National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science

2013 Monitoring and Tracking Wet Nitrogen Deposition at Rocky Mountain National Park

July 2015

Natural Resource Report NPS/NRSS/ARD/NRR—2015/997

ON THIS PAGE
Aspen trees in Rocky Mountain National Park.
Credit: National Park Service photo.

ON THE COVER
View of the Colorado River from Holzwarth Historic Site on the west side of Rocky Mountain National Park. Credit: National Park Service photo by Emi Buck

2013 Monitoring and Tracking Wet Nitrogen Deposition at Rocky Mountain National Park

July 2015

Natural Resource Report NPS/NRSS/ARD/NRR—2015/997

Kristi Morris[1]

Alisa Mast[2]

Dave Clow[2]

Greg Wetherbee
U.S. Geological Survey, Branch of Quality Systems, NADP External QA Project

Jill Baron
U.S. Geological Survey, Colorado State University, Natural Resource Ecology Laboratory

Curt Taipale
Colorado Department of Public Health and Environment, Air Pollution Control Division

Tamara Blett[1]

David Gay
National Atmospheric Deposition Program Office, Program Coordinator

Daniel Bowker
Colorado State University, Natural Resource Ecology Laboratory

[1]National Park Service, Air Resources Division
[2]U.S. Geological Survey, Colorado Water Science Center

The National Park Service, Natural Resource Stewardship and Science office in Fort Collins, Colorado, publishes a range of reports that address natural resource topics. These reports are of interest and applicability to a broad audience in the National Park Service and others in natural resource management, including scientists, conservation and environmental constituencies, and the public.

The Natural Resource Report Series is used to disseminate comprehensive information and analysis about natural resources and related topics concerning lands managed by the National Park Service. The series supports the advancement of science, informed decision-making, and the achievement of the National Park Service mission. The series also provides a forum for presenting more lengthy results that may not be accepted by publications with page limitations.

All manuscripts in the series receive the appropriate level of peer review to ensure that the information is scientifically credible, technically accurate, appropriately written for the intended audience, and designed and published in a professional manner.

This report received informal peer review by subject-matter experts who were not directly involved in the collection, analysis, or reporting of the data. Data presented in this report were collected and analyzed using methods based on established, peer-reviewed protocols, and were analyzed and interpreted within the guidelines of the protocols.

This report is available in digital format from Air Resources of the NPS website (http://www.nature.nps/air/), and the Natural Resource Publications Management website (http://www.nature.nps.gov/publications/nrpm/). To receive this report in a format optimized for screen readers, please email irma@nps.gov.

Please cite this publication as:

Morris, K., A. Mast, D. Clow, G. Wetherbee, J. Baron, C. Taipale, T. Blett, D. Gay, and D. Bowker. 2015. 2013 monitoring and tracking wet nitrogen deposition at Rocky Mountain National Park: June 2015. Natural Resource Report NPS/NRSS/ARD/NRR—2015/997. National Park Service, Fort Collins, Colorado.

NPS 121/129311, July 2015

Contents

Figures

Page

Tables

Page

Acknowledgments

The authors acknowledge Chris Lehmann, Mark Rhodes, Jim Cheatham, and Lisa Clarke Devore for their participation in numerous scientific discussions regarding the tracking of nitrogen deposition data. The authors also thank Tonnie Cummings, Amy Ludtke, Betty Palcsak, and Keith Lucey for their careful review of the report. Finally, the authors would like to thank Eric Richer for his years of work operating the monitoring site and volunteers that helped him. We also thank Kristi Gebhart for providing graphs, and Drew Bingham for providing the map.

1. Background Information on the Nitrogen Deposition Reduction Plan

In 2004, multiple agencies including the Colorado Department of Public Health and Environment (CDPHE), the National Park Service (NPS), and the U.S. Environmental Protection Agency (U.S. EPA) met to address the effects and trends of nitrogen deposition and related air quality issues at Rocky Mountain National Park (RMNP). These agencies signed a Memorandum of Understanding (MOU) to facilitate interagency coordination, calling the effort the "Rocky Mountain National Park Initiative." After much collaboration, the MOU agencies (CDPHE, NPS, and U.S. EPA) issued the Nitrogen Deposition Reduction Plan (NDRP) in 2007, which was endorsed by the three agencies and the Colorado Air Quality Control Commission (AQCC). The NDRP and other related documents are available on the CDPHE website: http://www.colorado.gov/cdphe/rmnpinitiative.

High elevation ecosystems at Rocky Mountain National Park are sensitive to atmospheric nitrogen deposition. Credit: National Park Service photo by Schonlau.

As part of the NDRP, the NPS adopted and the MOU agencies endorsed a wet deposition level of 1.5 kilograms of nitrogen per hectare per year (kg N/ha/yr) as a science-based threshold for identifying adverse ecosystem effects in RMNP. This threshold is based on decades of research and is the estimated "critical load" of wet nitrogen that can be utilized by sensitive ecosystems within RMNP before detrimental changes occur (Baron 2006). To achieve this threshold, referred to as the resource management goal, the MOU agencies have chosen a glidepath approach. This type of approach anticipates gradual improvement over time and is a commonly used regulatory structure for long-term, goal-oriented air quality planning.

The glidepath approach shown in figure 1 establishes the resource management goal for RMNP to be met over the course of 25 years. The baseline wet deposition at Loch Vale in RMNP was 3.0 kg N/ha/yr based on the 5-year rolling average annual data from 2002 to 2006. The first interim milestone was based on a reduction of wet nitrogen deposition from baseline conditions to 2.7 kg N/ha/yr in 2012. The next interim milestone is 2.4 kg N/ha/yr in 2017. Subsequent milestones will be assessed at 5-year intervals until the resource management goal of 1.5 kg N/ha/yr is achieved in the year 2032. The estimate for nitrogen deposition under natural pre-industrial conditions, 0.2 kg N/ha/yr also is shown in Figure 1 (Galloway et al. 1995 and 1996; Dentener 2001).

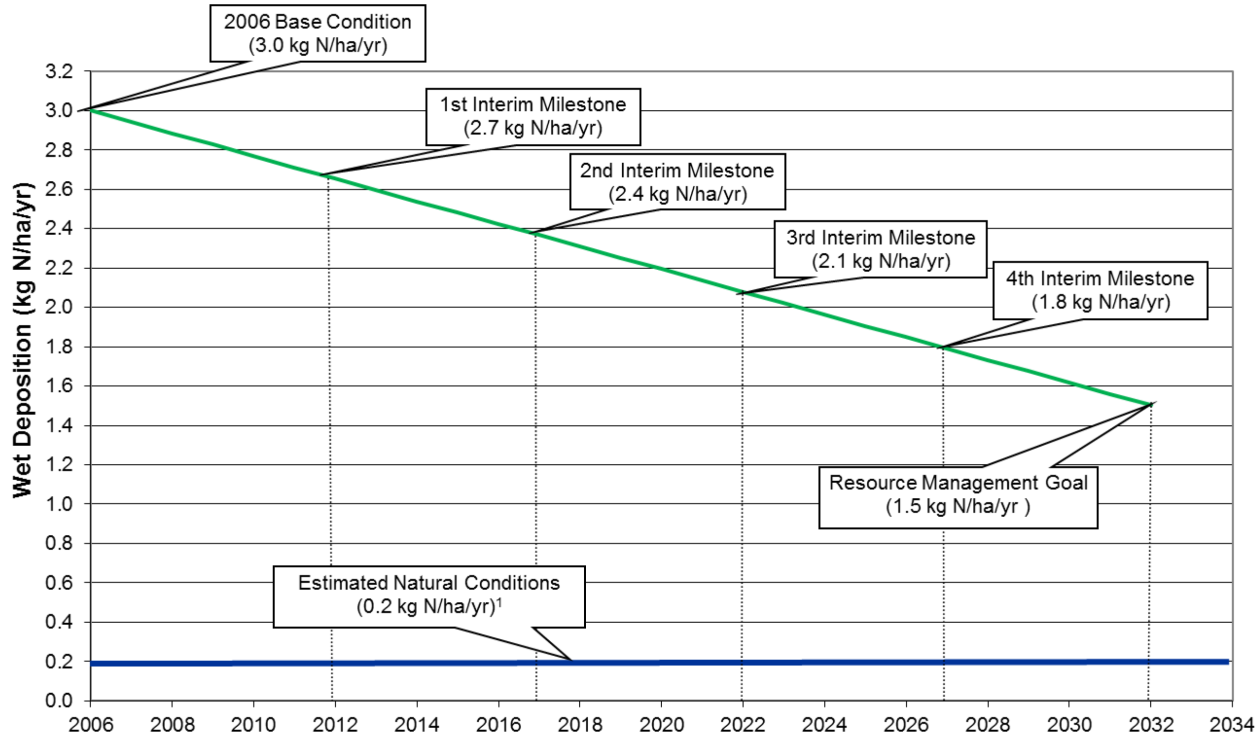

Figure 1. Nitrogen Deposition Reduction Plan glidepath. [1]Galloway et al. 1995 and 1996; Dentener 2001.

The Nitrogen Deposition Contingency Plan was developed to put corrective measures in place should the interim milestones not be achieved. A Nitrogen Deposition Data Tracking Plan was originally included as Appendix B of the Contingency Plan (https://www.colorado.gov/pacific/cdphe/nitrogen-reduction-contingency-plan). As part of the Tracking Plan, the MOU agencies report on wet deposition at the park and publish this peer-reviewed NPS report annually, independent of the Contingency Plan.

The MOU agencies meet by the fall of each year to discuss the latest analyses and determine if the Contingency Plan should be revised based on new information. In the years following the interim milestones (and within 180 days of issuance of the deposition data), the MOU agencies evaluate how nitrogen deposition has changed at RMNP and determine whether or not an interim milestone was achieved, and whether the Contingency Plan will be triggered, using the weight of evidence approach. The 2012 milestone of 2.7 kg/ha/yr was not met when wet deposition that year was recorded at 2.9 kg N/ha/yr. However, the MOU agencies agreed to not trigger the Contingency Plan due to the weight of evidence suggesting that wet nitrogen deposition at RMNP is no longer increasing and the anticipation of future emission reductions (See RMNP Initiative 2012 Milestone Report at https://www.colorado.gov/pacific/sites/default/files/AP_PO_RMNP-Initiative-2013-Milestone-Report.pdf). Should the weight of evidence suggest the 2017 milestone (2.4 kg N/ha/yr) cannot be achieved and there is greater departure from the glidepath and/or declining progress towards potential emission reductions, the MOU agencies may determine to trigger the Contingency Plan before the 2017 milestone evaluation.

2. Purpose

The purpose of this report is to inform the MOU agencies, stakeholders, and the public about the status and trends of wet nitrogen deposition at RMNP through 2013. In addition to other types of evidence, the MOU agencies use the information provided in this annual report to determine interim milestone achievements.

Wet deposition collectors at Loch Vale in Rocky Mountain NP.

3. Monitoring Wet Nitrogen Deposition

The resource management goal and interim milestones identified in the NDRP are based on wet nitrogen[1] deposition from nitrate and ammonium measurements at the Loch Vale site in RMNP. Monitoring data are collected through the National Atmospheric Deposition Program/National Trends Network (NADP/NTN). The NADP/NTN is a nationwide precipitation chemistry monitoring network and a cooperative effort among many different groups, including the U.S. Geological Survey, U.S. EPA, NPS, U.S. Department of Agriculture-National Institute of Food and Agriculture, State Agricultural Experiment Stations, National Oceanic and Atmospheric Administration, U.S. Fish and Wildlife Service, Bureau of Land Management, numerous universities, and other governmental and private entities. The NADP/NTN began monitoring in 1978 with 22 sites but grew rapidly in the early 1980s. Much of the expansion occurred during the implementation of monitoring under the National Acid Precipitation Assessment Program. Today, the network has over 250 sites spanning the continental U.S., Alaska, Puerto Rico, the U.S. Virgin Islands, and one site in Argentina.

The purpose of the network is to monitor geographical patterns for long-term trends in precipitation chemistry. Precipitation samples at each site are collected weekly and analyzed for pH, specific conductance, and sulfate, nitrate, ammonium, chloride, calcium, magnesium, potassium, and sodium concentrations by the NADP Central Analytical Laboratory in Champaign, Illinois. Each monitoring site consists of a precipitation collector and a precipitation gage. Quality assurance programs prescribe stringent quality control measures to monitor and enhance data accuracy and precision. Annual data are available on the NADP website approximately six months after completion of the

[1] The nitrogen measured by NADP/NTN is inorganic reactive nitrogen (from ammonium + nitrate), and all references to wet nitrogen deposition in this report refer to this portion of nitrogen deposition only.

calendar year. More information on these programs and the monitoring data can be found on the NADP website at http://nadp.isws.illinois.edu. NADP/NTN data are used widely in publications, including 233 peer-reviewed journal articles in 2014 (David Gay, NADP Program Office, personal communication, 2015). Data also are used extensively by the U.S. EPA to assess progress made by the Clean Air Act Acid Rain Program, which seeks to reduce the acidity of precipitation by reducing U.S. emissions of sulfur dioxide (SO_2) and nitrogen oxides (NO_X) (U.S. EPA 2011 and 2012). NADP data also are the cornerstone of the "National Acid Precipitation Assessment Program Report to Congress 2011" (Burns et al. 2012) and are used to assess progress under the U.S.-Canada Air Quality Agreement (U.S. EPA 2010).

4. Monitoring Wet Nitrogen Deposition in Rocky Mountain National Park

There are currently (2015) three NADP/NTN sites in RMNP. The original site in the Loch Vale watershed (CO98) (at an elevation of 3,159 meters - 10,364 feet) has been in operation since 1983. Data from Loch Vale are the primary focus of the NDRP because the resource management goal of 1.5 kg N/ha/yr wet deposition is based on NADP/NTN data from this site (http://nadp.isws.illinois.edu/sites/siteinfo.asp?id=CO98&net+NTN). The resource management goal was set to protect the most sensitive resources in the park which are located at the highest elevations. Routine monitoring in a remote, high elevation area presents several challenges. The samples from Loch Vale are collected each week by a dedicated site operator who hikes or snowshoes 5 kilometers (approximately 3 miles) to the monitoring site year-round. Equipment malfunction and/or inadequate solar power supply during the harsh winter months sometimes result in missed samples. Many upgrades have been made to the site over the years to increase power production and storage and site communications. Appendix A provides a history of modifications made to the Loch Vale NADP monitoring site.

From 2009–2014, the MOU agencies funded a second co-located site at Loch Vale (CO89) to evaluate overall variability in the NADP/NTN measurements. Results of the co-located site comparison are included in the appendices of previous monitoring reports (Morris et al., 2012, 2013, 2014). A comprehensive report covering the 5 years of co-located monitoring is in preparation.

The Beaver Meadows NADP/NTN site (CO19) is located at a lower elevation of 2,490 meters (8,169 feet) and has been in operation since 1980. In the summer of 2012, a new NADP/NTN site was installed in RMNP on the west side of the Continental Divide at Kawaneeche Meadow (CO09) at an elevation of 2,633 meters (8,638 feet). Annual wet N deposition at CO09 in 2013 was 1.88 kg N/ha/yr, which is much less than what is typically recorded at Loch Vale and Beaver Meadows on the east side of the Continental Divide. Once there are sufficient data (5 or more years) from this site, it will be included in the trends analyses.

5. Tracking Wet Nitrogen Deposition at Rocky Mountain National Park

The interim milestones in the NDRP are based on a 5-year rolling average of the annual wet nitrogen deposition data from the original Loch Vale NADP/NTN site in RMNP. As mentioned previously, the first interim milestone of the NDRP that called for the 5-year rolling average of wet nitrogen deposition at RMNP to be reduced from the baseline loading of 3.0 kg N/ha/yr in 2006 to 2.7 kg N/ha/yr in 2012 was not met. The next interim milestone is 2.4 kg N/ha/yr in 2017.

Another goal of the NDRP is to "reverse the trend of increasing nitrogen deposition at the park." Because determination of success or failure of the NDRP is made using the weight of evidence approach, several analyses are used to track nitrogen deposition at RMNP. These analyses may be expanded as additional information becomes available; they currently include the following: (1) assessment of progress along the glidepath, (2) long-term (>25 years) trend analyses for RMNP and other regional sites, and (3) short-term (5 and 7 years) trend analyses for RMNP and other regional sites. Each section below describes the data analyses for results obtained through 2013.

5.1 Assessment of progress along the glidepath

This assessment compares current wet nitrogen deposition (calculated as the most recent 5-year average) at the original Loch Vale NADP/NTN site to the interim milestones on the NDRP glidepath. Annual wet nitrogen deposition is calculated by multiplying the annual precipitation-weighted mean nitrogen concentration by the annual amount of precipitation (see Appendix B for explanation of NADP/NTN terms and calculations). Therefore, deposition values are influenced by the amount of precipitation in any given year, with wet years often having greater deposition and dry years often having lesser deposition. The rolling 5-year average of wet nitrogen deposition smooths the inter-annual variability caused by annual variations in precipitation. Data were obtained from the NADP/NTN website and screened for data completeness (Morris et al. 2012).

Figure 2 shows the annual (1984–2013) and 5-year (1988–2013) rolling average of wet nitrogen deposition at the Loch Vale NADP/NTN site. Annual precipitation and average precipitation over the 1984–2013 period are also shown. The 5-year rolling average of wet nitrogen deposition increased in the 1990s. Annual nitrogen deposition was particularly low in 1987 and 1988, which is in part due to precipitation amounts that were well below average; 1988 had the second lowest precipitation on record for Loch Vale. However, nitrogen concentrations were also lower during these 2 years, and while there is no clear explanation, lower concentrations were also observed at other NADP sites in the region (Figure 4). Since 1994, the 5-year rolling average of nitrogen deposition has been relatively stable even as Loch Vale experienced an extended period of below average precipitation from 1998–2008 (Figure 2). Annual precipitation amounts from 2009–2011 were well above the long-term average (1984–2013). However, annual precipitation dropped from 130 cm (51.2 inches) in 2011 to 90 cm (35.4 inches) in 2012, which contributed to the lowest annual deposition recorded in two decades (2.5 kg N/ha/yr). In contrast, 2013 recorded the highest precipitation in the history of the site at 141 cm (55.5 inches). This contributed to the highest annual deposition recorded over the history of the site (4.6 kg N/ha/yr). Nitrogen concentrations were also high in 2013.

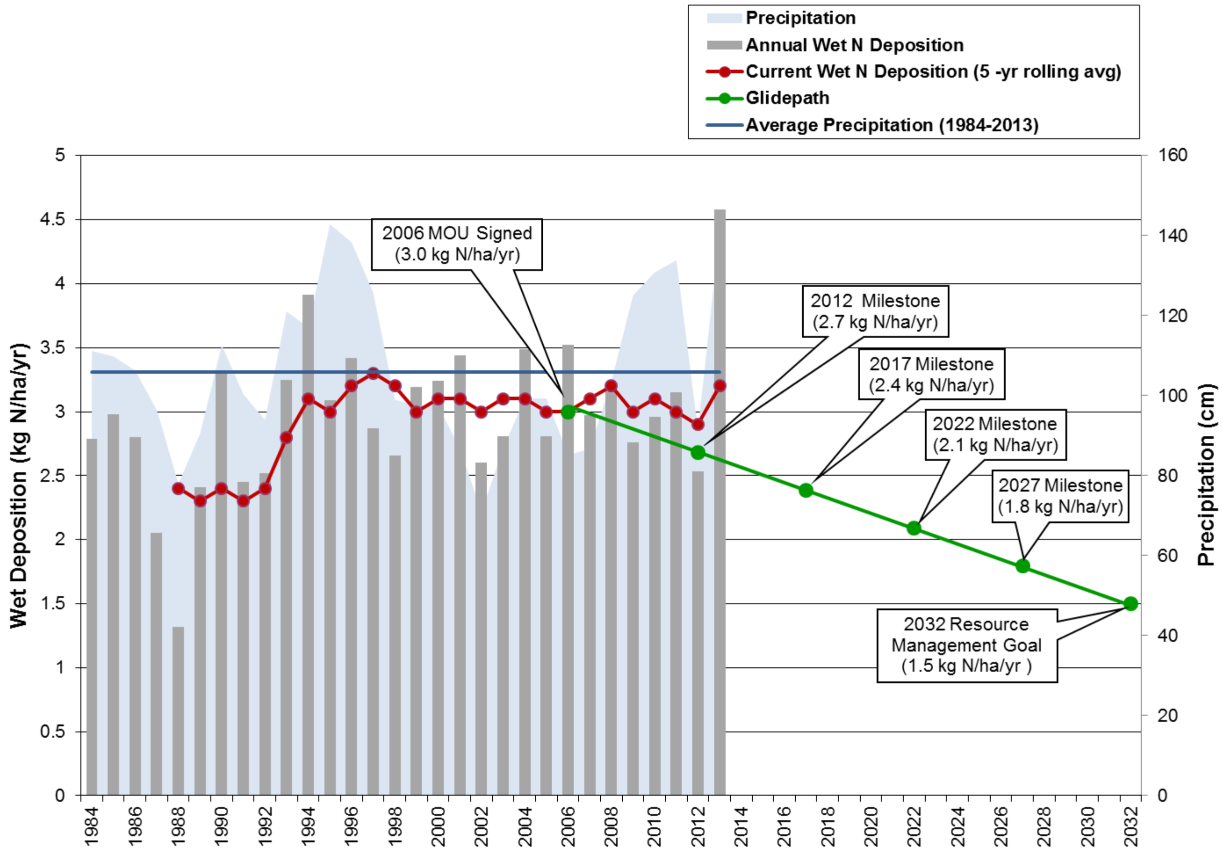

Figure 2. Wet nitrogen deposition and precipitation at Loch Vale in Rocky Mountain National Park compared to the Nitrogen Deposition Reduction Plan glidepath.

The glidepath model provides the foundation for the weight of evidence approach, and allows us to answer the question: **Is current wet nitrogen deposition in RMNP on or below the glidepath?** In 2013, the calculated 5-year average (2009–2013) of wet nitrogen deposition was 3.2 kg N/ha/yr, which is above the glidepath (Figure 2). Therefore, the answer to the question is: no, wet nitrogen deposition was not on or below the glidepath in 2013.

A USGS external quality assurance program has estimated variability in NADP/NTN measurements using co-located sites (duplicate sets of NADP/NTN instrumentation) within the NADP/NTN network since 1986 (Wetherbee et al. 2005). The USGS co-located sites are typically moved annually to test variability in different geographic areas. Only three of these sites have been located at high elevations in the western U.S. Results from the co-located site at Loch Vale will be used to estimate site-specific variability. As indicated previously, this analysis is in progress.

5.2 Long-term trend analyses for Rocky Mountain National Park and other regional sites

Changes in nitrogen in precipitation were evaluated over the 30-year period of record at the original Loch Vale site, which began operation in 1983. Statistical trends for several different parameters provide information on how nitrogen has changed over time and whether nitrogen inputs to RMNP ecosystems have increased, decreased, or remained unchanged. The parameters include wet nitrogen deposition (kg N/ha/yr), precipitation-weighted mean nitrate and ammonium concentrations in microequivalents per liter (µeq/L), and precipitation depth in centimeters (cm). Each parameter provides different information. Because ecosystems respond to nutrient deposition, trend analyses on deposition data provide ecological relevance to the resource management goal for RMNP. Meanwhile, trend analyses on concentrations provide information more closely coupled to air quality at individual sites and allow for comparison between sites.

In order to compare data from Loch Vale with other NADP/NTN sites exposed to similar Front Range emissions, the lower elevation site in the park (Beaver Meadows) and three sites located outside of the park are included in the analyses. These additional sites provide regional context and are listed in Table 1 and shown in Figure 3. The NADP/NTN sites at Niwot Saddle at 3,520 m (11,549 ft) and Sugarloaf at 2,524 m (8,281 ft) are located in the mountains 26.6 km (16.5 mi) and 36.2 km (22.5 mi) southeast of Loch Vale, respectively. The sites complement each other as paired monitoring sites with elevation differences similar to Loch Vale and Beaver Meadows. The NADP/NTN site at Pawnee is at a much lower elevation at 1,641 m (5,384 ft), located 96 km (59.7 mi) east of Loch Vale on the plains of eastern Colorado, near agricultural sources.

Table 1. NADP/NTN sites in and near Rocky Mountain National Park used in trends analyses.

Site Name	NADP/NTN Site ID	Period of Record	Elevation	Distance to Loch Vale
Loch Vale (RMNP)	CO98	30 yrs	3,159 m (10,364 ft)	-
Beaver Meadows (RMNP)	CO19	33 yrs	2,490 m (8,169 ft)	11 km (6.8 mi)
Niwot Saddle	CO02	29 yrs	3,520 m (11,549 ft)	26.6 km (16.5 mi)
Sugarloaf	CO94	27 yrs	2,524 m (8,281 ft)	36.2 km (22.5 mi)
Pawnee	CO22	34 yrs	1,641 m (5,384 ft)	96 km (59.7 mi)

Figures 4a–e show annual data for the period of record at each of the five sites for deposition, concentration, and precipitation. The Y-axes for each graph are different for each site in order to best show patterns over time. Precipitation amount varied substantially among these five Front Range sites over the periods of record, which range from 27–34 years. The higher elevation sites record much more precipitation than their lower elevation counterparts. Pawnee (at the lowest elevation) records the least amount of precipitation. It was a wet year for the Colorado Front Range in 2013, including a large snow event in April and precipitation events which preceded the September floods. All sites had a large increase in precipitation in 2013, except Niwot Saddle, where electrical issues with the rain gage for 5 weeks in April resulted in an underestimation of annual precipitation. Figure 5 shows that the April snow event resulted in more deposition at Loch Vale than the September rain due to higher spring-time concentrations.

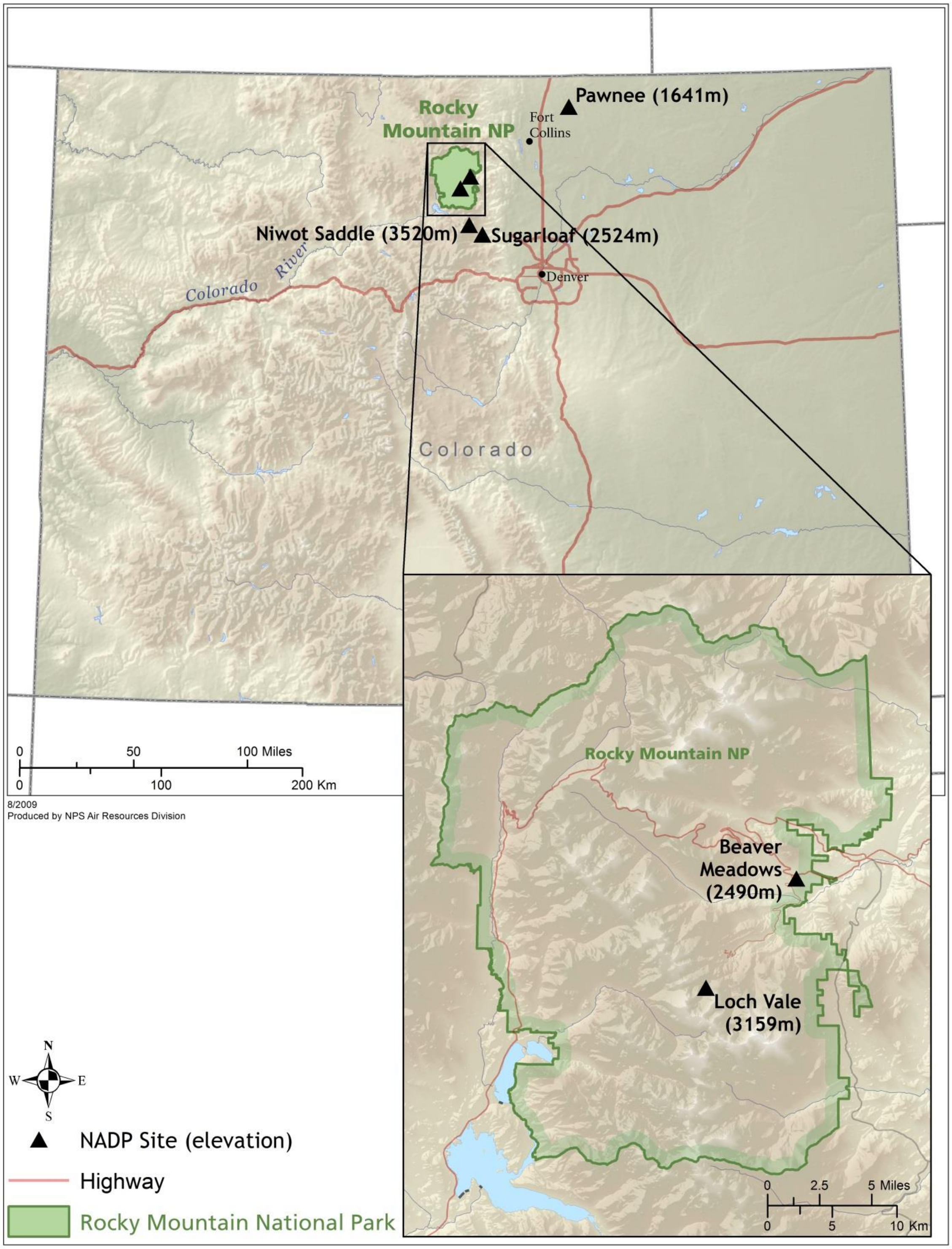

Figure 3. Map of NADP/NTN sites in and near Rocky Mountain National Park used in trends analysis. Elevation is shown in meters (m) in parentheses.

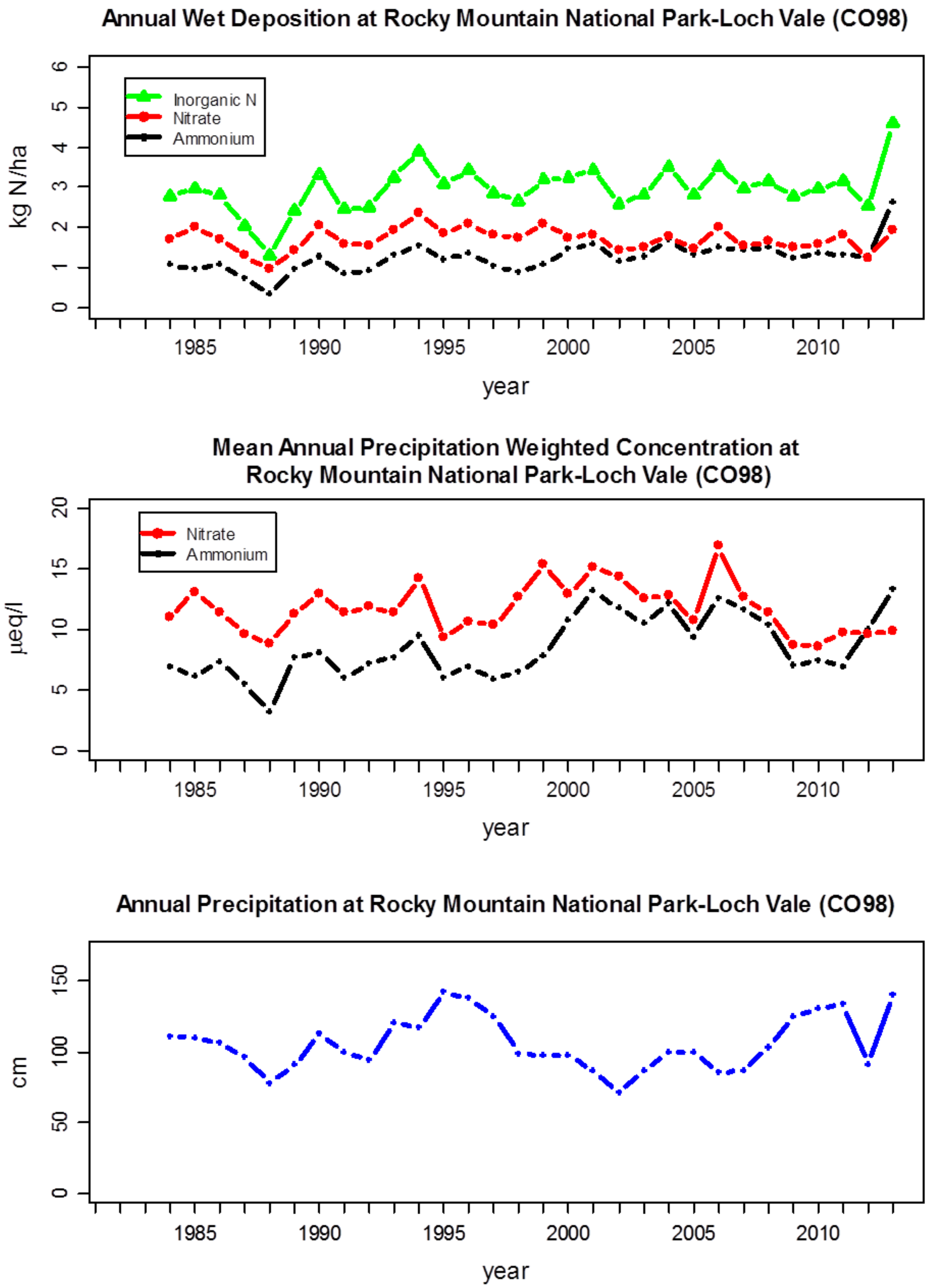

Figure 4a.Annual wet deposition, concentrations, and precipitation for RMNP – Loch Vale.

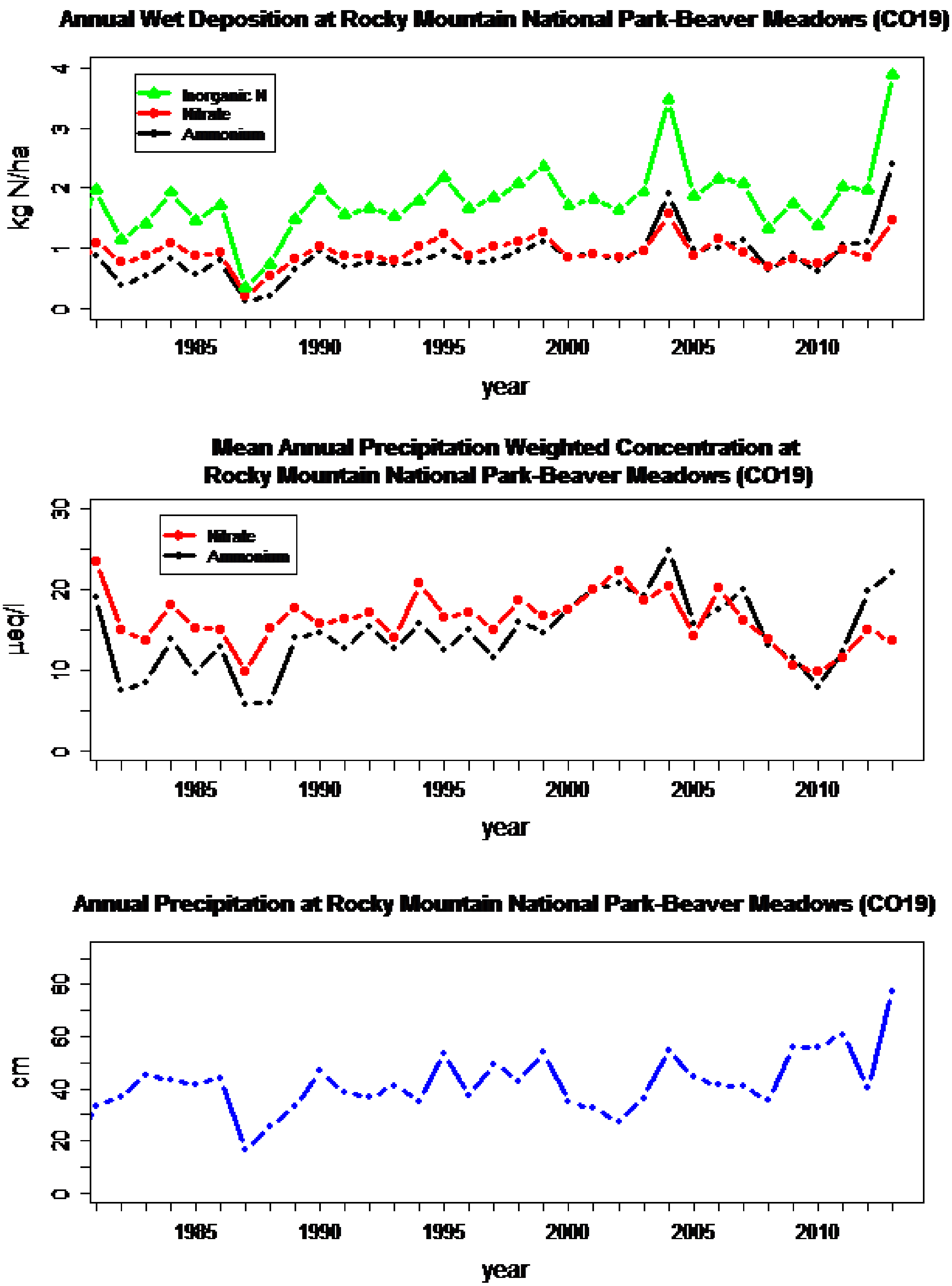

Figure 4b. Annual wet deposition, concentrations, and precipitation for RMNP – Beaver Meadows.

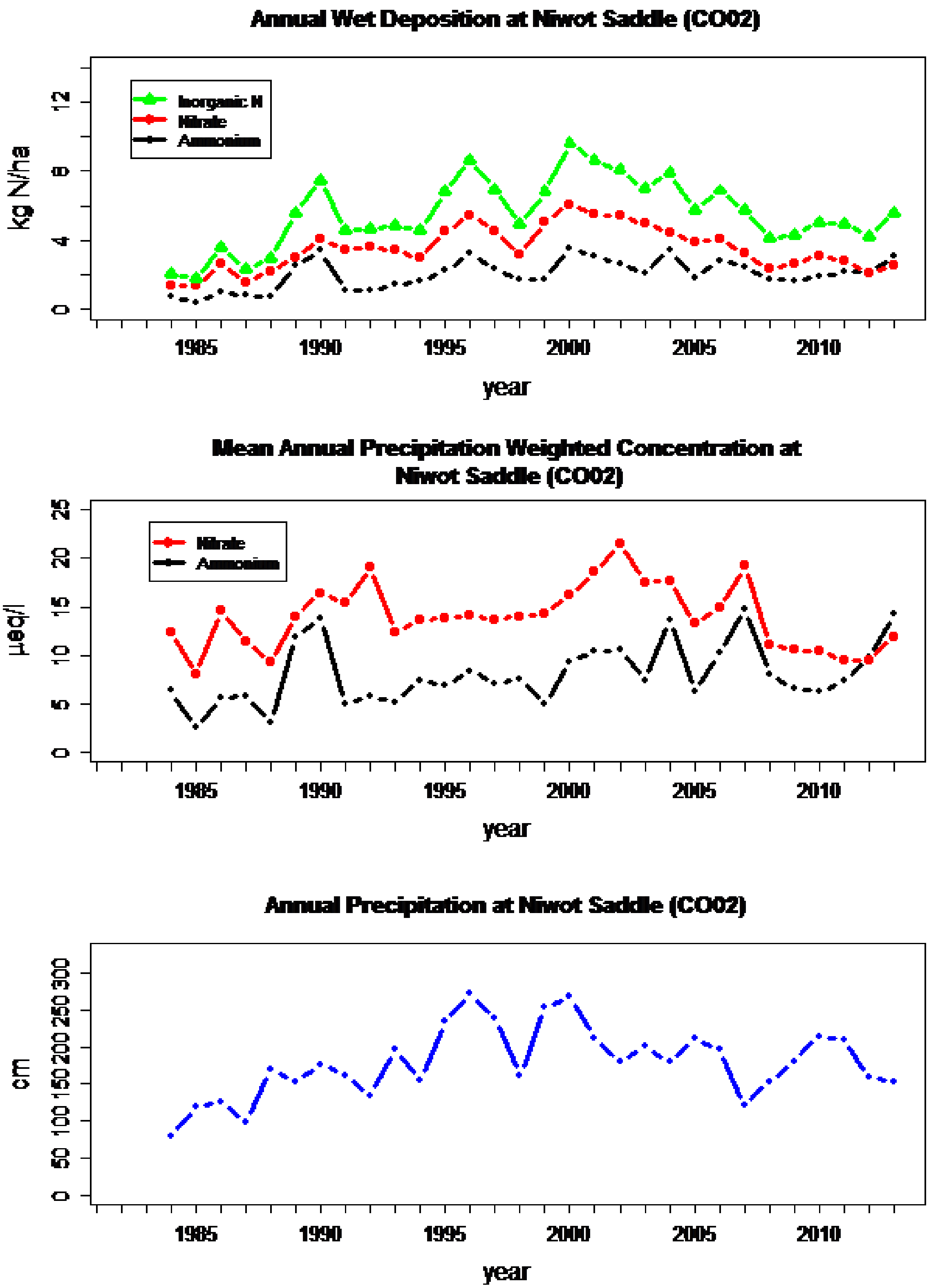

Figure 4c. Annual wet deposition, concentrations, and precipitation for Niwot Saddle.

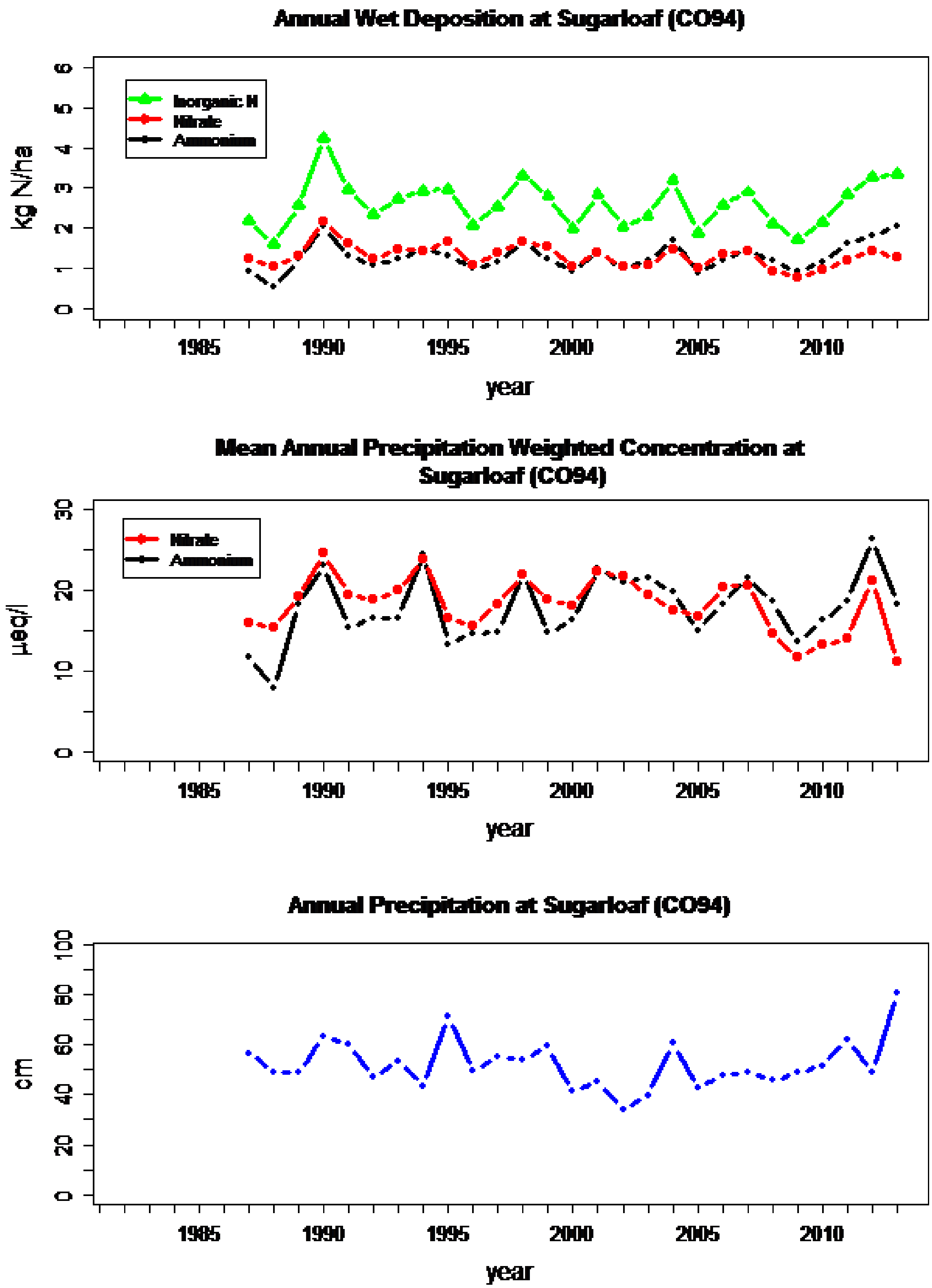

Figure 4d. Annual wet deposition, concentrations, and precipitation for Sugarloaf.

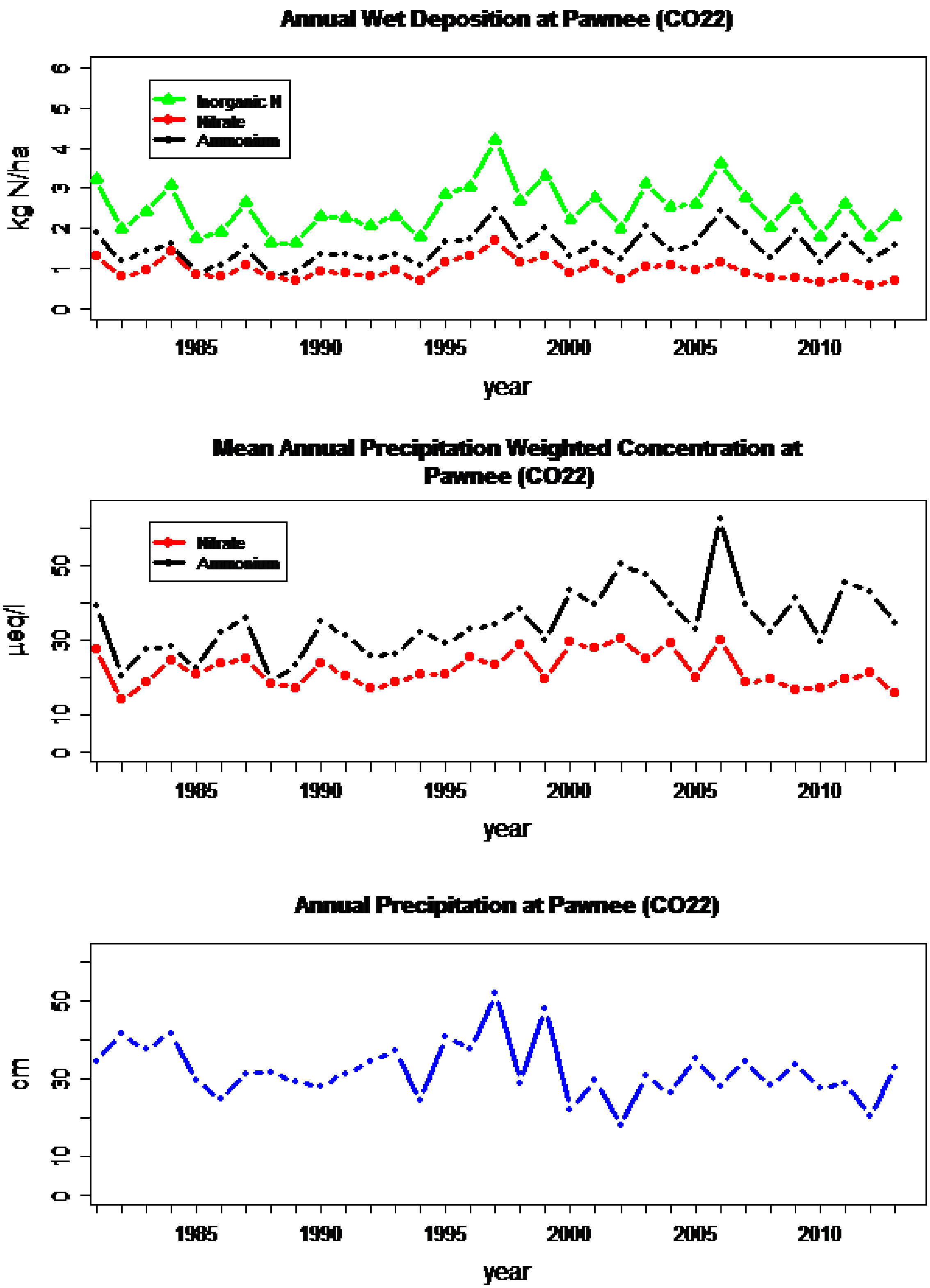

Figure 4e. Annual wet deposition, concentrations, and precipitation for Pawnee.

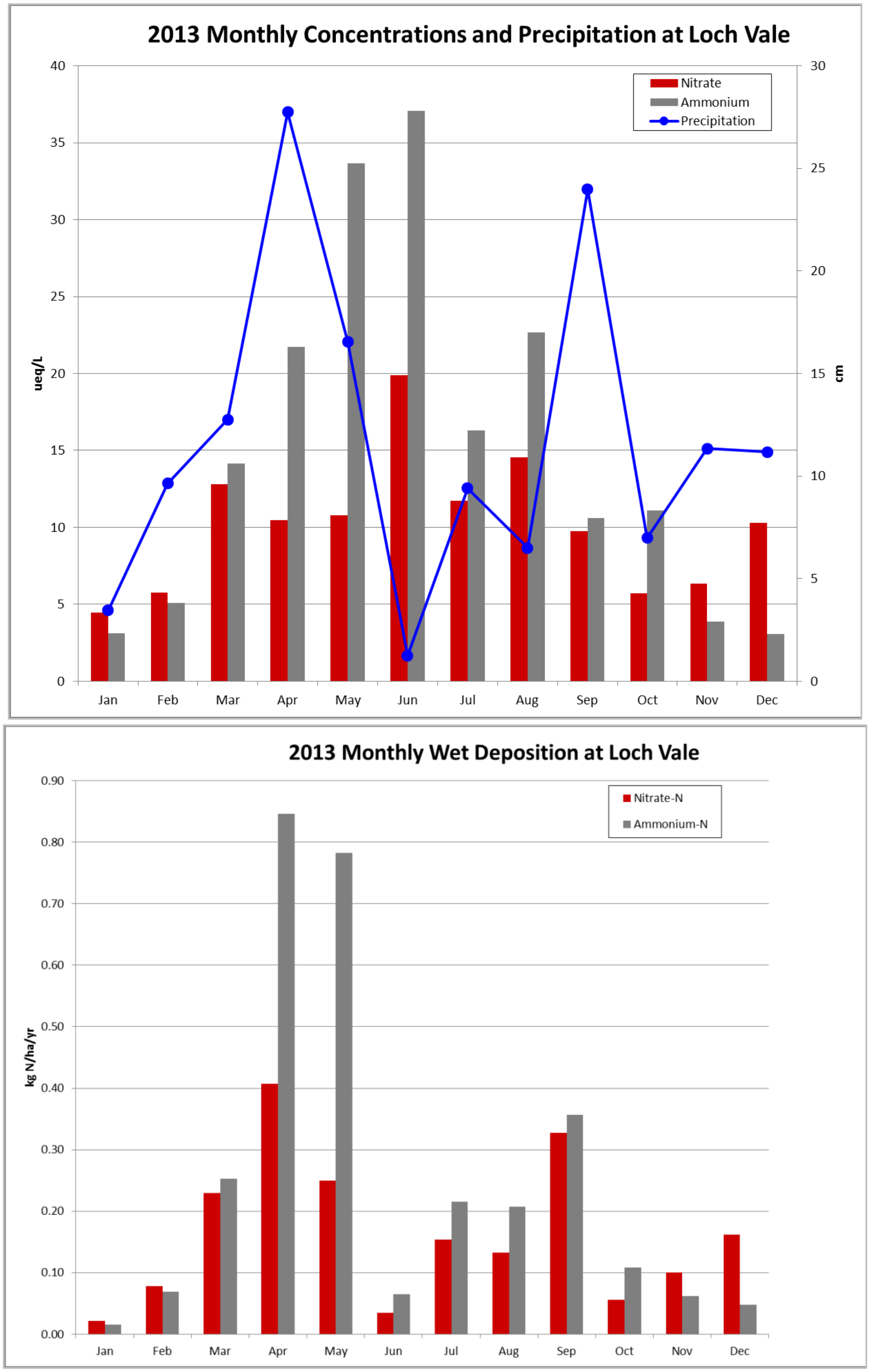

Figure 5. 2013 monthly data at Loch Vale; nitrate and ammonium concentrations and precipitation amount (top), nitrate-nitrogen and ammonium-nitrogen deposition (bottom).

Wet nitrogen deposition generally ranged from 1.0 to 6.0 kg N/ha/yr at the Front Range sites in 2013. This is the general range over the period of record as well, with the exception of Niwot Saddle, where deposition has often been above 6.0 kg N/ha/yr. Niwot Saddle is the only site included in this analysis that is located above treeline, where blowing snow has caused an over-estimation of deposition (Williams et al. 1998). Nitrate deposition was higher than ammonium deposition at Loch Vale until 2000 when contributions of ammonium and nitrate to nitrogen deposition became approximately equal. In 2013, ammonium deposition exceeded nitrate deposition at all five sites for the first time. However, at the Pawnee site, ammonium deposition has always been higher than nitrate deposition.

Concentrations were generally lower at the high elevation sites, where precipitation amount was greater. Through 2012, nitrate concentrations generally exceeded ammonium concentrations at all sites except Pawnee. In 2013, ammonium concentrations exceeded nitrate concentrations at all sites for the first time in the period of record.

Table 2 shows results from the trend analyses for the entire period of record. Trends were computed using a computer code available through the U.S. Geological Survey (USGS) for the Kendall family of trend tests (Helsel and Frans 2006, http://pubs.usgs.gov/sir/2005/5275/pdf/sir2005-5275.pdf). Trends in deposition and precipitation were run on annual data using the Mann-Kendall test. Trends in precipitation-weighted mean concentrations were run with seasonal (quarterly) data using the seasonal Kendall test. Trends were evaluated for statistical significance at the 95 percent confidence level (p-value $\leq$ 0.05). The seasonal Kendall test is a non-parametric statistical test that is capable of detecting trends in data sets that have strong seasonality, missing data, and non-normal data distribution. The test has become one of the most frequently used to determine trends in environmental data (Helsel et al. 2006). Examples of the use of the seasonal Kendall test to determine trends in atmospheric deposition data include Lehmann et al. (2005, 2011) and Ingersoll et al. (2008). Appendix C contains a detailed description of the methods used for trends analysis in this report.

Wet nitrogen deposition showed a statistically significant trend at only one site, where it was increasing at Beaver Meadows over the period of record (p-value=0.016). Precipitation amount also significantly increased at Beaver Meadows (p-value =0.034). Precipitation-weighted mean ammonium concentrations increased significantly over the period of record at four of the five Front Range sites including Loch Vale, Beaver Meadows, Niwot Saddle, and Pawnee (p-values $\leq$ 0.008). Precipitation-weighted mean nitrate concentrations decreased significantly at Sugar Loaf over the period of record (p-value $\leq$ 0.043).

Table 2. Results from long-term trends over the periods of record (through 2013). Significant trends were determined at the 95 percent confidence level (p-value ≤ 0.05).

Wet Nitrogen Deposition				
Site Name	*Start Year*	*Trend (kg N/ha/yr)*	*P-value*	*Significant Trends*
Loch Vale	1984	0.02	0.084	no trend
Beaver Meadows	1981	0.02	0.016	increasing
Niwot Saddle	1985	<0.01	0.870	no trend
Sugarloaf	1987	<0.01	0.803	no trend
Pawnee	1980	<0.01	0.882	no trend
Ammonium Precipitation-weighted Mean Concentrations				
Site Name	*Start Year*	*Trend (μeq/L/yr)*	*P-value*	*Significant Trends*
Loch Vale	1984	0.15	0.001	increasing
Beaver Meadows	1981	0.22	0.001	increasing
Niwot Saddle	1985	0.14	0.008	increasing
Sugarloaf	1987	0.15	0.051	no trend
Pawnee	1980	0.45	0.001	increasing
Nitrate Precipitation-weighted Mean Concentrations				
Site Name	*Start Year*	*Trend (μeq/L/yr)*	*P-value*	*Significant Trends*
Loch Vale	1984	<-0.01	0.820	no trend
Beaver Meadows	1981	-0.07	0.150	no trend
Niwot Saddle	1985	-0.02	0.809	no trend
Sugarloaf	1987	-0.16	0.043	decreasing
Pawnee	1980	-0.06	0.438	no trend
Precipitation				
Site Name	*Start Year*	*Trend (cm/yr)*	*P-value*	*Significant Trends*
Loch Vale	1984	0.16	0.831	no trend
Beaver Meadows	1981	0.46	0.034	increasing
Niwot Saddle	1985	1.15	0.353	no trend
Sugarloaf	1987	-0.05	0.868	no trend
Pawnee	1980	-0.18	0.075	no trend

The analysis of long-term trends allows us to answer the question: **Has nitrogen deposition decreased at RMNP and other sites in the region?** A significant increasing trend in wet nitrogen deposition at Loch Vale in RMNP was reported for 1984–2000 (p-value < 0.05) (Burns 2003). According to our analysis, the trend in wet nitrogen deposition at Loch Vale is no longer increasing, indicating progress toward NDRP goals. However, a significant increase in wet nitrogen deposition at Beaver Meadows in RMNP was reported for 1981–2013 (p-value=0.016). Increasing ammonium concentrations were also detected at four of the five sites.

Long-term trends at Loch Vale were in general consistent with trends at other Front Range sites, indicating that data from Loch Vale are not unique. Therefore, the answer to the question posed above is: nitrogen deposition has not decreased at Loch Vale in RMNP or other sites in the region over the long-term. In fact, nitrogen deposition significantly increased at Beaver Meadows in RMNP.

5.3 Short-term trend analyses for Rocky Mountain National Park and other regional sites

While long-term trends are more robust, trends in nitrogen deposition and concentrations over a more recent period of time are more relevant to recent changes in emissions. Determining significance of trends on shorter-time periods is more difficult because fewer data are used in the analysis. Due to this, trend analyses were evaluated using two time periods covering the last 5 (2009–2013) and 7 (2007–2013) years. Table 3 shows the results of the trend analysis for the individual sites, wherein statistically significant trends (p-value ≤ 0.05) are identified.

Table 3. Trend results for 5 year (2009–2013) and 7 year (2007–2013) time periods. Significant trends were determined at the 95 percent confidence level (p-value ≤ 0.05).

Wet Nitrogen Deposition						
Site Name	**5 year**			7 year		
	Trend (kg N/ha/yr)	*P-value*	*Significant Trends*	*Trend (kg N/ha/yr)*	*P-value*	*Significant Trends*
Loch Vale	0.20	0.462	no trend	0.05	1.000	no trend
Beaver Meadows	0.42	0.221	no trend	0.16	0.368	no trend
Niwot Saddle	0.25	0.807	no trend	0.04	1.000	no trend
Sugarloaf	0.42	0.028	increasing	0.24	0.133	no trend
Pawnee	-0.08	0.613	no trend	-0.06	0.288	no trend
Ammonium Precipitation-weighted Mean Concentrations						
Site Name	**5 year**			7 year		
	Trend (kg N/ha/yr)	*P-value*	*Trend (kg N/ha/yr)*	*P-value*	*Trend (kg N/ha/yr)*	*P-value*
Loch Vale	0.95	0.014	increasing	0.22	0.497	no trend
Beaver Meadows	2.14	0.020	increasing	0.55	0.329	no trend
Niwot Saddle	2.23	0.006	increasing	0.32	0.636	no trend
Sugarloaf	1.62	0.066	no trend	0.25	0.599	no trend
Pawnee	1.15	0.391	no trend	0.55	0.707	no trend

Table 3. (continued).

Nitrate Precipitation-weighted Mean Concentrations						
Site Name	**5 year**			7 year		
	Trend (kg N/ha/yr)	*P-value*	*Trend (kg N/ha/yr)*	*P-value*	*Trend (kg N/ha/yr)*	*P-value*
Loch Vale	0.43	0.270	no trend	-0.39	0.202	no trend
Beaver Meadows	0.99	0.178	no trend	0.07	0.822	no trend
Niwot Saddle	0.74	0.896	no trend	-0.52	0.098	no trend
Sugarloaf	0.31	0.270	no trend	-0.79	0.154	no trend
Pawnee	0.33	0.540	no trend	-0.04	0.822	no trend
Precipitation						
Site Name	**5 year**			7 year		
	Trend (kg N/ha/yr)	*P-value*	*Trend (kg N/ha/yr)*	*P-value*	*Trend (kg N/ha/yr)*	*P-value*
Loch Vale	3.07	0.462	no trend	5.79	0.072	no trend
Beaver Meadows	3.72	0.462	no trend	5.06	0.133	no trend
Niwot Saddle	-7.16	0.221	no trend	5.40	0.764	no trend
Sugarloaf	7.27	0.221	no trend	3.15	0.072	no trend
Pawnee	-1.30	0.807	no trend	-0.38	0.368	no trend

Wet nitrogen deposition significantly increased at Sugarloaf over the past 5 years (p-value=0.028). Precipitation-weighted mean ammonium concentrations increased at three of the five sites over the past 5 years, including Loch Vale, Beaver Meadows, and Niwot Saddle (p-values $\leq$ 0.020). This is the first time that significantly increasing trends in ammonium have been documented over the short-term. Previous reports documented significant decreases in nitrate concentrations at two to four sites (National Park Service, Air Resources Division 2011; Morris et al. 2012, 2013, 2014). However, with the addition of 2013 data and the exclusion of 2006 (a high concentration year), there are no significant trends. The analysis of short-term trends allows us to answer the question: **Has nitrogen deposition recently decreased at RMNP and at other sites in the region?** Results indicate that nitrogen deposition has not decreased at RMNP in the last 5 to 7 years.

6. Summary

Achievement of the goals of the NDRP will be determined by the weight of evidence. Results from the three analyses provided in this report are summarized below:

1. Is current wet nitrogen deposition in RMNP on or below the NDRP glidepath?
Wet nitrogen deposition (5-year rolling average) at Loch Vale in RMNP in 2013 was 3.2 kg N/ha/yr, which is above the glidepath.

2. Has wet nitrogen deposition decreased at RMNP and other sites in the region?
Wet nitrogen deposition has not decreased at RMNP or other sites in the region over the long-term. Over the entire period of record, wet nitrogen deposition showed no significant trend at Loch Vale in RMNP (1984-2013). A previously reported significant increase in wet nitrogen deposition at Loch Vale in RMNP for 1984–2009 is no longer significant, indicating some progress toward NDRP goals. Data from Beaver Meadows in RMNP, however, indicate an increase in wet nitrogen deposition and precipitation for the period of record (1981-2013). Over the long term, ammonium concentrations showed a statistically significant increasing trend at four of the five sites (Loch Vale, Beaver Meadows, Niwot Saddle, and Pawnee) and nitrate concentrations showed a significant decreasing trend at one site (Sugarloaf).

3. Has wet nitrogen deposition recently decreased at RMNP and at other sites in the region?
In more recent years (2007-2013), wet nitrogen deposition showed no significant trend at either the Loch Vale or Beaver Meadows monitoring sites in RMNP. However, there was a significant decrease in wet nitrogen deposition at Sugarloaf. Ammonium concentrations significantly increased at three of the five sites (Loch Vale, Beaver Meadows, and Niwot Saddle), while previous decreasing trends in nitrate concentrations were not detected.

References

Baron, J. S. 2006. Hindcasting nitrogen deposition to determine an ecological critical load. *Ecological Applications* 16(2): 433–439.

Burns, D. A. 2003. Atmospheric nitrogen deposition in the Rocky Mountains of Colorado and Southern Wyoming, USA – a review and new analysis of past study results. *Environmental Pollution* 37:921–932.

Burns, D. A., J. A. Lynch, B. J. Cosby, M. E. Fenn, J. S. Baron, US EPA Clean Air Markets Division. 2012. National Acid Precipitation Assessment Program Report to Congress 2011: An Integrated Assessment. National Science and Technology Council, Washington, DC, 114 p. Available on the Internet at http://ny.water.usgs.gov/projects/NAPAP.

Dentener, F. J. 2001. Personal communication with Tamara Blett, National Park Service. Globally modeled nitrogen maps for 1860.

Galloway, J. N., W. H. Schlesinger, H. Levy II, A. Michaels, J.L. Schnoor. 1995. Nitrogen fixation: Anthropogenic enhancement — environmental response. *Global Biogeochemical Cycles* 9(2): 235–252.

Galloway, J. N., W. C. Keene, G. E. Likens. 1996. Processes controlling the composition of precipitation at a remote Southern hemisphere location: Torres del Paine National Park, Chile. *Journal of Geophysical Research* 101(D3): 6883–6897.

Helsel, D. R. and L. M. Frans. 2006. Regional Kendall test for trend. *Environmental Science & Technology* 40(13): 4066–4073.

Helsel, D. R., D. K. Mueller, J. R. Slack. 2006. Computer program for the Kendall family of trend tests. U.S. Geological Survey Scientific Investigations Report 2005–5275, 4 pp. [http://pubs.usgs.gov/sir/2005/5275/pdf/sir2005-5275.pdf].

Ingersoll, G. P., M. A. Mast, D. H. Campbell, D. W. Clow, L. Nanus, J. T. Turk. 2008. Trends in snowpack chemistry and comparison to National Atmospheric Deposition Program results for the Rocky Mountains, U.S., 1993–2004. *Atmospheric Environment* 42: 6098–6113.

Lehmann, C. M. B., D. A. Gay. 2011. Monitoring long-term trends of acidic wet deposition in US precipitation: results from the National Atmospheric Deposition Program. *Power Plant Chemistry* 13(7): 386–393.

Lehmann, C. M. B., V. C. Bowersox, S. M. Larson. 2005. Spatial and temporal trends of precipitation chemistry in the United States, 1985–2002. *Environmental Pollution* 135: 347–361.

Morris, K., A. Mast, D. Clow, G. Wetherbee, J. Baron, C. Taipale, T. Blett, D. Gay, and E. Richer. 2012. 2010 monitoring and tracking wet nitrogen deposition at Rocky Mountain National Park: August 2012. Natural Resource Report NPS/NRSS/ARD/NRR—2012/562. National Park Service, Denver, Colorado.

Morris, K., A. Mast, D. Clow, G. Wetherbee, J. Baron, C. Taipale, T. Blett, D. Gay, and J. Heath. 2013. 2011 monitoring and tracking wet nitrogen deposition at Rocky Mountain National Park: August 2013. Natural Resource Report NPS/NRSS/ARD/NRR—2013/701. National Park Service, Denver, Colorado.

Morris, K., A. Mast, D. Clow, G. Wetherbee, J. Baron, C. Taipale, T. Blett, D. Gay, and J. Heath. 2014. 2012 monitoring and tracking wet nitrogen deposition at Rocky Mountain National Park: January 2014. Natural Resource Report NPS/NRSS/ARD/NRR—2014/XXX. National Park Service, Denver, Colorado.

National Park Service, Air Resources Division. 2011. 2009 monitoring and tracking wet nitrogen deposition at Rocky Mountain National Park: September 2011, Natural Resource Report NPS/NRSS/ARD/NRR-2011/442. National Park Service, Denver, Colorado.

U. S. Environmental Protection Agency (U.S. EPA). 2012. 2010 Progress Report: Environmental and health results. Washington, DC: U.S. EPA. June. Available on the Internet at http://www.epa.gov/airmarkets/progress/ARPCAIR10.html.

U. S. Environmental Protection Agency (U.S. EPA). 2011. 2010 Progress Report: Emission, compliance, and market analyses. Washington, DC: U.S. EPA. August. Available on the Internet at http://www.epa.gov/airmarkets/progress/ARPCAIR10_01.html.

U. S. Environmental Protection Agency (U.S. EPA). 2010. United States – Canada Air Quality Agreement Progress Report 2012. EPA-430-R-10-011. Washington, DC: U.S. EPA. October. Available on the Internet at http://www.epa.gov/airmarkets/progsregs/usca/docs/2010report.pdf.

Wetherbee, G. A., N.E. Latysh, J. D. Gordon. 2005. Spatial and temporal variability of the overall error of National Atmospheric Deposition Program measurements determined by the USGS collocated-sampler program, water years 1989–2001. *Environmental Pollution* 135: 407–418.

Williams, M.W., T. Bardsley, M. Rikkers. 1998. Overestimation of snow depth and inorganic nitrogen wetfall using NADP data, Niwot Ridge, Colorado. *Atmospheric Environment* 32: 3827–3833.

Appendix A: History of the Loch Vale NADP/NTN Monitoring Site

The original Loch Vale NADP/NTN site (CO98) was established in the summer of 1983, when the Aerochem Metrics Model 301 precipitation collector and mechanical Belfort rain gage were installed. During the summer of 2007, a newly approved electronic rain gage (ETI NOAH IV) was installed. The original Belfort and the new NOAH IV rain gages operated side-by-side for two years (2008 and 2009). Differences in recorded precipitation (approximately 5 percent) were negligible (National Park Service, Air Resources Division 2011; Richer and Baron 2011).

A second and temporary co-located NADP/NTN site (CO89) was installed at Loch Vale in the fall of 2009 for quality assurance assessments. The co-located sites operated side-by-side for five complete water years (2009-2014). During these years, this site consisted of two independent precipitation collectors and NOAH IV rain gages with satellite telemetry. The co-located gage was left in place in order to serve as a back-up, in the case the original rain gage is not operating.

The original Belfort rain gage was removed during the summer of 2010 and the co-located precipitation collector was removed during the fall of 2014 in an effort to keep the monitoring site footprint to a minimum in accordance with the park's wilderness policy. In fall 2011, the four solar panels were replaced with two higher efficiency, less-reflective panels and moved to a location of less snow accumulation.

Two ammonia passive samplers were installed in the park in the summer of 2011 as part of the NADP Ammonia Monitoring Network (AMoN); one at the Loch Vale NADP monitoring site (AMoN CO98) and one near the Long's Peak Ranger Station at the Clean Air Status and Trends Network (CASTNET) and Interagency Monitoring of Protected Visual Environments (IMPROVE) sites (AMoN CO88) at an elevation of 2,743 meters (8,999 feet). Data from these two sites are available at http://nadp.isws.illinois.edu/amon/. While the ammonia data are not included in the body of this report, they are shown in Appendix D due to the importance of ammonia gas to dry deposition and in order to show spatial patterns along the Front Range and within the park.

References

National Park Service, Air Resources Division. 2011. 2009 monitoring and tracking wet nitrogen deposition at Rocky Mountain National Park: September 2011, Natural Resource Report NPS/NRSS/ARD/NRR-2011/442. National Park Service, Denver, Colorado.

Richer, E. E. and J. S. Baron. 2011. Loch Vale Watershed long-term ecological research and monitoring program: Quality assurance report, 2003–09. U.S. Geological Survey Open-File Report 2011–1137, 22 p.

Table A-1. Loch Vale NADP/NTN monitoring site history.

Date	Event
Summer 1983	Site installed with precipitation collector and original Belfort rain gage (NADP/NTN site CO98).
Summer 2007	NOAH IV rain gage added (replaced Belfort rain gage once differences were documented).
Fall 2009	Co-located site (NADP/NTN site CO89) and telemetry installed, solar power and storage increased.
Summer 2010	Belfort rain gage removed.
Summer 2011	Passive ammonia samplers installed NADP/AMoN (site CO98 and site CO88)
Fall 2011	Solar panels replaced and relocated.
Fall 2014	Co-located precipitation collector removed. (Co-located rain gage remains.)

Appendix B: Explanation of NADP/NTN terms and calculations

The NADP/NTN collects weekly precipitation samples and records daily precipitation depths. Concentrations of sulfate, nitrate, chloride, ammonium, and base cations are determined by laboratory analysis and reported in units of mg/L. Hydrogen ion is reported as pH. Valid weekly precipitation samples are aggregated into precipitation-weighted mean concentrations for monthly, seasonal, and annual time periods by using Equation (1).

$$\overline{C}_{ppt.wt} = \frac{\sum_{i=1}^{n}\left(C_{w,i} \times P_{w,i}\right)}{\sum_{i=1}^{n} P_{w,i}} \qquad \text{(Eq. 1)}$$

where:

$\overline{C}_{ppt.wt}$ = precipitation-weighted mean concentration, mg/L

$C_{w,i}$ = precipitation concentration for weekly sample, mg/L

$P_{w,i}$ = precipitation depth for weekly sample, cm

n = number of events

Precipitation-weighted mean concentrations are used in order to simulate having one composite sample over the time period of interest. For example, a precipitation-weighted mean concentration for one year (or month or season) is equivalent to adding all of the weekly samples together into one sample and then determining the concentrations of ions in that sample.

Table B-1. Example: sample concentration and precipitation amount.

Sample	Concentration	Precipitation Amount
1	15 mg/L	1 cm
2	5 mg/L	6 cm

A precipitation-weighted mean concentration is more representative of the average concentration of the majority of the precipitation. In the above example, the precipitation-weighted mean concentration is 6.43 mg/L [(15 x 1 + 5 x 6)/(1+6)] and is more heavily influenced by the larger precipitation event, whereas an arithmetic mean is 10 mg/L.

Precipitation concentrations can also be presented in terms of microequivalents per liter (µeq/L). An equivalent is defined as a mass of an element that can combine with 1 gram of hydrogen in a chemical reaction. It is a way of normalizing for ionic charge. Nitrate ion has one negative charge [NO3-] and ammonium has one positive charge [NH4+], once converted to µeq/L the ion concentrations can be compared to each other. Concentrations in mg/L are converted to µeq/L by using the factors listed in the following table.

Table B-2. Conversion factors for ion concentrations, mg/L to µeq/L.

Ion	Conversion Factor
Ammonium	1 mg/L = 55.4371 µeq/L
Nitrate	1 mg/L = 16.12776 µeq/L

Wet deposition is calculated by multiplying the precipitation-weighted mean concentration for a period of time by the total amount of precipitation during that time (Equation 2).

$$D_w = \overline{C}_{ppt.wt} \times P_{TOT} \times 10^{-1} \qquad \text{(Eq. 2)}$$

where:

D_w = wet deposition, kg/ha

$\overline{C}_{ppt.wt}$ = precipitation-weighted mean concentration, mg/L

P_{TOT} = total precipitation depth measured by the rain gage for period, cm

Note: 1 mm of precipitation depth over 1 square meter = 1 liter.

Nitrogen deposition is calculated by summing the nitrogen (N) from nitrate (NO_3^-) deposition and ammonium (NH_4^+) deposition as shown in Equation 3. The conversion factors in the equation represent the molecular weight ratios of N to NH_4 and NO_3, respectively.

$$D_{IN} = \left(D_{NH_4^+} \times \frac{14.01}{18.01} \right) + \left(D_{NO_3^-} \times \frac{14.01}{62.01} \right) \qquad \text{(Eq. 3)}$$

where:

D_{IN} = wet deposition of N, kg/ha

$D_{NH_4^+}$ = wet deposition of NH_4, kg/ha

D_{NO_3-} = wet deposition of NO_3, kg/ha

Appendix C: Methods of Testing Trends in NADP Precipitation Chemistry Data

By M. Alisa Mast, U.S. Geological Survey

The trends in precipitation chemistry for this report will be run once a year for the parameters and sites listed below using the trend methods described in this document. The Seasonal Kendall Test (SKT) was used to evaluate trends in ammonium and nitrate concentrations in precipitation, which is consistent with other publications on trends in precipitation chemistry (Lehmann 2005 and 2011). The SKT performs a Mann-Kendall Test (MKT) for individual seasons of the year, and then combines the results into one overall test. Increasing the number of samples by a factor of 4 seasons strengthens the statistical results. However, the MKT was used for trends in nitrogen (N) deposition and precipitation amount, because seasonality is incorporated within the annual value (i.e. the SKT and MKT produce identical results for data sets with one season or annual data).

The SKT and MKT tests can be run using a computer code available from the USGS (Helsel et al. 2006). The computer code (Kendall.exe) and example files can be downloaded at http://pubs.usgs.gov/sir/2005/5275/downloads/.

A report describing the trend program is available at http://pubs.usgs.gov/sir/2005/5275/pdf/sir2005-5275.pdf.

NADP sites

- CO98 - Loch Vale
- CO19 - Beaver Meadows
- CO02 - Niwot Saddle
- CO94 - Sugarloaf
- CO22 - Pawnee

Parameters

- Seasonal precipitation-weighted mean NH_4^+ concentrations in µeq/L/yr (winter, spring, summer, fall)
- Seasonal precipitation-weighted mean NO_3^- concentrations in µeq/L/yr (winter, spring, summer, fall)
- Annual inorganic nitrogen deposition in kg N/ha/yr
- Annual precipitation amount in cm

Time frame

- Period of Record (POR)
- 5 year
- 7 year

Trend Tests

- Seasonal Kendall Test (SKT) for seasonal concentrations (NH_4 and NO_3)
- Mann Kendall Test (MKT) for annual inorganic nitrogen deposition and precipitation amount

Procedure

1. Retrieve Data

Annual and seasonal precipitation chemistry data can be retrieved from the National Atmospheric Deposition Program (NADP) web site at http://nadp.isws.illinois.edu/NTN/ntnData.aspx. Use "Custom Site List" to create a list and pull data for the 5 stations of interest (CO98, CO19, CO02, CO94, and CO22).

Retrieve seasonal data (winter, spring, summer, fall) for precipitation-weighted mean concentrations (in μeq/L) and annual data for deposition (in kg/ha/yr) and precipitation amount (in cm) based on calendar years (January to December). The seasonal and annual averages are computed by NADP using only valid samples. The winter seasonal data include the months of December, January, and February. Spring includes March, April, and May. Summer includes June, July, and August. Fall includes September, October, and November.

Pull data for the entire period of record in tab or comma delimited format and import into Excel or Access for further file formatting. In order to run the program you must remove all -9s from the file and replace with empty cells. Remove the first year of data from each station if it is incomplete (most stations began operation in the summer or fall months so the first year represents a partial year of data). Include all seasons and years when the NADP completeness criterion 2 is ≥ 90 percent (Morris et al. 2012).

2. Trend Calculations

This section describes how to set up input files and run the Seasonal Kendall test (SKT) and Mann-Kendall test (MKT) using the NADP data. Annual data (one season per year) tested with the SKT yields the same result as a MKT. Therefore both seasonal and annual results can be tested using the method outlined below.

The first line of each input file should follow this format:

2 0 NH_4 Concentrations Station CO02

It is important to have "2" in column 1 of line 1 and "0" in column 3 of line 1. A description can be added starting in column 9. The next lines of the file contain the data with Year in the first column, Season (winter = 1, spring = 2, summer = 3, fall = 4) in the second column and the Value (e.g. concentration) in the third column. The final files will be space delimited and should look something like the examples below. For annual deposition and precipitation data, set the season equal to 1 for all years. Delete any lines with missing values.

Example input file for seasonal data from station CO02:

```
2 0     NH4 Concentrations Station CO02

1980 1 3.71

1980 2 7.37
```

1980 3 16.85

1980 4 17.02

1981 1 4.21

1981 2 19.84

1981 3 26.22

1981 4 9.48

1982 1 5.76

1982 2 13.80

1982 3 14.85

1982 4 6.59

1983 1 3.27

1983 2 10.25

1983 3 8.87

1983 4 6.59

-----continued-----

To compute a trend, copy the “Kendall.exe” file into the directory that contains the input file. Double click on the Kendall.exe icon to start the program. Enter the input file name (e.g. NH4CO22.txt) and provide a name for the output file to which the results are written (e.g. NH4CO22out.txt).

An example of an output file is shown below. In this example, the trend was 0.3930 µeq/L/yr with a p-value of 0.0089. Because the period of record was longer than 10 years the adjusted p-value should be reported. This adjustment corrects for serial correlation in the data set.

Example output file:

Seasonal Kendall Test for Trend

US Geological Survey, 2005

Data set: NH4 Station CO02

The record is 31 complete calendar years with 4 seasons per year beginning in year 1980.

The tau correlation coefficient is 0.219

S = 407.

z = 3.450

p = 0.0006

p = 0.0089 adjusted for correlation among seasons (such as serial dependence)

The adjusted p-value should be used only for data with more than 10 annual values per season.

The estimated trend may be described by the equation:

Y = 22.48 + 0.3930 * Time

where Time = Year (as a decimal) - 1979.75
(beginning of first water year)

References

Helsel, D. R., D. K. Mueller, J. R. Slack. 2006. Computer program for the Kendall family of trend tests. U.S. Geological Survey Scientific Investigations Report 2005–5275, 4 pp. Available at http://pubs.usgs.gov/sir/2005/5275/pdf/sir2005-5275.pdf.

Lehmann, C. M. B., V. C. Bowersox, S. M. Larson. 2005. Spatial and temporal trends of precipitation chemistry in the United States, 1985–2002. *Environmental Pollution* 135: 347–361.

Lehmann, C. M. B., D. A. Gay. 2011. Monitoring long-term trends of acidic wet deposition in US precipitation: results from the National Atmospheric Deposition Program. *Power Plant Chemistry* 13(7): 386–393.

Morris, K., A. Mast, D. Clow, G. Wetherbee, J. Baron, C. Taipale, T. Blett, D. Gay, and E. Richer. 2012. 2010 monitoring and tracking wet nitrogen deposition at Rocky Mountain National Park: August 2012. Natural Resource Report NPS/NRSS/ARD/NRR—2012/562.

Appendix D: NADP Ammonia Monitoring Network (AMoN) data

Ammonia monitors were installed at two locations in RMNP in the summer of 2011 as part of the NADP Ammonia Monitoring Network (AMoN); one at the Loch Vale NADP monitoring site (AMoN CO98) at 3,159 meters (10,364 feet) and one near the Long's Peak Ranger Station (AMoN CO88) at a lower elevation of 2,743 meters (8,999 feet). Data are available at http://nadp.isws.illinois.edu/amon/ and are presented here for 2012–2013.

Figure D-1 compares ammonia concentrations at the RMNP sites versus the AMoN site in Fort Collins (AMoN CO13) at 1,570 meters (5,150 feet). Concentrations of ammonia are much higher at the Fort Collins site ranging mostly from 2-10 μg/m^3 during 2012 and 2013, while the RMNP sites recorded ammonia concentrations that were less than 1.5 μg/m^3 throughout the year.

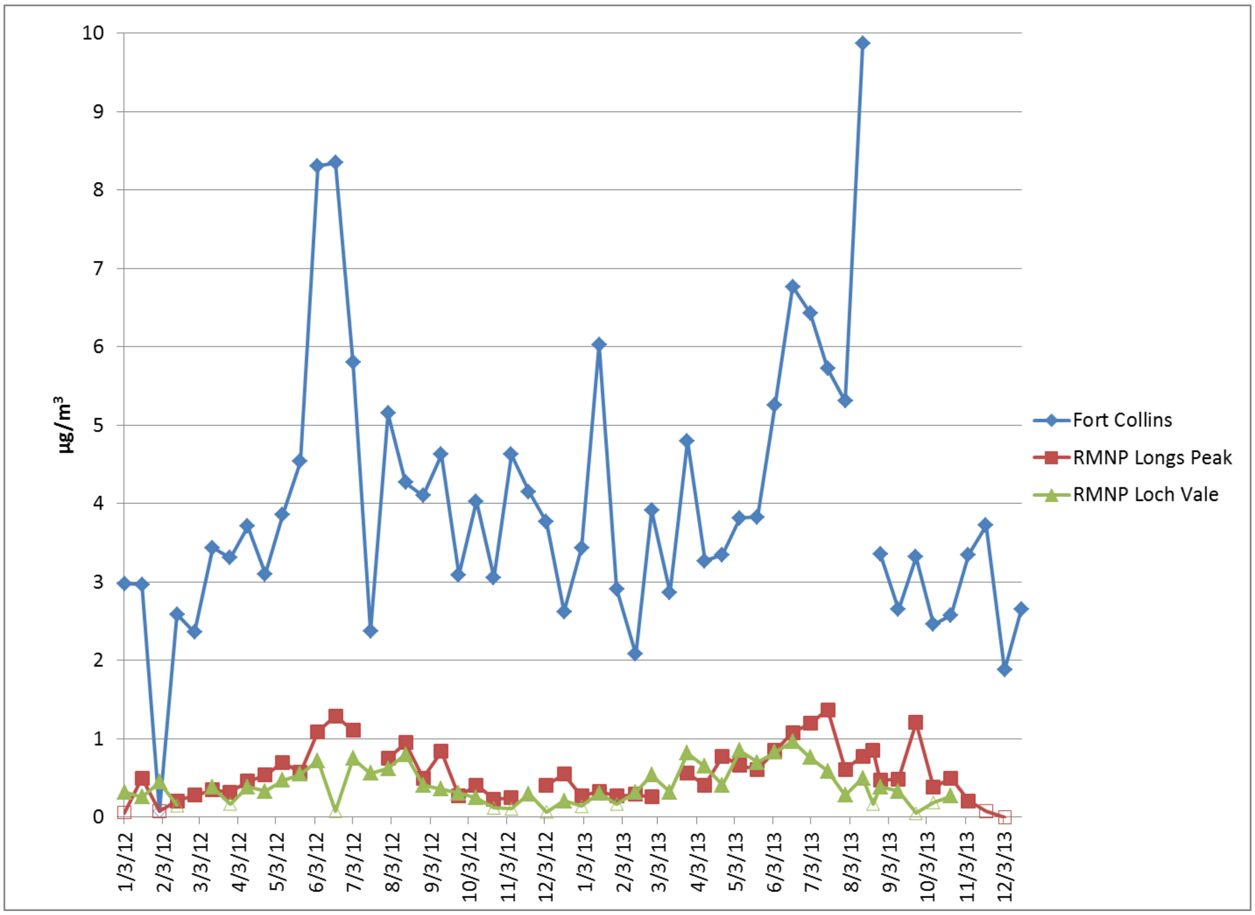

Figure D-1. Ammonia concentrations at Rocky Mountain National Park sites and a site in Fort Collins, 2012–2013.

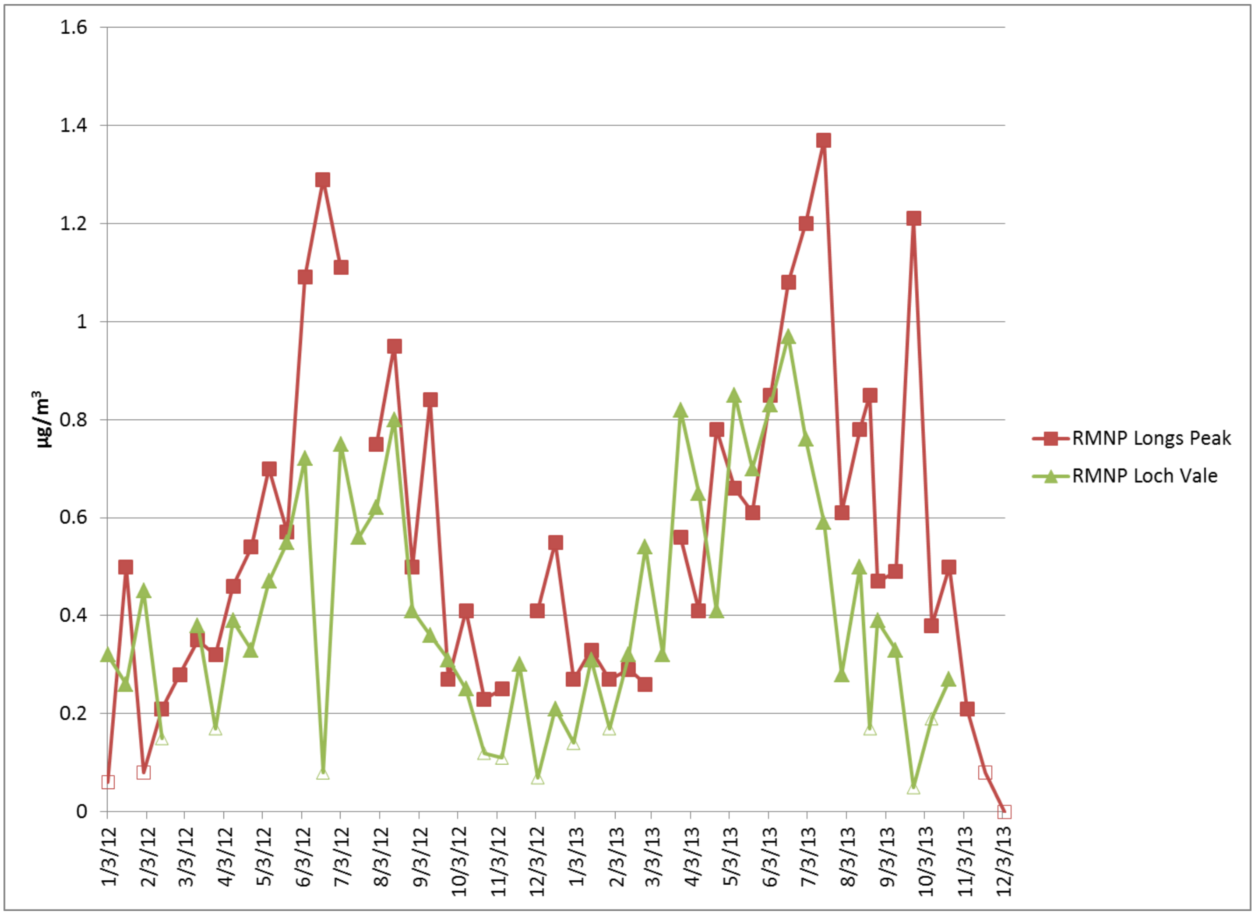

Figure D-2. Ammonia concentrations at Rocky Mountain National Park sites, 2012–2013.

Figure D-2 takes a closer look at the data from the two sites in RMNP. Ammonia concentrations tended to be higher at the lower elevation Longs Peak site. Empty markers indicate samples that were below the AMoN reporting limit, 0.2 µg/m^3. These values are considered less precise.

Ammonia data from AMoN are useful in identifying spatial and temporal patterns in and near the park, and will be used to validate atmospheric models. An algorithm is under development in partnership with the U.S. EPA and other stakeholders to estimate deposition from ammonia concentrations. Preliminary results are in evaluation, and a final methodology is pending approval by NADP.

NPS 121/129311, July 2015

National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science
1201 Oakridge Drive, Suite 150
Fort Collins, CO 80525

www.nature.nps.gov