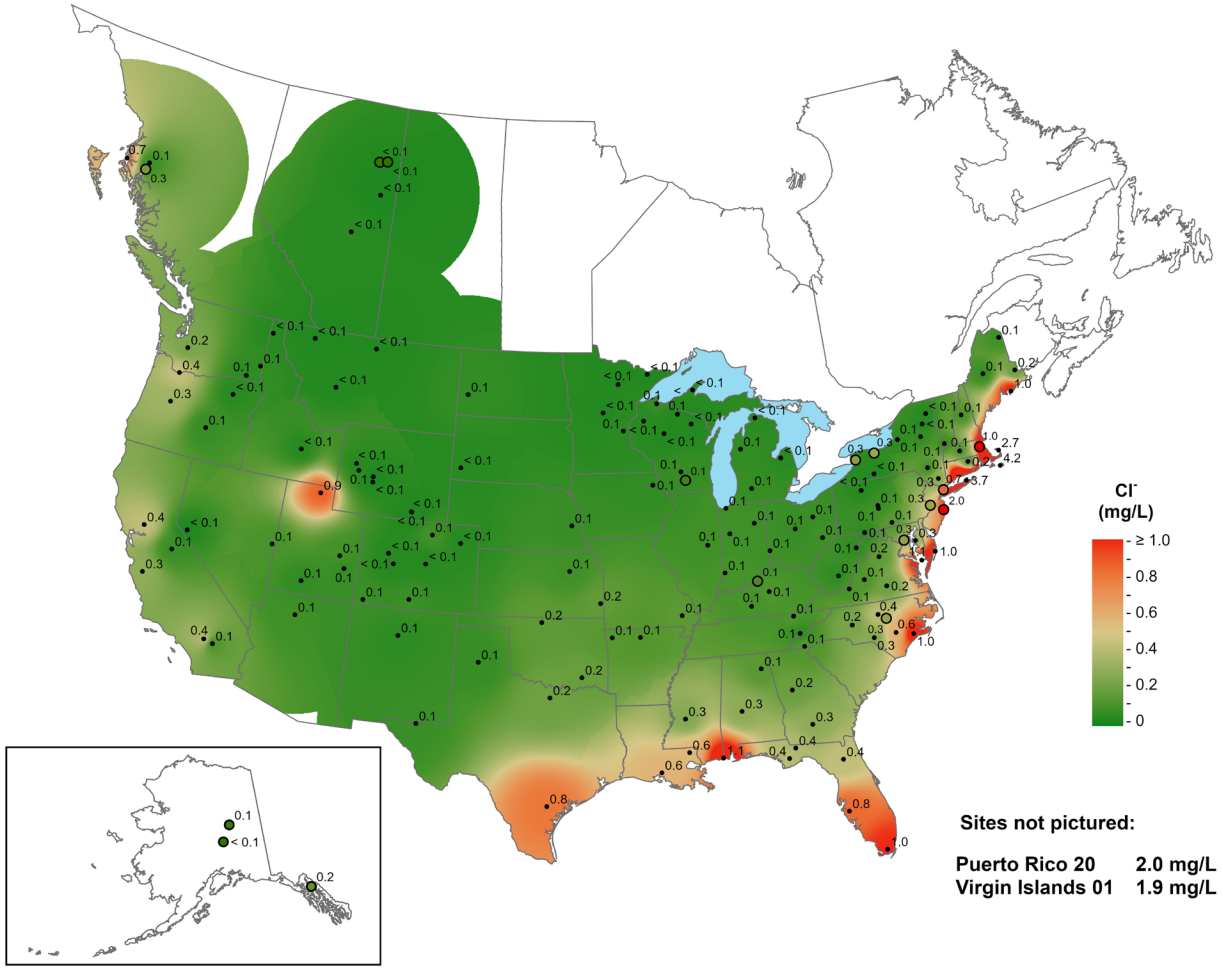
Calcium ion wet deposition, 2024.



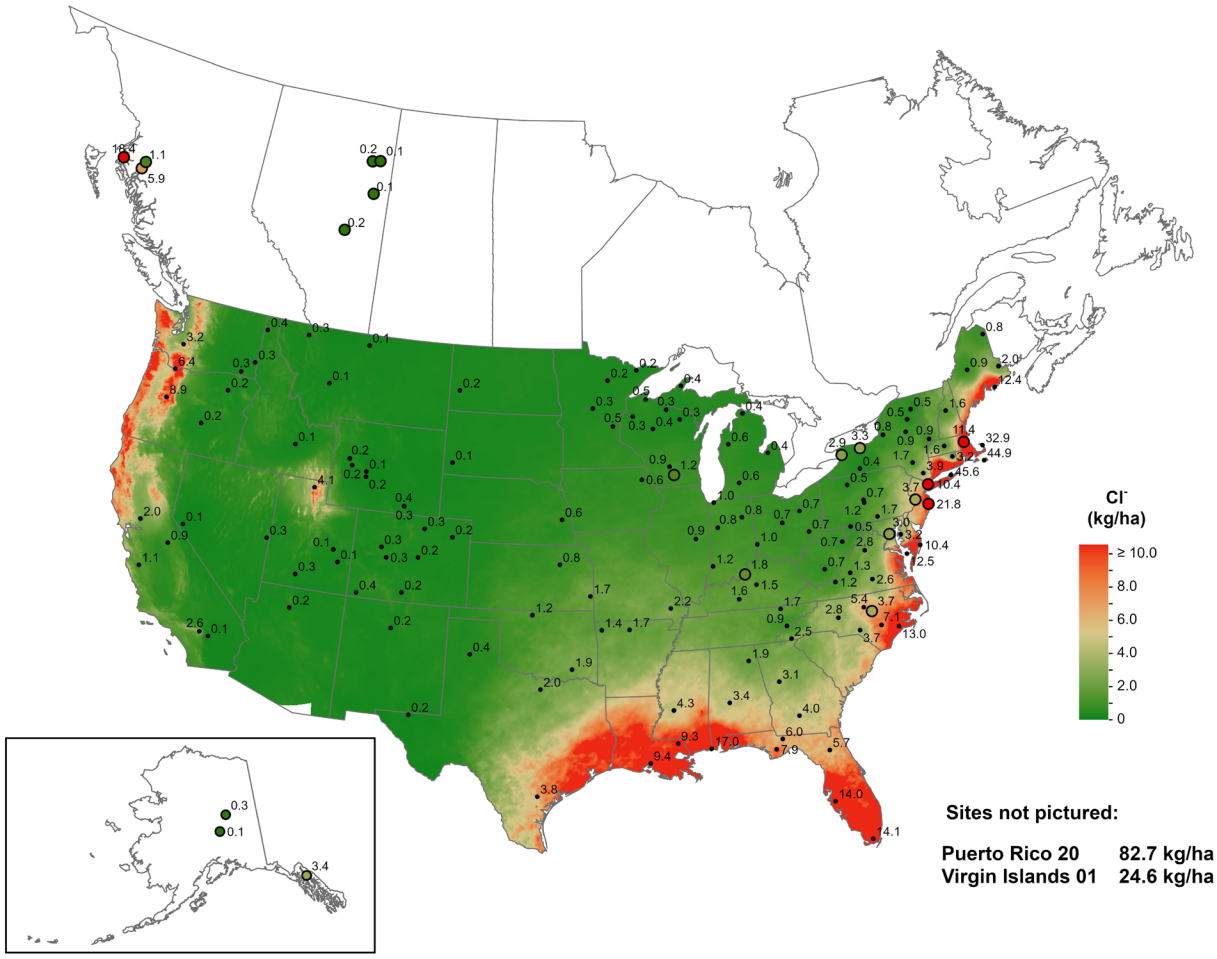
Magnesium ion concentration, 2024.



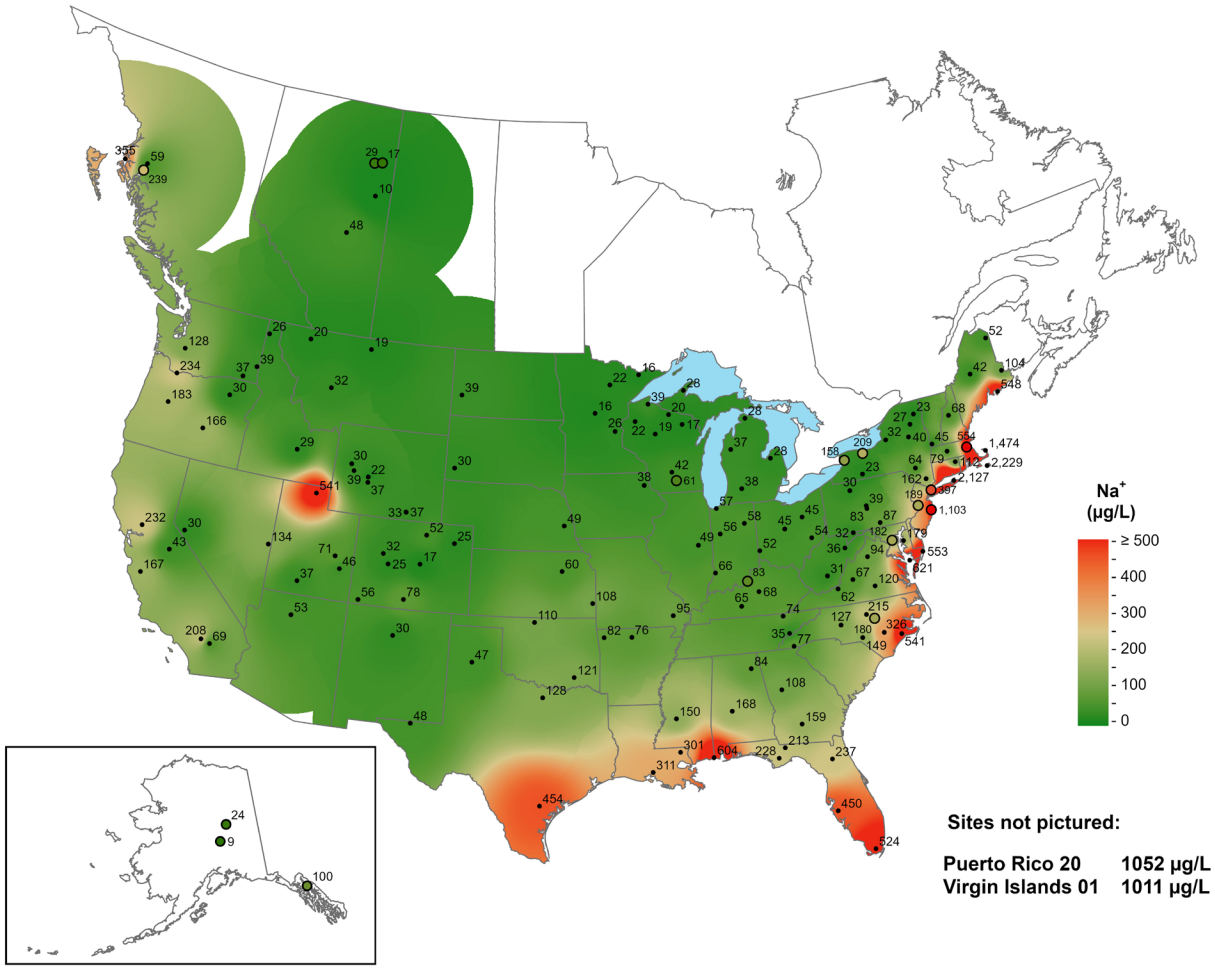
Magnesium ion wet deposition, 2024.



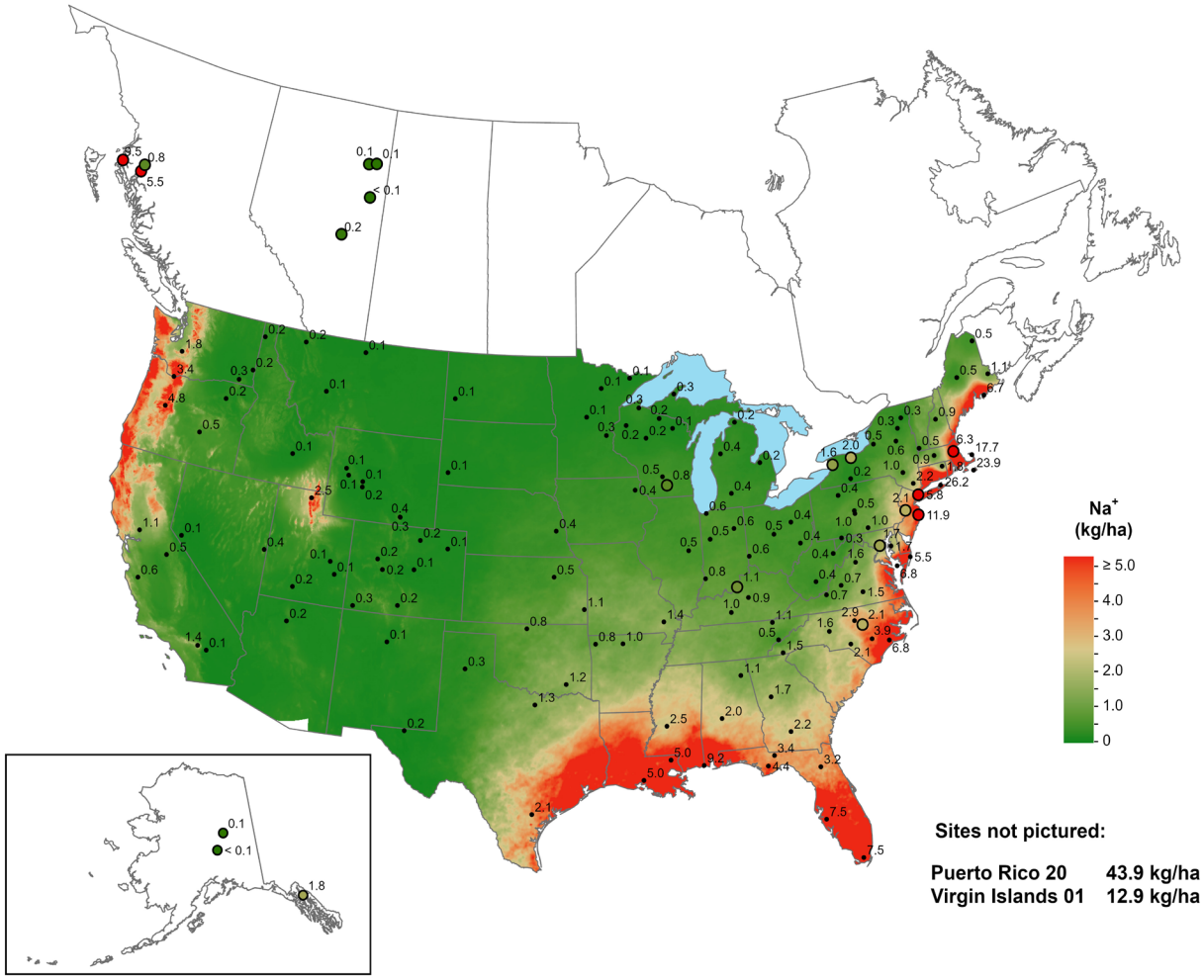
Chloride ion concentration, 2024.



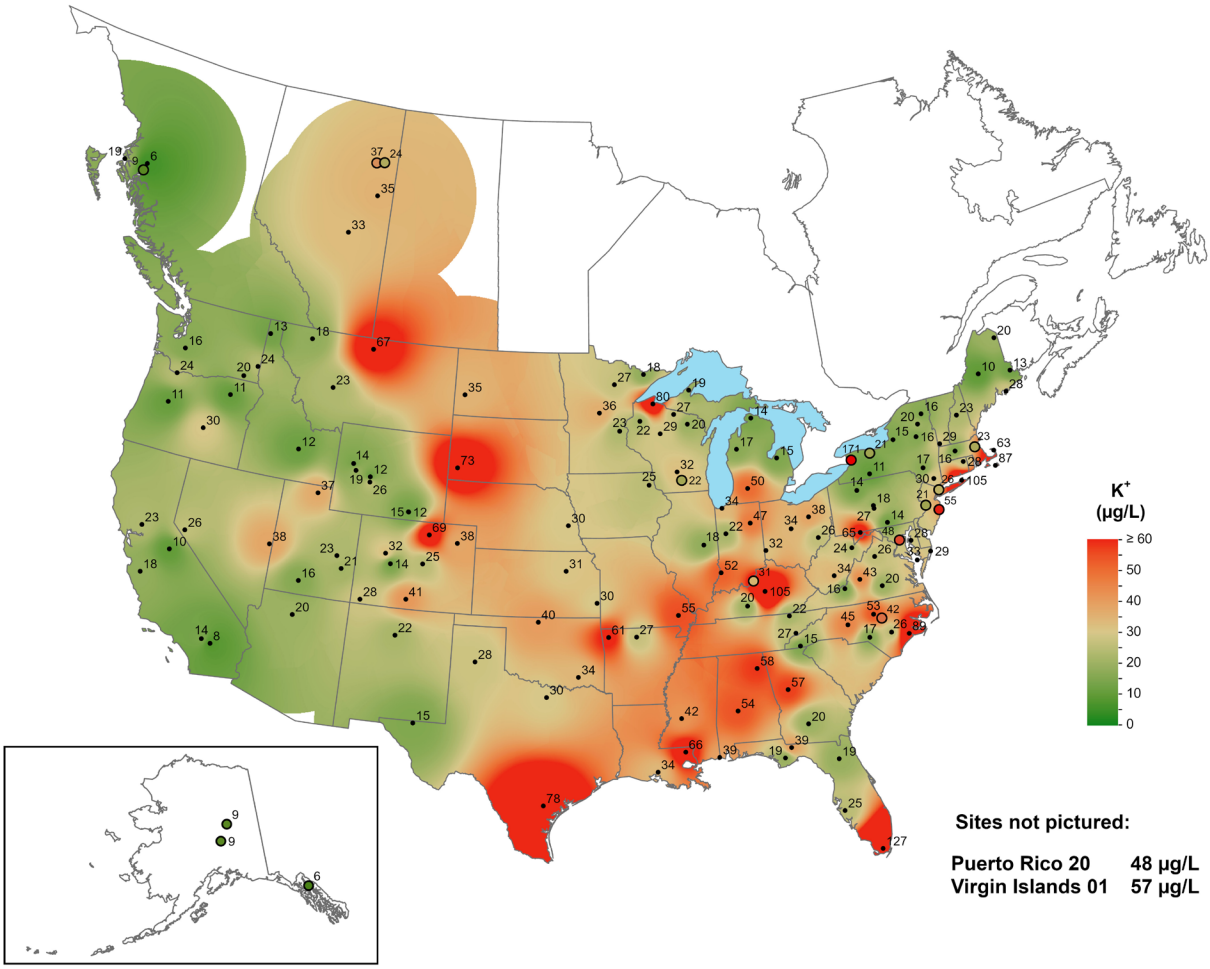
Chloride ion wet deposition, 2024.



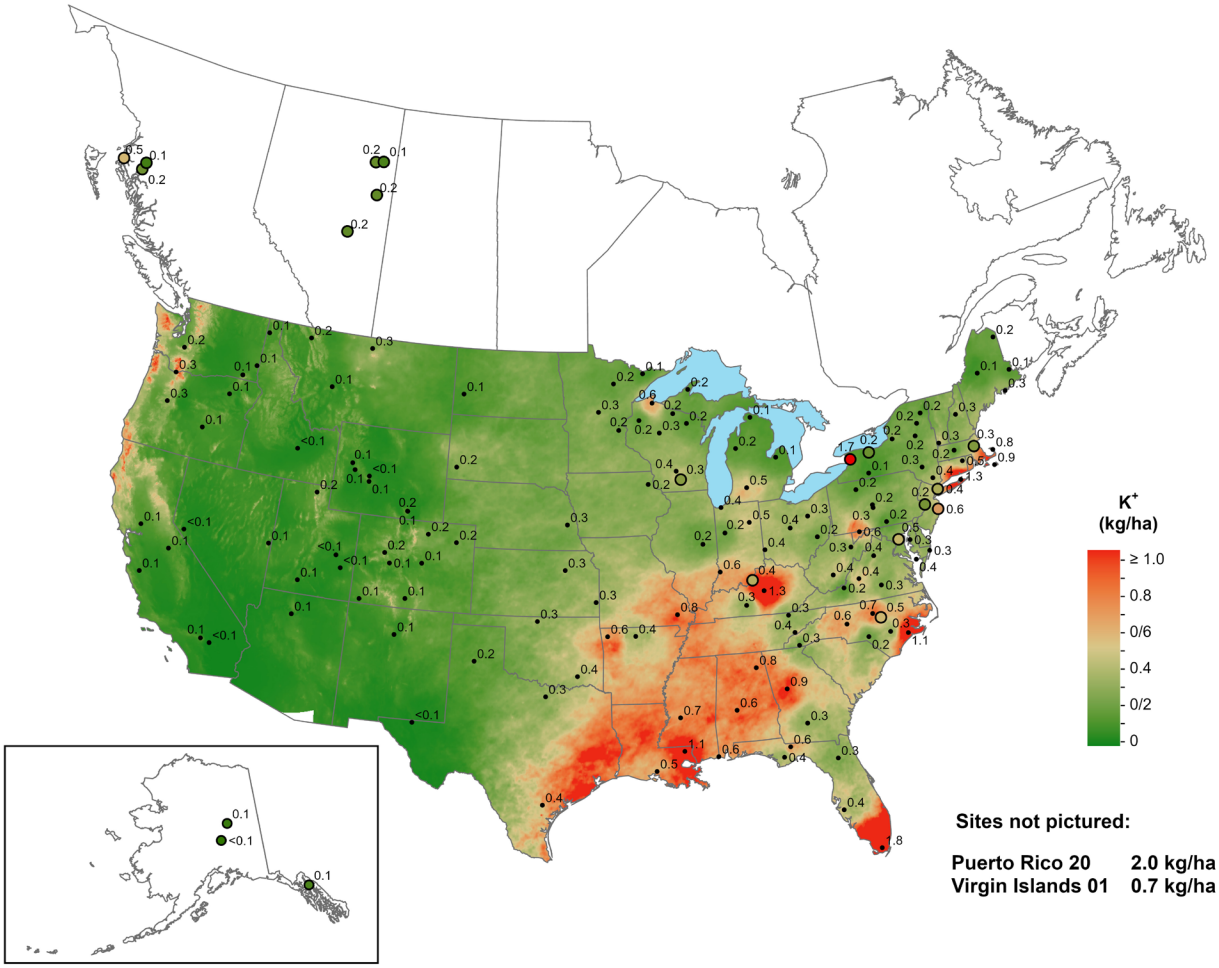
Sodium ion wet concentration, 2024.



Sodium ion wet deposition, 2024.



Potassium ion concentration, 2024.



Potassium ion wet deposition, 2024.

Mercury Deposition Network (MDN)

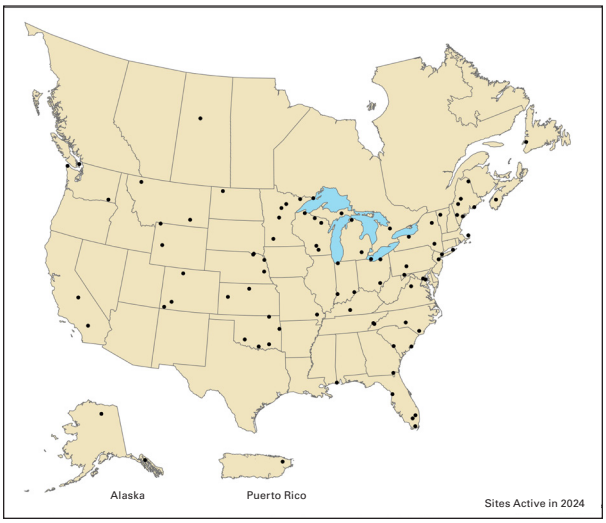
The MDN is the only network providing a long-term record for the concentration of mercury (Hg) in precipitation in North America. MDN sites follow standard procedures and use approved precipitation collectors and rain gages. The automated collector is similar to the NTN collector, but it is modified 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.

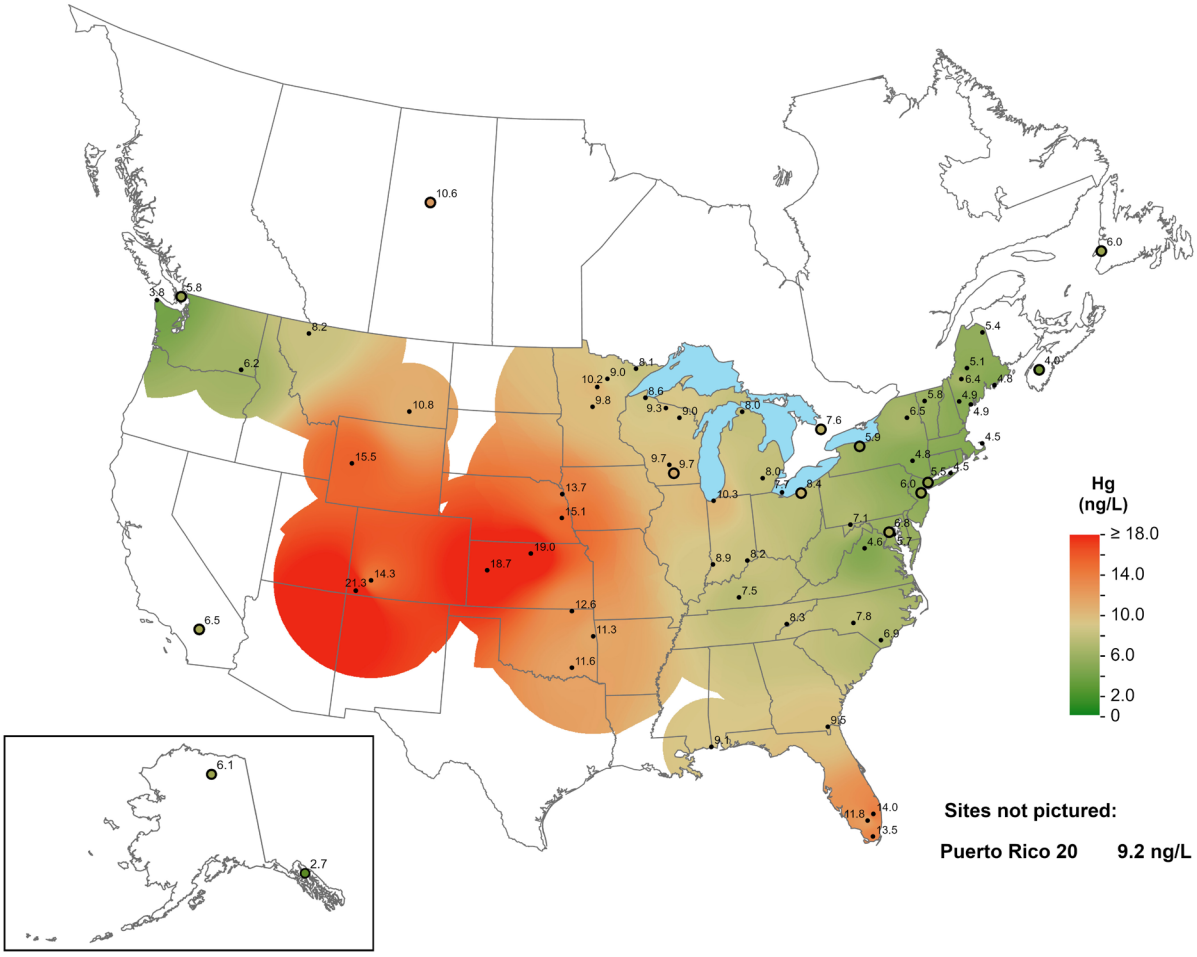
As of December 2024, there were 84 active MDN sites. Data from the MDN is available on the NADP website (http://nadp.slh.wisc.edu). Details about sample collection and analysis are available on the NADP website.

MDN Maps and Graphs

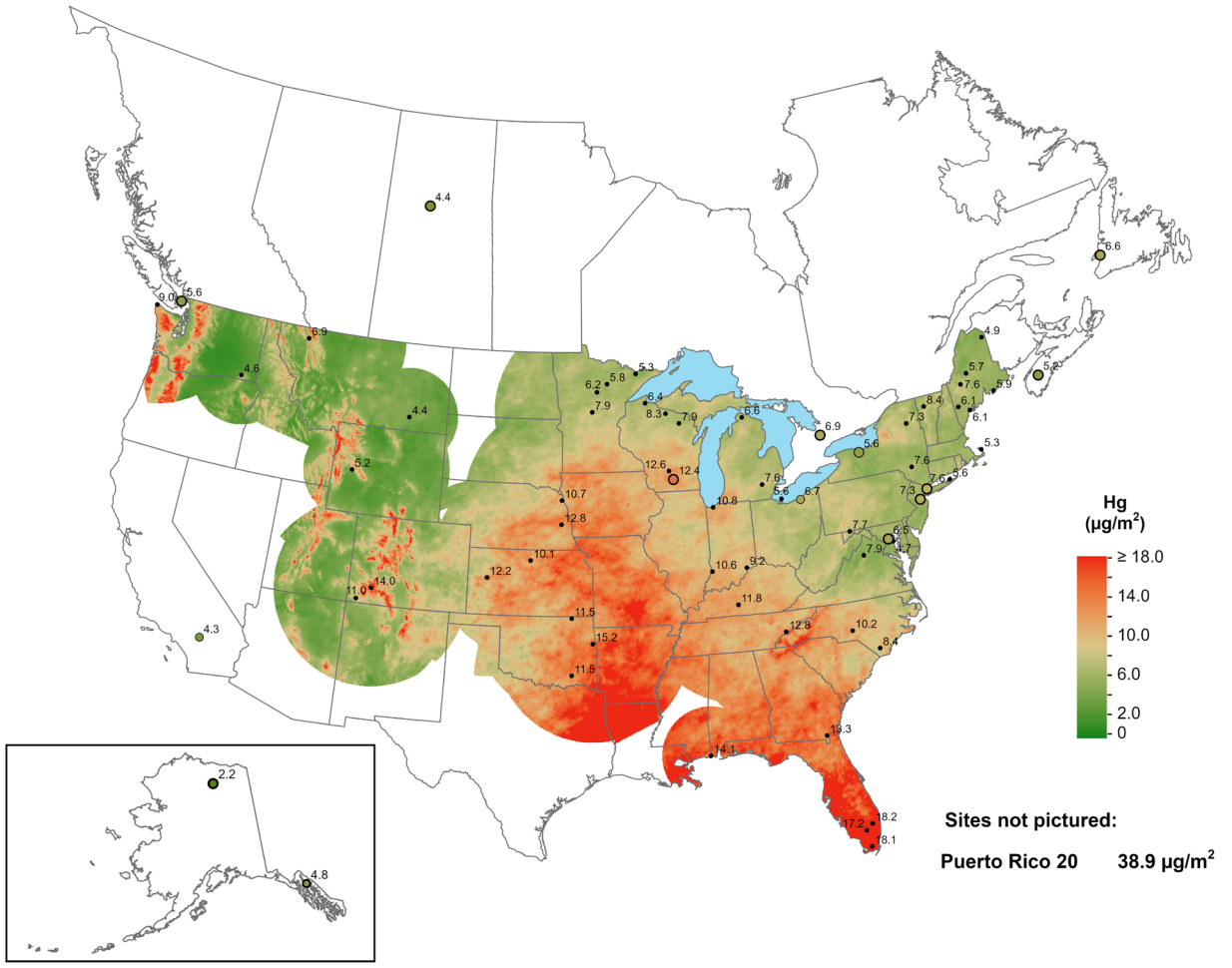
The maps on pages 35-36 show spatial variability in the precipitation-weighted mean concentration and wet deposition of total mercury across the United States.



Only sites meeting NADP completeness criteria are included. In 2024, 66 of 84 active sites met these criteria. Large variations in both mercury concentrations and wet-deposition are observed across the nation.



Total mercury concentration, 2024.



Total mercury wet deposition, 2024.

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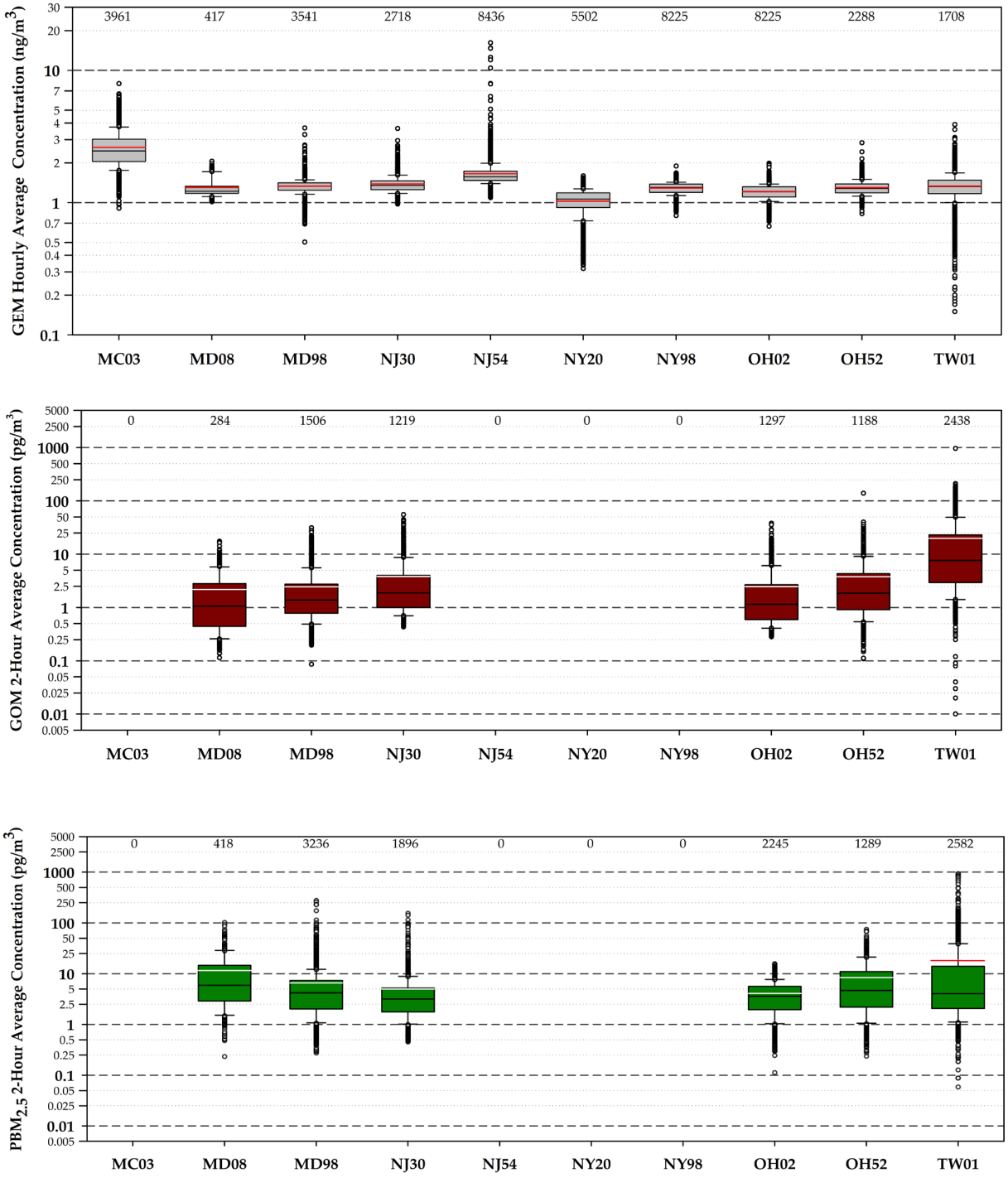
Atmospheric Mercury Network (AMNet)

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 2024, there were 8 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 2024. 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.

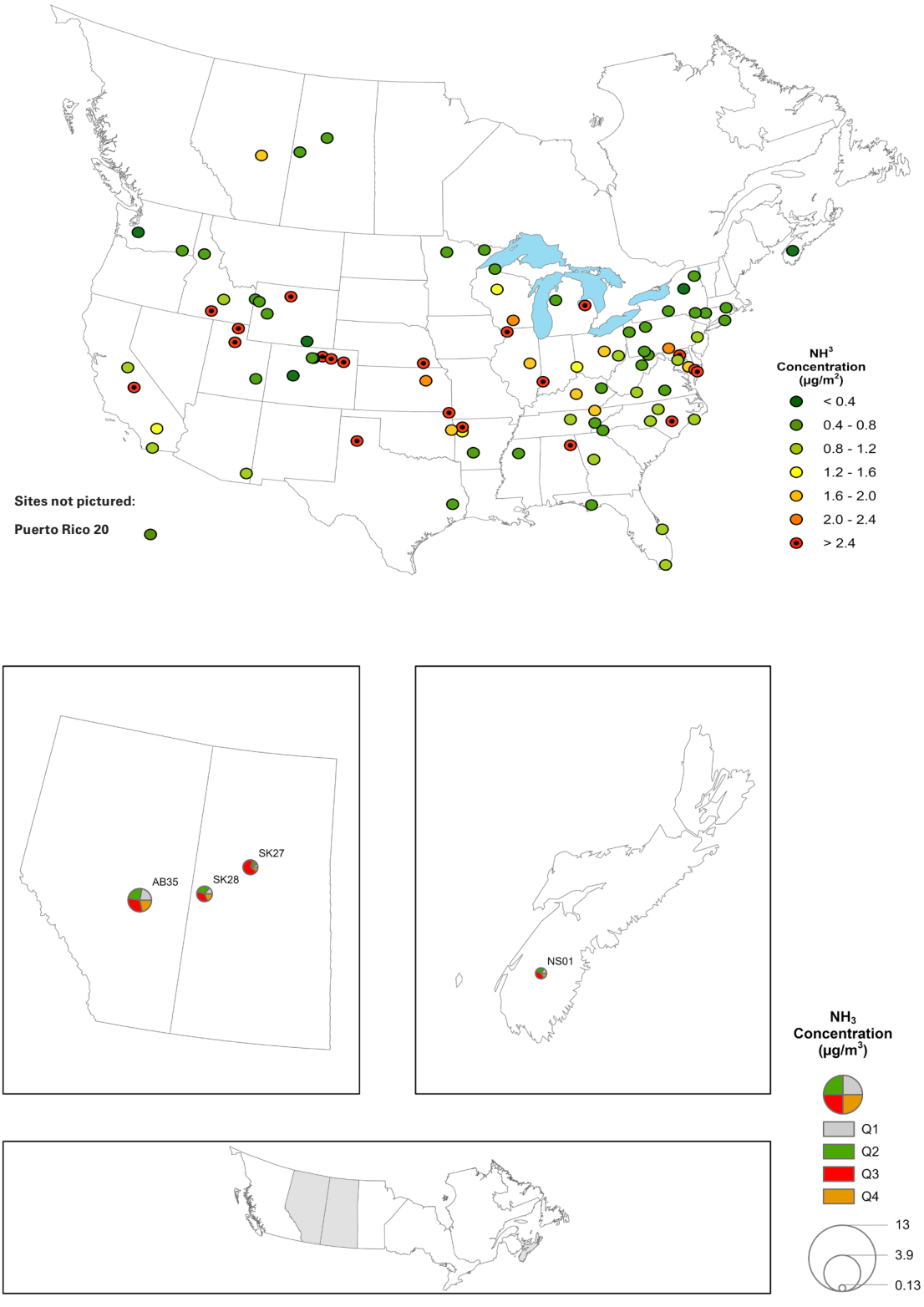
Ammonia Monitoring Network (AMoN)

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.

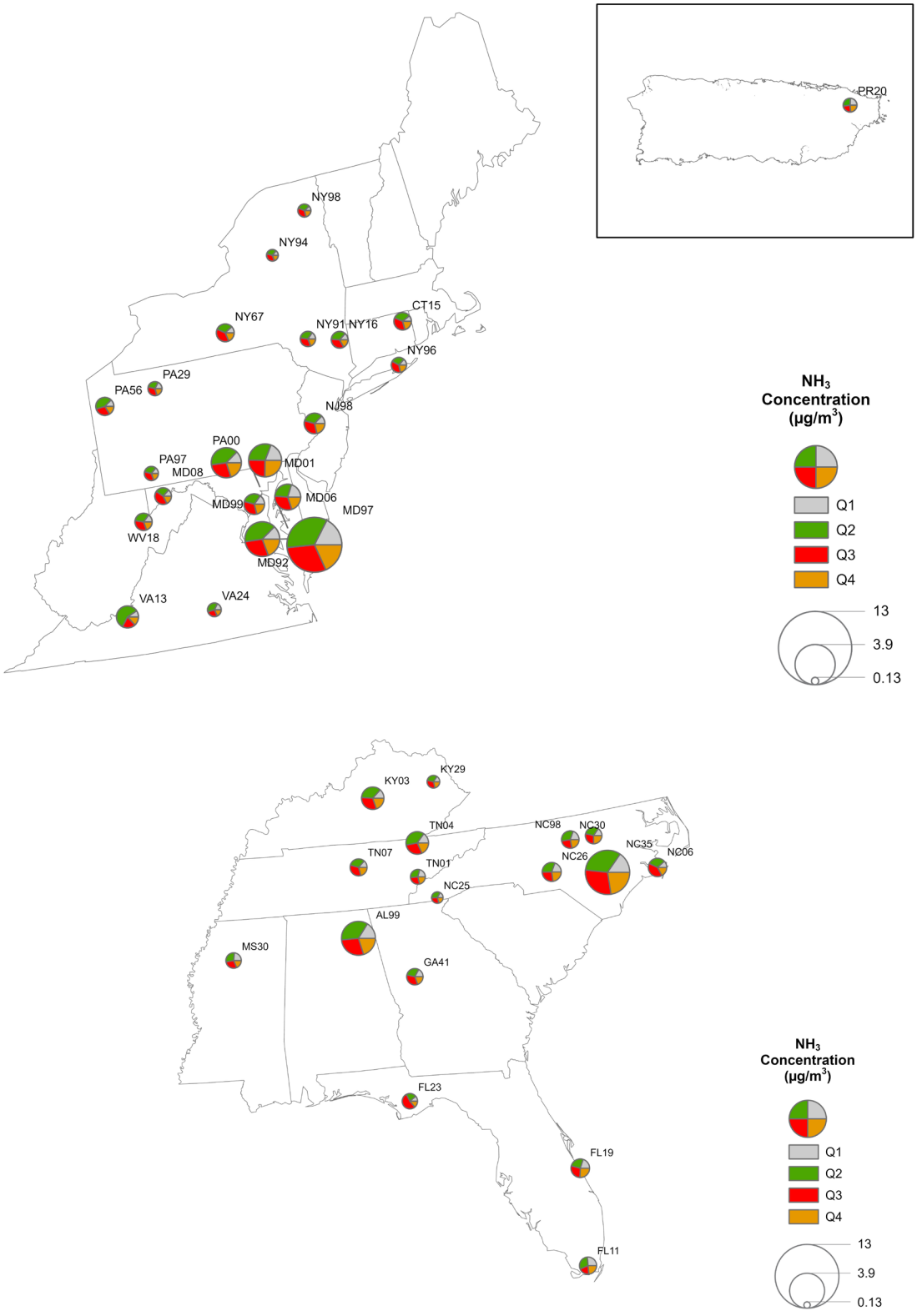
Sampling occurs over a two-week period, and all sites collect additional quality assurance samples on a rotating basis. This data is used to assess long-term NH_3 trends and changes in atmospheric chemistry, and to provide information for model development and verification.

As of December 2024, there were 103 AMoN sites. Data from the AMoN are available on the NADP website (https://nadp.slh.wisc.edu).

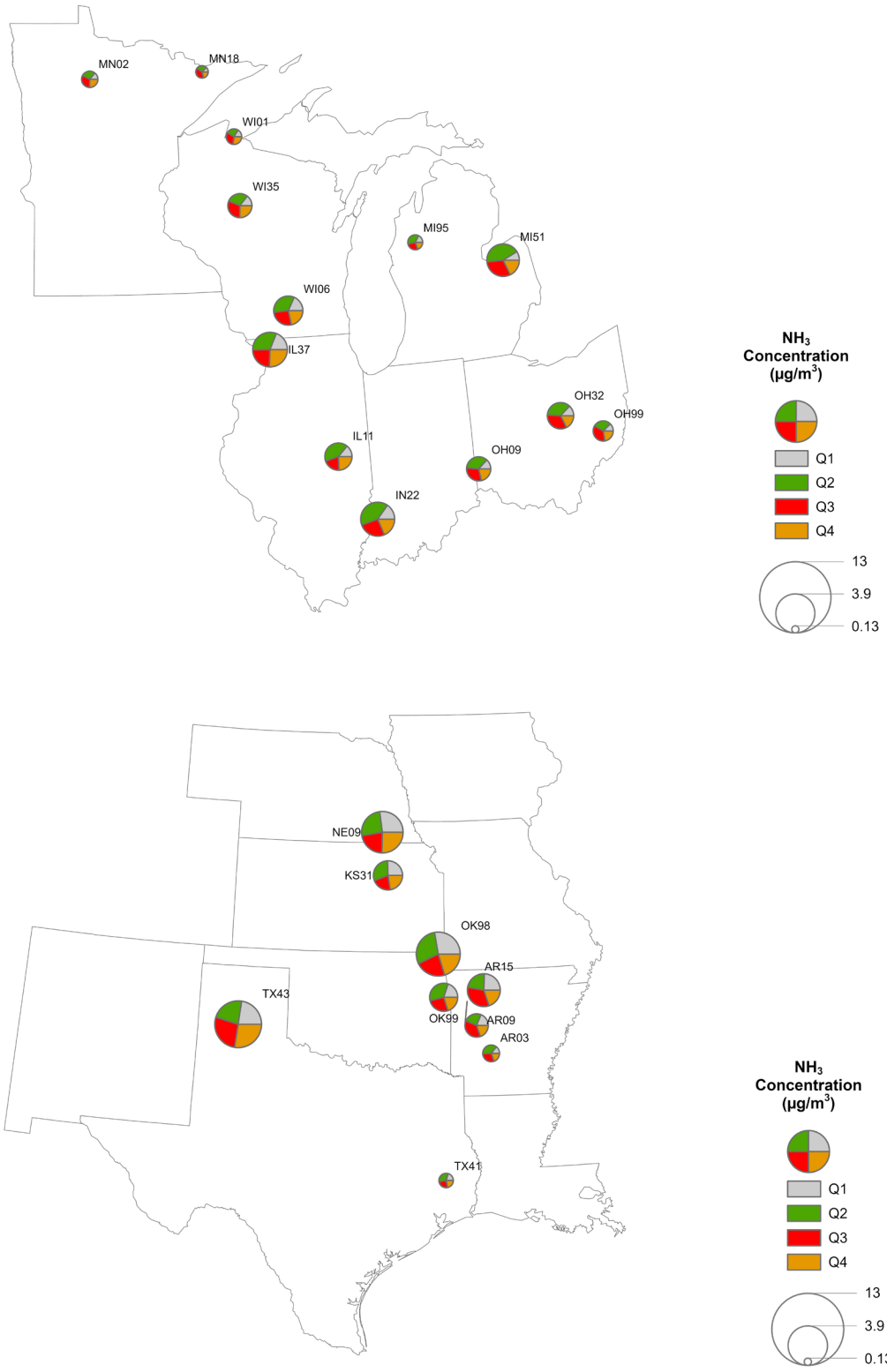
The figures on pages 41-44 show the distribution and seasonality of gaseous ammonia concentrations for each site meeting completeness criteria. In the first figure, circles represent annual average concentrations in micrograms per cubic meter (μg/m^3) at each site. In the following figures, the relative 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), 2024. 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), 2024. 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), 2024. 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), 2024. Size of the symbol in the bottom plot is relative to the annual concentration.

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Mercury Litterfall Network (MLN)

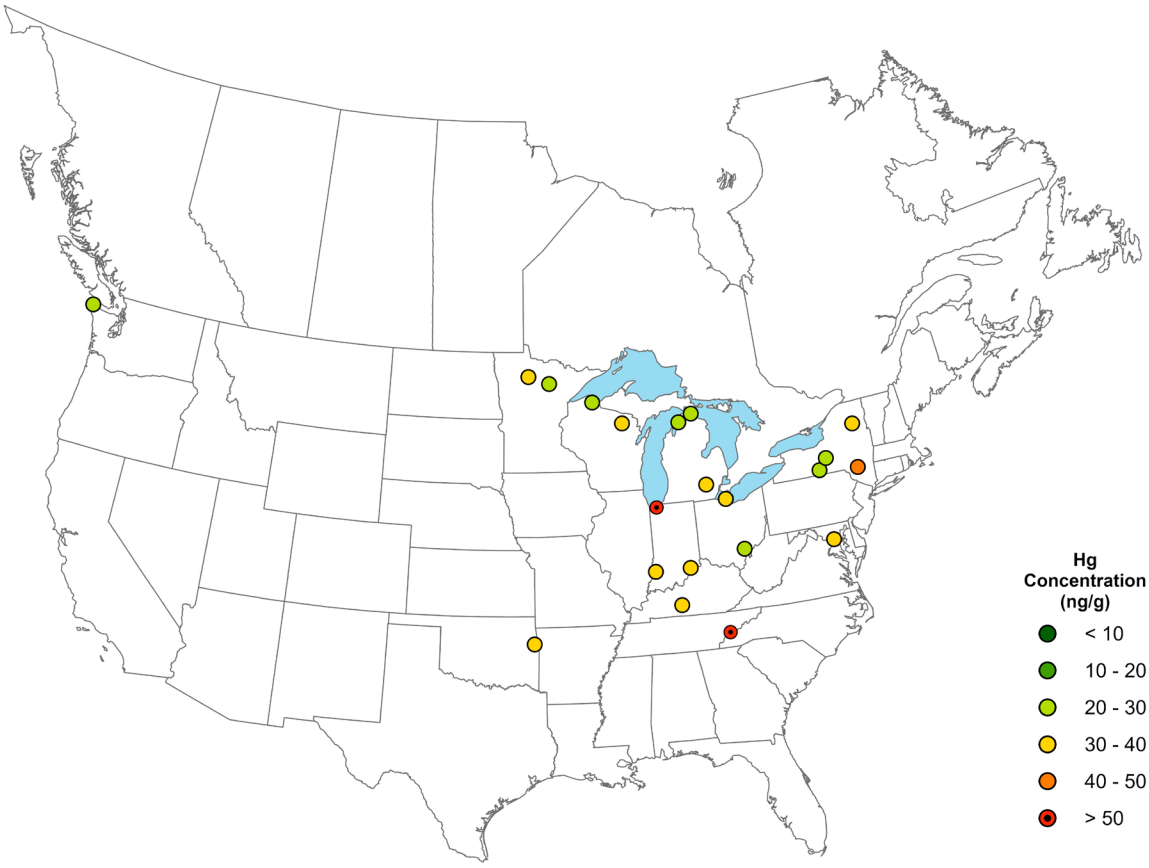
MLN sites measure concentrations of total mercury found in plant biomass litterfall associated with a forest overstory (leaves, twigs, debris, etc.) that fall to the forest floor. The network uses four passive collection samplers per site. The collectors are placed on the ground in randomized locations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

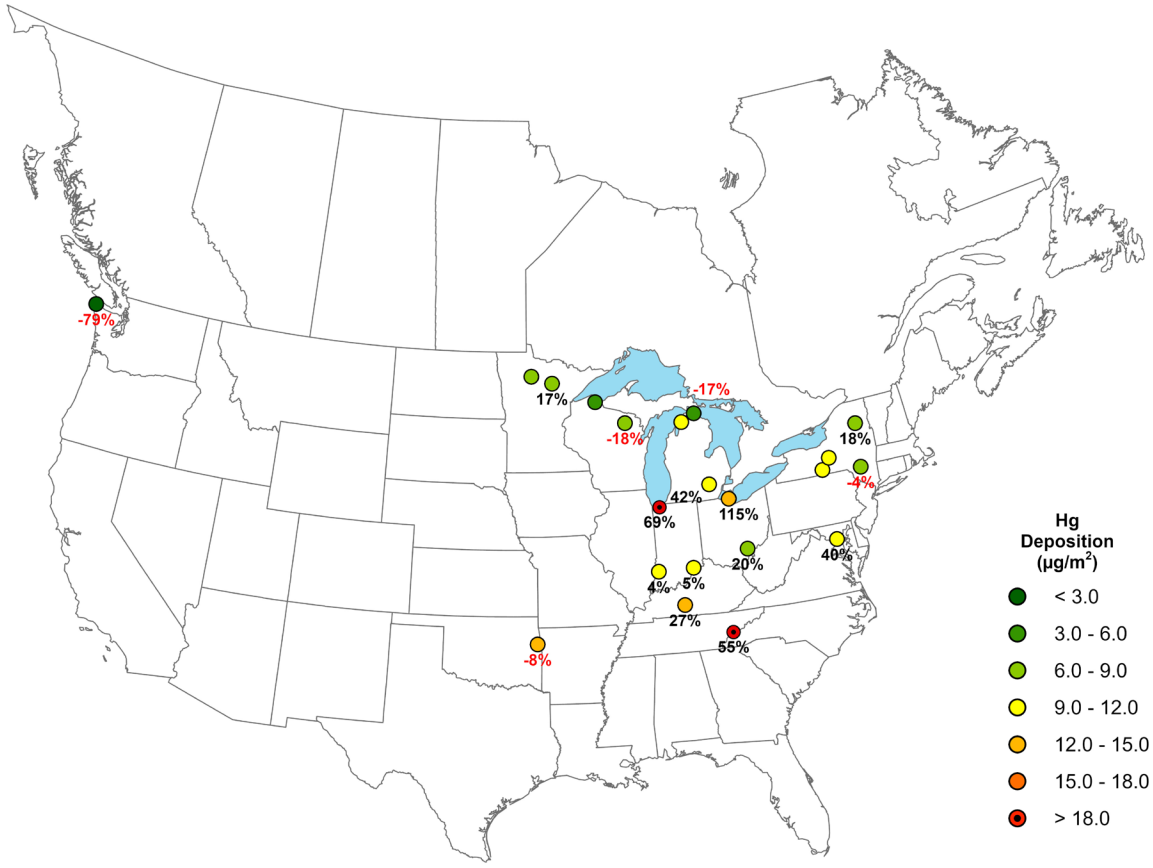
This data is used to assess deposition in this manner, for further study and comparisons to traditional wet and dry deposition of mercury in MDN and other measures. These measurements can be used for trends over time, and to provide information for model development and verification.

As of December 2024, there were 26 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, 2024.



Average total mercury flux with biomass per season, 2024. Numerical values are percentages of mercury biomass flux more than (black) and less than (red) the colocated MDN wet deposition flux.

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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, conclusions or recommendations expressed in this publication are those of the authors and should not be construed to represent any official USDA or U.S. Government determination or policy, the opinions of any of the program sponsors, or the University of Wisconsin-Madison.

http://nadp.slh.wisc.edu

Madison, WI: October 2025

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.