NADP Total Deposition Science Committee (TDep) Annual Report 2024-2025

Contents

Introduction

The National Atmospheric Deposition Program's (NADP) Science Committees focus on key areas of atmospheric deposition, scientific interest and/or applications. They are approved by the NADP Executive Committee (EC) and must be dissolved or renewed every four years. The Total Deposition Science Committee (TDep) was established in 2011, and the charter was most recently renewed in 2024 by the EC. The TDep mission is to improve estimates of atmospheric deposition by advancing the science of measuring and modeling atmospheric wet, dry, and total deposition. TDep provides a forum for the exchange of information on current and emerging issues among atmospheric scientists, ecosystem scientists, resource managers, and policy makers. The committee is open to anyone interested in contributing to the mission. The specific charges of TDep are:

- Support the national networks that monitor atmospheric deposition by providing information on emerging measurement techniques, model development, and uncertainties associated with these approaches.
- Identify and prioritize knowledge gaps in the field of measuring and modeling atmospheric deposition and advocate for research to bridge those gaps.
- Coordinate with NADP's Critical Loads of Atmospheric Deposition (CLAD) Science Committee and other groups to advocate for the use of the most scientifically defensible deposition estimates for critical loads and other environmental assessments.
- Provide expertise and advice on present and potential decisions and regulatory actions pertaining to the field of measuring and modeling atmospheric deposition.
- Encourage greater communication and collaboration between groups from different disciplines and countries with interests in atmospheric deposition.

Additional information can be found on the TDep website (http://nadp.slh.wisc.edu/committees/tdep/).

The TDep annual report serves as a summary and quick reference for the activity, progress, and accomplishments of TDep over the course of a year. Unlike previous years, this report spans both 2024 and 2025 due to many changes in the federal and research agencies that participate in TDep during that time. This combined report contains links to the 2024 and 2025 Spring and Fall Meeting notes, updates from each of the TDep workgroups, and descriptions and status updates on TDep-related products and research.

In 2024 TDep was directed by two **Co-chairs**, Amanda Cole (Environment and Climate Change Canada) and Colleen Baublitz (U.S. Environmental Protection Agency; EPA/Office of Air and Radiation; OAR). Kristen Foley (EPA/OAR) served as the TDep **Secretary**. In 2025 TDep was directed by two **Co-chairs**, Colleen Baublitz and Kristen Foley with Da Pan (Georgia Institute of Technology) serving as the TDep **Secretary**. The current leadership team (as of January 2026) is Kristen Foley and Da Pan as Co-chairs and Michael Barna (Air Resources Division of the National Park Service) serving as TDep Secretary. The TDep Steering Committee meets quarterly to establish meeting agendas, share information on upcoming opportunities for outreach, and identify project priorities. The **Steering Committee** is made up of past Co-chairs, Working Group leaders, representatives of major NADP-funding agencies, and atmospheric and ecosystem scientists closely involved with the TDep mission. For 2024 and 2025, the Steering Committee members included: Amanda Cole, Irene Cheng (Environment and Climate Change Canada; ECCC), Colleen Baublitz, Kristen Foley, Greg Beachley,

Melissa Puchalski, Ian Rumsey (EPA/Office of Air and Radiation; OAR), Mike Bell, Bret Schichtel (National Park Service; NPS), Ryan Fulgham (EPA/OASES), Selma Isil, Chris Rogers (WSP), John Walker, Yongqiang Liu (U.S. Department of Agriculture; USDA/Forest Service; FS), April Leytem (USDA/Agricultural Research Service; ARS) and Jeff Herrick (EPA/ORD) .

TDep is organized into a workgroup format to provide structure and organization within the committee. This format helps to distribute workloads, provides more accessibility of projects and opportunities to committee members, and promotes more collaborative work. Descriptions and updates from these workgroups are included herein.

Annual Summary of TDep Accomplishments

It was another productive year for TDep. Below is a snapshot of the 2024 and 2025 accomplishments.

- **Annual TDep MMF output for versions 2025.01.** Version 2025.01 was originally made public in December 2025 and includes a minor correction to the aggregation periods for the hourly to weekly aggregation of EQUATES estimates. The impact of the correction was minor with differences ranging between ±5% in dry species and occurring only in 2005-7, 2011-12, 2017-18. This version was used to produce the current TDep MMF maps and include the most recent year 2024. The maps and grids are now available on the website: https://nadp.slh.wisc.edu/committees/tdep/.
- **Hosted a Measurement Workshop at Spring NADP meeting.** Facilitated by Kristi Morris (NPS) and Bret Schichtel (NPS), the Measurement and Monitoring Workgroup organized a one-day workshop during the Spring 2024 TDep meeting to discuss reactive nitrogen, total nitrogen and phosphorous measurements and determine how recent advances may inform network evolution and TDep MMF activities.
- **Invited representatives of non-NADP networks to share results of related research at the Fall 2024 TDep meeting.** Tracy Dombek (RTI) presented on total soluble organic nitrogen measurements in CSN and IMPROVE samples. Christine Braban (CEH) presented new monitoring and modelling efforts to improve understanding of fog deposition in the UK.
- **Launch of Stakeholder Workgroup seminar series.** The Stakeholders Workgroup led by Ian Rumsey (EPA) launched the Agricultural Stakeholders Webinar Series titled “Atmospheric Nitrogen Deposition: Sources, Impacts and Management”, which aims to improve understanding of the role of agriculture in nitrogen deposition with a focus on enhancing coordination and engagement between stakeholders to address research gaps.

General Updates

Da Pan was elected as TDep secretary and Kristen Foley was promoted to TDep Co-chair at the Fall 2024 TDep meeting. Michael Barna was elected as TDep secretary, and Da Pan was promoted to TDep Co-chair at the Fall 2025 TDep meeting.

Meeting notes for TDep biannual Science Committee meetings were approved and posted on the TDep website.

- Spring 2024 Meeting Notes
- Fall 2024 Meeting Notes
- Spring 2025 Meeting Notes

TDep Workgroup Updates

In 2019, TDep adopted and organized into a Workgroup structure to promote collaborative work. The format has served to help to distribute workloads, make projects more accessible to a broader audience, and advance research between the spring and fall meetings.

The current workgroups include:

- Agriculture Stakeholder Workgroup (Lead: Ian Rumsey)
- Measurement Model Fusion (MMF) Workgroup (Lead: Greg Beachley)
- Measurement Workgroup (Lead: Bret Schichtel)

Agriculture Stakeholder Workgroup

Lead: Ian Rumsey, EPA (rumsey.ian@epa.gov)

Workgroup Objectives:

- Increase communication across scientific communities (i.e., atmospheric chemistry, ecology).
- Create new opportunities for collaborative research by promoting the inclusion of deposition science in grant programs.
- Advance the integration of TDep science into existing research programs across stakeholder groups.
- Facilitate communication among program managers within stakeholder Agencies and user groups.

Current Project:

- The Agricultural Stakeholders Webinar Series titled “Atmospheric Nitrogen Deposition: Sources, Impacts and Management” is the current focus of this workgroup. This webinar series aims to improve understanding of the role of agriculture in nitrogen deposition with a focus on enhancing coordination and engagement between stakeholders to address research gaps. The Agricultural Stakeholders Webinar Series was promoted by organizing a preceding webinar in the Livestock & Poultry Environmental Learning Community webinar series that introduced stakeholders to the topic. Two webinars for the Agricultural Stakeholders Webinar Series were organized that provided an overview of atmospheric nitrogen deposition and its impact on water resources and ecosystem critical loads.

Measurement Model Fusion Workgroup

Lead: Greg Beachley, EPA (beachley.gregory@epa.gov)

The objective of this workgroup is to be the caretakers of the TDep MMF code and manage the annual product outputs available on the TDep website

(https://nadp.slh.wisc.edu/committees/tdep/). Workgroup members discuss and conduct research to identify needs, potential improvements and vet any modifications to the TDep MMF application to ensure it stays current with the state of deposition science. This includes ensuring the timeliness and quality of annual products. The quality assurance activities include assessments of deposition uncertainty as this workgroup has been tasked with the duties of the former Deposition Uncertainty Workgroup and is focused on understanding the uncertainty that exists in measurements and models used to estimate the deposition of nitrogen (N) and sulfur (S). For this effort, the group coordinates with the CLAD committee to further understand how uncertainty in deposition flux impacts critical load development and critical load exceedance.

An additional objective of this workgroup is to coordinate outreach specifically related to the TDep MMF product, which includes specific stakeholder questions and requests involving the TDep MMF products.

Examples of Current Projects:

- The TDep MMF is currently being updated to include EQUATES wet deposition data. This will be included as an annual product. Evaluations will occur with previous versions to assess the impact of this improvement.
- The TDep MMF products will be updated to include wet deposition measurements on a weekly interval for shorter aggregation periods of total deposition. Research and evaluation will determine which aggregate periods should be made available as a public product.
- The TDep methodology includes creating gridded weekly concentration fields by using Inverse Distance Weighting (IDW) to interpolate measured concentrations to the CMAQ grid. The IDW is performed using a maximum distance of influence that is species and season specific based on CMAQ output for 2002-2009. The methodology is being updated to establish new distances based on 2002-2019 model data. We are also investigating how the maximum distance of influence changes across years and regions.
- TDep has partnered with the NADP WSLH to select an Association of Public Health Laboratory (APHL) Fellow, Liam Trinhnguyen, to work on the following projects:
    - The TDep MMF scripts have been revised for architecture and workflow and will be made Publically available on GitHub.
    - Development of a machine-learning based protocol to utilize chemical, temporal, and geospatial statistical relationships of existing data to impute estimates for missing observation data.

Measurement Workgroup

Leads: Bret Schichtel, NPS (Bret_Schichtel@nps.gov), Kristi Morris, NPS (2024)

Workgroup Objectives:

- Support national networks relevant to atmospheric deposition by providing information on emerging measurement techniques and their uncertainties.
- Identify and prioritize knowledge gaps in current direct and indirect monitoring of atmospheric deposition and promote research to address those gaps, including monitoring in urban environments.

- Promote and support the incorporation of monitoring data into TDep products and workgroups and scientific and regulatory assessments.
- Facilitate communication between monitoring data generators and users.

Current Project:

- The Workgroup hosted a full-day workshop on reactive nitrogen and phosphorus measurements at the NADP 2024 Spring Meeting. The workshop brought together researchers and the deposition monitoring community to discuss reactive nitrogen and phosphorous measurements, share information on the state of the science, and determine how recent advances may be used to (1) fill monitoring gaps, (2) help routine networks evolve to address these monitoring gaps, and (3) improve total deposition estimates for critical loads assessments. The workshop consisted of 11 invited presentations and two panel discussions, one focused on ambient and dry deposition measurements of reduced nitrogen, and the other focused on measurements of total and organic nitrogen and phosphorus in wet and dry components of deposition. Highlights of the discussion included (a) strategies to supplement monitoring in a time of declining budgets, such as making linkages to human health, climate, and environmental justice, and (2) the idea to propose a handful of multi-organizational supersites to capture a suite of deposition parameters and complement lower-cost regional sites. These ideas will be further explored in a planned workshop report and white paper.

TDep Project Tracker

TDep uses the annual report to communicate a "TDep Project Tracker". The objectives of the project tracker are to 1) allow TDep members to highlight research and products motivated by or relevant to the TDep mission and 2) log ideas that cannot be currently acted on so that they are not lost. The TDep Project Tracker will be included in each year's annual report and will be presented and discussed at biannual TDep meetings to solicit audience feedback and endorsement.

Current research and products motivated by or relevant to the TDep mission

- **TDep Network Optimization Study (Mike Bell, NPS and Greg Beachley, EPA)**

  TDep MMF relies on spatially robust, routine measurement networks to produce reliable continuous estimates of dry, wet, and total deposition. This project assesses potential changes in TDep estimates due to ongoing network optimization efforts across several NADP federal partners. Analyses have been conducted for different scenarios which meet different objectives by funding partners and the TDep Science Committee provides an effective forum for cross-agency engagement. Site characteristics such as elevation, geospatial proximity, and similarities of concentrations have been considered. Looking forward, this work may be used toward identifying opportunities to improve networks that feed TDep (i.e., NADP NTN and CASTNET).

- **AMoN Flux Characterization Pilot Study update (Melissa Puchalski, EPA)**

A project is currently underway (EPA/WSP) to develop a methodology to estimate net and component NH_3 fluxes using two-week integrated NH_3 concentrations at AMoN sites. Phase I measurements of micrometeorology, biogeochemistry, and canopy physical characteristics at three AMoN pilot sites: Duke Forest, NC; Bondville, IL; and Chiricahua National Monument, AZ are complete and results have been summarized in an EPA report. Phase II of the project is underway, in which a bidirectional NH_3 model is being used to assess seasonal and annual net and component NH3 fluxes across the AMoN network. Phase I measurements are used to parameterize the model and to assess sensitivities associated with the use of time-integrated concentration measurements, modeled versus measured meteorological inputs, and parameterizations of soil and vegetation emission potentials. A journal article led by Colleen Baublitz is expected to be completed in 2026.

This project directly addresses research gaps presented in the TDep Reactive Nitrogen (Nr) deposition White Paper in applying a bidirectional ammonia air-surface exchange model at NADP AMoN sites (See White Paper section 3.2.1).

- **Reactive N flux measurements by eddy covariance (Ryan Fulgham, EPA)**

Thermal and photolytic converter methods can be combined with fast nitric oxide chemiluminescence detection to quantify canopy-scale fluxes of reactive N by eddy covariance. A project is underway (EPA/WSP) to develop an inlet system for a two-channel chemiluminescence instrument for deployment at Duke Forest. The inlet system will include a photolytic converter for NO_2, a heated molybdenum converter for total NOy, and a heated stainless-steel converter for total reactive N. By employing dual chemiluminescence reaction cells, fluxes can be measured in one of two modes for continuous concurrent flux measurements of (Mode 1) NO_2 and total NOy or (Mode 2) total NOy and total reactive N. This combination of fluxes allows for assessment of the contribution of NO_2 to total NOy fluxes and, by comparing total NOy and total reactive N, the relative fractions of reduced versus oxidized forms of reactive N dry deposition. The Total N, NOy, NO_2 converter/inlet system was tested at EPA laboratories and deployed at Duke Forest hardwood tower in 2024.

This project directly addresses research gaps presented in the TDep Reactive Nitrogen (Nr) deposition White Paper for process-level flux measurements (see White Paper Sections 3.1.1 and 3.1.1.1).

- **Low-cost dry deposition system (Ryan Fulgham, EPA)**

Datasets of dry deposition of reactive nitrogen are lacking due to the cost and complexity of online micrometeorological flux measurements. A low-cost dry deposition measurement system suitable for routine network operation is needed. In collaboration with USDA, EPA has constructed and is testing a conditional time-averaged gradient (COTAG) system for measurement of speciated dry deposition of NH3 on weekly to monthly timescales. Two systems were deployed in southern Idaho. A design package for the EPA COTAG, including mechanical drawings, wiring schematics, field and

lab SOPs, has also been completed. WSP has completed construction of a third system for delivery to EPA in 2026.

This research project directly addresses research gaps presented in the TDep Reactive Nitrogen (Nr) deposition White Paper in 3.1 Measured total Nr deposition budgets, particularly for 3.1.2.4. Low-cost method for routine monitoring of air-surface exchange of Nr compounds.

- **Water soluble organic nitrogen (WSON) aerosol pilot study status (Melissa Puchalski, EPA)**

EPA and WSP conducted a special study using samples collected from five CASTNET sites: Great Smoky Mountains National Park, TN; Kickapoo Tribe in Kansas, KS; Rocky Mountain National Park, CO; Salamonie Reservoir, IN; and Washington Crossing State Park, NJ. The study involved analyzing the Teflon filter extracts (the 1st stage in the CASTNET filter pack which captures particles) for total nitrogen. Precision and detection limits for total N and total water-soluble organic nitrogen (WSON), calculated as the difference between a Shimadzu combustion/chemiluminescence total nitrogen measurement and the particulate NO_3^- (ion chromatography) and NH_4^+ (colorimetry) measured using standard CASTNET methods were assessed.

In early 2021, a 12-week study of more comprehensive testing of sample handling and storage effects on WSON was conducted. Split samples were analyzed from a test site in Gainesville and co-located filter packs from Mackville, KY (MCK131/231). The results indicated that further testing was needed to reduce the blank values and improve precision. To this end, WSP acquired a Seal Analytical colorimetric autoanalyzer for the total N and NH_4^+ measurements. Use of colorimetry for both Total N and NH_4^+ reduces instrument cross-calibration requirements and aligns with the WSLH SNiPiT method for Total N in precipitation. A 12-month study, analyzing filters from 27 CASTNet sites (25 locations), began in winter 2022 following WSP's acquisition of SEAL analyzer. Analysis of final datasets is underway with a draft journal article anticipated in early 2026.

This project directly addresses research gaps presented in the TDep Reactive Nitrogen (Nr) deposition White Paper, which includes development of routine methods to quantify organic nitrogen in (See White Paper section 3.1, particularly subsections 3.1.2.5 and 3.1.2.4). This project will also advance the science of routine ON measurements (See White Paper section 3.4 specifically subsection 3.4.1).

- **Evaluation of the Sampler for Nitrogen & Phosphorus in Total (SNiPiT)**

A collaborative field and laboratory evaluation study of the SNiPiT Total Nitrogen/Total Phosphorous (TN/TP) add-on to the NTN is underway. The goal is to quantify the uncertainty in the sample collection and analysis procedures and develop standard operating procedures for the deployment of the SNiPiT samplers in a routine monitoring network. Study participants include those from Colorado State University (CSU), EPA, Forest Service, WSLH and RTI. Samples from Collocated samplers at Colorado State University (CSU), Duke Forest, NC and Coweeta, NC will be collected. The samples will be split between the CSU, WSLH and RTI laboratories for analysis.

CSU has procured the Skalar SAN++ continuous flow analyzer for measuring low levels of phosphate. The instrument has a detection limit ~0.1 μg/l and successfully measured phosphate concentrations

below 0.7 μg/l in wet deposition samples collected at Mammoth Cave, NP. The sample collection at the three monitoring sites was to begin in the summer of 2025. However, new SNiPiT samplers had high P blanks values, which would contaminate the collected samples. The cause of the high P sampler blanks is under investigation as well as alternative materials to manufacture the SNiPiT samplers from.

This research project directly addresses gaps presented in the TDep Reactive Nitrogen (Nr) deposition White Paper to develop routine methods to quantify organic nitrogen in 3.1 Measured total Nr deposition budgets, particularly for 3.1.1.1 'Measurements of air-surface exchange of Nr in natural ecosystems across North America' and 3.1.2.5 'Characterization of organic nitrogen in air and precipitation'. This also addresses knowledge gaps for routine organic nitrogen (ON) measurements identified in 3.4 'Spatial and Temporal Patterns of total Nr deposition', specifically for subsection 3.4.1 'Relationship of long-term Nr trends in emission and deposition'.

- **WMO Atmospheric Deposition Initiative (Amanda Cole, ECCC; Measurement Model Fusion workgroup)**

TDep members Amanda Cole and Greg Beachley are members of a steering committee for the WMO's Atmospheric Deposition Initiative (WADI). This project was formerly known as the Measurement-Model Fusion for Global Total Atmospheric Deposition Initiative (MMF-GTAD) but was renamed in 2025. The long-term goal of this initiative is to produce high-quality maps and estimates of fluxes of atmospheric pollutants on a global scale in a semi-operational manner, drawing from the methods and expertise of TDep and other regional MMF deposition products. In 2024 and 2025, the steering committee moved forward with multiple projects, for example: (1) development of an ozone deposition tool with options for testing the sensitivity of different land cover, meteorology and dry deposition schemes; (2) application of machine learning methods to combine measured data and global model output; (3) evaluation of deposition output from two global operational models (ECMWF-CAMS and GEOS-CF) for accuracy and suitability for MMF; (4) support to Barcelona Supercomputing Centre for creation of a harmonized global wet deposition dataset for this evaluation and other MMF applications.

- **Measurements of NH_3 and other reactive N dry deposition fluxes in Rocky Mountain National Park (RMNP) (Bret Schichtel, NPS)**

A project funded through an EPA Regional Applied Research Effort (RARE) grant, with additional funding from the National Park Service, is now in its second year. This collaborative project between EPA ORD, EPA Region 8, NPS and Colorado State University (CSU) seeks to measure NH_3 and other reactive N dry deposition fluxes in RMNP and along the NH_3 transport path from agricultural sources on the Front Range to the Park. The first set of flux measurements was collected during the summer of 2021 over an evergreen forest in RMNP. During 2022, flux measurements were collected at a grassland site (NOAA Table Mountain facility) near Boulder, CO. In addition to direct flux measurements, seasonal and annual NH_3 fluxes were modeled using measurements of NH_3 air concentrations, micrometeorology, and soil and vegetation emission potentials. A final report has been submitted to EPA, and the following journal article was recently accepted for publication, led by CSU (Naimie et al., 2025).:

- Naimie, L. E., Pan, D., Sullivan, A. P., Walker, J. T., Djurkovic, A., Schichtel, B. A., and Collett Jr., J. L. (2025) Sensitivity of Simulated Ammonia Fluxes in Rocky Mountain National Park to Measurement Time Resolution and Meteorological Inputs, EGUsphere [preprint], https://doi.org/10.5194/egusphere-2025-1167.
- Naimie, L. E. (2025) Fertilization of remote ecosystem from reactive nitrogen and phosphorus. Doctoral Dissertation, Colorado State University.

This research project directly addresses research gaps presented in the TDep Reactive Nitrogen (Nr) deposition White Paper for 3.4 "Spatial and Temporal Patterns of total Nr deposition", specifically for 3.4.2 "Spatial variability of ammonia in agricultural regions".

- **Sensitivity of critical loads to modeled deposition estimates (Todd McDonnell, E&S Environmental Chemistry; Mike Bell, NPS; Measurement Model Fusion Workgroup)**

This report quantifies differences in atmospheric deposition estimates generated by two modeling approaches (Total Deposition [TDep] and Community Multiscale Air Quality [CMAQ]) using representative annual deposition estimates for 2017 across the conterminous US. Given that TDep represents a measurement-based adjustment of CMAQ model results, this project evaluates the extent to which those adjustments affect the magnitude and spatial extent of critical load exceedances as compared with using deposition estimates directly from CMAQ for all National Park Service (NPS) units with available data. This analysis showed that selection of the deposition data source was most important in consideration of CL exceedance for lichen species richness. The extent of CL exceedance was less affected by the deposition data source for CLs to protect herbaceous species richness and surface water acidification. Results from this study can be used to guide natural resource management and policy in the context of understanding uncertainty in air pollution effects caused by atmospheric N and S deposition across a broad set of federally protected NPS units. The results can also provide insight into where local deposition measurements elucidate risk to ecosystem health. The full report can be found here: https://irma.nps.gov/DataStore/Reference/Profile/2305350

- **Comparison of modeled deposition to throughfall measurements (Mike Bell, NPS; Measurement Model Fusion Workgroup)**

This project was a collaboration between the NPS (Mike Bell), US Forest Service (Mark Fenn), and San Francisco State University (Leora Nanus) to compare measured values of N and S throughfall to TDep model outputs from corresponding years. After expanding the dataset from a subset to all ion exchange resin (IER) samples, the analysis confirmed no strong correlation or consistent incongruity between measured deposition with throughfall collectors and modeled deposition from the CMAQ and TDep maps. The timing of exposures, different ecosystems, and lack of data on tree type all played into the lack of informative results. The null results of this analysis have informed a potential future study that will better mimic current interpolation procedures and/or integrate monthly model outputs.

This research project assessed research gaps presented in the TDep Reactive Nitrogen deposition White paper (see sections 3.1.1.3 and 3.2.4).

- **Using epiphytic lichen tissue nitrogen content to understand TDep uncertainty in the Pacific Northwest (Measurement Model Fusion Workgroup)**

This is an on-going project with the NPS (Mike Bell), US Forest Service (Linda Geiser; retired), and Washington State University (Dave Evans/Meaghan Petix) using tissue nitrogen concentrations from epiphytic lichen species and lichen community structure as bioindicators of deposition in the Pacific Northwest. Correlation of tissue N, tissue isotopic concentration, and deposition values will be evaluated to assess consistency of tissue to model values and isotopes will be used to assess sources of pollutants impacting lichen health. One manuscript evaluating N stable isotopes in lichen tissue was published in 2024 (Petix et al. 2024), and a second evaluating lichen N tissue concentration and stable isotope values to assess air pollution in the region was published in 2025 (Petix et al. 2025). A final manuscript evaluating lichen community structure relative to air quality and environmental gradients will be published this year.

- **Using disaggregated N deposition model estimates to evaluate critical loads (Measurement Model Fusion workgroup)**

A project with the NPS, FS, and EPA (Mike Bell, John Walker, Jesse Bash – now with the Norwegian Meteorological Institute) assesses differences in critical load exceedances based on the scale at which deposition is modeled. Phase I of this project used land-use specific dry deposition estimates at a 500m scale developed for the Chesapeake Bay to assess changes to critical loads exceedances at Shenandoah National Park and the Otter Creek Wilderness. Based in part by the value added by this analysis, disaggregated dry deposition measurements are now available for all years of the CMAQ EQUATES time-series and can be used for further critical load analysis: https://dataverse.unc.edu/dataset.xhtml?persistentId=doi:10.15139/S3/ERHAAZ

This research project will address research gaps presented in the TDep Reactive Nitrogen deposition White paper (see sections 3.2.4).

- **Wet deposition measurements during the Study of Winter Air Pollution in Toronto (Amanda Cole, ECCC)**

The Study of Winter Air Pollution in Toronto (SWAPIT) was an intensive measurement campaign in early 2024 led by Environment and Climate Change Canada (ECCC). Its goal was to improve the state of knowledge about air pollution during understudied winter conditions relevant to Canadian cities. Wet deposition was measured at two sites for 4-6 weeks and one site for a full year to provide a first look at gradients within the city and surrounding region. Where possible, sites were collocated with air quality measurements including nitrogen and sulphur species to constrain high-resolution models of atmospheric emissions, processing and deposition. Data have been finalized and analysis is underway.

This research project addresses research gaps described in the TDep Reactive Nitrogen (Nr) deposition White Paper under 3.1.1 Process-Level Measurements, specifically 3.1.1.4 “Total atmospheric N_r deposition in urban areas” and 3.1.1.5 “Snow and atmospheric deposition.”

- **Operational ADAGIO model-measurement fusion product development (Irene Cheng, ECCC)**

ECCC has been developing a model-measurement fusion product called ADAGIO (Atmospheric Deposition Analysis Generated by Interpolation of model and Observations), which combines output from the Global Environmental Multiscale – Modelling Air quality and CHemistry (GEM-MACH) model and ground-based measurement data using the optimal interpolation technique. ADAGIO produces gridded surface atmospheric concentration and deposition estimates for nitrogen, sulfur, and ground-level ozone across Canada and the U.S. Two papers were published in 2025, one on the ADAGIO wet deposition fusion method and results for 2010, 2013-2016, and 2019 (Robichaud et al., 2025) and one on the dry deposition fusion method and associated results (Robichaud et al., 2026). In addition, work is underway to develop an operational ADAGIO product with the goal of producing annual deposition estimates from 2019 onwards and make the data product publicly accessible. The milestones from 2024-25 include the transfer of knowledge and scripts, porting of programs from SAS software to R, testing and validating the wet and dry deposition fusion procedures, improving measurement quality (e.g. AMoN data), and producing ADAGIO outputs for 2014-2016 and 2019-2021. Work is ongoing to unify the data processing system and improve automation. Progress was reported at the Fall 2024 TDep Meeting.

This project supports efforts to enhance coordination for stakeholder needs as identified in the TDep Reactive Nitrogen (Nr) deposition White Paper, specifically, 4.1.3. Quantifying and reducing uncertainty in deposition estimates used for critical loads applications.

- **Improve estimates of atmospheric smoke deposition (Yongqiang Liu, USDA/FS; Measurement Model Fusion workgroup)**

The existing TDep Measurement-Model Fusion (TDep MMF) approach does not specifically provide estimates of smoke deposition. Also, the networks primarily used for the current TDep MMF product do not provide measurements at the time and spatial resolution needed for estimating smoke deposition. This project aims to address these challenges through applying satellite products and field measurement data. Current research works on synthesizing the status and research gaps in smoke deposition estimates and sensitivity of smoke simulations of individual fire cases to smoke radiative forcing. Future research will focus on improving smoke aerosol schemes and specifications in CMAQ, simulating and/or analyzing smoke transport and deposition of historical wildland fires, and incorporating smoke deposition estimates into the existing TDep MMF products.

- **Impacts of biomass burning on particulate matter and wet deposition in the western US. (John Walker, USDA/FS)**

EPA, CSU, WSLH, NPS and U.S. Forest Service are collaborating on an EPA ROAR project to assess the role of biomass burning in trends of air quality and wet deposition in the western US. During the

first phase of the project, the NOAA Hazard Mapping System has been used to characterize smoke frequency and extent at CASTNET and IMPROVE sites since 2010. Trends in smoke occurrence have been assessed along with relationships between particulate matter chemistry and smoke metrics including the total number of days of the sampling period in which smoke was observed (CASTNET), summed daily smoke density for the sample period (CASTNET), and maximum daily smoke metric (IMPROVE). Trends in quality data from CASTNET and IMPROVE were correlated with days when smoke was likely present during the 2010-2020 time period. Trends in known wildfire smoke tracers (K+, NH4+) were present along with other pollutants that may indicate other biogeochemical processes occuring during wildfire events. A similar analysis of NTN precipitation chemistry and deposition is forthcoming, including measurements of black carbon and levoglucosan at select NTN sites. A publication is expected to be submitted in late 2026.

TDep Publications Submitted or Published in 2024-2025 (non-comprehensive)

Published:

- Leytem, A.B., J.T. Walker, Z. Wu, K. Nouwakpo, C. Baublitz, J. Bash, G. Beachley, 2024. Spatial Distribution of Ammonia Concentrations and Modeled Dry Deposition in an Intensive Dairy Production Region. *Atmosphere*, 15, 15. 10.3390/atmos15010015.

- McDonnell, T.C., B. Knees, M.D. Bell, E. Felker-Quinn, 2024. Exceedance of critical loads of nitrogen and sulfur deposition across national parks: Comparing 2015–2017 CMAQ and TDep model outputs. Science Report. NPS/SR—2024/173. National Park Service. Fort Collins, Colorado. https://doi.org/10.36967/2305350

- Naimie, L. E., Pan, D., Sullivan, A. P., Walker, J. T., Djurkovic, A., Schichtel, B. A., and Collett Jr., J. L., 2025. Sensitivity of Simulated Ammonia Fluxes in Rocky Mountain National Park to Measurement Time Resolution and Meteorological Inputs, *EGUsphere* [preprint], https://doi.org/10.5194/egusphere-2025-1167, 2025.

- Pan, D., D. L. Mauzerall, R. Wang, X. H. Guo, M. Puchalski, Y. X. Guo, S. J. Song, D. Tong, A. P. Sullivan, B. A. Schichtel, J. L. Collett, Jr. and M. A. Zondlo, 2024. Regime shift in secondary inorganic aerosol formation and nitrogen deposition in the rural United States. *Nature Geoscience* **17**(7): 23.

- Petix, M. I., M. D. Bell, and R. D. Evans. 2025. Assessing nitrogen deposition and chemistry in mountainous regions of Olympic National Park and North Cascades National Park Service Complex, Pacific Northwest, USA. *Oecologia* 207:59.

- Petix, M.I., M.D. Bell, D.G. Williams, and R.D. Evans, 2024. Utilizing δ15N of biomonitors to assess N emission sources and deposition chemistry. *Ecological Indicators* 169:112866.

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