NADP Total Deposition Science Committee (TDep) Annual Report 2022

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 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 2020. 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; and
- 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/).

TDep is currently directed by two **Co-chairs**, Ryan Fulgham (U.S. Environmental Protection Agency; EPA/Office of Research and Development; ORD), and Amanda Cole (Environment Climate Change Canada; ECCC). Colleen Baublitz (EPA/Office of Air Quality Planning and Standards; OAQPS) is the TDep **Secretary**. The TDep Steering Committee meets bi-monthly 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, EOS representatives, representatives of major NADP-funding agencies, and atmospheric and ecosystem scientists closely involved with the TDep mission. For 2022, the Steering Committee members included: Ryan Fulgham, Amanda Cole, Colleen Baublitz, Greg Beachley (EPA/Office of Air and Radiation; OAR), Mike Bell (National Park Service; NPS), Katie Benedict (Los Alamos National Laboratory), Selma Isil (Wood), Chris Rogers (Wood), Kristi Morris (NPS), Melissa Puchalski (EPA/OAR), Bret Schichtel (NPS), John Walker (EPA/ORD), Kristen Foley (EPA/ORD), and Greg Wetherbee (U.S. Geological Survey; USGS).

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

This annual report serves as a summary and quick reference for the activity, progress, and accomplishments of TDep over the course of 2022. It contains links to the biannual meeting notes, updates from each of the TDep workgroups, and descriptions and status updates on TDep-related products and research.

Annual Summary of TDep Accomplishments

It was another productive year for TDep. Below is a snapshot of the 2022 accomplishments.

- **TDep MMF output for versions 2021.01 and 2022.01.** Version 2021.01 was made public in July 2022 and was updated with version 2022.01 in November 2022. In addition to the grids and images for these versions, gif movies of trends from 2000 to 2021 for each species were published on the TDep website. Both new versions utilize the EQUATES deposition time-series using CMAQ v5.3.2 which now spans from 2002 to 2019.

- **Measurement and Monitoring Workgroup was formed and announced at the Fall 2022 TDep meeting.** Draft mission statement, "Assess and advance air quality monitoring related to pollutant deposition in support of the NADP TDep Science Committee goals as well as scientific and regulatory activities."

- **Hosted an ozone deposition session at Spring TDep meeting.** Jeff Herrick (EPA) presented an overview of the Critical Loads of Atmospheric Deposition (CLAD) science committee's Working Group 6, with the goals to coordinate research efforts of ozone effects on ecosystems and develop ozone Critical Levels for North America. Olivia Clifton (NASA) was invited to give a summary of ozone deposition modelling under the Air Quality Model Evaluation and Intercomparison Initiative (AQMEII) Phase 4. This was followed by a discussion on what TDep could contribute to improving ozone deposition estimates in support of effects studies.

General Updates

Colleen Baublitz was elected as TDep secretary at the Fall 2022 hybrid TDep meeting, Amanda Cole was promoted to TDep Co-chair.

The Education and Outreach Subcommittee (EOS) enacted guidance that biannual meeting notes for each committee should be approved electronically approximately 6 weeks after convening to help meet committee objectives more effectively between each meeting.

Due to the pandemic, TDep held hybrid (virtual and in-person) meetings for the Spring and Fall 2022. Feedback was largely positive on the meetings. We hope to continue to incorporate some level of virtual participation.

TDep Workgroup Updates

In 2019, TDep adopted and organized into a Workgroup structure to promote collaborative work. It is hoped that the new format will 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:

- Stakeholder Workgroup (Lead: John Walker)
- Measurement Model Fusion (MMF) Workgroup (Lead: Greg Beachley)
- Deposition Uncertainty Workgroup (Lead: Mike Bell)
- Urban Deposition Workgroup (CityDep; Lead: Greg Wetherbee)
- Measurement and Monitoring Workgroup (Co-Leads: Bret Schichtel and Kristi Morris)

Stakeholder Workgroup *Lead:* John Walker, EPA (walker.johnt@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 needs into existing research programs across stakeholder groups
- Facilitate communication among program managers within stakeholder Agencies and user groups

Examples of Current Projects (Project descriptions listed in TDep Project Tracker):

- Participation in USDA North Central Regional Development Committee Project developed by Rich Grant (Purdue University) and colleagues: 'NCDC233 Sources and Fate of NH_3 Across the Region'. The first annual meeting was held virtually on November 30th 2021. Project leads were identified to coordinate research around the three research objectives. The participants will meet again in the Spring prior to the NADP meeting.

- Planning for Agricultural Stakeholder Forum in 2024

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 model and manage product outputs (https://nadp.slh.wisc.edu/committees/tdep/). Workgroup members will conduct research and have discussions to ensure that the TDep MMF stays current with the state of deposition science. The group will respond to any questions and requests involving the TDep MMF products. The workgroup will meet quarterly.

The workgroup is organized into the following task-groups: Product Development, Outreach, and Improvements. The Product Development Taskgroup will manage version updates and oversee the quality assurance/quality control protocols. The Outreach task-group will focus on content of the TDep

Total Deposition maps website, messaging (i.e. social media alerts), and identifying new stakeholders and collaborators. The Improvements task-group will focus on development of long-term improvements to the TDep MMF and helping to keep the TDep MMF current with the state of the science.

Examples of Current Projects (Project descriptions listed in TDep Project Tracker):

- Implementing corrections to the next TDep version (2022.02) and subsequent QA for planned Spring 2023 release.
- A publication focusing on improvements made to the 2021.01 TDep MMF with comparison to the archived 2018.01 version is in preparation.
- Preparation of conference presentations of deposition trends predicted with the TDep MMF methods.
- Extended coverage of TDep MMF grids to include coastal locations.
- Incorporation of CMAQ wet deposition data into the TDep MMF model

Deposition Uncertainty Workgroup

Lead: Mike Bell, NPS (michael_d_bell@nps.gov)

Workgroup Objectives:

The objectives of this working group are to understand the uncertainty that exists in measurements and models used to estimate the deposition of nitrogen (N) and sulfur (S) and how it impacts critical load development and critical load exceedance.

Examples of current projects:

2022 was generally a quiet year for the group, as members continued their individual projects, but we didn't meet often to advance many shared efforts. The two main outputs were:

1. Putting more effort into working directly with the Measurement-Model Fusion Working Group to ensure that areas of known map uncertainty are being considered in future updates. Now that the new model script has been implemented, we want to continue communication with the MMF-WG to share areas of the US where there appears to be misalignment of deposition values among models as well as where recent research can enhance model performance. Keeping this line of communication open will make sure that the areas of high importance are prioritized in future updates.
2. Following the effort of the CLAD Critical Load Uncertainty Working Group, this group experimented with creating a 5-point categorical ranking of uncertainty based on the calculated weighted deposition uncertainty metric (WDUM), distance from an NTN site, distance from a CASTNET site, distance from a large city, range of precipitation within a model cell, and range of elevation within a model cell. This was put together as an example of what areas have consistent factors that influence our knowledge of deposition. To advance this effort, each category will need to be evaluated in the future to better define the boundaries around

category values and how they interact with local environmental factors.

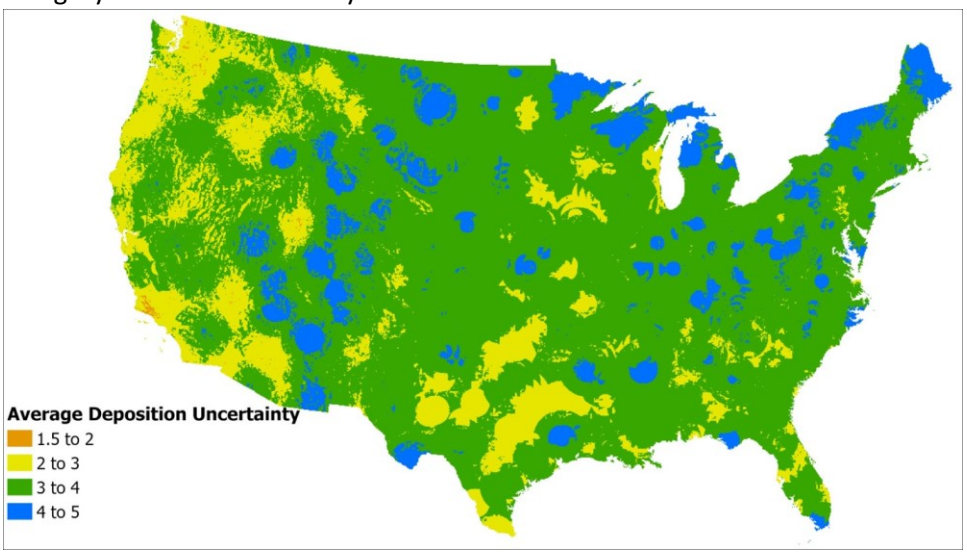

Figure 1. Average deposition uncertainty of the six metrics used in the analysis. Lower values represent more uncertain deposition calculation and higher values represent areas where deposition is expected to align with the model.

While we are working to expand on the inputs for developing the WDUM, we plan to update the WDUM map using the same methods for current deposition years from the new model runs.

In addition to these tasks, members have continued to work on and discuss projects related to uncertainty including:

- Comparing new TDep to old TDep and how it changes CL exceedances (Todd McDonnell, E&S Environmental),
- Disaggregating CMAQ model to 500m scale based on landcover (Jesse Bash/Colleen Baublitz, EPA,
- Comparing flux data to throughfall measurements at Duke forest (John Walker),
- Comparing throughfall data to NADP/CMAQ models (Leora Nanus, SFSU),
- Using lichen tissue N to assess CMAQ/TDep models (Meaghan Petix, WSU),
- AQMEII Comparison of deposition models with critical loads (Paul Makar),

Comparing modeled and measured ammonia deposition at AMoN sites (Colleen Baublitz, EPA),

Urban Deposition Workgroup (CityDep)

Lead: Greg Wetherbee, USGS (wetherbe@usgs.gov)

Workgroup Objectives:

- The mission of the CityDep Work Group is to enhance the National Atmospheric Deposition Program by expanding monitoring and other data-gathering opportunities through collaborative research on air-quality and atmospheric deposition of pollutants and their effects on ecological and public health in urban environments.

Examples of Current Projects:

- A Research Coordination Network proposal to the National Science Foundation is in progress, currently led by Alexandra Ponette. The idea was brought forward by Rich Pouyat in 2019 to fund outreach to cities to promote ambient air and deposition monitoring.
- Analysis of data collected by the Network for Urban Atmospheric Nitrogen Chemistry (NUANC) is continuing and have been used in Wetherbee et al., 2022 (see TDep Publications) and a publication in review

Measurement and Monitoring Workgroup

Co-Leads: Bret Schichtel, NP (schichtel@cira.colostate.edu) and Kristi Morris, NPS (Krist_Morris@nps.gov)

Workgroup Objectives:

The TDEP Measurement Workgroup was formed in 2022. The group will focus on measurements of nitrogen and phosphorous with the mission and objectives as follows:

Assess and advance air quality monitoring related to pollutant deposition in support of the NADP program; the Total Deposition (TDep) Science Committee, and scientific and regulatory activities.

- 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
- 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

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

- **AMoN Flux Characterization Pilot Study update (John Walker, 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. An EPA report is near completion (Fall 2023) that describes the 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. Phase II of the project is progressing, where Phase I measurements are being used to parameterize a bidirectional NH_3 model for implementation across the AMoN network, including assessment of uncertainties associated with the use of time-integrated concentration measurements, use of modeled meteorological inputs, and parameterizations of soil and vegetation emission potentials.

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 (John Walker, 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 is undergoing laboratory testing at EPA with deployment at Duke Forest hardwood tower in Summer 2023.

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 (John Walker, 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 reactive N (NH_3, HNO_3, HONO, NO_3^-, NH_4^+) on weekly to monthly time-scales. One COTAG system was upgraded in October 2021 and was deployed spring 2022 to a new site in Idaho. A second system with improved flow monitoring was also deployed in Idaho. A third system will be constructed and deployed at Duke Forest in spring 2024. A design package for the EPA COTAG, including mechanical drawings, wiring schematics, field and lab SOPs, has also been completed. Wood is building the EPA COTAG system with expected delivery by end of 2023.

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 (John Walker, EPA)**

EPA and Wood conducted a special study using samples collected from five CASTNET sites: Great Smoky Mountain 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. While the results have since improved, EPA has decided to delay the next phase of the study so that a new Seal Analytical colorimetric autoanalyzer can be used for the total N analysis. Use of colorimetry for both Total N and NH_4^+ will reduce instrument cross-calibration requirements and will be consistent with the WSLH SNiPiT method for Total N in precipitation. A 12-month study began winter 2022 following Wood's acquisition of a new SEAL total N analyzer. Filters from 27 CASTNET sites (25 locations) will be analyzed for Total N once the new analyzer is online. A subset of sites will also receive the SNiPiT wet deposition total N/total P collector for co-located measurements of total and organic N in aerosols and precipitation.

This project directly addresses research gaps presented in the TDep Reactive Nitrogen (Nr) deposition White Paper, which include 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).

- **Testing of the NADP total N / total P wet deposition sampler (WSLH)**

The Wisconsin State Laboratory of Hygiene (WSLH) is developing a collector and analytical methods for measurement of total water soluble organic nitrogen (WSON) and phosphorus (P) in precipitation. The prototype collector (SNIPIT) fits on the outside of the NTN bucket and is pre-charged with acid to avoid microbial processing and sorption of N and P. Chris Worley presented on the status of this project at the 2021 Fall TDep meeting, finding on average organic N and organic P accounted for 13% and <10% of total N and total P, respectively, during the pilot study in Madison, WI. However, many measurements of organic N and total P were below the method detection limits and some negative values were identified, which require further inquiry.

This research project directly addresses research 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'.

- **Improving characterization of reduced nitrogen at IMPROVE and CSN monitoring sites**

The goal of increasing reduced nitrogen measurements remains important for the TDep community and is shared by other monitoring groups and existing networks. There has been interest over the years in exploring the use of acid-impregnated filters that could be added to sites in existing networks such as

IMPROVE and CSN. Chen et al. (2014) used acid-impregnated filters deployed as part of the IMPROVE at sites primarily in Colorado and other western states. EPA, NPS, and Wood collaborated to run a similar set up for IMPROVE equipment plus a CSN module with an impregnated filter during the 2017 warm season at two sites in the southeastern United States (Duke Forest, NC and Gainesville, FL). Data analysis occurred during late 2017 and 2018, and a summary report was completed during 2019 (https://www.epa.gov/castnet/castnet-special-studies). Additional testing of the cellulose filters is needed to identify if there are biases introduced caused by the filter ratings, but the project is delayed owing to pandemic and funding issues. Evaluation of the filters will resume at a future date.

This research project directly addresses research gaps presented in the TDep Reative Nitrogen (Nr) deposition White Paper for 3.4 'Spatial and Temporal Patterns of total Nr deposition', specifically for 3.4.1 'Relationship of long-term Nr trends in emission and deposition' and 3.4.2 'Spatial variability of ammonia in agricultural regions'.

- **WMO Measurement-Model Fusion for Global Total Atmospheric Deposition Initiative (Amanda Cole; Measurement Model Fusion workgroup)**

TDep members Amanda Cole and Greg Beachley are members of a steering committee for the WMO's MMF-GTAD initiative. 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. Short-term projects include an overview paper, an initial proof-of-concept set of maps for a single year, and extension of a Swedish MMF product over Europe. An overview paper led by Joshua Fu (University of Tennessee) was published in early 2022 in Environmental Science and Technology. A virtual symposium on measurement-model fusion techniques was hosted in September 2022 to share MMF techniques for precipitation depth, ambient concentrations and deposition as well as identify client needs. Work on the global proof-of-concept maps advanced, with nitrogen and sulfur deposition maps produced by combining the 2010 HTAP multi-model mean with deposition data (Joshua Fu) and a successful trial of applying the TDep method to estimate ozone deposition (Jeffrey Geddes and Bo Wang, Boston University).

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

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 will be modeled using measurements of NH_3 air concentrations, micrometeorology, and soil and vegetation emission potentials. A final project report is expected summer of 2023.

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 (Mike Bell, NPS; Deposition Uncertainty Workgroup)**

A new project from the NPS (Mike Bell), US Forest Service (Mark Fenn), and San Francisco State University (Leora Nanus) compares measured values of N and S throughfall to TDep model outputs from corresponding years. The initial phase of the study will compare deposition measurements from IER columns to modeled data in the western US. Researchers will assess conditions where measurements align best in hopes of advancing our understanding of model uncertainty.

This research project will address 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 (Deposition Uncertainty Workgroup)**

An on-going project with the NPS (Mike Bell), US Forest Service (Linda Geiser), and Washington State University (Dave Evans/Meaghan Petix) using tissue nitrogen concentrations from epiphytic lichen species as bioindicators of deposition. Correlation of tissue N, tissue isotopic concentration, and deposition values will be evaluated will be evaluated to assess consistency of tissue to model values and better understand deposition patterns on a fine scale.

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

- **Using disaggregated N deposition model estimates to evaluate critical loads (Deposition Uncertainty Workgroup)**

A continuing project with the NPS (Mike Bell) and the EPA/ORD (Jesse Bash/John Walker) assesses differences in critical load exceedances based on the scale at which deposition is modeled. Phase I of this project will use 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. Exceedances will be compared to CMAQ and TDep total N estimates. The manuscript is currently being developed.

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

- **Analysis of metals on nanoparticles from Urban deposition sites (NUANC) (CityDep workgroup)**

James Ranville (Colorado School of Mines) and his students, Aaron Goodman, and Carmen Villarruel are analyzing the metals on nanoparticles obtained from NUANC site samples, especially from CO86. They will be conducting research on the Marshall Fire that destroyed 1,000 homes in a suburban community only a few kilometers from CO86 in 2021.

This research project will address research gaps presented in the TDep Reactive Nitrogen deposition White paper (see section 3.1.1.4) in understanding deposition to urban areas and developing source apportionment methods (see section 3.3.1).

- **Modeling 15N-NH3 stable isotope data to identify Urban Ammonia Sources (CityDep Workgroup)**

Dave Felix (Texas A&M Univ.) is preparing a paper on urban ammonia sources in Denver by modeling 15N-NH3 stable isotope data obtained at the NUANC sites during 2018. The paper is expected to be in review during summer 2022.

This paper will address research gaps presented in the TDep Reactive Nitrogen deposition White paper (see section 3.1.1.4) in understanding deposition to urban areas and developing source apportionment methods (see section 3.3.1).

- **Investigation of phosphorus (P) contributions from urban sources (Pamela Templer; CityDep workgroup)**

Pamela Templer is guiding an undergraduate study at Boston University to investigate phosphorous (P) contributions from urban sources.

- **Dry Deposition of P at NADP sites using samples collected with Aerochem Metrics Dry Side Inserts (DSIs) (Janice Brahney; CityDep Workgroup)**

A project led by Janice Brahney (Utah State University) investigating dry deposition of P at NADP sites using samples collected with Aerochem Metrics Dry Side Inserts (DSIs) recently invented by the group.

Outlook for 2022 research and products motivated by TDep mission

- **NSF RCN proposal (Leora Nanus, Alexandra Ponette, and Pam Templar; CityDep)**
- **Peer-reviewed manuscript describing the modernized TDep Measurement Model Fusion model and evaluation of results with the archived model (Measurement Model Fusion Workgroup)**

This manuscript presents the modernized TDep MMF model (2021.01) and directly compares estimates with the archived (2018.02) model using the same 2010 input dataset to quantify the differences due to the method changes. This will build on the results presented by Greg Beachley at the 2021 Fall NADP Science Symposium.

Project Ideas for the future

- **Incorporation of measurement data from intensive studies (e.g Urban measurements) into TDep MMF model estimates (Measurement Model Fusion Workgroup)**

Initial ideas for inclusion of NO_2 data from SLAMS, measurements of passive NH_3 in the Greeley, CO area, throughfall measurements (including Duke Forest), and deposition in urban areas.

- **Quantify the radius of influence of urban air pollution on interpolated wet-deposition spatial data products (CityDep and Measurement Model Fusion Workgroup)**

Recent TDep Publications (submitted or published since 2022)

Published:

- Cheng, I., Zhang, L., He, Z., Cathcart, H., Houle, D., Cole, A., Feng, J., O'Brien, J., Macdonald, A. M., Aherne, J., & Brook, J., 2022. Long-term declines in atmospheric nitrogen and sulfur deposition reduce critical loads exceedances at multiple Canadian rural sites, 2000–2018. *Atmos. Chem. Phys.*, *22*, 14631–14656. https://doi.org/10.5194/acp-22-14631-2022
- Fu, J.S., Carmichael, G.R., Dentener, F., Aas, W., Andersson, C., Barrie, L.A., Cole, A., Galy-Lacaux, C., Geddes, J., Itahashi, S., Kanakidou, M., Labrador, L., Paulot, F., Schwede, D., Tan, J., Vet, R. 2022. Improving Estimates of Sulfur, Nitrogen, and Ozone Total Deposition through Multi-Model and Measurement-Model Fusion Approaches. Environ. Sci. Technol. 56 (4), 2134–2142. https://doi.org/10.1021/acs.est.1c05929
- Wetherbee, G., Wieczorek, M., Robertson, D., Saad, D., Novick, J., and Mast, M.A., 2022, *Estimating urban air pollution contribution to South Platte River nitrogen loads with National Atmospheric Deposition Program data and SPARROW model*, J. Env. Manage. 301, 113861. https://www.sciencedirect.com/science/article/pii/S030147972101923X?via%3Dihub.
- Heindel, R. C., Murphy, S. F., Repert, D. A., Wetherbee, G. A., Liethen, A. E., Clow, D. W., & Halamka, T. A. (2022). Elevated nitrogen deposition to fire-prone forests adjacent to urban and agricultural areas, Colorado Front Range, USA. *Earth's Future*, 10, e2021EF002373. https://doi.org/10.1029/2021EF002373

In review:

- Wetherbee, G.A., in Review, *Atmospheric Deposition of Inorganic Nitrogen at the Rocky Flats National Wildlife Refuge, 2017 – 2019*.