

NRSP3-The National Atmospheric Deposition Program (NADP)

University of Wisconsin Madison

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MANAGE PROJECT

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EDIT

Performing Department

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Results

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1

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10/23/2024

Annual Report

NRSP #3 The National Atmospheric Deposition Program (NADP)

2025

In 2-3 sentences, briefly describe the issue or problem your project is trying to address.

The movement of pollution into any ecosystem, whether a managed agricultural system or a natural and unmanaged system, changes the chemical nature of this ecosystem. Many pollutants move through the atmosphere from a pollution source to an endpoint ecosystem, and this change is a very important to monitor, track, and understand.

The National Atmospheric Deposition Program (NADP) measures a range of chemical constituents across the United States to track how pollutants from the atmosphere enter ecosystems through precipitation (wet deposition) or the air (dry deposition). With continued measurement, NADP provides the data necessary to determine whether spatial and temporal trends in concentration and wet/dry deposition exist, understand the direction and magnitude of chemical deposition trends and impacts of regulatory control measures, and understand the impacts on agricultural systems. These research measurements and data are used by researchers to study and determine the impact this pollution flow has on any/all ecosystems in North America. The NADP measures the concentration and deposition rates of the following

constituents: pH (H ion), specific conductance, sulfate, nitrate, ammonium, ortho-phosphate, chloride, calcium, magnesium, sodium, potassium, and mercury in precipitation; and mercury gases and ammonia in the atmosphere (for dry deposition estimates).

This project specifically provides management and coordination of NADP's five nationwide (with some international sites) networks: 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). This agreement also provides site support, chemical analysis, and data validation for the approximately 48 SAES National Trends Network sites (of 232 total sites) covered in this agreement.

The goals of the NADP are to:

1. Use best practices to conduct measurements of atmospheric and precipitation chemistry;
2. Follow standard methods and procedures to ensure that measurements are made with the utmost quality and are equivalent between sites and over time;
3. Provide these measurements freely available to all users, with a particular emphasis on the research community and educators; and
4. Advance environmental measurement science through rigorous method development and testing, collaboration with the broader scientific community, and a commitment to outreach and data accessibility.

The NADP operates in a cooperative manner with technical and administrative guidance from the NADP Executive Committee and from cooperators (researchers, etc.) and subcommittees. All work described here is conducted in accordance with the NADP Quality Management Plan (<https://nadp.slh.wisc.edu/quality-assurance/>). All NADP data are available free of charge to any and all users.

This report is the 1st year of a 5-year multistate project (National Research Support Project #3), running from 2025-2029.

Briefly describe in non-technical terms how your major activities helped you achieve or make significant progress towards the original goals and objectives.

The National Research Support Project-No. 3 (NRSP-3) provides a framework for cooperation among State Agricultural Experiment Stations, the USDA-NIFA, and other cooperating governmental and non-governmental organizations. The NADP provides quality-assured data and information on the exposure of managed and natural ecosystems and cultural resources to

acidic compounds, nutrients, base cations, and mercury in precipitation and through dry deposition of several of these compounds.

Specifically, researchers use NADP data to investigate the impacts of atmospheric deposition on the productivity of managed and natural ecosystems; the chemistry of estuarine, surface, and ground waters; and the biodiversity in forests, shrubs, grasslands, deserts, and alpine vegetation. Researchers also use NADP mercury data to examine the link between environmental and dietary mercury to human health (agriculture research priority of food safety).

In support of our measurement goals, the NADP's principal output is the collection of weekly or other periodic samples from its constituent networks. During this reporting period, analytical data was reported for approximately 11,700 NTN samples, 3,800 MDN samples, 3,300 AMON samples, and 100 MLN samples. AMNet sites operate very differently from these networks, and use continuous onsite instruments. Each NTN sample is assessed for ten separate analytes (pH {H ion}, specific conductance, sulfate, nitrate, ammonium, chloride, calcium, magnesium, sodium, potassium). All analytical results undergo an extensive quality assurance review before release, and all data are released when completed.

As a National Research Support Project, the NADP's principal goal and responsibility is to produce data that the research community uses. To track performance of this goal, the NADP counts the number of research journal and report publications each year that use NADP data. During calendar year 2024, we identified 161 publications (including many dissertations and theses) that used NADP data in some important way to further their research (191 articles in 2023). These publication counts and searchable database functionality will continue over the life of the program (complete lists here: <https://nadp.slh.wisc.edu/pubs/nadp-bibliography/>).

For researchers to use and trust our data, quality assurance of this data is necessary. The NADP uses standard operating procedures (SOP) for all sampling, laboratory, and data processes. The NADP has established best practice methods over the 48 years of program existence (<https://nadp.slh.wisc.edu/siteops/>). The NADP continually evaluates and updates these standard methods and procedures through guidance of the NADP Network Operation Subcommittee (NOS). We have quality assurance staff (1.3 FTEs) that continually review methods and data to ensure quality, and ongoing performance. Copies of any SOP and available upon request (<https://nadp.slh.wisc.edu/quality-assurance/>). The NADP laboratories and Program Office (PO) typically undergo external biannual review to identify systemic problems, improve performance, and provide external program checks. The PO and laboratories were audited in a combined approach on October 1-2, 2024 (just after this project year). The findings of this audit were summarized in a report and the NADP provided written responses documenting actions taken to address each concern.

To support the research data use goals of the NADP and the NRSP program, the NADP provides data access and availability to everyone at no charge from the NADP website (<https://nadp.slh.wisc.edu/>). This website offers online retrieval of all individual data points (weekly and biweekly), seasonal and annual averages, trend plots, concentration and deposition maps, reports, and manuals. Downloads of data remained strong during 2024, and we are working to add programming to the website to count data downloads and collect information about our data users. Internet availability of NADP data is the primary dissemination route.

In October 2022, the Executive Committee made a decision to release precipitation measurements as a new and independent data set (without chemistry, ~350 sites). A soft launch of this additional data was completed in September 2025, providing 15-minute, hourly, and daily precipitation data for all NADP sites with precipitation collectors. The data is available on the NADP Precipitation Network website (<https://nadp.slh.wisc.edu/networks/nadp-precipitation-network/>).

The NADP annual map series of atmospheric concentrations, wet deposition fluxes, and report was developed and compiled in the fall of 2025 for the 2024 data and maps. The 2024 Map Summary was released in late 2025. For each summary, NADP produces a series of 23 national maps of wet deposition concentration and flux for all analytes, and summary figures for each gaseous network. Individual maps are filed by network, year, and constituent, and can be downloaded in several formats.

The NADP also strives to advance environmental measurement science (another goal) through discussion, testing of new methods, assisting others making similar measurements, and new approaches. The NADP recently hosted and organized three meetings where these ideas were discussed: the Fall Scientific meeting, the Spring Business meeting, and the Summer Budget meeting. A diverse group of participants attended these meetings, including university researchers, SAES researchers, NIFA, a variety of federal agencies (EPA, USGS, NPS, Forest Service, FWS, BLM. and NOAA), and many state government organizations, and Native American tribes. All meeting proceedings, minutes and most presentations are available on our website (<https://nadp.slh.wisc.edu/conferences/>).

Here are a few specific examples of new measurements/procedures being considered by NADP.

- **PFAS Subnetwork:** A new pilot network was approved for the monitoring of per- and polyfluoroalkyl substances (PFAS) in NTN precipitation at the Fall 2023 meeting. Discussion for this network has occurred over the last several project periods, building on several years of PFAS initiatives. The subnetwork will become an official part of NADP in Spring 2026. Weekly samples will be analyzed for 34 specific compounds. This network will be of particular interest to the USDA/SAES since atmospheric loading of

PFAS to agricultural lands can be substantial. Two ARS sites in Colorado are funded and should begin operation in the next few months. More information about the network is available on the NADP website (<https://nadp.slh.wisc.edu/pfas-sub-network/>).

- **New MDN Collection Bag:** The current MDN sample train is silicon glass, which requires expensive weekly re-cleaning. The NADP is working on redesigning the NADP sample train, such as determining whether samples can be collected in a plastic sampling train or collected in bags. We should make significant progress on this change during this next project period.
- **Total Nitrogen and Total Phosphorus Sampler (TNTP):** The effort continues to add total N and total P capability (and by subtraction, organic nitrogen (ON) and phosphorus (OP)) to the regular NTN analyses. This required the development of a supplemental sampler that works with the standard NTN sampler. Preliminary testing began in 2025 that continues into 2026. This study is a combined with the NPS and Colorado State University. Analytical performance of the TN measurement is good, with ongoing work on the TP measurement. Difficulties remain with low volumes and low pH, but work on possible solutions continues. This TNTP data will interest agricultural scientists, since N and P are such important agricultural compounds. TNTP measurements are also important for understanding algal blooms/eutrophication in lakes and rivers and the connection to agricultural activities.
- **Black Carbon (BC) in precipitation:** BC measurements were made at 12 western US sites (with EPA support) over two spring summer periods. This project will be used to measure the basic BC variability over time and space, and will be used to further define a clear wildfire wet deposition signal.
- **Passive Mercury Pilot:** A new pilot network measuring quarterly gaseous elemental mercury concentrations at 10 sites began in December 2024 and will continue for another year.

Briefly describe how your target audience (direct contact) benefited from your project's activities.

The NADP provides fundamental measurements that support informed decisions on environmental and agricultural issues related to precipitation and deposition chemistry, as well as atmospheric mercury and ammonia. Data from our monitoring effort are used by a wide variety of scientists for a number of research topic areas, principally for atmospheric and environmental pollution research. Data are used by many agriculturalists and ecologists studying the input of compounds to forest, soils, and biota. Our data are used by policymakers

to make informed decisions on agriculturally important topics. Our data are also used in many different educational areas including chemical, agricultural, and environmental sciences; are used at many different educational levels including elementary, secondary and post-secondary; and are used for many different theses and dissertations. All data are available free of charge via the NADP website (<http://nadp.slh.wisc.edu/>), and can be used by our target audience as they wish. In 2024, 161 research publications used the NADP data, including 14 dissertations and 12 theses.

The following are several examples of the use of this SAES funding to support agriculturally relevant research journal articles from 2024 and 2025:

- Schmadel et al., 2024. Seasonally varying contributions of contemporaneous and lagged sources of instream total nitrogen and phosphorus load across the Illinois River basin. *Science of The Total Environment* 955: 176816.
<https://doi.org/10.1016/j.scitotenv.2024.176816>.

The authors determine the nutrient sources of streams across the Illinois River valley (~10 rivers) in an effort to improve water resource management. The authors used a dynamic SPARROW (Spatially Referenced Regressions on Watershed attributes) model to simulate seasonal and source-specific total nitrogen (TN) and total phosphorus (TP) loads. Results showed that a third of the TN and a quarter of the TP instream load originated from non-point sources of land-application, lagging by more than a season. This lagged mass was the largest overall TN source, originating from fertilizer, manure, atmospheric deposition and fixation, and urban land uses. Treated wastewater effluent was the largest TP source exported from the basin (39% of TP, 15% of TN load), and dominated the urban Chicago River load in the upper Illinois River near Chicago. Lower river loading was attributed primarily to a mix of agricultural sources and their lagged fractions. With appropriate datasets, the models could be extended to other basins or time periods.

The authors use long-term and weekly NADP deposition measurements at about 5 sites across IL, from 2000 to 2020.

- Diaz et al., 2024. High resolution concentration-discharge relationships in managed watersheds: A 30+ year analysis. *Applied Geochemistry* 175: 106192.
<https://doi.org/10.1016/j.apgeochem.2024.106192>.

The authors discuss measurements and relationships of chemical discharge from agricultural operations in western Ohio. They focused on the chemical concentration and discharge relationship over a 30-year period, using both agricultural, suburban and forested landscapes. They also compared baseflow to precipitation events. One main conclusion was that highly managed agricultural watersheds with no stream baseflow had static chemical behavior, while

mixed use areas had changed much more over time. They also documented that chemical outflow was influenced by many factors, including soil and baseflow geochemistry, pore fluid concentration, and land type/land use legacy effects. These observations may transfer to other agricultural lands.

The authors used weekly NADP values from the OH49 site in Ohio for precipitation and all analytes in the study from 2000-2011 to define the wet deposition of site compounds. Deposition input was used to compare to discharge outflow.

- Gibson et al., 2024. Groundwater recharge response to reduced irrigation pumping: Checkbook irrigation and the water savings payment plan. *Water* 16(20): 2910. DOI: 10.3390/w16202910.

The authors discuss the need for accurate irrigation estimates within agricultural operations, with a goal of ensuring long-term groundwater availability and avoiding needless loss of water to the watershed. They investigated water savings at three 65-acre Nebraska sites with varying soil, management practices and groundwater depths. The authors conclude that groundwater response times to pumping (using chloride as a tracer) are short and water savings are small (50-900 mm depth over 10 years with 120 mm/year reduction), and that sandy soil with shallow groundwater have minimal savings. The model developed with this work agrees with measurements to about 80 percentage.

NADP chloride data was used in the water mass balance from a number of sites over multiple years in the Nebraska area.

- Kumanan, V., 2024. Variability and drivers of system-level nitrogen use efficiency and surplus across conterminous united states. Master's Thesis, Agricultural and Biological Engineering, Pennsylvania State University.
<https://etda.libraries.psu.edu/catalog/29327vkk5154>.

Kumanan (Masters Thesis) used a large amount data to investigate nitrogen (N) use efficiency (NUE) over the coterminous U.S. and over multiple major crops. First, Kumanan found that the diversity of different N source input types had a large impact to county level NUE, since the type of N source effected the rates of N biological fixation. This result was clear given the decrease in manure usage. Second, Kumanan found that irrigation rates further control NUE and N surplus rates, and offer the best predictor for NUE and N surplus, and is more important than growing degree days, vapor pressure deficit, soil texture, soil structure, and depth to groundwater. The author used artificial intelligence models for his predictive ability.

Kumanan use NADP data from all U.S. sites, for many years in the nitrogen balance information in his observations and modeling.

- Shukla et al., 2024. Retrofitting agricultural detention systems can economically enhance nitrogen treatment with payment for services approach. *Science of The Total Environment* 954: 176145. <https://doi.org/10.1016/j.scitotenv.2024.176145>.

The authors investigate the water quality of agricultural stormwater detention areas (SDA), beginning with evaluation of an SDA in the Florida Everglades and focusing on baseline N. With simplification of the flow design and compartmentalization, increase in flow elevation, and channel plugs, the total N retentions doubled (7500 kg from 3700 kg), and a similar trend was observed with water volume. The authors concluded that water retention drives N retention. Actual costs for the retrofit and increase detention were much less than traditional N retention methods. A modeling effort calculated that a scaled-up facility could reduce N discharge from one basin in the Everglades by 50%.

The authors used the wet deposition values from the NADP Everglade's site, and also estimated dry deposition (for total N deposition) from the NADP wet deposition for their box model estimates.

- Timilsina et al., 2024. Assessing the Multifaceted Tradeoffs of Agricultural Conservation Practices on Ecosystem Services in the Midwest US. *Sustainability* 16(13): 5622. <https://doi.org/10.3390/su16135622>.

The authors studied the potential effects of conservation practices on soil health, crop productivity, and greenhouse gas emissions at an ARS agricultural site in northern Ohio (Maumee River basin) using the DeNitrification–DeComposition (DNDC) model for the period 1998–2020. Several crops were considered including corn, soybean, rye, silage corn, winter wheat, and alfalfa. Several improvements were noted, including by applying half the total N to corn through synthetic fertilizer during spring increased yield and soil organic carbon and sequestration of carbon, over fall applications. No-till practices lowered warming gases and higher carbon sequestration, but with lower yields. Substituting synthetic fertilizer with manure for corn production improved corn yield.

The authors used weekly nitrogen deposition data from the nearby NADP site for over 20 years of observations (1987-2020).

- Vo et al., 2024. Impact of Recent Agricultural Ammonia Increases on Fine Particulate Matter Burden over the Midwestern United States. *ACS Earth and Space Chemistry* 8(11): 2209-2217. <https://doi.org/10.1021/acsearthspacechem.4c00180>.

The authors studied the impact of increasing ammonia (NH₃) emissions on Midwest air quality. Ammonia levels form atmospheric particulates easily, and some of the major sources are agricultural activities. The study included the years 2007 to 2019 with NH₃ observations and

modeling. Increasing atmospheric concentrations and wet deposition (+20%) of NH₃/ammonium (NH₄) were clear in all seasons. Agricultural NH₃ is estimated to contribute 40% of the particulate matter measured, and is particularly high in the Midwest, relative to the US in general. Finally, agricultural NH₃ emissions have a disproportionate role in degrading air quality.

The authors used NADP data for both NH₃ concentrations (53 AMoN sites covering 34 states from 2008 to 2019, and 10 Midwest sites) and wet deposition of NH₄ (162 US NTN sites from 2007 to 2019, and 31 Midwest sites).

- Bruulsema et al., 2024. The Role of Sulfur in Meeting 4R Nutrient Stewardship Goals. *Crops & Soils* 57(3): 34-39. DOI: 10.1002/crso.20360. AG Connection (American Society of Agronomy).

The authors reassert the importance that sulfur plays in 4R plant nutrition (“right fertilizer source, at the right rate, the right time, and in the right place). Sulfur is (1) an essential plant nutrient applied to optimize yields, (2) there may be a need to replenish the sulfur removed from the soil by crop harvests, and (3) some sulfur may have additional benefits through effects on soil pH and nitrogen processes. Needed sulfur additions have been evident for several years now, and the authors focus on these necessities in an article meant for outreach to working agricultural professionals concerning sustainable addition of sulfur fertilizers.

The authors published NADP maps from the years 2000 and 2022 as evidence of atmospheric sulfur reductions over the years, and the needs to appropriate sulfur addition to specific crops.

- Leitao et al., 2025. Nitrogen budget and environmental losses from irrigated corn in the Suwannee River Basin, North Florida. *Journal of Environmental Management* 385. <https://doi.org/10.1016/j.jenvman.2025.125720>.

This study assesses the impact of increasing fertilizer N rates on the N budget and environmental losses in a specific corn species at two plots at the North Florida Research and Education center in Live Oak, Florida. The authors found that the dominant environmental loss mechanism was N leaching, but best management practices, such as split application of fertilizer and sensor-based irrigation, help to mitigate risk of N loss.

The authors used wet deposition values from the NADP’s Sumatra site (FL23) in their study.

Briefly describe how the broader public (indirect contact) benefited from your project's activities.

Given that the NADP data are made available to all, and that all our data are fundamental observations, the data is used for a wide variety of issues important to the United States. The

research impacts have been noted previously, therefore see the full set of journal articles utilizing the NADP data (<https://nadp.slh.wisc.edu/pubs/nadp-bibliography/>).

Additionally, our data is used by many government agencies (federal, state, tribal) to make more informed policy decisions. The NADP, in addition to SAES, is heavily funded by federal and state agencies, and the NADP data is used by these agencies to better understand the science of deposition and pollution flow through ecosystems.

The NADP data is also used in many different dissertations and theses, improving the quality of graduate education in many areas (agriculture, environmental, geographic, engineering). We typically have NADP data used in about 15 graduate-level dissertations or theses every year, in addition to a growing number of undergraduate theses. NADP data has also been used in undergraduate education, such as in textbook materials, real world observations for projects, and statistical education.

With the leadership of the SAES scientists, and the highly diverse nature of this NRSP, there are many nationally important issues that NADP data and information can and do contribute toward. Based on the USDA's newly announced research and development priorities, several areas align with the monitoring objectives of the NADP. Most directly, USDA's emphasis on promoting soil health to regenerate long-term productivity of land connects with NADP's mission, as atmospheric deposition of nitrogen, sulfur, and other chemicals directly influences soil chemistry, acidification, and nutrient cycling on agricultural lands. Additionally, USDA's priority of protecting the integrity of American agriculture from invasive species and disease has relevance to NADP monitoring, as atmospheric deposition of pollutants and nutrients can alter ecosystem conditions in ways that affect pest and pathogen dynamics. Finally, USDA's focus on increasing farmer profitability through reduced inputs overlaps with NADP's work, given that wet and dry deposition of reactive nitrogen contributes measurable quantities of plant-available nitrogen to agricultural soils — a resource that, when quantified, can inform fertilizer management decisions and reduce input costs for producers.

Overall, one of the principal advantages of the NRSP-3, is that it is a science-based observation network that can be restructured with additional techniques to look for a variety of pollutants (herbicides, pesticides, etc.), disease vectors, physical bodies (plastic), and others moving through the atmosphere. This would require legislative action with NADP committees.

The NADP data is being used to address the following challenges:

- Studying mercury contamination in U.S. fish, through monitoring the main addition of mercury to water bodies (precipitation);
- Documenting the presence of inorganic pollutant gases and aerosols in the atmosphere;

- Assessing the accelerated chemical weathering of material and cultural resources, such as limestone buildings and monuments;
- Evaluating the effectiveness of the Clean Air Act and Clean Water Act;
- Monitoring precipitation acidity and impact on soils and water;
- Understanding the impacts of nitrogen deposition on native and invasive species in national parks, forests, and lakes;
- Quantifying nitrogen and phosphorus deposition contributions to algal blooms;
- Documenting growing ammonia emissions (including from agriculture) impacts on nitrogen deposition, which drives a shift in atmospheric chemistry and particulate levels;
- Linking nitrogen deposition to estuarine eutrophication and related low dissolved oxygen concentrations in lakes and rivers.

These bullets only briefly describe a number of research areas where the NADP data has been used to address agricultural and environmental problems. The NADP cooperates with similar organizations in Canada and Mexico to evaluate similar issues on a continental scale, and with similar organizations in Europe and Asia to help evaluate these issues in the Northern Hemisphere and around the Earth.

Describe and explain any major changes or problems encountered in approach. Additionally, note opportunities for training and professional development provided, how results have been disseminated to communities of interest, and any new details regarding what the project or program plans to do during the next reporting period to accomplish the goals.

The NADP is a monitoring cooperative, and strives to make the same measurements every year with the same methods in a consistent manner. No substantive changes are planned for the operations of the network. Outside of normal issues with inflation, the networks are operating well. However, the NADP is continually considering ways to make the network operation more efficient, increase the throughput of samples, and reduce the costs of laboratory services. Several methods we are considering include the improved mercury collection vessel, automation of several laboratory steps, and an improved data review system.

As mentioned above, the NADP is also continually expanding the pollutants monitored that are relevant to the current research direction, such as:

- Monitoring PFAS in precipitation;
- Evaluating a new sampler for total nitrogen and total phosphorus in precipitation;
- Assessing mercury concentrations in the air using a new passive sampler;
- Measuring black carbon in precipitation, which is a wildfire smoke tracer.

The NADP regularly trains site operators on our equipment and methods. We hold online video meetings, video presentations, and provide onsite training. Additionally, operators are able to call our phone support line with questions and requests for assistance. The NADP provides these resources for approximately 60-70 site operators every year.

The NADP's Annual Scientific Symposium, in addition to other conferences and meetings, fosters the dissemination of NADP data to key stakeholders and researchers. At the 2024 Scientific Symposium in Duluth, MN (hybrid), we had approximately 40 oral presentations and 20 posters. The NADP was also able to provide seven student travel awards for the conference. Details of the meetings are available on the NADP website (<https://nadp.slh.wisc.edu/conferences/>). The NADP also holds special meetings that provide professional development on topics not covered at our two annual meetings. For instance, in Spring 2022, the Mercury in the Environment and Links to Deposition (MELD) ad hoc Science Committee held an organizational meeting. Additionally, the NADP has hired Association of Public Health Laboratories interns (5 interns during the past project year) that were employed to assist and learn about the various analytical as well as data management activities of the NADP.