



2021 Data Summary of Wet Nitrogen Deposition at Rocky Mountain National Park



Photograph of view from Loch Vale towards Timberline Falls in Rocky Mountain National Park.
NPS / JIM CHEATHAM

2021 data summary of wet nitrogen deposition at Rocky Mountain National Park

Science Report NPS/SR—2024/109

Kristi Morris

National Park Service
Air Resources Division
P.O. Box 25287
Denver, Colorado 80225-0287

Please cite this publication as:

Morris, K. 2024. 2021 data summary of wet nitrogen deposition at Rocky Mountain National Park. Science Report NPS/SR—2024/109. National Park Service, Fort Collins, Colorado.
<https://doi.org/10.36967/2303290>

The National Park Service Science Report Series disseminates information, analysis, and results of scientific studies and related topics concerning resources and lands managed by the National Park Service. The series supports the advancement of science, informed decisionmaking, and the achievement of the National Park Service mission.

All manuscripts in the series receive the appropriate level of peer review to ensure that the information is scientifically credible and technically accurate.

Views, statements, findings, conclusions, recommendations, and data in this report do not necessarily reflect views and policies of the National Park Service, U.S. Department of the Interior. Mention of trade names or commercial products does not constitute endorsement or recommendation for use by the U.S. Government.

The Department of the Interior protects and manages the nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors its special responsibilities to American Indians, Alaska Natives, and affiliated Island Communities.

This report is available in digital format from the [National Park Service DataStore](#) and the [Natural Resource Publications Management website](#). If you have difficulty accessing information in this publication, particularly if using assistive technology, please email irma@nps.gov.

Contents

	Page
Figures.....	iii
Tables	iv
Abstract	v
Introduction.....	6
Methods and Results	7
Summary	20
Literature Cited	21

Figures

	Page
Figure 1. The glidepath, annual and 5-year average wet N deposition, and precipitation.	7
Figure 2. Annual N deposition, nitrate and ammonium concentrations, and precipitation at Rocky Mountain National Park - Loch Vale (CO98).	9
Figure 3. Annual N deposition, nitrate and ammonium concentrations, and precipitation at Rocky Mountain National Park - Beaver Meadows (CO19)	10
Figure 4. Annual N deposition, nitrate and ammonium concentrations, and precipitation data at Rocky Mountain National Park - Kawuneechee Meadow (CO09).	11
Figure 5. Annual N deposition, nitrate and ammonium concentrations, and precipitation at Niwot Saddle (CO90).	12
Figure 6. Annual N deposition, nitrate and ammonium concentrations, and precipitation at Niwot Ridge - Southeast (CO90).	13
Figure 7. Annual N deposition, nitrate and ammonium concentrations, and precipitation at Sugarloaf (CO94).	14
Figure 8. Annual N deposition, nitrate and ammonium concentrations, and precipitation at Pawnee (CO22).	15

Tables

	Page
Table 1. Long-term trends in wet nitrogen deposition over the period of record (through 2021).	16
Table 2. Long-term trends in precipitation-weighted mean ammonium concentrations over the period of record (through 2021). S.....	16
Table 3. Long-term trends in precipitation-weighted mean nitrate concentrations over the period of record (through 2021).....	16
Table 4. Long-term trends of precipitation over the period of record (through 2021).....	17
Table 5. Trends of wet nitrogen deposition since 2006 (2006–2021) and 7 year (2015–2021) time periods.	18
Table 6. Trends for precipitation-weighted mean ammonium concentrations since 2006 (2006–2021) and 7 year (2015–2021) time periods.....	18
Table 7. Trends for precipitation-weighted mean nitrate concentrations since 2006 (2006–2021) and 7 year (2015–2021) time periods.	19
Table 8. Trends for precipitation since 2006 (2006–2021) and 7 year (2015–2021) time periods.....	19

Abstract

The National Park Service is working with the Colorado Department of Public Health and Environment and the Environmental Protection Agency Region 8 (referred to as the Memorandum of Understanding agencies) to reduce atmospheric nitrogen deposition at Rocky Mountain National Park (RMNP) due to its detrimental effects on park ecosystems. The data summarized in this report inform these agencies, stakeholders, and the public about the current status and trends of nitrogen deposition in accordance with the RMNP Nitrogen Deposition Reduction Plan (NDRP). Analyses include assessment of progress along the glidepath and trend analyses for RMNP and other regional sites for the following time periods: long-term/period of record (>33 years), since the 2006 inception of the NDRP (currently 16 years), and short-term (the most recent 7 years). Wet N deposition in 2021 at Loch Vale in RMNP was above the glidepath. Long-term trends show that N deposition levels are stable (no trend), with ammonium concentrations increasing at most of sites and nitrate concentrations decreasing at all sites. Shorter-term trends indicate that ammonium concentrations are stable, but nitrate concentrations are decreasing at all sites that met criteria for 2006-2021.

Introduction

The purpose of this data summary is to inform the Memorandum of Understanding (MOU) agencies, stakeholders, and the public about the current status and trends of wet nitrogen (N) deposition in accordance with the [Nitrogen Deposition Reduction Plan](#) (NDRP) for Rocky Mountain National Park (RMNP). Full reports on Monitoring and Tracking Wet Nitrogen Deposition at RMNP were peer-reviewed and published annually from 2009 to 2013. In 2014, however, it was decided that a summary of the data would be compiled and distributed annually between milestone years. This data summary is reviewed by the MOU agencies including the National Park Service, the Environmental Protection Agency Region 8 and the Colorado Department of Public Health and Environment.

For future milestone years (2022, 2027, and 2032), the necessity for a full report and external review will be determined by the MOU agencies.

The analyses presented here to track wet nitrogen deposition at RMNP, include:

1. assessment of progress along the glidepath, and
2. trend analyses for RMNP and other regional sites for the following time periods:
 - a. long-term/period of record (>32 years),
 - b. since 2006 (inception of the NDRP, 16 years), and
 - c. short-term (the most recent 7 years).

Methods and Results

Background information and a complete description of the monitoring are provided in the last full report, [2017 Monitoring and Tracking Wet Nitrogen Deposition at Rocky Mountain National Park](#) (Morris et al. 2019). There were several changes made to the methods in 2018, including a new approach for data substitution when data (sample concentrations and precipitation amounts) were invalid or missing, and more strict criteria for reporting significant trends over time (Morris 2021, Schichtel et al. 2019).

Figure 1 shows that annual and 5-year rolling average wet N deposition compared to the NDRP glidepath, which has milestones every 5-years and the resource management goal of 1.5 kg/ha/yr in 2032. The figure also shows annual and the long-term average precipitation. Wet N deposition in 2021 was above 4.0 kg N/ha/yr and was the second highest on record. The 2021 5-year rolling average (2.95 ± 0.18 kg N/ha/yr) remained above the glidepath (~ 2.3 kg N/ha/yr). Precipitation in 2021 (145 cm) was above average (117 cm).

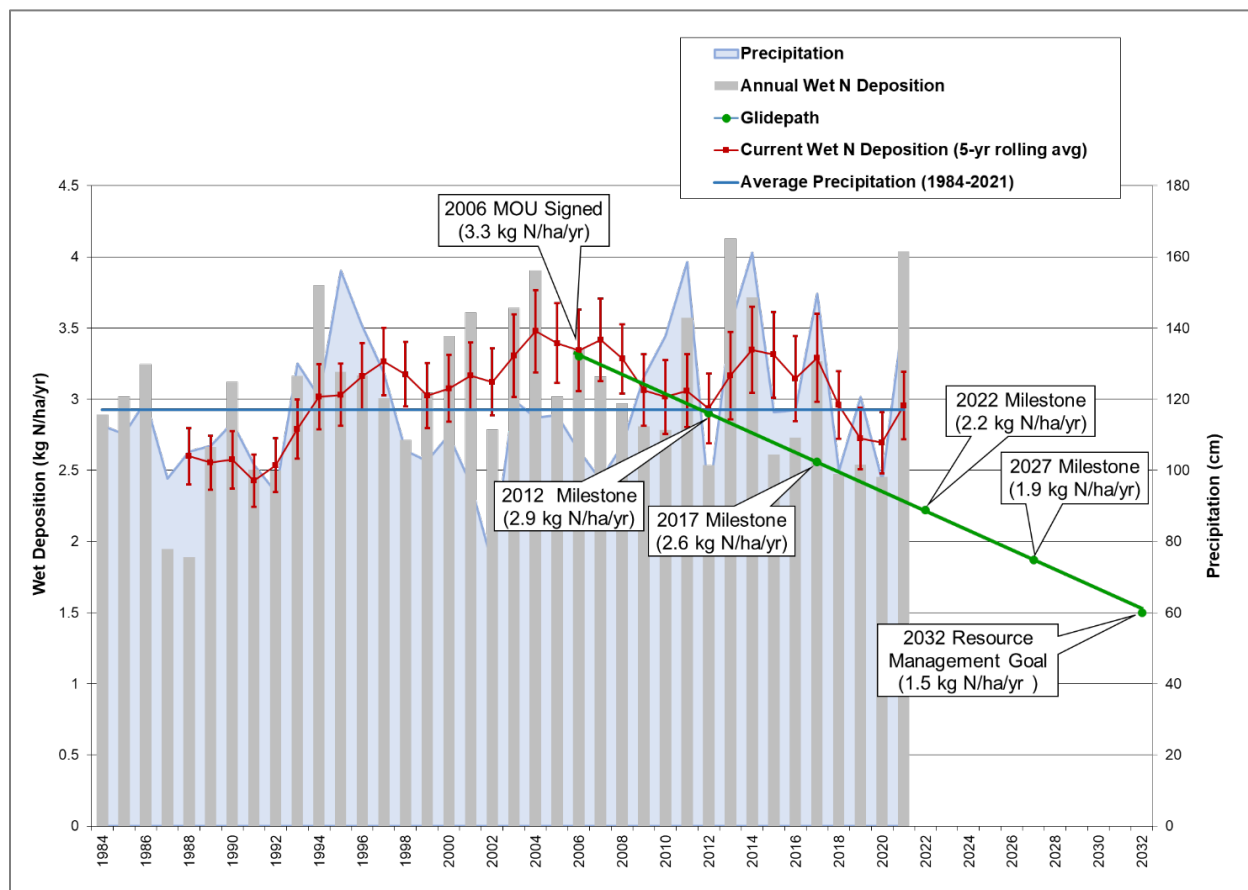


Figure 1. The glidepath, annual and 5-year average wet N deposition, and precipitation. Error bars are based on a Monte Carlo simulation.

As noted for Figure 1, precipitation at RMNP Loch Vale in 2021 was higher than average and wet N deposition was above 4.0 kg N/ha/yr, the second highest on record. Figure 2 shows that the concentration of ammonium in 2021 was also the highest on record.

Figures 2-8 show wet N deposition generally ranged from 2.0 to 4.0 kg N/ha/yr at six sites in 2021, except for Kawuneechee Meadow (1.0 kg N/ha/yr). Patterns in nitrate and ammonium deposition were similar for all sites except for Kawuneechee Meadow which is on the western slope and furthest from sources along the Front Range, and Pawnee which is closest to agricultural sources. Nitrate deposition was higher than ammonium deposition at most sites until 2010. From 2010 to 2013, ammonium deposition began exceeding nitrate deposition. However, ammonium deposition has always been higher than nitrate deposition at the Pawnee site.

Concentrations were generally lower at the higher elevation sites, where precipitation amount was greater. Between 2008 and 2013, ammonium concentrations began exceeding nitrate concentrations at all sites except for Kawuneechee Meadow, where the shift occurred in 2017. Concentrations of ammonium have always been higher than nitrate at the Pawnee site.

Tables 1- 8 show long-term (period of record >33 years) and short-term (since the 2006 inception of the NDRP and the most recent 7 years) trends for wet N deposition, ammonium and nitrate concentrations, and precipitation.

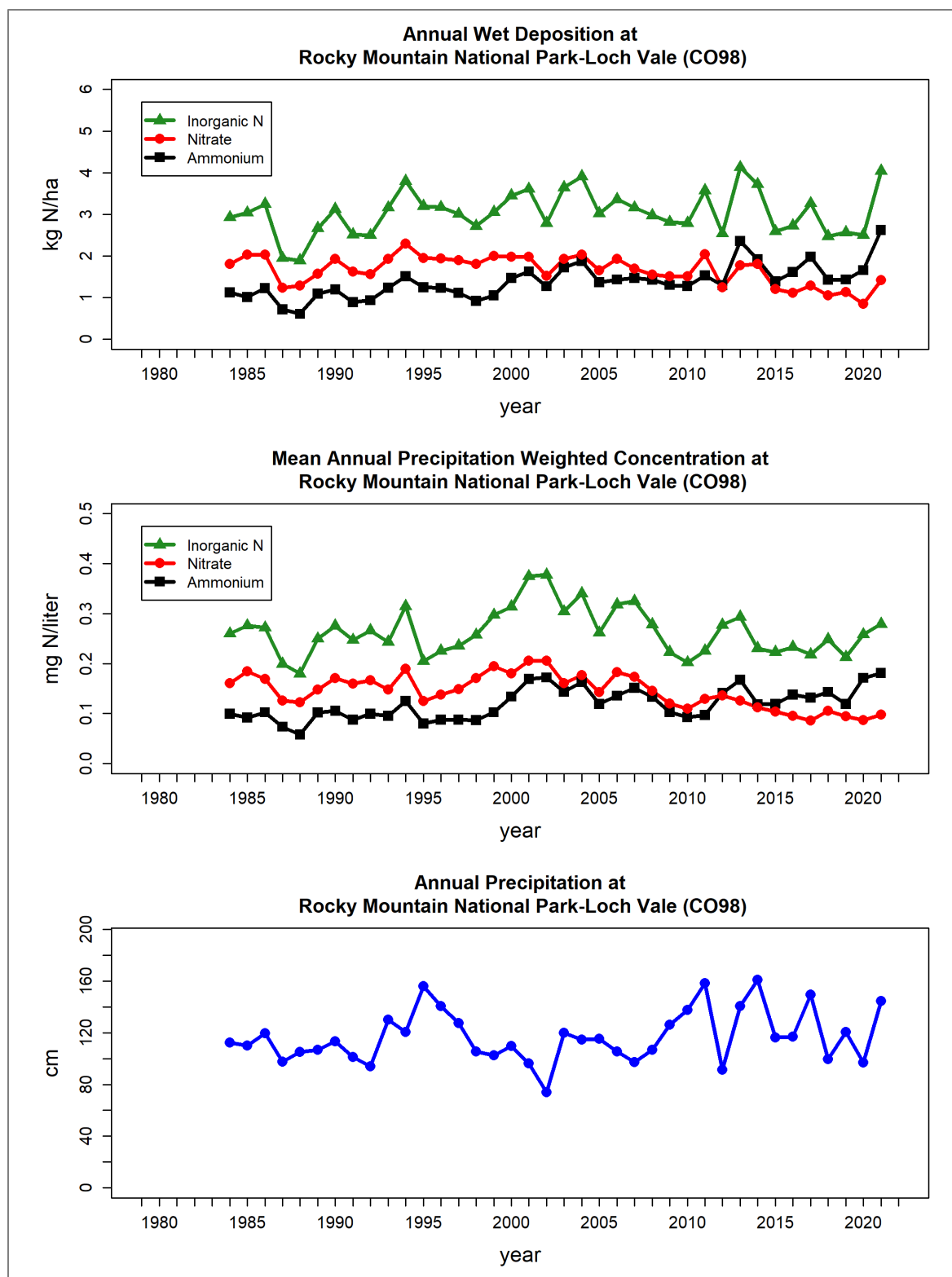


Figure 2. Annual N deposition, nitrate and ammonium concentrations, and precipitation at Rocky Mountain National Park - Loch Vale (CO98). Missing/invalid sample concentration and precipitation amounts were modeled using data substitution methods described in Morris 2021 and Schichtel et al. 2019.

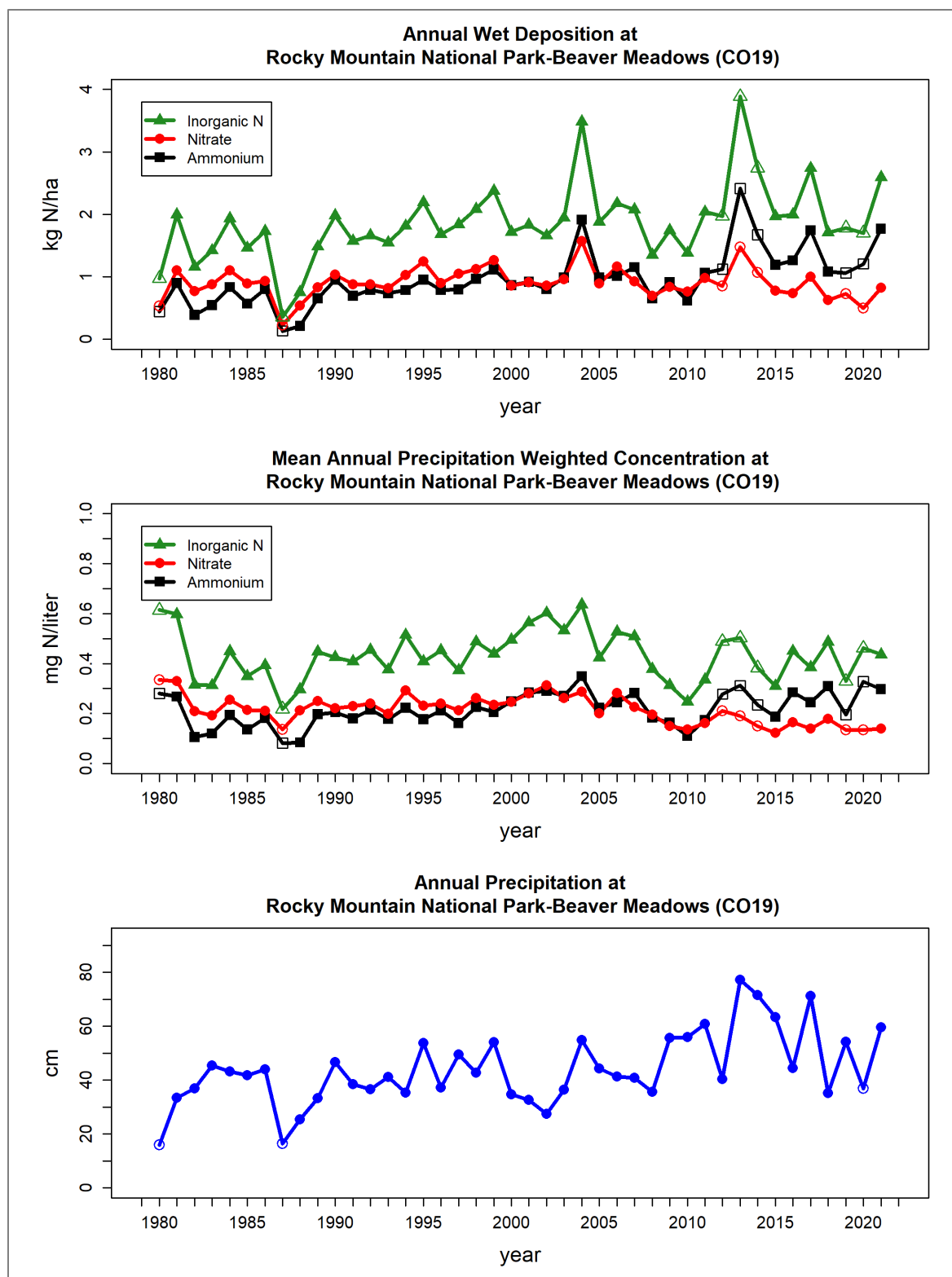


Figure 3. Annual N deposition, nitrate and ammonium concentrations, and precipitation at Rocky Mountain National Park - Beaver Meadows (CO19). Open symbols demark years when NADP Data Completeness were not met.

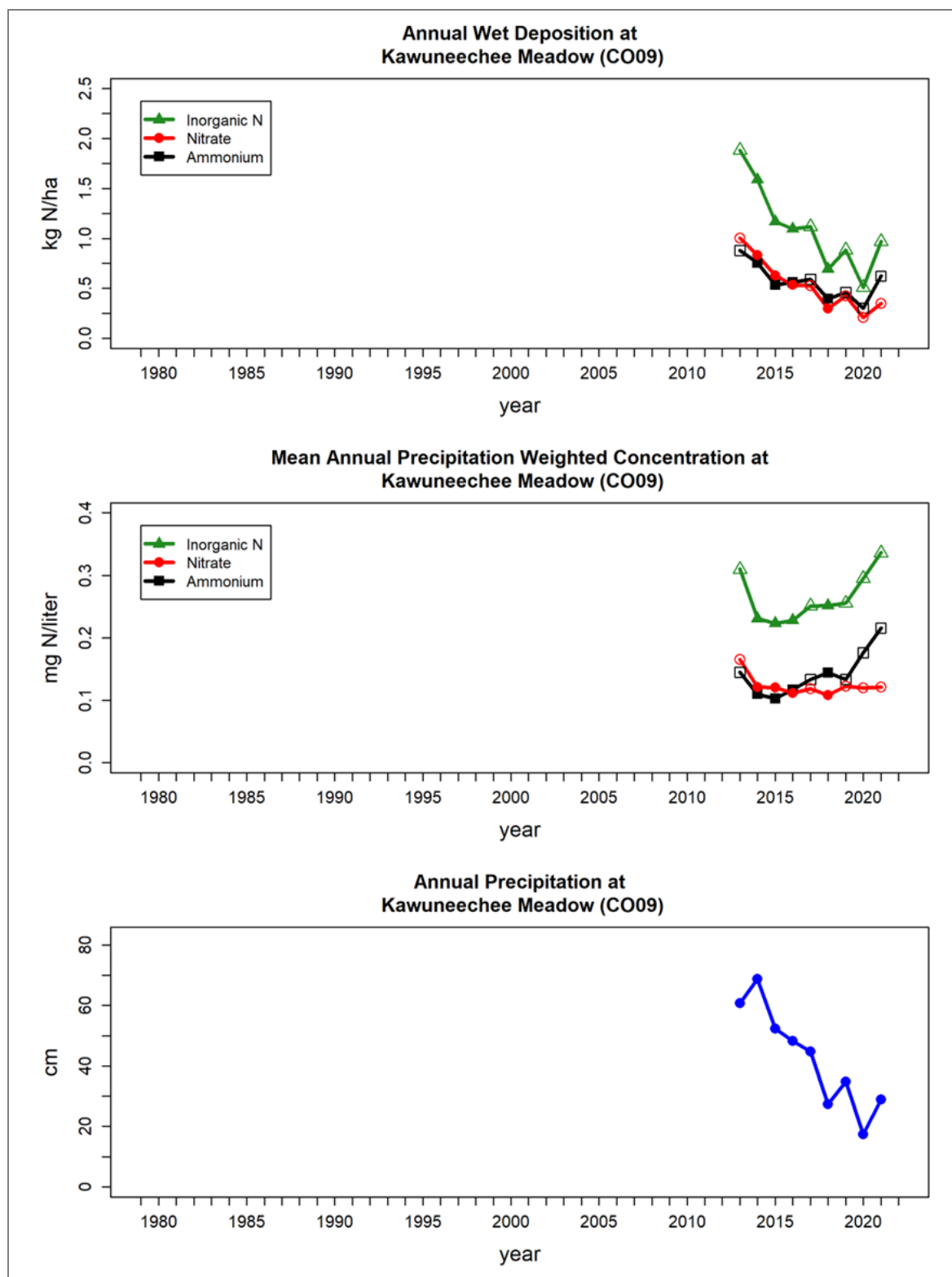


Figure 4. Annual N deposition, nitrate and ammonium concentrations, and precipitation data at Rocky Mountain National Park - Kawuneechee Meadow (CO09). Open symbols demark years when NADP Data Completeness were not met.

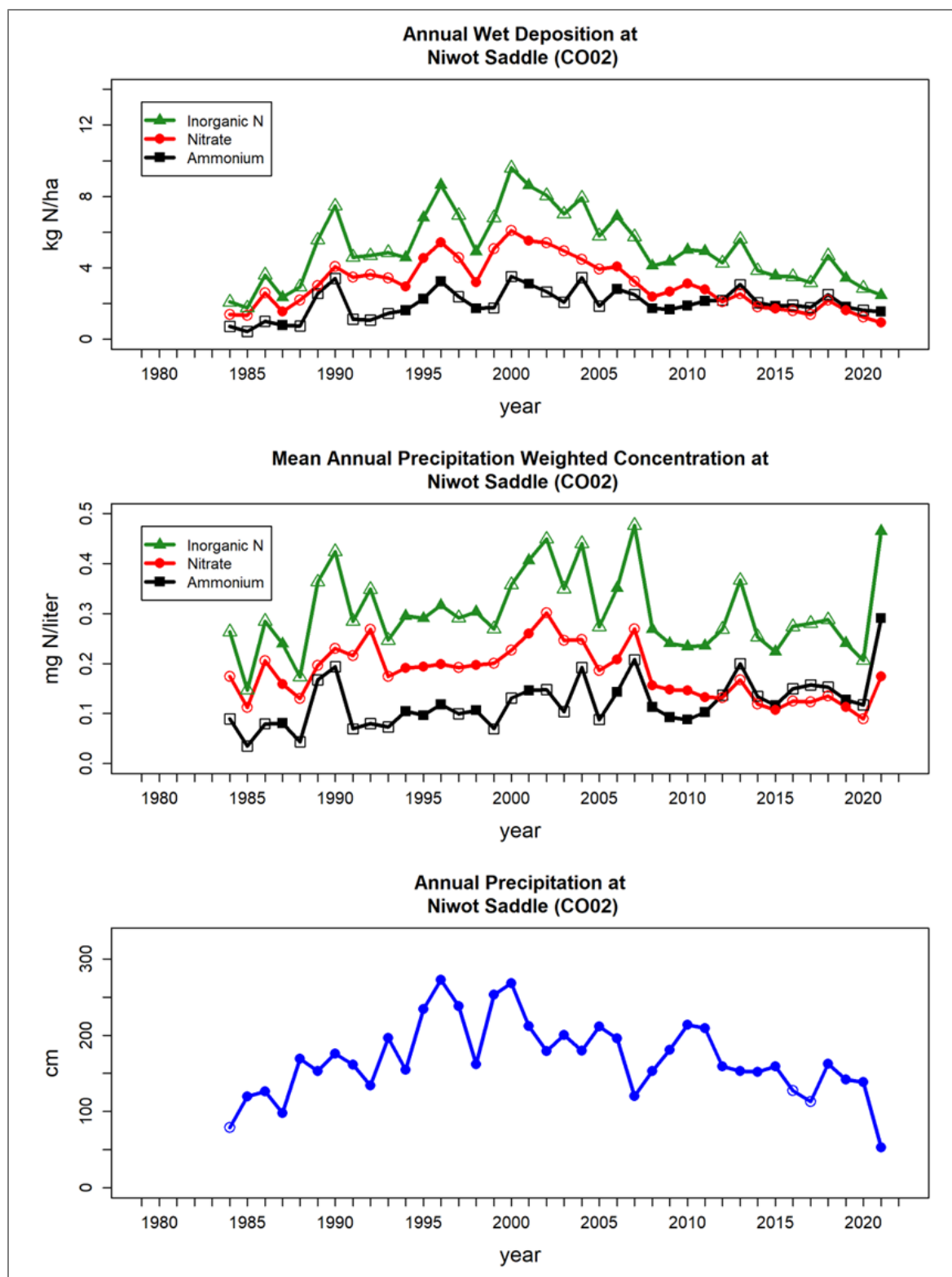


Figure 5. Annual N deposition, nitrate and ammonium concentrations, and precipitation at Niwot Saddle (CO90). Open symbols demark years when NADP Data Completeness were not met.

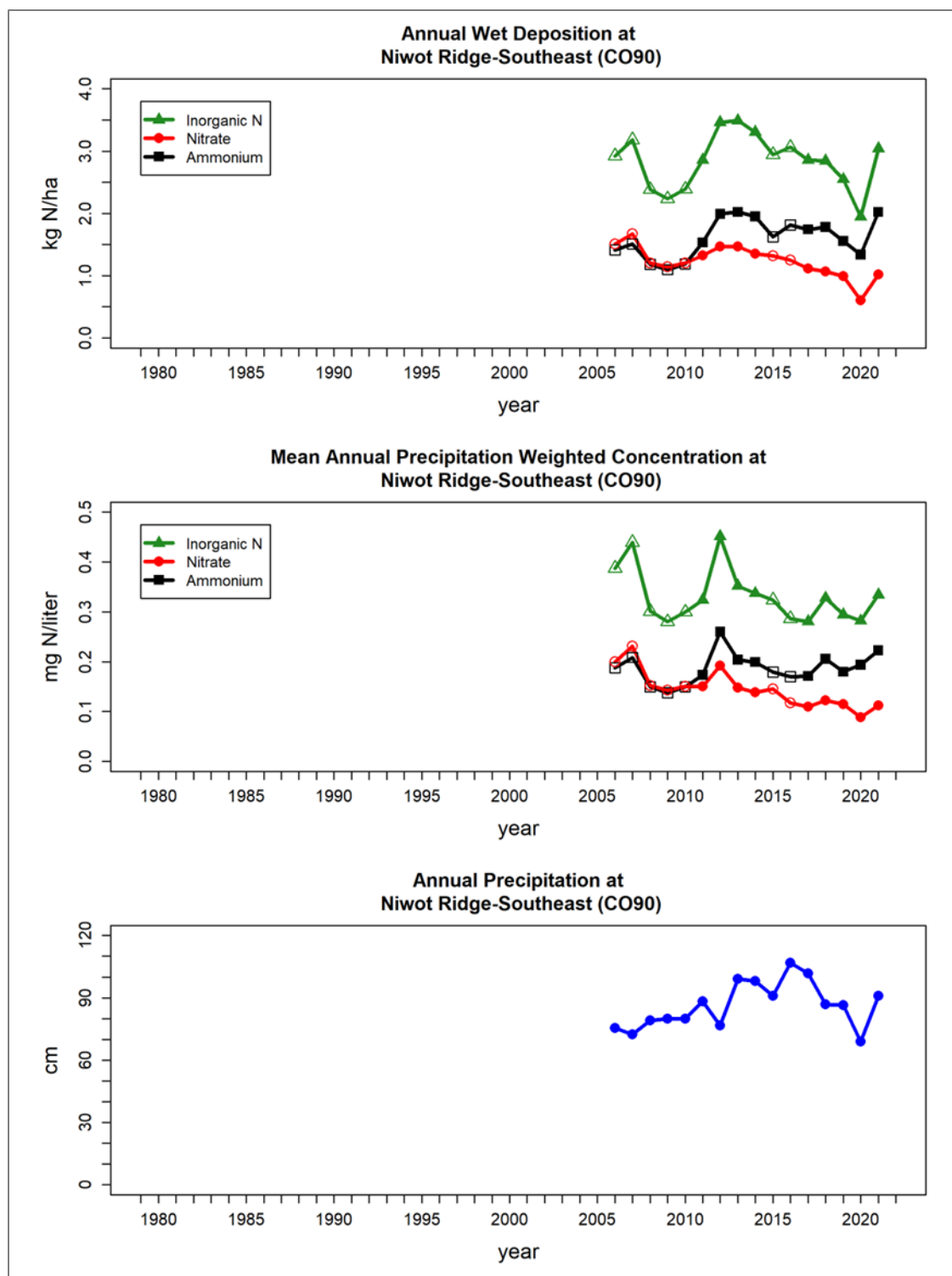


Figure 6. Annual N deposition, nitrate and ammonium concentrations, and precipitation at Niwot Ridge - Southeast (CO90). Open symbols demark years when NADP Data Completeness were not met.

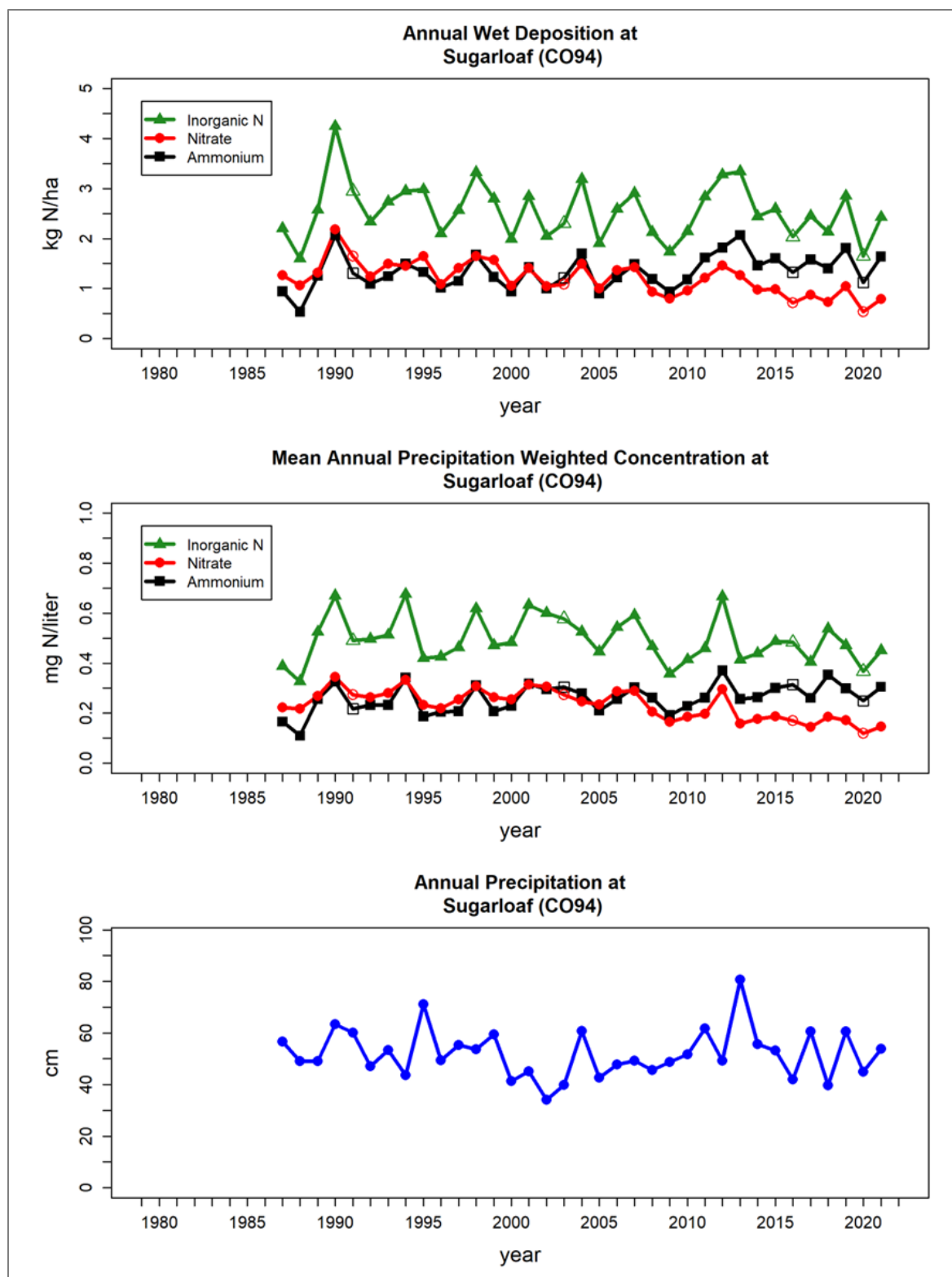


Figure 7. Annual N deposition, nitrate and ammonium concentrations, and precipitation at Sugarloaf (CO94). Open symbols demark years when NADP Data Completeness were not met.

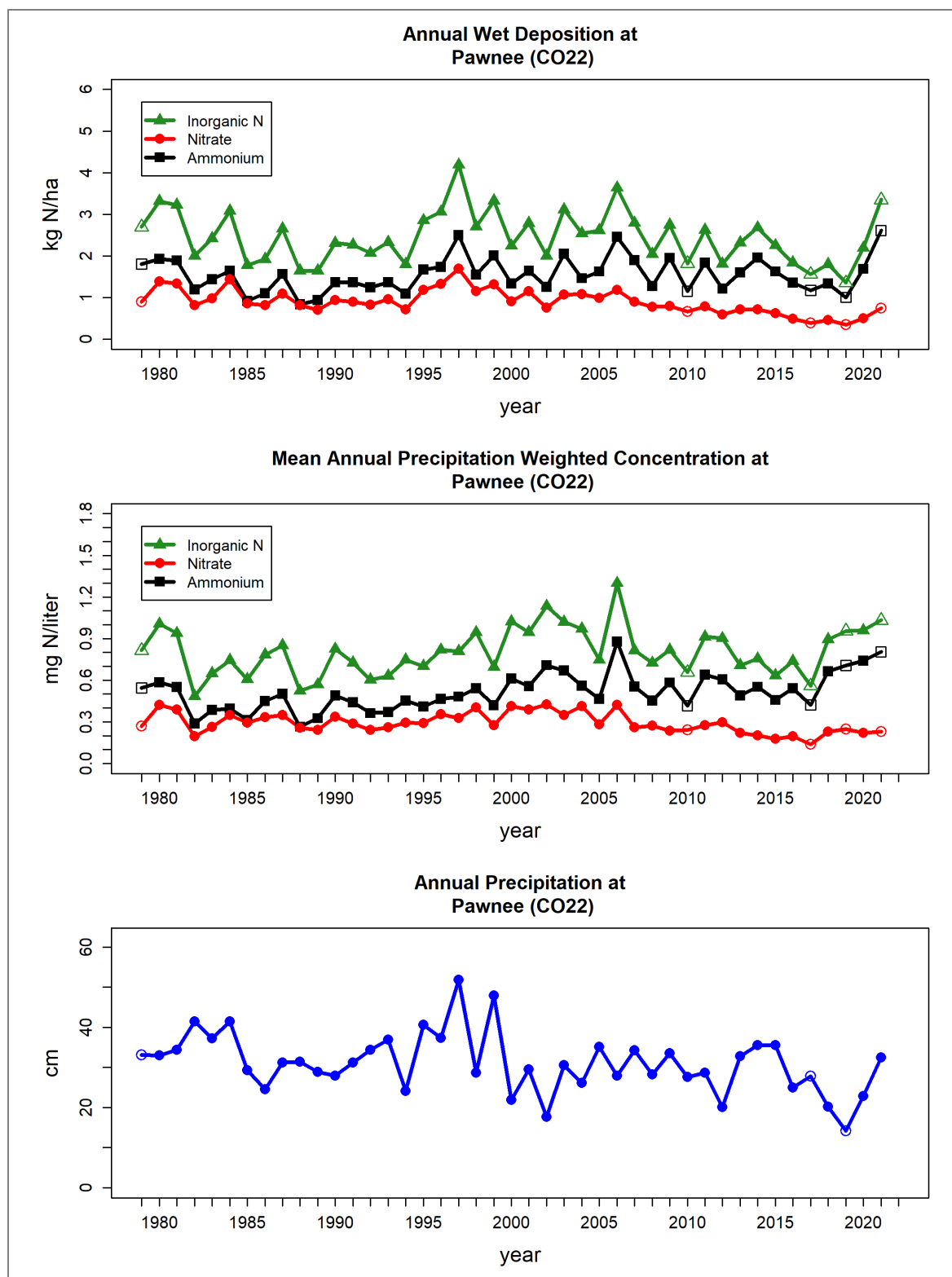


Figure 8. Annual N deposition, nitrate and ammonium concentrations, and precipitation at Pawnee (CO22). Open symbols demark years when NADP Data Completeness were not met.

Table 1. Long-term trends in wet nitrogen deposition over the period of record (through 2021). Significant trends were determined at the 95 percent confidence level (p-value ≤ 0.05). [NA, trend not available due to failure to meet data completeness criteria].

Site Name	Start Year	Trend (kg N/ha/yr)	P-value	Significant Trends
Loch Vale	1984	0.010	0.333	no trend
Beaver Meadows	1981	0.016	0.008	increasing
Niwot Saddle	1986	NA	NA	NA
Sugarloaf	1987	0.001	0.932	no trend
Pawnee	1980	-0.005	0.633	no trend

Table 2. Long-term trends in precipitation-weighted mean ammonium concentrations over the period of record (through 2021). Significant trends were determined at the 95 percent confidence level (p-value ≤ 0.05). [NA, trend not available due to failure to meet data completeness criteria].

Site Name	Start Year	Trend ($\mu\text{eq/L/yr}$)	P-value	Significant Trends
Loch Vale	1984	0.132	0.000	increasing
Beaver Meadows	1981	0.222	0.000	increasing
Niwot Saddle	1986	NA	NA	NA
Sugarloaf	1987	0.127	0.092	no trend
Pawnee	1980	0.307	0.004	increasing

Table 3. Long-term trends in precipitation-weighted mean nitrate concentrations over the period of record (through 2021). Significant trends were determined at the 95 percent confidence level (p-value ≤ 0.05). [NA, trend not available due to failure to meet data completeness criteria].

Site Name	Start Year	Trend ($\mu\text{eq/L/yr}$)	P-value	Significant Trends
Loch Vale	1984	-0.119	0.001	decreasing
Beaver Meadows	1981	-0.158	0.003	decreasing
Niwot Saddle	1986	NA	NA	NA
Sugarloaf	1987	-0.250	0.000	decreasing
Pawnee	1980	-0.219	0.005	decreasing

Table 4. Long-term trends of precipitation over the period of record (through 2021). Significant trends were determined at the 95 percent confidence level ($p\text{-value} \leq 0.05$). [NA, trend not available due to failure to meet data completeness criteria].

Site Name	Start Year	Trend (cm/yr)	P-value	Significant Trends
Loch Vale	1984	0.537	0.082	no trend
Beaver Meadows	1981	0.430	0.016	increasing
Niwot Saddle	1986	NA	NA	NA
Sugarloaf	1987	0.114	0.541	no trend
Pawnee	1980	-0.186	0.056	no trend

Table 5. Trends of wet nitrogen deposition since 2006 (2006–2021) and 7 year (2015–2021) time periods. Significant trends were determined at the 95 percent confidence level (p-value ≤ 0.05). [NA, trend not available due to failure to meet data completeness criteria]. Kawuneechee Meadow began monitoring in 2013.

Site Name	Since 2006 NDRP Inception (16 year)			7 year		
	Trend ($\mu\text{eq/L/yr}$)	P-value	Significant Trends	Trend ($\mu\text{eq/L/yr}$)	P-value	Significant Trends
Loch Vale	0.094	0.357	no trend	0.376	0.154	no trend
Beaver Meadows	0.302	0.122	no trend	0.997	0.072	no trend
Kawuneechee Meadow	–	–	–	NA	NA	NA
Niwot Saddle	NA	NA	NA	NA	NA	NA
Niwot Ridge- Southeast	NA	NA	NA	0.573	0.275	no trend
Sugarloaf	0.082	0.469	no trend	0.8125	0.303	no trend
Pawnee	-0.043	0.941	no trend	NA	NA	NA

Table 6. Trends for precipitation-weighted mean ammonium concentrations since 2006 (2006–2021) and 7 year (2015–2021) time periods. Significant trends were determined at the 95 percent confidence level (p-value ≤ 0.05). [NA, trend not available due to failure to meet data completeness criteria]. Kawuneechee Meadow began monitoring in 2013.

Site Name	Since 2006 NDRP Inception (16 year)			7 year		
	Trend (kg N/ha/yr)	P-value	Significant Trends	Trend (kg N/ha/yr)	P-value	Significant Trends
Loch Vale	-0.034	0.224	no trend	0.013	1.000	no trend
Beaver Meadows	0.037	0.640	no trend	0.072	0.807	no trend
Kawuneechee Meadow	–	–	–	NA	NA	NA
Niwot Saddle	NA	NA	NA	NA	NA	NA
Niwot Ridge- Southeast	NA	NA	NA	-0.051	1.000	no trend
Sugarloaf	0.000	1.000	no trend	-0.016	0.807	no trend
Pawnee	-0.080	0.016	decreasing	NA	NA	NA

Table 7. Trends for precipitation-weighted mean nitrate concentrations since 2006 (2006–2021) and 7 year (2015–2021) time periods. Significant trends were determined at the 95 percent confidence level (p-value ≤ 0.05). [NA, trend not available due to failure to meet data completeness criteria]. Kawuneechee Meadow began monitoring in 2013.

Site Name	Since 2006 NDRP Inception (16 year)			7 year		
	Trend (µeq/L/yr)	P-value	Significant Trends	Trend (µeq/L/yr)	P-value	Significant Trends
Loch Vale	-0.329	>0.001	decreasing	-0.131	0.202	no trend
Beaver Meadows	-0.311	0.029	decreasing	-0.097	0.764	no trend
Kawuneechee Meadow	–	–	–	NA	NA	NA
Niwot Saddle	NA	NA	NA	NA	NA	NA
Niwot Ridge- Southeast	NA	NA	NA	-0.134	0.585	no trend
Sugarloaf	-0.520	0.014	decreasing	-0.188	0.440	no trend
Pawnee	-0.826	0.008	decreasing	NA	NA	NA

Table 8. Trends for precipitation since 2006 (2006–2021) and 7 year (2015–2021) time periods. Significant trends were determined at the 95 percent confidence level (p-value ≤ 0.05). [NA, trend not available due to failure to meet data completeness criteria]. Kawuneechee Meadow began monitoring in 2013.

Site Name	Since 2006 NDRP Inception (16 year)			7 year		
	Trend (cm/yr)	P-value	Significant Trends	Trend (cm/yr)	P-value	Significant Trends
Loch Vale	1.046	0.500	no trend	0.685	1.000	no trend
Beaver Meadows	1.281	0.213	no trend	-1.787	0.807	no trend
Kawuneechee Meadow	–	–	–	NA	NA	NA
Niwot Saddle	NA	NA	NA	NA	NA	NA
Niwot Ridge- Southeast	NA	NA	NA	-5.17	0.462	no trend
Sugarloaf	0.736	0.125	no trend	0.035	1.000	no trend
Pawnee	-0.369	0.631	no trend	NA	NA	NA

Summary

The analyses presented in this data summary allow us to answer the following questions based on the RMNPI NDRP and MOU agency work:

- Is current wet nitrogen deposition in RMNP on or below the NDRP glidepath?
 - Current wet N deposition (5-year rolling average) in 2021 at Loch Vale in RMNP was 2.95 ± 0.18 kg/ha/yr which is 0.65 kg/ha/yr above the glidepath (~2.3 kg/ha/yr) and outside the 95% confidence interval.
- Has wet nitrogen deposition decreased at RMNP and other sites in the region over the long-term (period of record)?
 - Wet N deposition has not decreased at RMNP or other sites in the region over the long-term (Table 1). Trend analyses show no trend for all sites, except Beaver Meadows in RMNP. Data from Beaver Meadows indicate an increase in wet N deposition and precipitation for the period of record. Ammonium concentration data show an increase at both sites in RMNP and Pawnee but no trend at Sugarloaf over the long-term. Nitrate concentration data show a decreasing trend at all sites that met data completion criteria over the long-term.
- Has wet nitrogen deposition decreased at RMNP and other sites in the region since the inception of the NDRP in 2006?
 - Wet N deposition decreased at Loch Vale in RMNP for the first time since the inception of the NDRP, from 2006 to 2020, however, with the addition of 2021 data (2006-2021), there is no trend again. Wet N deposition remained stable at Beaver Meadows and Sugarloaf but decreased at Pawnee during this time frame. Concentrations of ammonium showed no trends at all sites and concentrations of nitrate decreased at all four sites that met completion criteria.
- Has wet nitrogen deposition decreased at RMNP and at other sites in the region in the short-term (7 year)?
 - Wet N deposition has not recently decreased at RMNP or other sites in the region. Concentrations of ammonium and nitrate showed no trends at all sites as did precipitation.

Literature Cited

- Morris, K. 2021. 2018/2019 data summary of wet nitrogen deposition at Rocky Mountain National Park. Natural Resource Report NPS/NRSS/ARD/NRR—2021/2339. National Park Service, Fort Collins, Colorado. <https://doi.org/10.36967/nrr-2288455>.
- Morris, K., A. Mast, G. Wetherbee, J. Baron, J. Cheatham, J. Bromberg, L. Devore, J. Hou, K. Gebhart, M. Bell, D. Gay, M. Olson, T. Weinmann, and D. Bowker. 2019. 2017 Monitoring and tracking wet nitrogen deposition at Rocky Mountain National Park: February 2019. Natural Resource Report NPS/NRSS/ARD/NRR—2019/1905. National Park Service, Fort Collins, Colorado.
- Schichtel, B.A., Gebhart, K.A., Morris, K.H., Cheatham, J.R., Vimont, J., Larson, R.S. and Beachley, G., 2019. Long-term trends of wet inorganic nitrogen deposition in Rocky Mountain National Park: Influence of missing data imputation methods and associated uncertainty. *Science of the total environment*, 687, pp.817

National Park Service
U.S. Department of the Interior



Science Report NPS/SR—2024/109
<https://doi.org/10.36967/2303290>

Natural Resource Stewardship and Science

1201 Oakridge Drive, Suite 150
Fort Collins, CO 80525