Rocky Mountain National Park Initiative: 2012 Nitrogen Deposition Milestone Report

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EXECUTIVE SUMMARY

The Colorado Department of Public Health and Environment (CDPHE), the Environmental Protection Agency (EPA), and the National Park Service (NPS) formed the Rocky Mountain National Park Initiative in 2005 to address air pollution issues within Rocky Mountain National Park (RMNP). This collaboration focuses on monitoring the effects and trends of nitrogen deposition within RMNP and addressing air quality issues that have a direct impact on ecosystems and visibility within RMNP. The three agencies, through a joint Memorandum of Understanding (MOU), work collaboratively with interested stakeholder groups to understand the status of nitrogen deposition and ecosystem impacts at the park, sources of emissions, and approaches to resolve the nitrogen deposition issue in RMNP. In 2007, the three agencies issued the Nitrogen Deposition Reduction Plan (NDRP), with milestones for achieving nitrogen deposition reductions that protect park resources over time. Subsequently, a Contingency Plan was issued that outlined corrective measures to be taken in the event a deposition reduction milestone described in the NDRP is not realized.

This document serves as a progress report, highlighting milestones, policy and management developments, advances in industry best practices, and new research since the release of the NRDP. The report addresses two key items: (1) whether the 2012 interim nitrogen deposition reduction milestone has been achieved; and (2) whether the RMNP Nitrogen Deposition Contingency Plan will be triggered. This report provides evidence and makes recommendations based on the current state of knowledge and consensus of the three MOU Agencies. Note that while impaired visibility and elevated ozone levels at RMNP are also air quality concerns of the Initiative, this report only focuses on atmospheric nitrogen deposition.

The NDRP documents how ecosystem health first began to decline at high-elevation areas on the east side of RMNP between 1950 and 1964 as indicated by a shift in aquatic biota from a natural to a disturbed condition. The beginning of this shift corresponded to a critical load of wet nitrogen deposition of 1.5 kilograms of nitrogen per hectare per year (kg N/ha/yr). This threshold has been designated the resource management goal for restoration of healthy ecosystems at high elevation areas of RMNP. The NDRP relies on a "glidepath" approach to achieve the resource management goal by the year 2032 with interim milestones at five-year intervals. The first interim milestone of the NDRP calls for wet nitrogen deposition at RMNP to be reduced from the baseline loading of 3.1 kg N/ha/yr in 2006 to 2.7 kg N/ha/yr in 2012.

A variety of monitoring data and statistical analyses are assessed using a "weight of evidence" approach to determine whether the milestone has been reached, and whether the contingency plan should be triggered. As of the end of 2012, wet nitrogen deposition at Loch Vale in RMNP was 2.9 kg N/ha/yr, which is above the first interim milestone of 2.7 kg N/ha/yr. However, over the last decade, the trend in wet nitrogen deposition at Loch Vale has shifted from increasing to stable. While this does not meet the goal of reaching a decreasing trend in wet nitrogen deposition, or hitting the milestone exactly, it is a shift in the right direction. Trends on more recent data for the two major components of nitrogen deposition, nitrate and ammonium, show that nitrate concentrations are decreasing at the majority of sites in the region while ammonium trends are stable.

Identifying nitrogen source categories and source areas allow the MOU Agencies to determine whether additional emissions reductions are needed in the future that reduce nitrogen deposition in RMNP. Measurements and modeling analyses illustrate that anthropogenic NO_x (nitrogen oxides) and ammonia

emissions from industrial, mobile, and agricultural sources appear to be significant contributors to particulate nitrate formation in RMNP during the spring and fall months. Results from the RoMANS studies suggest that a substantial portion of the deposited nitrogen originates from sources within Colorado. These studies also indicate that during spring and fall large scale weather events, significant concentrations of reduced and oxidized nitrogen move from the eastern urban and agricultural areas of the state (Front Range, Greeley, and northeastern Colorado) into RMNP.

Current emission inventories, trends, and special studies help establish whether nitrogen-related emissions (NO_x and ammonia) are likely to be declining or increasing in the future. Recent demographic trends show an increase in population in the Denver Metropolitan Area (DMA) of about 9% from 2006 – 2010 and vehicle miles traveled per person are anticipated to increase about 12% from 2011 – 2017 in the DMA. Estimates of total cattle, farms, harvested crops, and hogs (as of 2012) all remain at about the same level as they were in 2008. Nationally, NO_2, used as a surrogate to estimate NO_x, emissions decreased substantially, with a 33% decrease from 2001 to 2010. In the DMA region, levels showed a 34% overall decrease from 1990 to 2010. Ammonia emissions nationally have remained fairly stable since 2002. At this time, there are no long-term ammonia emission trends available for the DMA or the state of Colorado.

CDPHE uses emission inventories to track sources of nitrogen within its boundaries. These emission inventories use atmospheric models and other technical tools to estimate NO_x and ammonia emissions. Several emission inventories concur that livestock and fertilizer are the two biggest source categories of ammonia, followed by fire or highway vehicle sources, depending on the area. Consistent with those inventories, a study conducted by Colorado State University researchers showed measured ambient concentrations of ammonia in the eastern agricultural areas were two to four times higher than concentrations in the northern urban corridor (Ft. Collins and Loveland). Highway vehicles and electric utility fuel combustion represent over 60% of the NO_x emissions statewide. Off-highway and industrial fuel combustion contribute about 30% of NO_x emissions in Colorado. Percentages are similar for the DMA area. Recent CDPHE estimates show that oil and gas point and area sources contribute about 17.5% of total statewide NO_x emissions, although the extent of predicted future development is uncertain. Emission estimates for this source category will continue to be refined and tracked in the future.

Efforts to improve Colorado’s nitrogen emission inventory data are ongoing and include the recent WestJump Air Quality Modeling Study (WestJumpAQMS) and the Three-State Data Warehouse and Air Quality Study (Three-State Study). The WestJumpAQMS evaluates the EPA’s National Emissions Inventory (NEI), used to estimate and identify source categories that might need to be updated or improved, including ammonia emission estimates from livestock operations and agricultural fertilizer application and NO_x emissions from oil and gas activities. The Three-State Study provides tools for air quality planning for state and federal partners regarding impacts from ozone and other pollutants. The MOU agencies are involved in several collaborative inventory and research initiative efforts that will improve both ammonia and NO_x inventories and real-time emission knowledge in the coming years.

Many current and future emission reduction activities are planned and anticipated over the next decade. Several significant upcoming NO_x emission reductions are noted, including natural gas compressor engine Best Available Control Technology (BACT) requirements, retrofit controls on larger engines, Regional Haze provisions, statewide regulatory regimes, federal on- and off-road standards, and other programs. By 2018, a combined statewide approximate 37% NO_x reduction is estimated, which is anticipated to decrease nitrogen deposition in RMNP.

Much attention has been paid to developing strategies and options for reducing ammonia emissions. The Agriculture (Ag) Subcommittee was formed under the RMNP Initiative in 2006 to address concerns about ammonia contributions to nitrogen deposition in RMNP and to involve agricultural producers in exploring voluntary options for reducing ammonia in their operations. The Ag Subcommittee has supported multiple ongoing research efforts, including several Colorado State University (CSU) studies evaluating best management practices (BMPs) and assessments of trends in local ammonia emissions. A promising project coming out of this group's efforts was recently funded with the help of numerous partners, including the MOU agencies, to develop an Early Warning System (EWS), which will notify agricultural producers to avoid practices that may lead to large releases of ammonia on particular days where upslope weather conditions are predicted. Additionally, the Ag Subcommittee is developing an adaptive five-year plan to help achieve nitrogen reduction goals in RMNP, which will include research, monitoring, and outreach plans.

Assessing nitrogen emissions within RMNP and emissions reduction efforts from within RMNP itself plays an important part in understanding the complete picture of nitrogen inputs to high elevation ecosystems. Within RMNP, multiple projects are in place to help reduce mobile source emissions, including a visitor transportation system that connects popular destinations in the park and town of Estes Park. Additionally, RMNP is increasing the park's fleet efficiency by educating drivers on fuel saving practices and optimizing fleet size and composition. Energy biodiesel powered generators were installed in 2005 at the Alpine Visitor Center. RMNP is a designated Climate Friendly Park and has a Green Team that organizes implementation of green ideas to help RMNP operations become more sustainable. An Environmental Management System is in place to achieve 100% compliance with applicable environmental laws and regulations, and to further increase sustainability of RMNP operations, including a goal to reduce energy usage 30% by the year 2015.

This report uses a "weight of the evidence" approach to determine whether the 2012 interim milestone has been achieved and whether the RMNP Nitrogen Deposition Contingency Plan will be triggered. Based on the weight of the evidence presented, the MOU Agencies agree that although wet nitrogen deposition is above the glidepath milestone for 2012, nitrogen deposition has stabilized and has not been increasing in recent years. Significant NO_x emission reductions anticipated in Colorado over the next five years through state and federal regulatory mechanisms should have a positive effect on nitrogen deposition reductions at RMNP.

The efforts of the Ag Subcommittee continues to make progress by the development of an adaptive five-year plan that gives the MOU agencies confidence in future ammonia emissions reductions. The agencies concur that allowing developing and current strategies adequate time to show effectiveness is prudent.

Therefore, the MOU agencies conclude that the 2012 interim milestone has not been achieved. However, the RMNP Nitrogen Deposition Contingency Plan shall not be triggered at this time. The MOU Agencies will complete the following steps to ensure progress continues during the next five-year period leading up to the 2017 Milestone Report evaluation.

Next steps for the MOU agencies include a review and update of the 2010 Contingency Plan, continued work on ammonia and NO_x emission inventory improvements, ongoing stakeholder collaboration, and continued evaluation of nitrogen deposition reduction over time. The agencies will continue to monitor nitrogen deposition levels as strategies are implemented to determine whether additional steps are needed, in or prior to 2017, to meet the next milestone.

1. Introduction & Background

1.1. History

The Colorado Department of Public Health and Environment (CDPHE), the Environmental Protection Agency (EPA), and the National Park Service (NPS) formed the "Rocky Mountain National Park Initiative" in 2005. This interagency effort addresses air pollution issues in Rocky Mountain National Park (RMNP), specifically the effects and trends of nitrogen deposition in RMNP, and monitors related air quality issues including elevated ozone concentrations and visibility impairment. This effort in part resulted from a petition to the Department of the Interior from the Environmental Defense Fund and Colorado Trout Unlimited to "carry out its legal responsibilities to protect RMNP from harmful air pollution," referring specifically to atmospheric nitrogen deposition. These agencies signed a Memorandum of Understanding (MOU) and agreed to pursue a more in-depth review of the issues and a course of action to address them.

While impaired visibility and elevated ozone levels are air quality concerns at RMNP have been the subject of some discussion within the Initiative, the 2012 Nitrogen Deposition Milestone Report only focuses on the nitrogen deposition issue. Ozone is being addressed via the National Ambient Air Quality Standards and associated designations and State Implementation Plans (SIPs). Visibility is being addressed in the Regional Haze process and associated SIP. The ozone and Regional Haze processes both contribute to nitrogen oxide (NO_x) reductions, consequently reducing nitrogen deposition in RMNP as well. The NO_x reductions that will occur in the future as a result of these programs and SIPs were considered in this Report. The RMNP MOU agencies will continue to monitor these issues as they affect RMNP.

MOU agency staff collaborated to produce technical and policy papers, culminating in the issuance of the Nitrogen Deposition Reduction Plan (NDRP) in 2007. RMNP Superintendent Vaughn Baker approved a "critical load" for N deposition as a "resource management goal" for RMNP. As required by the NDRP, the MOU agencies developed a Contingency Plan that outlines corrective measures that will be implemented in the event that interim deposition goals described in the NDRP are not realized. The Colorado Air Quality Control Commission (AQCC) endorsed the Contingency Plan in June 2010.

1.2. Nitrogen Deposition in RMNP

Several laws mandate the National Park Service (NPS) to maintain and preserve natural conditions at RMNP for future generations. These laws include the 1915 legislation that established RMNP, the National Park Service Organic Act (1916), the Wilderness Act (1964) and the Clean Air Act Amendments (1977). RMNP is designated as a Class I air quality area as defined by the Clean Air Act.[1] RMNP was created to preserve the high elevation landscapes and wilderness character of the southern Rocky Mountains, and to provide the freest recreational use of and access to the park's scenic beauties, wildlife, natural features and processes, and cultural objects. Two-thirds of the park is near or above treeline, where park managers protect fragile high-elevation ecosystems.

Atmospheric deposition is the process by which airborne pollutants are deposited to water, soils and vegetation. Nitrogen deposition consists of both wet and dry components. Wet deposition occurs when pollutants are deposited in combination with precipitation, predominantly rain and snow, but also by clouds and fog. Dry deposition of particles and gases occur by more complex processes in the absence of precipitation.

The importance of atmospheric nitrogen deposition relative to the natural processes and character of RMNP has become better understood over time, as scientific research and monitoring that began in the early 1980's have documented various changes to ecosystems in RMNP. These changes include forest and soil biogeochemical changes, enhanced microbial activity in soils, increased nitrogen in lakes and streams, elevated levels of nitrogen in spruce tree chemistry, and shifts in species of aquatic plants as well as shifts in alpine tundra plant communities favoring sedges and grasses over the natural wildflower flora. These changes reduce biodiversity, increase potential for insect and disease outbreaks, decrease the ability of natural ecosystems to respond to changing climate conditions, and contribute in general to unhealthy conditions in sensitive ecosystems. RMNP's unique resources will continue to be harmed if nitrogen deposition remains constant or increases. Modifications of historical patterns in precipitation and temperature resulting from climate change are already beginning to alter ecosystems in RMNP. Excess nitrogen deposition stresses sensitive ecosystems, making them less resilient in adapting and responding to the effects of climate change.

High-elevation ecosystems in RMNP are particularly vulnerable to atmospheric nitrogen deposition, and show changes at lower deposition levels than do other ecosystems in the eastern United States. This sensitivity is based on several factors: (1) granitic bedrock and shallow soils found in the park do not provide much chemical buffering from the acidifying effects of excess nitrogen; (2) short growing seasons at high-elevations limit the amount of time plants have to absorb nitrogen for growth during the year; and (3) aquatic and terrestrial plants at high elevations evolved under very low nitrogen conditions and are better adapted for nitrogen impoverishment rather than nitrogen enrichment.

1.3. Nitrogen Deposition Research

The 2007 RMNP NDRP summarized the effects of nitrogen (N) deposition on RMNP ecosystems based on the science documented in over 80 peer reviewed journal articles. Since that time a large number of new studies and review articles relevant to RMNP and similar western forested ecosystems have been published. This new information supports the conclusions in the original papers, and also provides more detail about the types of impacts to ecosystems that may be expected at various levels of nitrogen deposition (Pardo et al., 2011).

[1] The Clean Air Act Amendments (1977) designate specific areas across the United States into different Class regarding air quality. Most areas are designated Class II, which allows a moderate amount of air quality deterioration. Colorado has 12 designated Class I areas, including RMNP. These areas have been defined as areas of environmental concern in which little or no growth can occur, and are afforded the highest level of air quality protection.

Critical loads are measures used to quantify harmful pollution levels and to set goals for resource protection or restoration on federal lands. Exceeding critical loads for nitrogen can cause ecosystem nitrogen saturation and resulting impacts, biotic community changes, or acidification. A critical load is a term used to describe the amount of pollution that starts chemical, physical, or biological changes in sensitive ecosystems. More specifically, a critical load has been defined as "the quantitative estimate of an exposure to one or more pollutants below which significant harmful effects on specified sensitive elements of the environment do not occur according to present knowledge."

One of the most important updates to previously conducted research refines and lowers the nitrogen critical loads at which natural alpine plant communities begin to be affected by nitrogen deposition (Bowman et al., 2012). Wet deposition is measured in kilograms of nitrogen per hectare (10,000 square meters) per year (kg N/ha/yr). While the critical load for protection of alpine plant communities was previously estimated at 4 kg N/ha/yr, based on research at nearby Niwot Ridge (Bowman et al., 2006), RMNP-specific research recommends nitrogen critical loads for vegetation at 3 kg N/ha/yr for protecting natural plant communities and ecosystems in RMNP (Bowman et al., 2011). A summary of the critical loads developed over the past few years that are applicable to RMNP is provided in Table 1.

Table 1: Nitrogen Critical Loads Applicable to RMNP[1,4]

Critical Load (kg N/ha/yr)[2]	Deposition Measure	Ecosystem Effect	Basis	Reliability[3]	Reference
0.2	Wet nitrogen	No effect- natural background deposition	Wet deposition avg. at remote sites in AK & HI	##	http://nadp.sws.uiuc.edu/
1.0	Wet nitrogen	Nutrient enrichment (diatoms)	Average of 285 Rocky Mtn. Lakes	##	Baron et al., 2011
1.5	Wet nitrogen	Diatom species shifts	RMNP & other Rocky Mtn sites	##	Baron et al., 2006; Saros et al., 2011
3	Modeled total nitrogen	Lichen community changes	Pacific NW	##	Geiser et al., 2010
3	Ambient nitrogen + additions	Alpine vegetation	RMNP	##	Bowman et al., 2011
3.1	Nitrogen as Canopy throughfall	Lichen community changes	Sierra Nevada	##	Fenn et al., 2008
3.0	Total (PRISM corrected) nitrogen	Nutrient enrichment (diatoms)	Average of 285 Rocky Mtn. Lakes	##	Baron et al., 2011
<4	Wet nitrogen	Foliar chemistry, mineralization, nitrification, nitrate leaching	RMNP	##	Reuth & Baron, 2002; Reuth et al., 2003
4	Ambient nitrogen + additions	Alpine vegetation (change in Carex rupestris indicator sp. cover)	Niwot Ridge	##	Bowman et al., 2006
4.0	Total (PRISM corrected) nitrogen	Episodic acidification of surface waters	Average of 285 Rocky Mtn. Lakes	##	Baron et al., 2011
4	Wet nitrogen	Episodic acidification of surface waters in Colorado Front Range	Niwot Ridge	#	Williams and Tonnesson, 2000
9	Ambient nitrogen + additions	Nitrate leaching below rooting zone in alpine	RMNP	##	Bowman et al., 2011
10	Ambient nitrogen + additions	Community changes in alpine vegetation	South Rockies, Niwot Ridge	##	Bowman et al., 2006
14	Ambient nitrogen + additions	Nitrate increases in soil solution in alpine	RMNP	##	Bowman et al., 2011

1. As summarized in Pardo, et al., 2011 *Assessment of Nitrogen Deposition Effects and Empirical Critical Loads of Nitrogen for Ecoregions of the United State, USDA Forest Service GTR-NRS-80;* along with other, more recent (2011 and later) sources
2. Where ranges are listed in the original literature, the lower end of the range is shown here
3. ## =Highly reliable; #= Fairly reliable; Note: other N critical load estimates from modeling studies are available, however as reliability is considered lower ("(#) expert judgment") these are not shown in the table.
4. Shaded cells are selected as most representative of RMNP critical load, based on proximity to RMNP, reliability, and representative of ecosystem types found in RMNP.

1.4. Critical Load Determination

The critical load approved by Superintendent Baker and included in the NDRP was based on published research (Baron et. al, 2006) that indicates excess nitrogen deposition caused ecosystem health to decline at high-elevation areas on the east side of RMNP between 1950 and 1964 as indicated by a shift in aquatic biota from a natural to a disturbed condition. Managers of RMNP determined that all the biological, physical and chemical changes were caused by nitrogen deposition and they concluded that this pollutant was continuing to result in significant harmful effects on park ecosystems east of the Continental Divide. The beginning of this decline in condition of sensitive ecosystems in the park corresponds to a critical load of wet nitrogen deposition of 1.5 kg N/ha/yr, which has become the target goal (management goal) for restoration A summary graphic illustrating the key nitrogen critical loads most relevant to RMNP ecosystems, is shown in Figure 1.

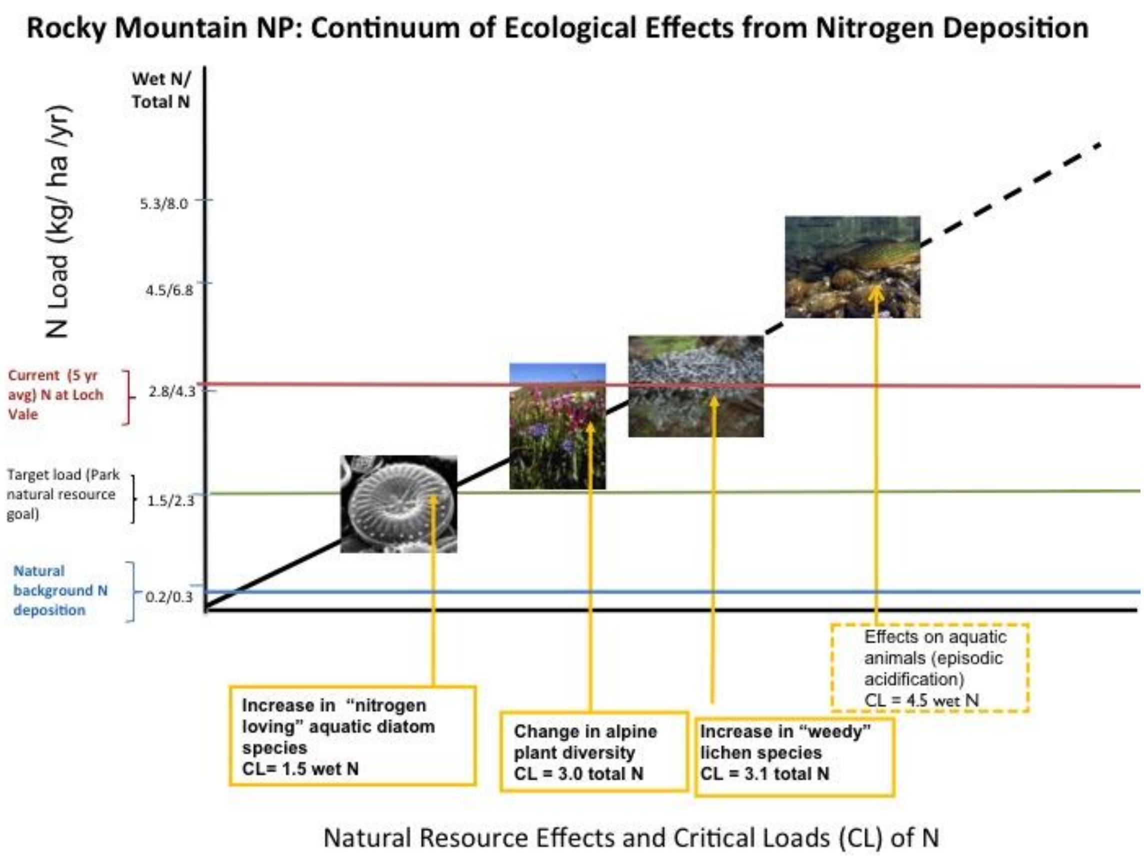

Figure 1: RMNP Continuum of Ecological Effects from Nitrogen Deposition

The critical load was based on data collected from the original National Atmospheric Deposition Program/National Trends Network (NADP/NTN) site in the Loch Vale watershed in RMNP (monitoring location CO98). The site has been collecting wet deposition data since 1983 and is located at high-elevation (10,634 feet) near some of the park's most sensitive resources. Dry deposition measurements are not available at high elevation within the park so the critical load is based only on wet nitrogen deposition.

The NADP/NTN[2] is a nationwide precipitation chemistry monitoring network and cooperative effort among many different entities, including the U.S. Geological Survey, EPA, NPS, U.S. Department of Agriculture, state agricultural experimental stations, U.S. Fish and Wildlife Service, and numerous universities and other governmental and private entities.

There are four NADP/NTN sites located in RMNP. Two co-located sites are at Loch Vale at an elevation of 10,364 feet. The second site was installed in 2009 to evaluate the overall variability in the measurements. The site at Beaver Meadows is located at a lower elevation of 8,169 feet. The site at Kawaneeche Meadow was just installed in 2012 and is located on the west side of the Continental Divide at an elevation of 8,639 feet. The annual data from this site will be included in future reports and trend analyses when the period of record is sufficient.

More than half of the total deposition at the park is wet deposition. Wet deposition is calculated by multiplying a chemical concentration by the precipitation amount. Reliance on a wet deposition critical load to protect park resources assumes that total deposition will decrease as wet deposition decreases.

The critical load defining the thresholds for aquatic ecosystem changes due to eutrophication (excess nitrogen) at RMNP is 1.5 kg N/ha/yr, which is about half the current level of wet nitrogen deposition at the Loch Vale monitoring site on the east side of RMNP (2.9 kg N/ha/yr on a five-year rolling average from 2008 – 2012). The critical load value, however, is similar to deposition levels measured in Colorado on the west side of the Continental Divide, where ecosystems are relatively healthy (Baron et al., 2000), supporting the selection of 1.5 kg N/ha/yr wet deposition as a reasonable target for maintaining natural ecosystems in RMNP.

1.5. Glidepath Description and Progress Assessment

The RMNP Initiative selected the glidepath approach for achieving the resource management goal. This approach is used in regional haze planning, strives for gradual improvement over time, and is an accepted regulatory/policy structure for long-term, goal-oriented air quality planning. The glidepath approach allows for the setting of interim milestones for the purpose of demonstrating and assessing progress over time. An interim milestone is defined as being between the current condition and the ultimate resource management goal.

Because ecosystems in RMNP show signs of degradation, it is important to quickly reverse the increasing trend in nitrogen deposition. The focus of this report is on the first interim milestone, which requires a reduction of wet nitrogen deposition from current conditions to 2.7 kg N/ha/yr (a 13% reduction from the 2000 – 2004 five-year average of 3.1 kg N/ha/yr) in 2012. This first interim milestone target amount was based on recent research and chosen to prevent the additional accumulation of nitrogen in alpine soils that may encourage the growth of grasses over alpine wildflowers (Bowman et al., 2006, 2011). Progress towards interim target goals will be evaluated at five-year intervals starting in 2012 until the resource management goal of 1.5 kg N/ha/yr is achieved in the target year 2032. Table 2 illustrates the interim milestones. Figure 2 demonstrates the current deposition in comparison to the first interim milestone.

[2] More information on the program and the monitoring data can be found on the NADP website at http://nadp.sws.uiuc.edu/.

Table 2: Glidepath Interim Milestones

2012	2017	2022	2027	2032
2.7 kg N/ha/yr	2.4 kg N/ha/yr	2.1 kg N/ha/yr	1.8 kg N/ha/yr	1.5 kg N/ha/yr

Current conditions are based on a 5-year rolling average of the annual wet nitrogen[3] deposition data from the Loch Vale NADP/NTN site in RMNP. In 2012, the calculated 5-year average (2008–2012) of wet nitrogen deposition was 2.9 kg N/ha/yr. This value is 0.20 kg N/ha/yr higher than the 2012 interim milestone.

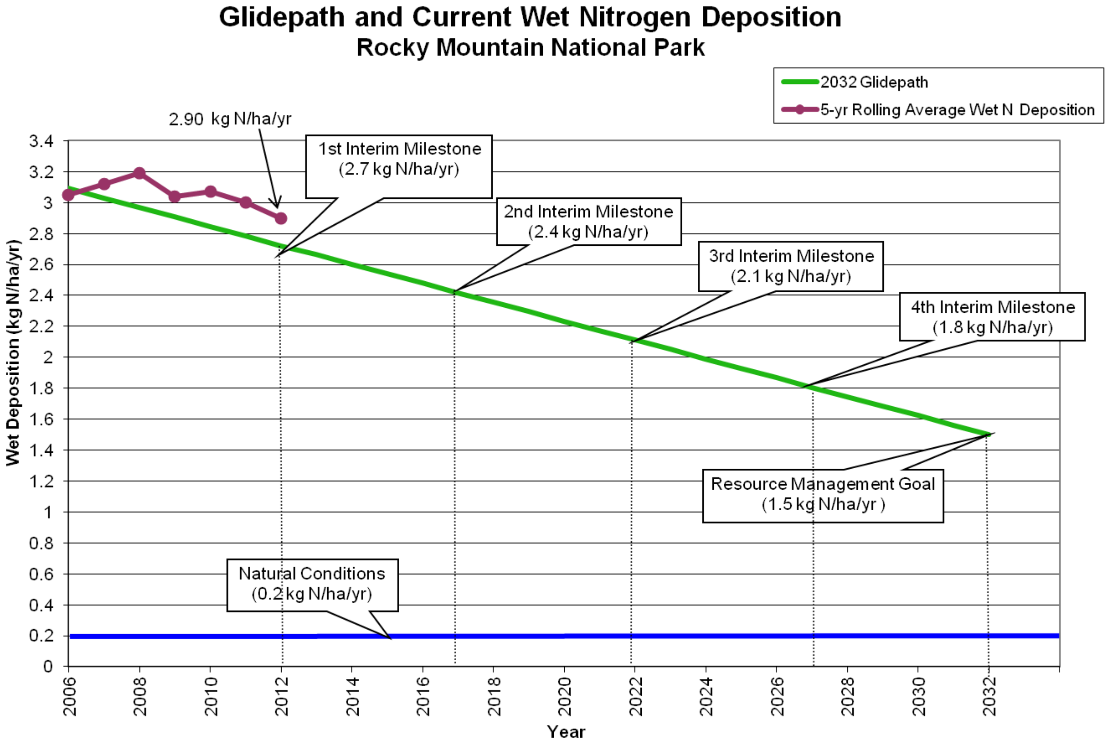

Figure 2: RMNP Glidepath and Current Deposition

1.6. Weight of the Evidence Approach

In the eight years since the first multi-agency meeting, significant progress towards reducing nitrogen deposition in RMNP has been made. During this time, valuable lessons have been learned, stakeholder partnerships developed, outreach conducted, and new information gathered. This report provides an assessment of the 2012 nitrogen deposition interim milestone using a weight of the evidence approach. "Weight of evidence" in this case refers to using multiple types of information to determine (1) whether the 2012 Nitrogen Deposition Interim Milestone was met, and (2) whether the RMNP Nitrogen Deposition Contingency Plan will be triggered.

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

There are numerous factors that affect deposition: emission amounts and type (e.g. different forms of nitrogen pollutants), amount and distance from area of deposit, atmospheric chemical transformations of those emissions, topography, and local- and regional-scale meteorology including precipitation. Currently, there are no viable techniques available that directly measure the contribution of a particular emission source to nitrogen deposition in RMNP, therefore multiple technical analyses using existing and new data are considered and interpreted to provide a weight of evidence upon which policy decisions can be based.

Types of evidence detailed in this report include:

- Deposition patterns and trends on regional and national levels;
- Source category and attribution analyses and studies;
- Emission inventories, including significant source categories;
- Emission trends using several different techniques, including modeling, monitoring, and other scientific assessments;
- Current and future emission inventory improvements;
- Demographic trends;
- Current and future emission reduction activities, including a discussion regarding regulatory versus voluntary approaches;
- Ammonia-focused projects from both local and national perspectives; and
- In-park emissions and reduction activities.

2. Deposition Trends

2.1. Regional Nitrogen Deposition Patterns and Trends

In addition to assessing progress along the glidepath, the MOU agencies compared trends in wet nitrogen deposition data from Loch Vale to other NADP/NTN sites on the eastern slope of the Front Range that are exposed to similar emissions: the lower elevation site in RMNP (Beaver Meadows) and three sites located outside of RMNP (Morris et al., 2014). The NADP/NTN sites at Niwot Saddle and Sugarloaf are located in the mountains southeast of Loch Vale. The sites complement each other as paired high elevation and low elevation monitoring sites, just like Loch Vale and Beaver Meadows in RMNP. The NADP/NTN site at Pawnee is at a much lower elevation, located east of Loch Vale on the plains of eastern Colorado. These additional sites provide regional context and are listed in Table 3 and shown in Figure 3.

Table 3: NADP/NTN sites in and near RMNP used in trends analysis

Site Name	NADP/NTN Site ID	Period of Record	Elevation	Distance to Loch Vale
Loch Vale (RMNP)	CO98	29 yrs	10,364 feet	-
Beaver Meadows (RMNP)	CO19	33 yrs	8,169 feet	6.8 miles
Niwot Saddle	CO02	29 yrs	11,549 feet	16.5 miles
Sugarloaf	CO94	26 yrs	8,281 feet	22.5 miles

Pawnee	CO22	33 yrs	5,384 feet	59.7 miles

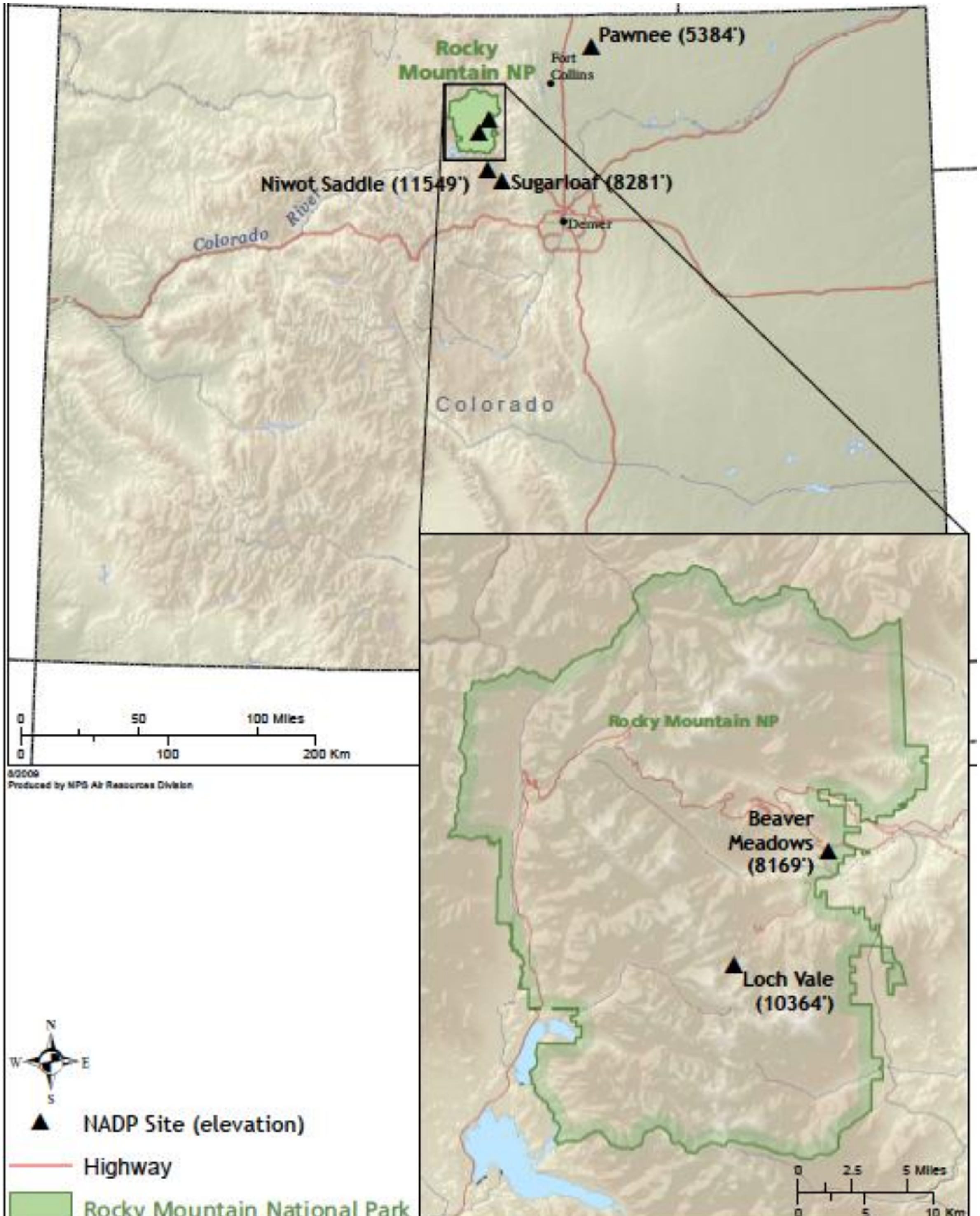

Figure 3: NADP/NTN Site Map of sites in or near RMNP used in trends analysis. Elevation is shown in feet in parentheses.

The parameters that were assessed include wet nitrogen deposition (kg N/ha/yr), precipitation-weighted mean nitrate and ammonium concentrations (µeq/L), and precipitation depth. Each parameter provides different information. Ecosystems respond to nutrient deposition so deposition data provide ecological relevance to the resource management goal for RMNP (Pardo et al., 2011c). Concentration data more closely relate to ambient air quality at individual sites and allow for comparison among sites. Precipitation data shows how the amount influences concentration values and deposition estimates.

Figure 4 through Figure 8 show the annual data for the period of record at each of the five sites for deposition, concentration, and precipitation. General patterns are identified below; however, note that the Y-axis for each graph is different for each site in order to best show patterns over time. Precipitation amounts varied substantially among these five Front Range sites over the periods of record, which range from 26 – 33 years. During the period of record, the higher elevation sites recorded much more precipitation than their lower elevation counterparts. Pawnee, at the lowest elevation, recorded the least amount of precipitation.

In general, wet nitrogen deposition ranged from 1 to 4 kg N/ha/yr, except for Niwot Saddle, where recorded levels were much higher. Niwot Saddle is the only site included in this analysis that is located above treeline, where deposition is over-estimated due to the over collection of blowing snow (Williams et al., 1998). Nitrate deposition was higher at Loch Vale until 2000 when contributions of ammonium and nitrate to nitrogen deposition became approximately equal. Nitrate deposition was higher at Niwot Saddle until the last five years, including 2012 when contributions of ammonium and nitrate deposition were equal. Nitrate and ammonium deposition (kg N/ha/yr) were approximately equal at Beaver Meadows and Sugarloaf throughout the period of record.

Ammonium deposition was consistently higher than nitrate deposition at Pawnee.
In general, nitrate concentrations have exceeded ammonium concentrations over the period of record at all sites except Pawnee, where ammonium concentrations are higher. However, in 2012, ammonium concentrations either equaled or exceeded nitrate concentrations at all sites. Concentrations were typically lower at the high elevation sites, where precipitation amount was greater.

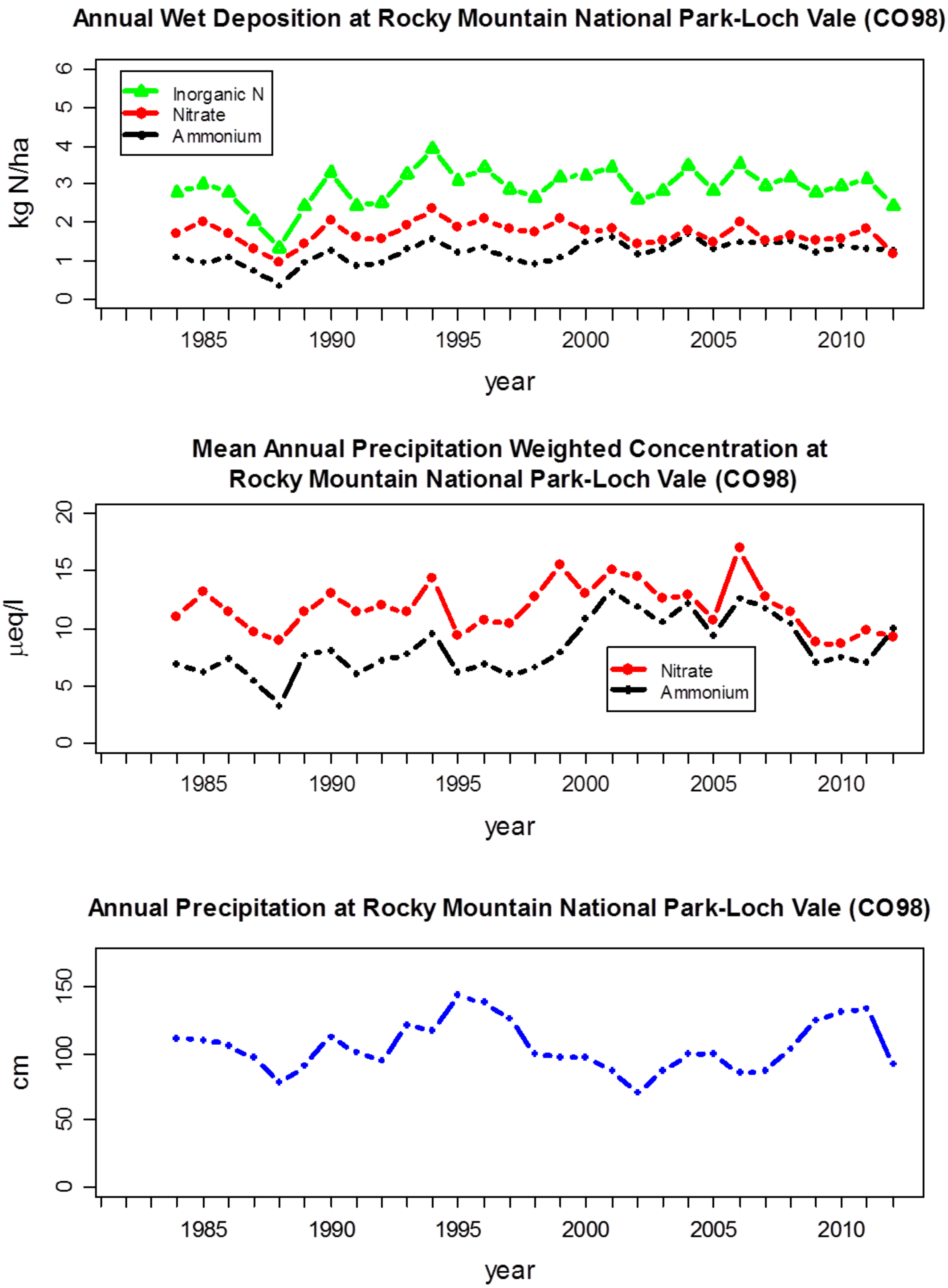

Figure 4: Deposition concentrations and precipitation for Loch Vale

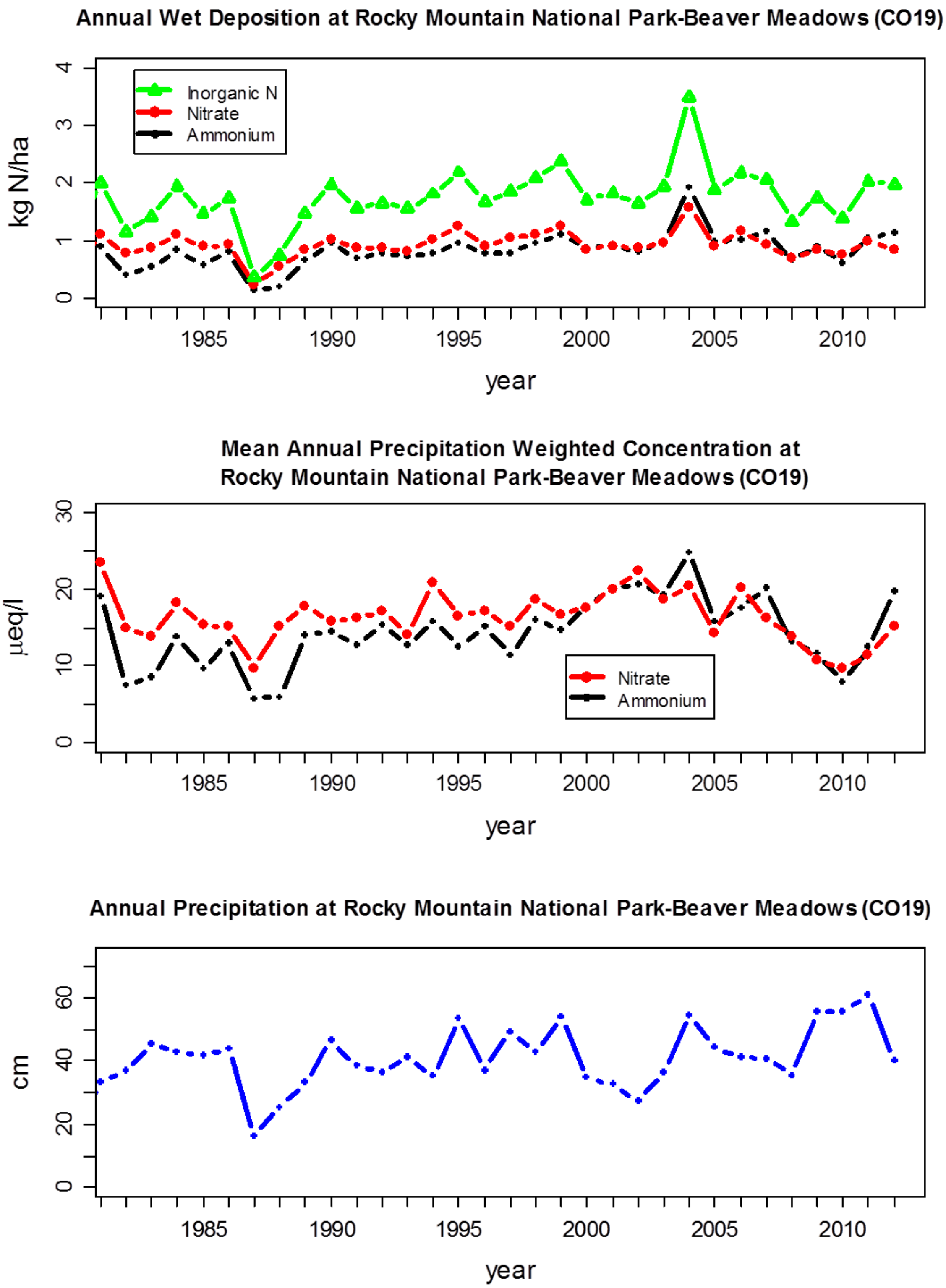

Figure 5: Deposition concentrations and precipitation for Beaver Meadows

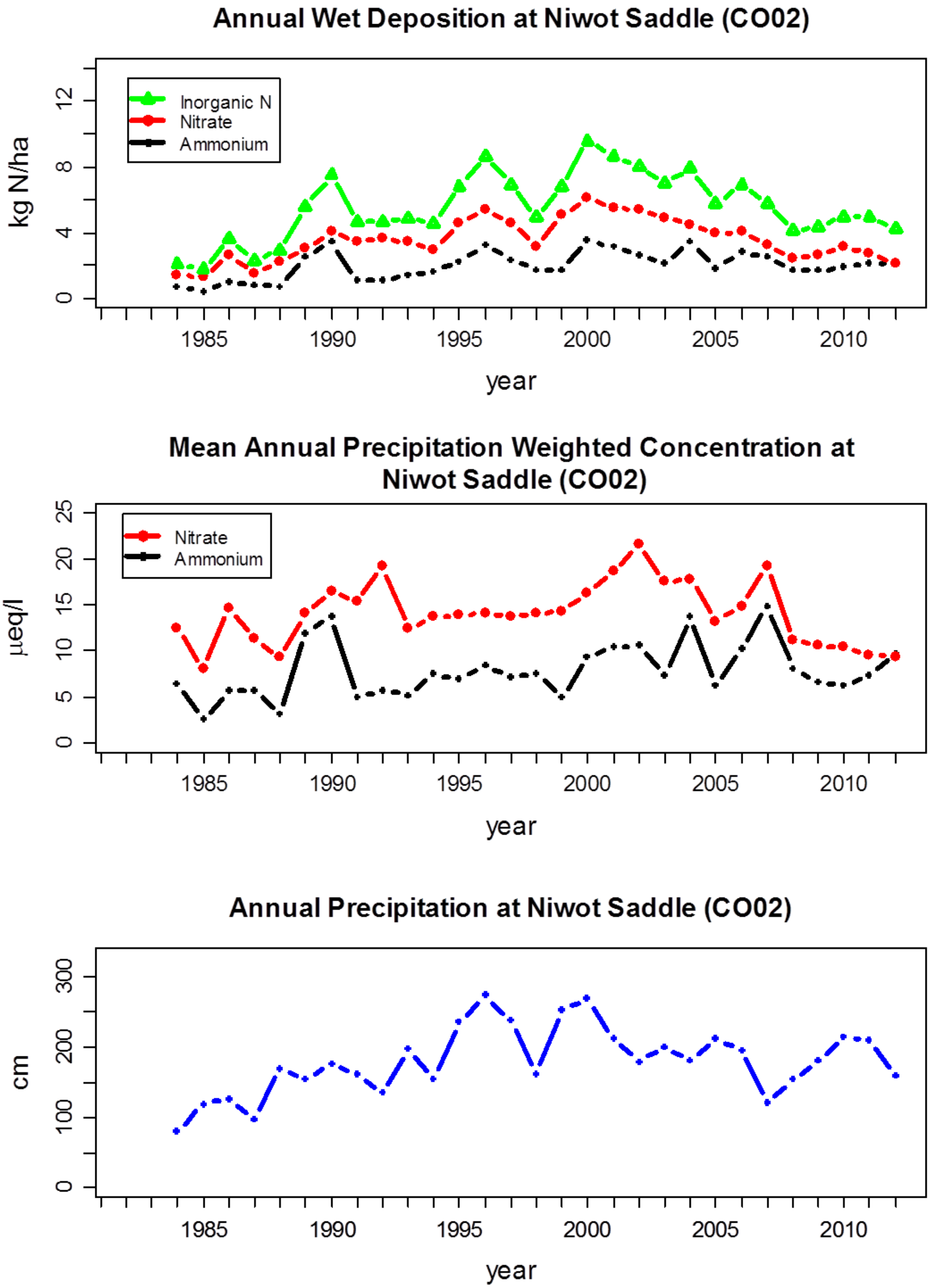

Figure 6: Deposition Concentrations and Precipitation for Niwot Saddle

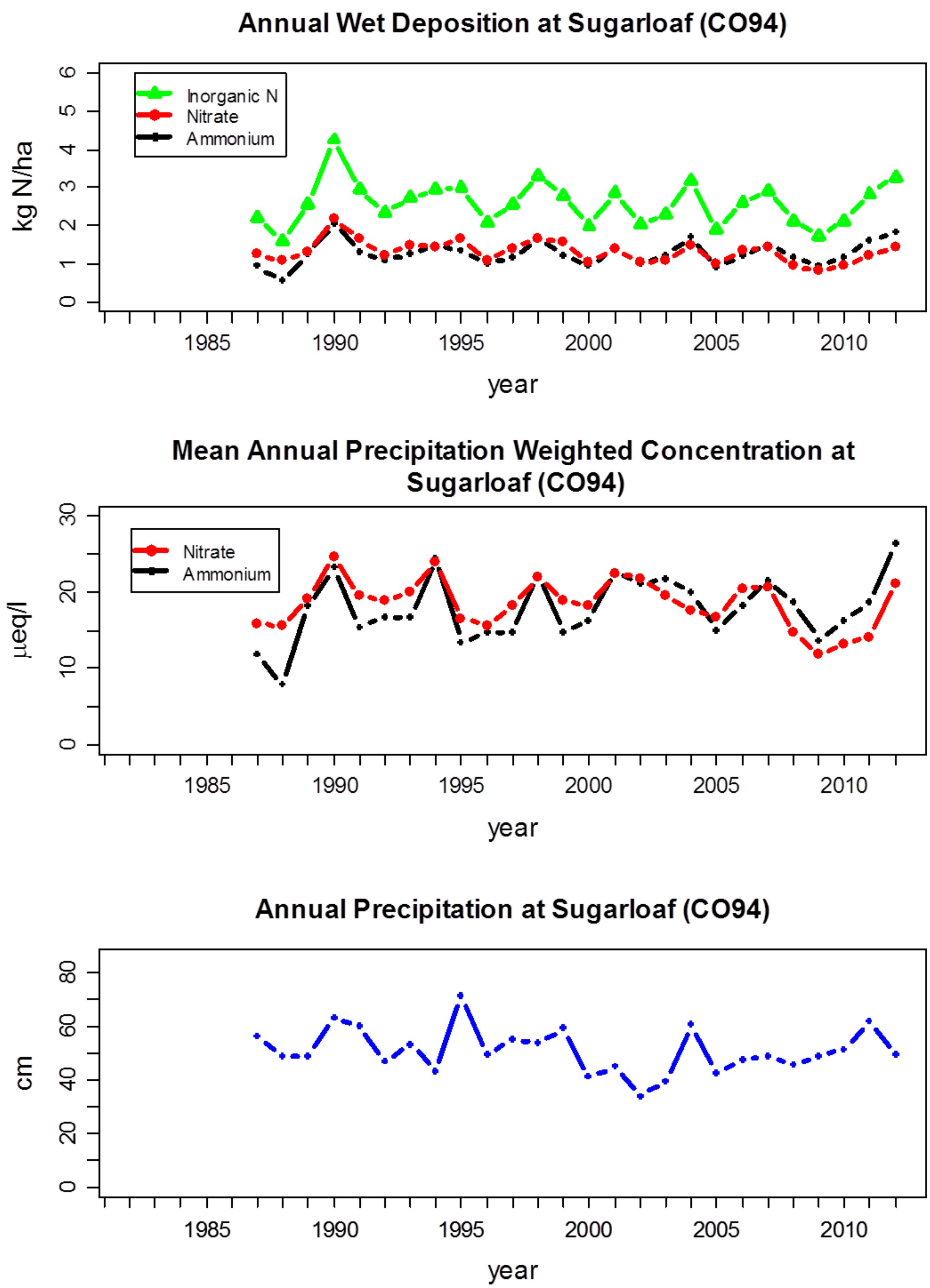

Figure 7: Deposition Concentrations and Precipitation for Sugarloaf

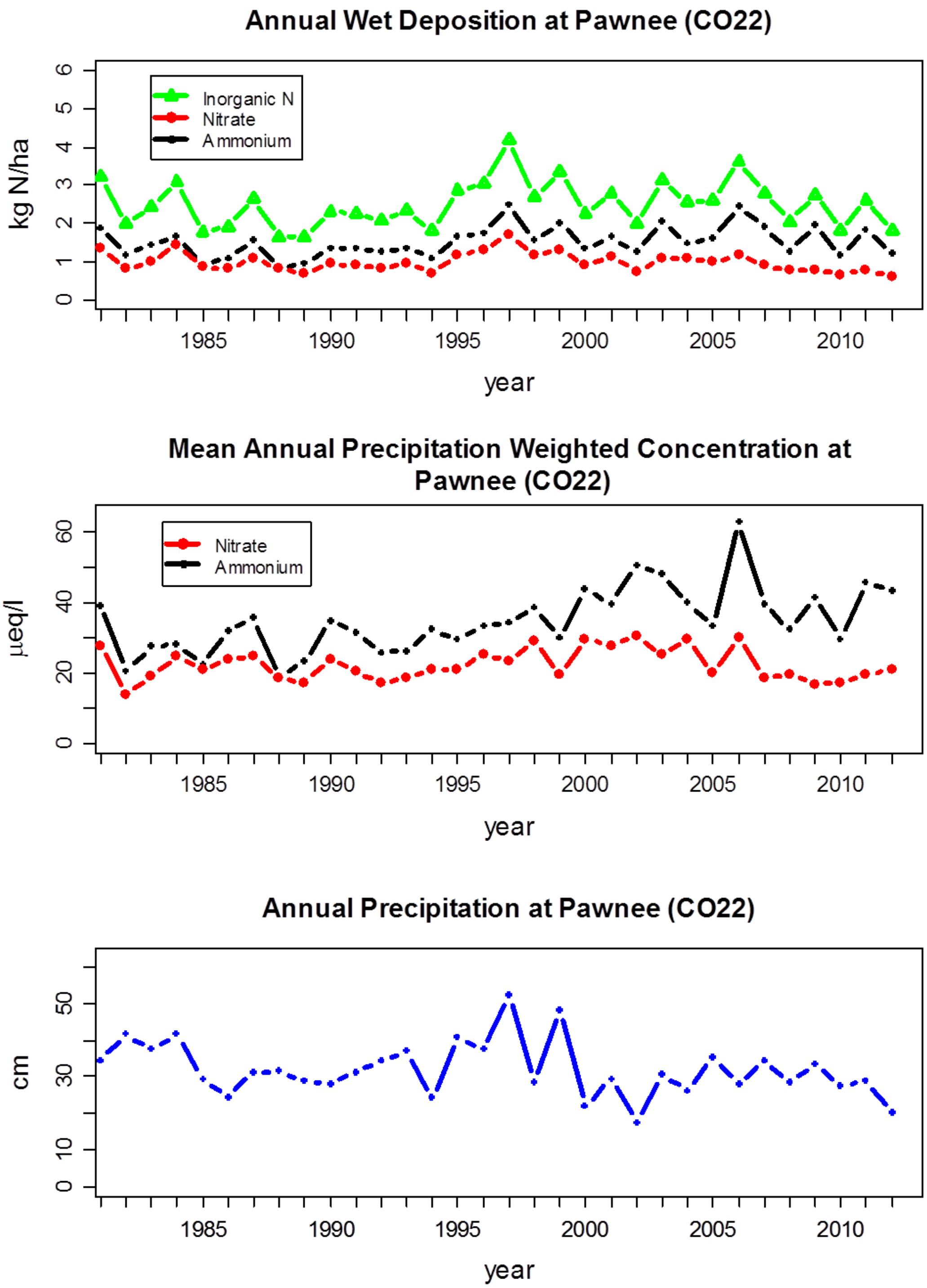

Figure 8: Deposition Concentrations and Precipitation for Pawnee

Trends in wet nitrogen deposition, ammonium and nitrate concentrations, and precipitation amount were evaluated over the period of record at the Loch Vale and other regional sites providing information on how nitrogen has changed over time and whether nitrogen inputs to RMNP ecosystems have increased, decreased, or remained unchanged, shown in Table 4. Trends in wet deposition and precipitation amount were evaluated with the Mann Kendall test, while trends in concentrations were evaluated with the seasonal Kendall test (USGS, 2005). Temporal trends were evaluated for statistical significance at the 95 percent confidence level (p-value ≤ 0.05).

Table 4: Results from long-term trends over the period of record (through 2012)

Wet Nitrogen Deposition				
Site Name	*Start Year*	*Trend (kg N/ha/yr)*	*P-value*	*Significant Trends*
Loch Vale	1984	0.02	0.223	no trend
Beaver Meadows	1981	0.01	0.047	increasing
Niwot Saddle	1985	0.01	0.861	no trend
Sugarloaf	1987	<-0.01	0.826	no trend
Pawnee	1980	<0.01	0.815	no trend
Ammonium Precipitation-weighted Mean Concentrations				
Site Name	*Start Year*	*Trend (µeq/L/yr)*	*P-value*	*Significant Trends*
Loch Vale	1984	0.14	0.001	increasing
Beaver Meadows	1981	0.20	0.001	increasing
Niwot Saddle	1985	0.12	0.019	increasing
Sugarloaf	1987	0.15	0.054	no trend
Pawnee	1980	0.47	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	0.988	no trend
Beaver Meadows	1981	-0.06	0.264	no trend
Niwot Saddle	1985	-0.01	0.961	no trend
Sugarloaf	1987	-0.12	0.145	no trend
Pawnee	1980	-0.02	0.727	no trend
Precipitation				
Site Name	*Start Year*	*Trend (cm/yr)*	*P-value*	*Significant Trends*
Loch Vale	1984	-0.07	0.807	no trend
Beaver Meadows	1981	0.35	0.089	no trend
Niwot Saddle	1985	1.59	0.169	no trend
Sugarloaf	1987	-0.19	0.454	no trend
Pawnee	1980	-0.19	0.053	no trend

One goal of the NDRP is to “reverse the trend of increasing nitrogen deposition at RMNP.” In particular, a significant increasing trend in wet nitrogen deposition was noted at Loch Vale in RMNP for 1984 –2000 (p-value < 0.05) (Burns, 2003). With the addition of 2010, 2011, and 2012 data, the trend in deposition was no longer statistically significant at Loch Vale (Morris et al., 2012; Morris et al., 2013; Morris et al., 2014).

A statistically significant increasing trend in wet nitrogen deposition was detected at only one site, Beaver Meadows in RMNP for 1981- 2012 (p-value = 0.047). 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 ≤ 0.019). There were no significant trends in precipitation-weighted mean nitrate concentrations or precipitation amount at any of the five sites over the period of record.

Figure 9 depicts the precipitation-weighted mean concentrations comparing ammonium to nitrate and nitrate to ammonium ratios over time. This graph demonstrates that over the long-term record, ammonium is generally increasing relative to nitrate. Note that the data can be highly variable from year to year, reflected in the R^2 values that indicate how well the data points fit the ratio lines. Consequently, these ratios are yet another tool to assess concentrations over time and should not be used alone to observe future outcomes or trends in the data due to relatively high annual variability.

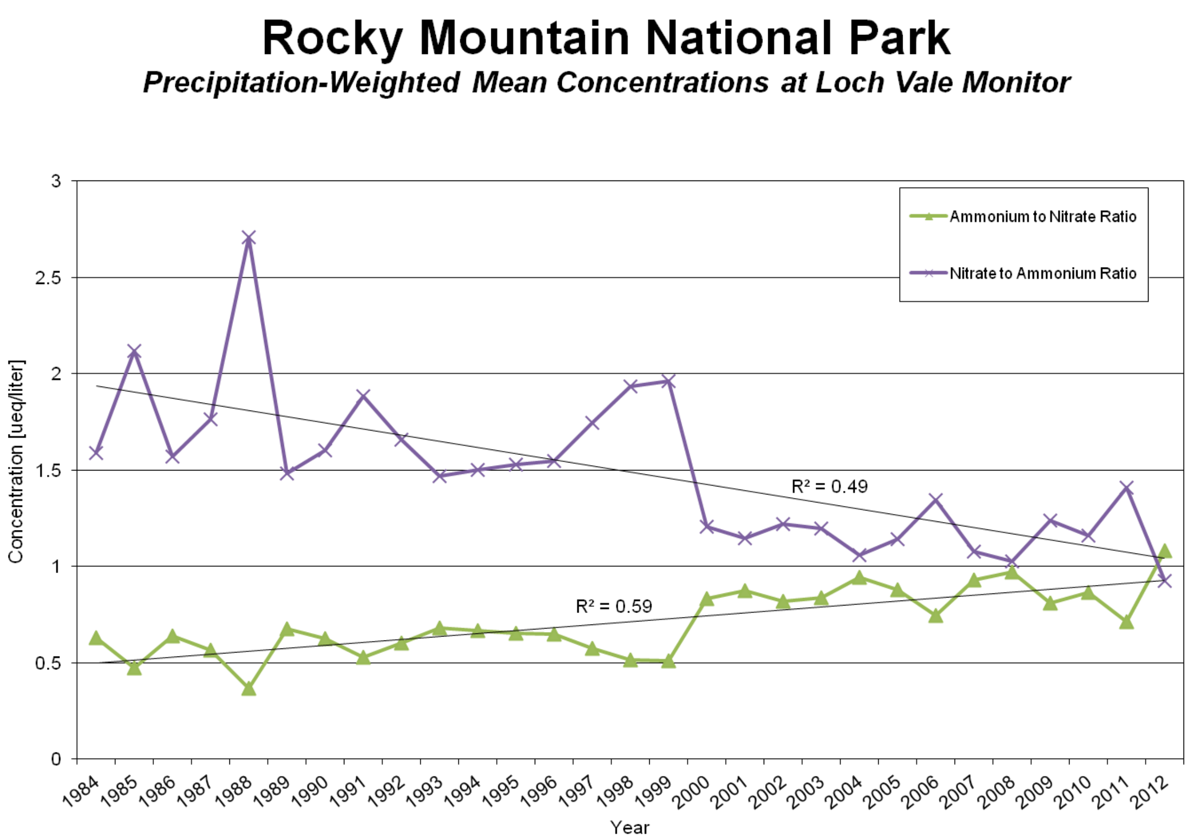

Figure 9: Precipitation-Weighted Mean Concentrations at Loch Vale

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 statistical trends on shorter-time periods is more difficult because less data is used in the analysis. Due to this, trend analyses were evaluated using two time periods covering the last five (2008–2012) and seven (2006–2012) years. Table 5 shows the results of the trend analysis for the individual sites, identifying the statistically significant trends (p-value ≤ 0.05).

Table 5: Trend results for 5 year (2008–2012) and 7 year (2006–2012) time periods

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	-0.10	0.462	no trend	-0.10	0.133	no trend
Beaver Meadows	0.15	0.221	no trend	-0.03	0.548	no trend
Niwot Saddle	0.14	0.806	no trend	-0.29	0.230	no trend
Sugarloaf	0.42	0.086	no trend	0.07	0.548	no trend
Pawnee	-0.06	0.613	no trend	-0.20	0.048	decreasing

Ammonium Precipitation-weighted Mean Concentrations

Site Name	5-year			7-year		
	Trend (μeq/L/yr)	*P-value*	*Significant Trends*	*Trend (μeq/L/yr)*	*P-value*	*Significant Trends*
Loch Vale	0.67	0.217	no trend	0.00	1.000	no trend
Beaver Meadows	0.75	0.270	no trend	-0.42	0.329	no trend
Niwot Saddle	0.49	0.292	no trend	-0.01	1.000	no trend
Sugarloaf	0.71	0.178	no trend	0.03	0.940	no trend
Pawnee	3.40	0.270	no trend	-0.50	0.499	no trend

Nitrate Precipitation-weighted Mean Concentrations						
Site Name	5-year			7-year		
	Trend (µeq/L/yr)	*P-value*	*Significant Trends*	*Trend (µeq/L/yr)*	*P-value*	*Significant Trends*
Loch Vale	-0.03	1.000	no trend	-0.63	0.029	decreasing
Beaver Meadows	0.68	0.391	no trend	-0.71	0.154	no trend
Niwot Saddle	-0.25	0.514	no trend	-0.72	0.006	decreasing
Sugarloaf	0.28	0.391	no trend	-1.25	0.043	decreasing
Pawnee	0.99	0.540	no trend	-0.61	0.409	no trend

Precipitation						
Site Name	5-year			7-year		
	Trend (cm/yr)	*P-value*	*Significant Trends*	*Trend (cm/yr)*	*P-value*	*Significant Trends*
Loch Vale	3.72	0.806	no trend	9.19	0.072	no trend
Beaver Meadows	1.87	0.462	no trend	2.56	0.548	no trend
Niwot Saddle	7.89	0.806	no trend	4.45	0.548	no trend
Sugarloaf	3.03	0.221	no trend	0.92	0.133	no trend
Pawnee	-2.23	0.462	no trend	-1.3	0.368	no trend

There were no significant trends in wet nitrogen deposition at RMNP over the shorter period of record, but there was a significant decrease at Pawnee over the past 7 years (p-value=0.048). Precipitation-weighted mean ammonium concentrations were level, showing no significant trends. Loch Vale, Niwot Saddle, and Sugarloaf showed statistically significant decreases in precipitation-weighted mean nitrate concentrations over the 7-year time period (p-values $\leq$ 0.043).

2.2. National Nitrogen Deposition Patterns and Trends

Wet nitrogen deposition across the United States is shown in Figure 10 for 2012. The map shows that wet nitrogen deposition is generally higher in the East than the West. In the West, higher deposition generally occurs at higher elevations because of the increase in precipitation.

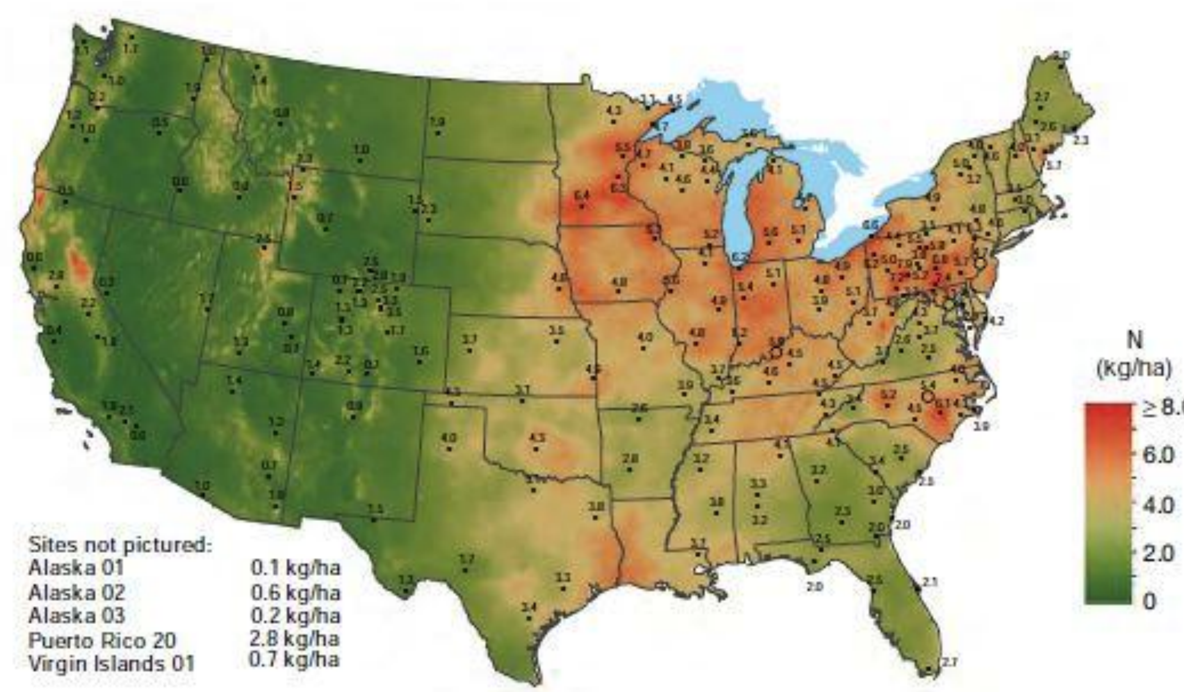

Figure 10: Wet Nitrogen Deposition, 2012 (National Atmospheric Deposition Program/National Trends Network)

Trends in ammonium and nitrate concentrations are shown for the United States for 1985 to 2009 (updated from Lehmann et al., 2005) in Figure 11 and Figure 12. Trends at RMNP and sites along the Front Range are consistent with the trends shown in the national maps (Morris et al., 2011). The majority of trends in ammonium concentrations from 1985 to 2009 increased significantly (p-value ≤ 0.10) across the United States, with the highest percentage of change occurring in the West. The majority of trends in nitrate concentrations decreased significantly from 1985 to 2009 (p-value ≤ 0.10) particularly in the eastern part of the country and along the west coast, depicted in Figure 12. Sites within the Intermountain West showed both increases and decreases, but most were not significant.

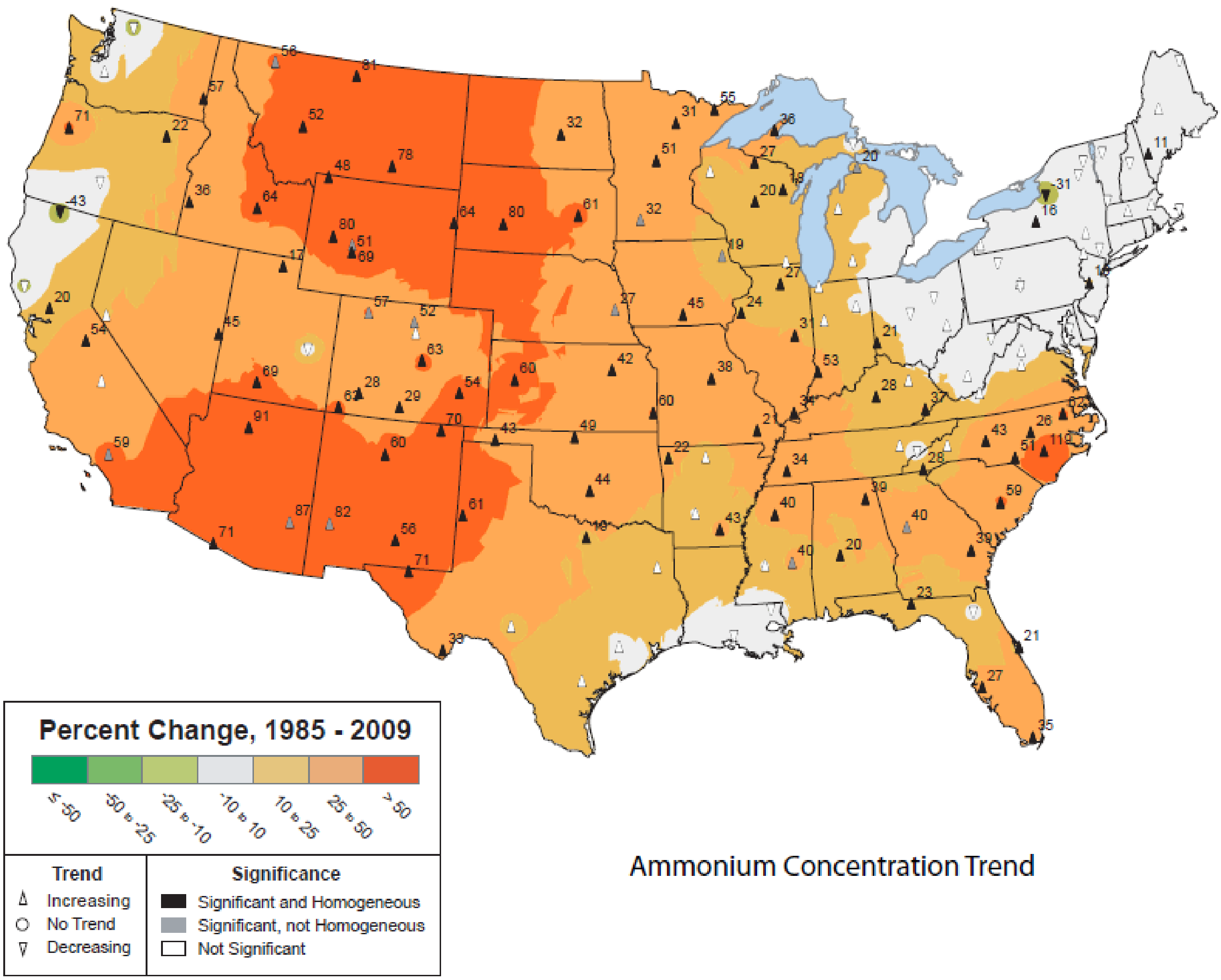

Figure 11: Trend significance and percent change 1985 to 2009 for ammonium concentration. Numeric values indicated at sites with a significant trend.

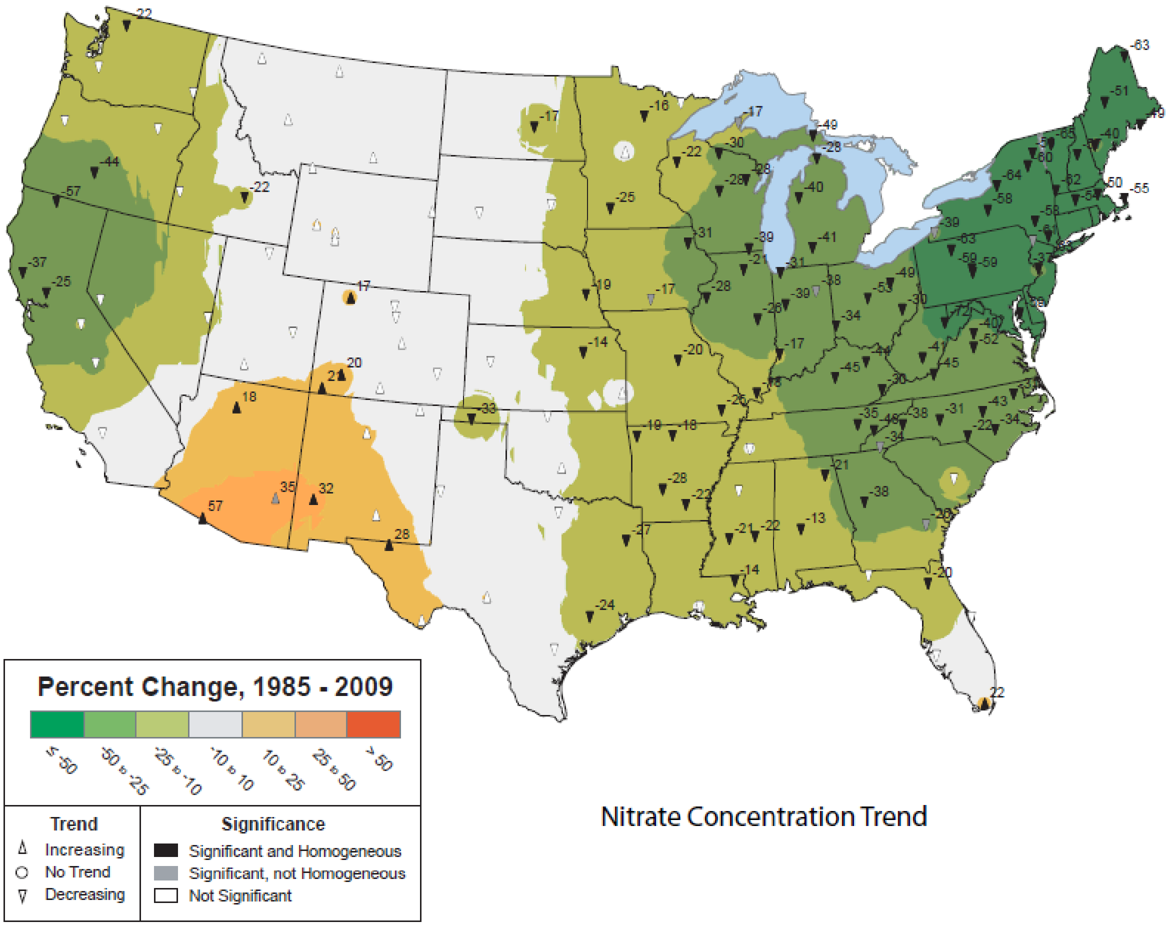

Figure 12: Trend significance and percent change 1985 to 2009 for nitrate concentration. Numeric values indicated at sites with a significant trend.

Figure 13 shows ammonia concentrations from the NADP Ammonia Monitoring Network (AMoN), which began in 2010. The AMoN is the only network that provides a consistent, long-term record of ammonia gas concentrations across the United States. Ammonia is an important gas that contributes to nitrogen dry deposition. These concentrations are presented here to provide information on the spatial patterns within and outside of the park. AMoN sites were installed at Loch Vale (10,364 feet) and at the base of Longs Peak (8,999 feet) in 2011. Concentrations at both sites were less than 1 $\mu g/m^3$ of ammonia during 2012, but were usually higher at Longs Peak. Concentrations of ammonia at an AMoN site in Fort Collins (5,151 feet) were much higher (2 – 7 $\mu g/m^3$).

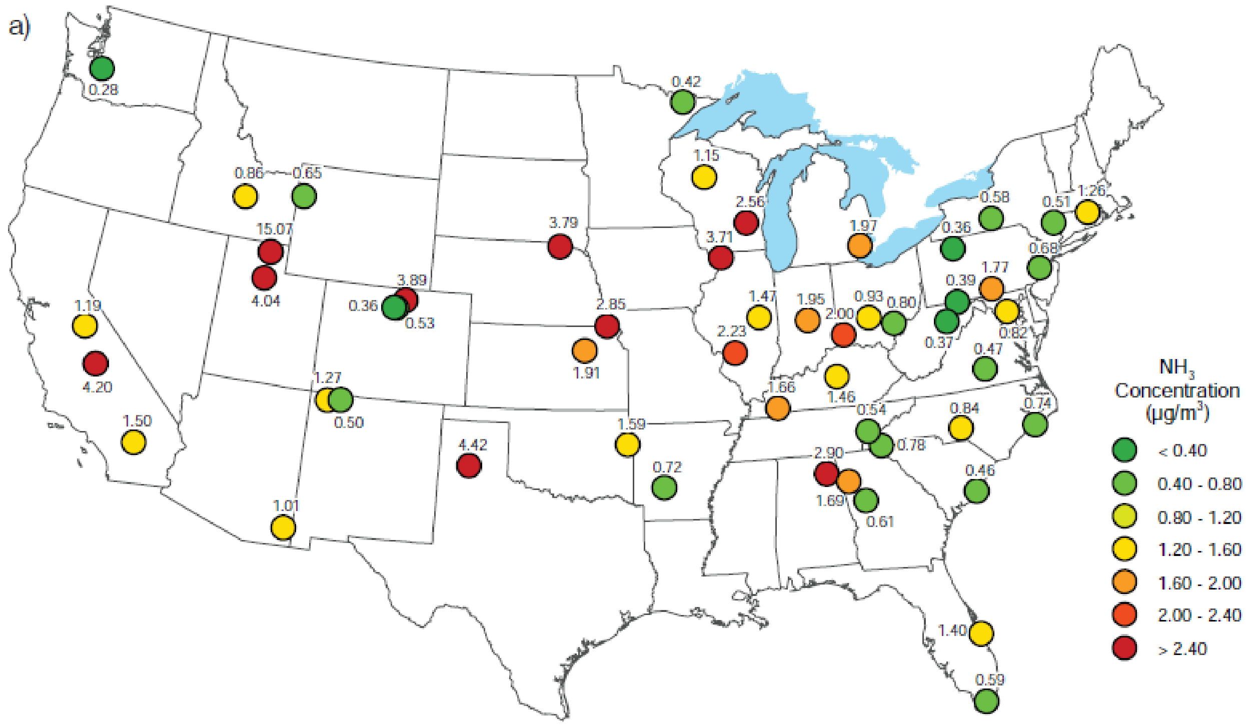

Figure 13: Ammonia concentrations at NADP AMoN Sites in 2012 (NADP)

3. Source Category and Source Area Attribution Analyses

3.1. Primary and Secondary Particulates

Airborne particulate matter can be a source of deposition in RMNP, particularly during precipitation events. Particulates can be emitted directly or form through secondary reactions between aerosol or gas-phase air pollutants. Both natural and anthropogenic sources contribute to directly emitted particulates, which can include windblown dust, fires, vehicle traffic and industrial sources. Typical sources leading to the formation of secondary particulates include fuel combustion, fires, vehicle traffic, industrial sources and agricultural operations.

Secondary particulate nitrate is formed when nitric acid reacts with ammonia creating ammonium nitrate (NH_4NO_3). Particulate sodium nitrate and calcium nitrate can also be formed near coastal areas and in dusty environments respectively. Measurements in RMNP indicate the majority of the fine particulate nitrate is in the form of ammonium nitrate. Figure 14 provides the particulate nitrate ambient air concentrations from the Interagency Monitoring of Protected Visual Environments (IMPROVE) RMNP monitor[4] over a five-year period (2007-2011). Figure 15 shows that the long-term annual trend for ammonium nitrate in ambient air is generally flat, but a downward trend is indicated in recent years.

[4] In the IMPROVE network, the RMNP monitor is designated ROMO1.

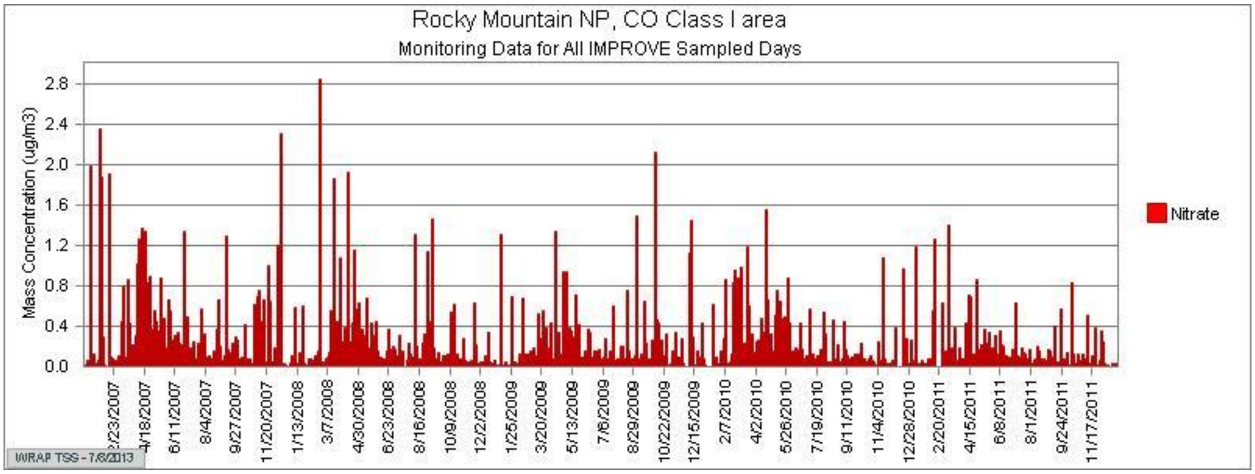

Figure 14: RMNP IMPROVE Monitor Daily Nitrate Mass Concentration

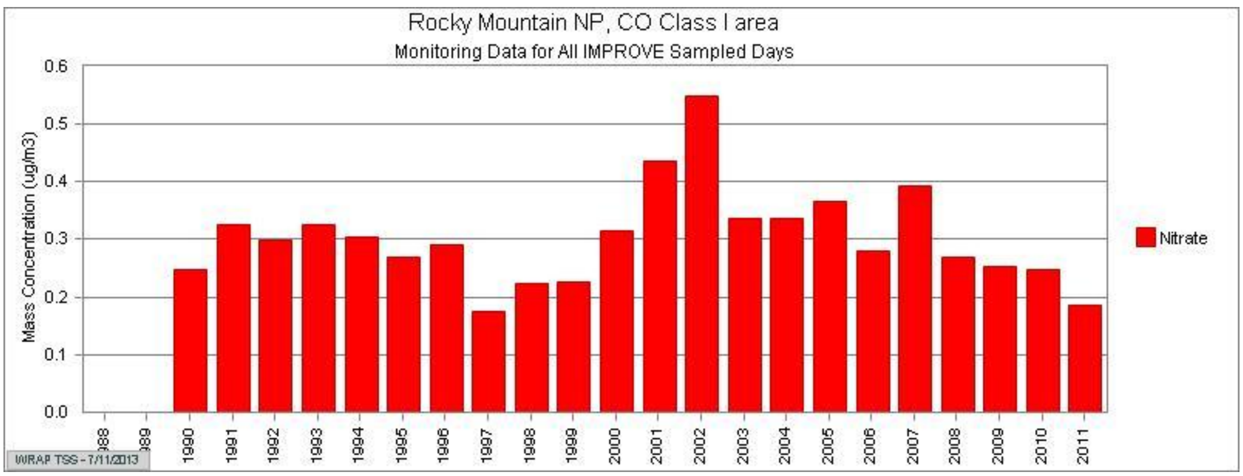

Figure 15: RMNP IMPROVE Monitor Annual Nitrate Mass Concentration

Since NO_x emissions, one of the sources of nitrogen deposition in RMNP, can also react with volatile organic compounds (VOCs) emissions in the presence of sunlight to form ozone, it is important to assess the relationship these emissions may have on secondary particulate formation. Secondary particulates can contribute to both dry and wet deposition; however, contributions can be highly variable depending on the chemical composition and deposit location.

In 2008 and 2009, the Western Regional Air Partnership (WRAP) Regional Modeling Center conducted regional photochemical modeling[5] using PM Source Apportionment Technology (PSAT) to determine primary and secondary particulate matter contributions from anthropogenic and natural sources. During the summertime months when VOC emissions are generally highest, this modeling suggests that anthropogenic VOC emissions are a very small contributor to the formation of anthropogenic secondary organic aerosol, denoted in red in Figure 16. Therefore, it can be surmised that VOC emissions are not a significant contributor to secondary particulate formation in RMNP. Consequently, man-made VOC emissions are not considered a significant contributor to deposition in RMNP.

[5] Analysis conducted using Community Multi-scale Air Quality model with 36 km continental grid scale. Model output can be found at the following website: http://vista.cira.colostate.edu/tss/Results/HazePlanning.aspx

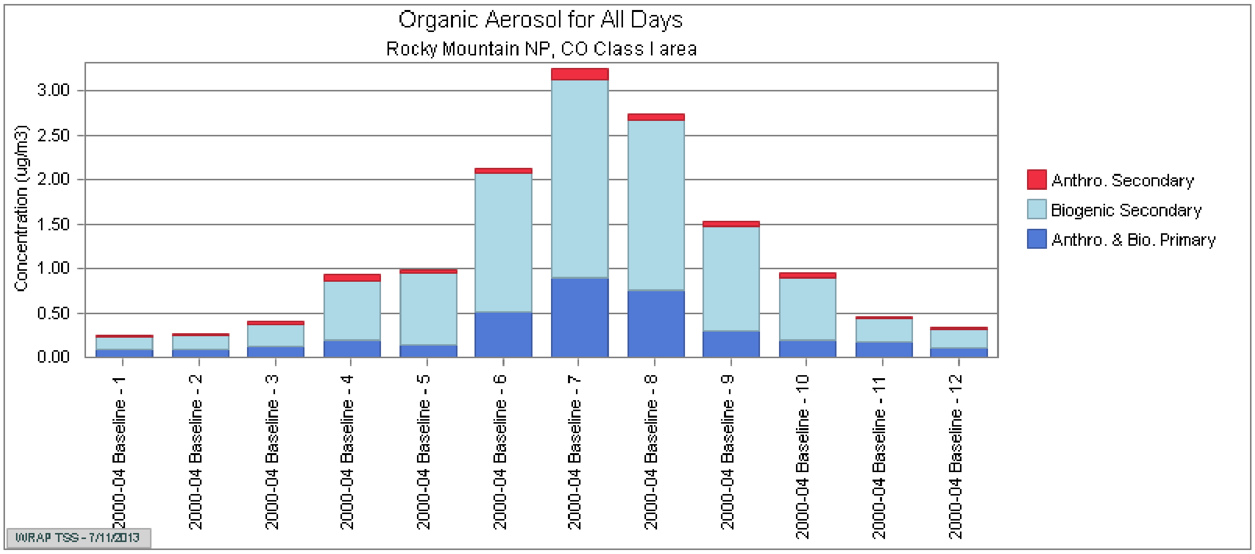

Figure 16: 2000 Baseline Monthly Modeled Organic Aerosol Concentrations for RMNP

In contrast, PSAT modeling indicates that anthropogenic NO_x emissions from point and mobile sources appear to be significant contributors to the formation of particulate nitrate in RMNP during the spring, fall, and winter months, shown in Figure 17. The highest concentrations are observed in the late fall. Based on this analysis, it appears that nitrate secondary particulate deposition in RMNP is largely driven by anthropogenic NO_x emissions during the fall and spring. However, NO_x emissions do appear to have an indirect role in minimizing nitrate formation during the summer because of primary involvement in ozone formation, indicated in columns 5 – 9 of Figure 17.

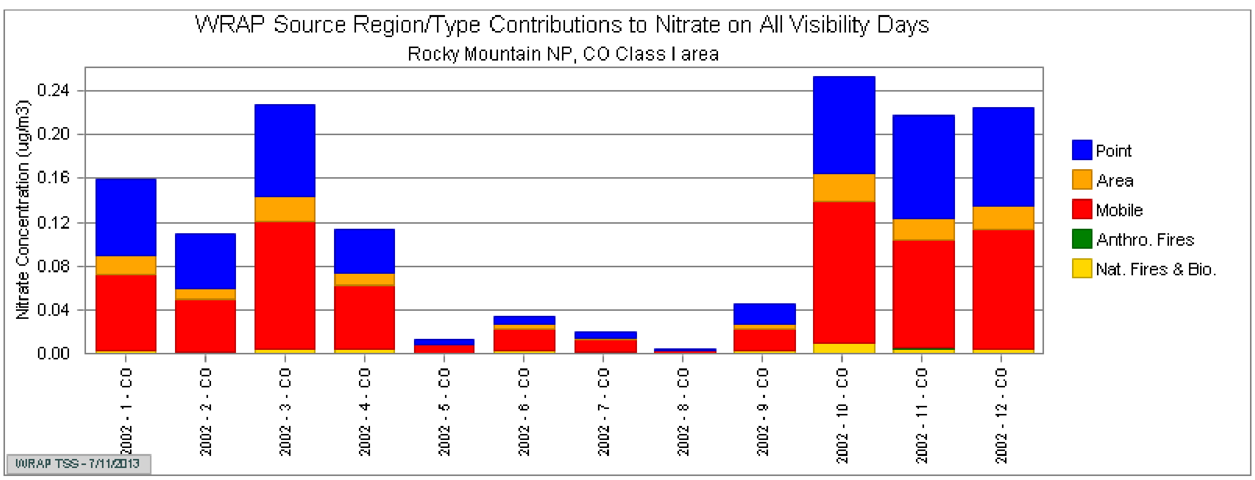

Figure 17: 2002 Baseline Monthly Modeled Nitrate Concentrations for RMNP

3.2. RoMANS I & II Summary

Two field studies were conducted in and around RMNP with the primary objective to better understand the composition and levels of the deposited reactive nitrogen in the park and the contribution of source regions to reactive nitrogen in RMNP. Reactive nitrogen includes nitrogen species capable of cascading through the environment, with oxidized forms being nitrous oxide (N_2O), nitrate (NO_3), and reduced forms comprised of ammonia (NH_3) and ammonium (NH_4). The non-reactive, inert, form is nitrogen gas (N_2), which comprises about 80% of the earth's atmosphere and does not contribute to the environmental impacts noted above. Reactive and non-reactive forms of nitrogen are formed both naturally and anthropogenically.

The first study, the Rocky Mountain Atmospheric Nitrogen and Sulfur Study (RoMANS I) was conducted for a spring and summer period in 2006, while the second (RoMANS II) was a yearlong study from November 2008 through November 2009. Sulfur contributes to degraded visibility in RMNP and is being addressed through the regional haze process. Therefore, this summary focuses on the nitrogen portion of the research to examine impacts regarding nitrogen deposition.

3.2.1. Study Methods

RoMANS I was conducted during a spring and summer period with a wide geographic distribution, containing sites such as Loch Vale and other RMNP sites as well as at sites across the northern half of the state of Colorado. A core monitoring site was established on the eastern side of RMNP near the Long's Peak trailhead, and contained the most extensive suite of monitoring instruments. During RoMANS II, monitoring was conducted at the core site, but for a longer time period. The yearlong duration of RoMANS II allowed for the study of reactive nitrogen deposition in other seasons.

During the two studies, historical and current meteorological data were extensively analyzed and incorporated into the air quality data and modeling analyses. Data and modeling analyses used a weight-of-the-evidence approach to compare and contrast results from multiple analysis techniques, including:

- Concentration gradients (relative ambient concentrations of a pollutant in different parts of the state);
- Pollution wind roses: a qualitative analysis that associates pollutant concentrations in RMNP with wind direction;
- Back trajectories: trajectories model regional transport pathways to RMNP for a given time period and were used in qualitative analyses to associate transport from source regions and along transport pathways with pollutant concentrations;
- Trajectory mass balance: a transport receptor model that gives semi-quantitative estimates of contributions from defined source regions
- Chemical transport models to simulate the emission and fate of reactive nitrogen emissions species;
- Hybrid transport receptor model: a quantitative assessment of the contributions from defined source regions. In this method, the transport of emissions from the source regions was estimated using the chemical transport model. These transport estimates were compared against measured pollutant concentrations to estimate the contributions from the source regions.

3.2.2. Study Outcomes

During the spring and summer 2006 field campaigns in the RoMANS I study, approximately two-thirds of the total measured nitrogen deposition was due to wet processes, with ammonium in-state sources estimated to contribute the highest amounts (34% spring and summer), followed by in-state nitrate sources (24% spring, 28% summer) (Beem et al., 2010). The study also revealed that wet deposition of organic nitrogen[6] is an important contributor (17% spring, 12% summer) to the total nitrogen deposition budget. Dry deposition of ammonia was also an important contributor (14% spring, 16% summer), while dry deposition of nitric acid, particulate nitrate, and particulate ammonium were of less importance with a combined contribution of less than 12% in both seasons.

The primary conclusions on the source regions responsible for the reactive nitrogen deposition in RMNP for both studies were consistent. Results of these two studies suggest that a substantial portion of deposited nitrogen originates from within the state of Colorado. More than half of the reduced nitrogen (ammonia/ammonium) is estimated to come from Colorado sources with 70% estimated during RoMANS I and 55% estimated during RoMANS II. Less than half of the oxidized nitrogen (nitric acid/nitrate) is estimated to originate from Colorado sources with approximately 40% coming from Colorado sources in RoMANS I. RoMANS II focused on ammonia apportionment and does not provide oxidized nitrogen origin estimates. These results suggest that reducing Colorado reactive nitrogen emissions can significantly reduce deposition in RMNP.

The RoMANS studies indicate that during spring and fall large scale weather events, also called synoptic scale upslope events, high concentrations of reduced and oxidized reactive nitrogen move from the eastern urban and agricultural areas of the state (Front Range, Greeley and northeastern Colorado) into RMNP. The transport from the east is also responsible for heavy precipitation, due to topographically forced lifting of the westward moving air, which effectively deposits the reactive nitrogen. These events are infrequent, but remain significant contributors to RMNP reactive nitrogen deposition. For example, in April 2006 during the RoMANS I campaign, a single two day event accounted for over 70% of the reactive nitrogen deposition in that month. Synoptic scale upslope forcing also occurs in the winter and summer months with less frequency. Transport is predominantly from the west of RMNP. However, transport from the east is associated with higher ammonia/ammonium and nitric acid/nitrate. In addition, precipitation is more likely to occur with the upslope easterly transport particularly during the summer months.

Semi-quantitative analyses using measured surface meteorological data and ammonia concentrations suggest that during ROMANs II, 44% and 56% of the annual ambient ammonia concentrations were associated with transport from the east and west, respectively. During precipitation events, this changed to 55% and 42% from the east and west, respectively. Trajectory analyses show that the distance scales of transport were smaller when transport was from the east compared to the west, indicating a higher probability of Colorado sources contributing to RMNP during eastern transport. Together, these results suggest that Colorado sources east of RMNP are significant contributors to reactive nitrogen deposition in RMNP.

In contrast to the semi-quantitative results, source attribution results from RoMANS II, based upon modeled meteorology and chemical transport and hybrid models, estimate that about 20% of the

[6] Organic nitrogen (ON) is composed of many compounds containing different fractions and bonds of nitrogen, carbon and other molecules, such as methylamine. Despite its apparent abundance in the atmosphere, ambient concentrations and deposition of ON are not measured in any routine monitoring program and often not measured in special field studies, therefore limiting our understanding of ON. This is partly due to the difficulty in measuring many of the ON compounds. Sources of ON also vary. It can be formed in the atmosphere by reactions between inorganic nitrogen compounds and VOCs. They are directly emitted into the atmosphere by source such as biomass burning and agriculture activities. The origin and fate of ON compounds in the atmosphere is still not well understood and remains an important uncertainty in investigations in reactive nitrogen deposition.

ambient ammonia is from eastern Colorado sources, such as the Front Range, Greeley and northeastern Colorado. The modeled meteorology underestimates the easterly transport associated with the convective mountain-valley circulation. This is most significant during the summer months with ammonia concentrations peak. It is thought that these are lower bound estimates for contributions from Colorado sources east of RMNP. In addition, distant sources west of the park were found to be significant contributors to ammonia/ammonium and nitric acid/nitrate concentrations. For example, source contribution estimates for ambient ammonia from California, Utah, and the Idaho Snake River Valley varied from 7 – 12%. This implies that there are regional components to both reduced and oxidized nitrogen deposition in RMNP.

In RoMANS I, a spring and summer period were modeled and analyzed. One finding was that local sources were potentially a significant contributor to summertime reactive nitrogen deposition. However, local contributions to reactive nitrogen deposition during the summer months were likely overestimated based on the results of RoMANS II, which used an updated modeling system and emission inventory as well as a full year of data. Along with this information, analysis of continuous monitoring data of multiple air pollutants at RMNP and laboratory studies of emissions from RMNP soil cores concluded that local (within RMNP and surroundings of up to about 30 miles in diameter) sources of ammonia are not a significant contributor to the annual ambient and deposited ammonia at RMNP.

3.2.3. GrandTReNDS and RoMANS Comparison

Grand Teton National Park (GTNP) is in the vicinity of some significant air pollution sources and is also home to sensitive alpine ecosystems. GTNP is located east of large agricultural operations in Idaho's Snake River Valley and northwest of growing oil and gas operations in western Wyoming. Although GTNP is popular with visitors, it has not historically hosted air quality or deposition monitoring stations. The Grand Tetons Reactive Nitrogen Deposition Study (GrandTReNDS) was conducted from April to September of 2011 to better understand the composition of reactive nitrogen deposited in the Grand Teton region and its origin. At the study's peak, twelve monitoring stations were in operation in GTNP and the surrounding region. A core measurement site was located on the west side of GTNP at the Grand Targhee ski resort. Other key measurement stations were located further west near Driggs, Idaho and on the east side of the park at the National Oceanic and Atmospheric Administration Climate Monitoring Station. Due to weather constraints, most monitoring was conducted from July through September 2011.

During the sampling period, reduced nitrogen, i.e. ammonia/ammonium, accounted for almost 60% of the reactive nitrogen deposition in GTNP, compared to about 50% measured during the RoMANS studies. Wet deposited organic nitrogen accounted for over 15% of the reactive nitrogen deposition at GTNP. A similar amount was measured at RMNP. This combined with the finding that organic nitrogen accounts for more than 20% of the reactive nitrogen measured in snow pack samples throughout the Rocky Mountains illustrates the importance of organic nitrogen to deposition in this region. Note that EPA is investigating ways to routinely measure organic nitrogen in the NADP wet deposition network.

Biomass burning events appear to contribute to large pulses of measured ammonia and gaseous organic nitrogen at GTNP. Biomass burning throughout the western United States also likely contributes to background ambient ammonia, nitrate and organic nitrogen during the summer months and is likely an important contributor to reactive nitrogen deposition in GTNP, RMNP and other sensitive ecosystems in the Rocky Mountains.

The GTNP modeling results suggest that ammonia/ammonium deposition is primarily a local scale issue with sources in the Idaho Snake River Valley and northern Utah being important contributors. The results of the GrandTReNDS study support the likelihood that local (in-state) sources, such as the Colorado Front Range, are important contributors to nitrogen deposition in RMNP. However, it should be noted that nitrogen deposition in RMNP is also impacted by distant out-of-state source regions more so than in GTNP.

3.2.4. Effects of Planned NOx Emission Reductions on Nitrogen Deposition in RMNP

Regional air quality modeling was conducted to examine how surface ozone concentrations would respond to anticipated reductions in future emissions of NO_x in the Denver Metro Area/North Front Range (DMA/NFR) (Environ, 2012). This modeling was also used to look at the NOx reduction effects on nitrogen deposition at RMNP. Baseline year (2008) and future year (2018) air pollution levels were simulated with a regional air quality model termed the Comprehensive Air Quality Model with Extensions. Significant reductions in DMA/NFR NOx emissions are expected by 2018, as illustrated in Figure 18, as a result of the Colorado Regional Haze State Implementation Plan, as well as decreasing tailpipe emissions from mobile sources due to federal emission standards and other state. Daily NO_x emissions are estimated to drop from 401 tons/day in 2008 to 249 tons/day in 2018, an approximate 38% daily reduction.

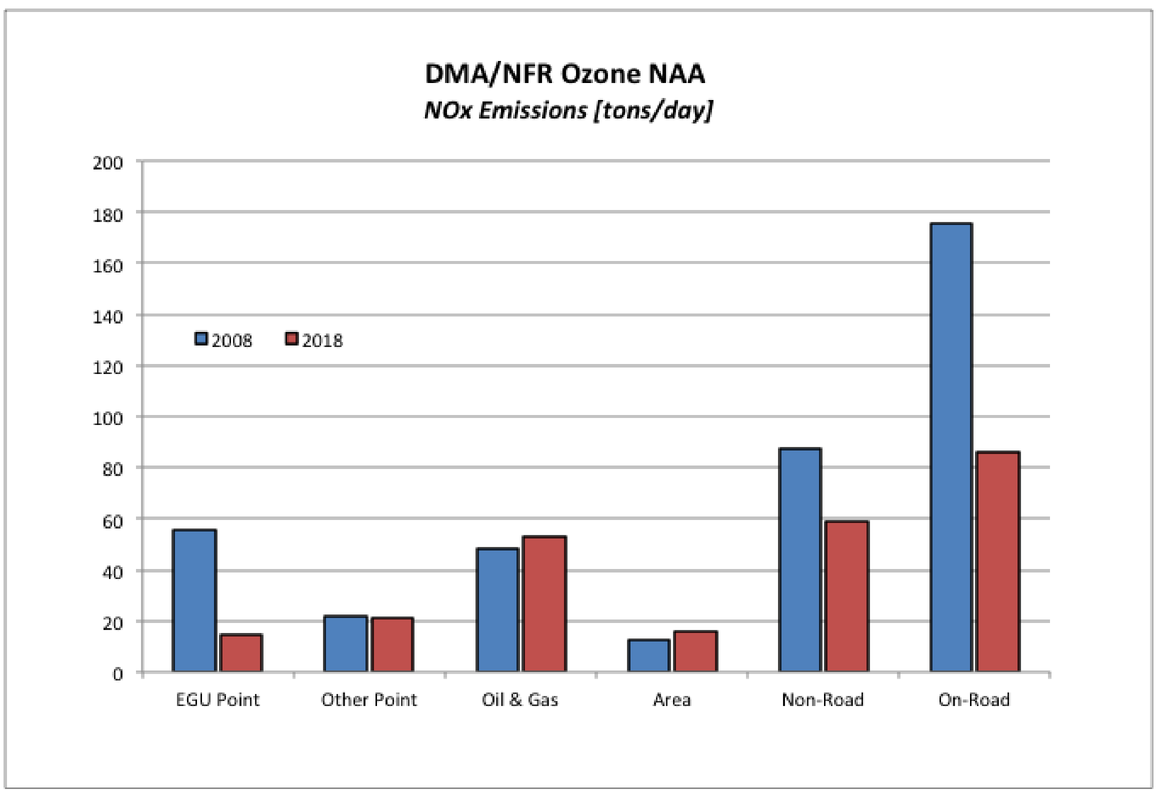

Figure 18: Estimated (2008) and future (2018) NO_x emissions (tons/day) in the DMA/NFR Ozone Nonattainment Area

The simulation period spans the four months of May through August, when ozone levels are highest in the DMA/NFR area. A full year simulation would have been preferable to replicate and carefully evaluate different seasonal wind patterns, emission sources, and nitrogen species. Regardless, this study still gives an indication as to how nitrogen deposition at RMNP will respond to future NO_x emission reductions.

The modeling study provides additional verification that oxidized nitrogen species that contribute to nitrogen deposition at RMNP, such as nitric acid and particulate nitrate, are strongly influenced by NO_x mitigation within the DMA/NFR. Figure 19 shows the change in simulated nitrogen deposition in north-central Colorado from 2008 to 2018 during the May to August timeframe. In this example, both wet and dry deposition of all of the nitrogen-containing species predicted by the regional air quality model are considered, representing a larger pool of species than is reported by the deposition monitoring networks. Clearly, the largest decrease in nitrogen deposition occurs in the DMA/NFR, but changes are also evident at RMNP, ranging from 0.1 kg N/ha on the western boundary of RMNP to 0.6 kg N/ha along the eastern edge. Very strong concentration gradients are apparent at the eastern edge of RMNP, reflecting both the distribution of NO_x sources and complex terrain within RMNP.

Although it is encouraging that future nitrogen deposition is predicted to decrease, the limitations of applying this modeling platform, which again was primarily designed to evaluate ozone and not nitrogen deposition, should be noted. For example, future ammonia emissions were left at current levels, even though they are uncertain. Previous research at RMNP indicates that a substantial portion of the overall nitrogen deposition budget can be attributed to ammonia, and hence its role in future deposition is likely underestimated. Future NO_x emissions from rapidly expanding oil and gas development in Colorado are uncertain but are continually assessed by CDPHE and other stakeholders. This is discussed further in Section 4.8.3.

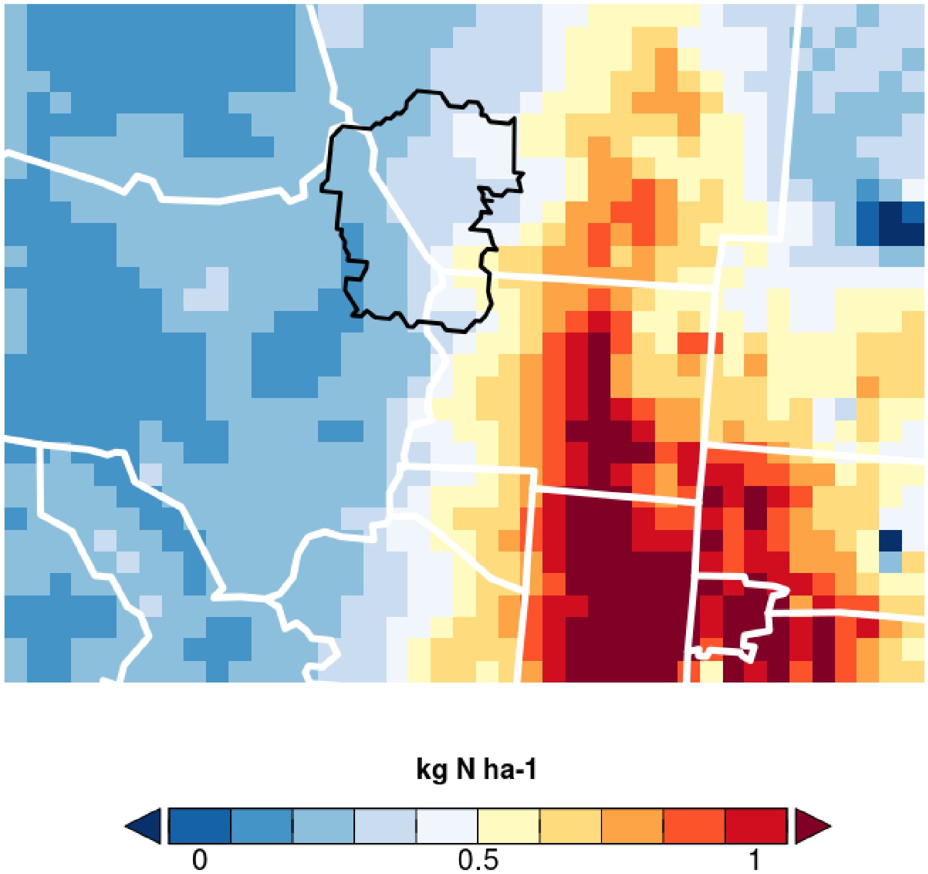

Figure 19: Reductions in simulated nitrogen deposition in north-central Colorado (May - August 2008). RMNP is outlined in black. Horizontal model grid resolution is 4 km.

4. Emission Inventories, Trends, and Studies

4.1. Background

The EPA develops and maintains the National Emissions Inventory (NEI). The NEI is a comprehensive and detailed estimate of air emissions of both criteria and hazardous air pollutants from all air emissions sources in the United States. Nitrogen emissions inventoried in the NEI are NO_x and ammonia. Since other nitrogen compounds are not directly emitted, they are not inventoried, but typically modeled, monitored, or researched as described earlier. The NEI is prepared every three years by the EPA and is based primarily upon emission estimates and emission model inputs provided by state, local, and tribal air agencies for sources in their jurisdictions, and supplemented by data developed by the EPA. The version of the NEI used in this report is Version 3 of the 2008 NEI (2008 NEIv3[7]) that CDPHE obtained from the EPA during August 2013 for the state of Colorado.

Emission inventories are useful in the context that they can provide characterization of temporal emission trends, emissions budgeting for regulatory and compliance purposes, and help predict

[7] http://www.epa.gov/ttn/chief/net/2008inventory.html

ambient pollutant concentrations using air quality models and data reporting. However, inventories may change drastically as new data methodologies emerge even if actual ‘ground-level’ emissions have not. For example, EPA determined highway vehicle NO_x emissions using the Motor Vehicle Emission Simulator (MOVES) model for the first time in the 2008 NEI. The revised approach predicts higher NO_x and PM emissions than included in the 2005 NEI, which was based on the MOBILE6 model. MOVES and MOBILE6 are emission factor models for predicting gram per mile emissions of NO_x, hydrocarbons, carbon monoxide, carbon dioxide, particulate matter (PM), and toxics from cars, trucks, and motorcycles under various conditions. However, actual highway vehicle emissions have not increased, but rather the scientific understanding of pollutant emissions has improved. This example highlights the fact that while emission inventories are an important tool in the weight of the evidence approach, caution must be exercised when examining inventory data.

It is important to note that the MOU agencies recognize that while the NEI is the most comprehensive national emission inventory available in the United States, other entities such as the Western Regional Air Partnership (WRAP), Carnegie Mellon University (CMU), Cooperative Institute for Research in the Atmosphere, and CDPHE continue to investigate and improve data and methodologies associated with emission inventories, discussed in Sections 4.5 and 4.8. The NEI is not the only emission inventory source available and may not always be the best source of information, such as in the case of oil and gas emissions or with some ammonia inventory categories. Different inventories are developed for different purposes. The NEI is a national inventory with homogenous methods applied nationally. However, regional and local inventories are developed or being developed which are more detailed (e.g. one of the modeling studies uses the WRAP Phase III Oil and Gas inventory, which is more detailed than the NEI). CDPHE has participated in numerous workgroups to bolster inventory knowledge to develop Colorado- specific bottom-up emissions, both internally within CDPHE and externally by working with other entities, further discussed in Section 4.8.4.

4.2. Demographic and Emission Trends

Recent demographic trends show an increase in the developed landscape within Colorado. According to the Denver Regional Council of Governments, the nine counties of the Denver Metropolitan Area (DMA) had a population of 2,719,432 and households totaling 1,069,791 in 2006. In the year 2010, the DMA had a population of 2,985,595 and 1,177,354 households, showing an increase in population of about 9% in a four-year period. From the 2011 to 2017 time period, vehicle miles traveled per person are projected to increase about 12% in the DMA.

During the 1990s, this nine county region, including Boulder, Gilpin, Clear Creek, Jefferson, Douglas, Arapahoe, Adams, Denver and Broomfield, added 90 square miles of urban area, growing from 410 square miles in the year 1990 to 500 square miles by the year 2000. Of the more than 200,000 people added to the region, 45% located in areas not previously urbanized. It is predicted that by the year 2022, Colorado will lose another 3.1 million acres of agricultural land to urban development, according to Environment Colorado Research and Policy Center.

To the extent there are not reliable inventories for ammonia emissions, inventories and trends regarding the sources themselves are relevant. For example, total cattle, farms, harvested crops, and hogs all remain at about the same level as they were in 2008 as shown in Figure 20 –Figure

22. It should be noted that the number of agricultural producers is no longer tracked, so this information is not included in this report.

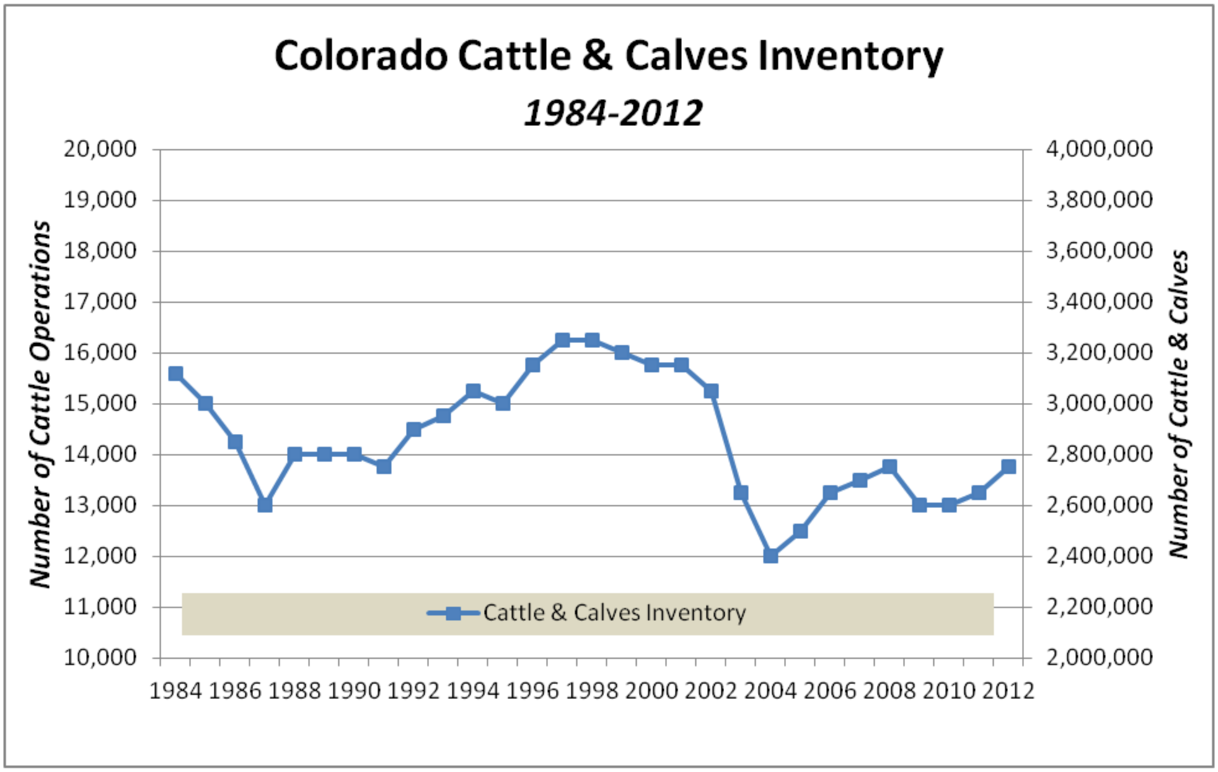

Figure 20: Colorado Cattle & Calves Inventory (1984-2012)

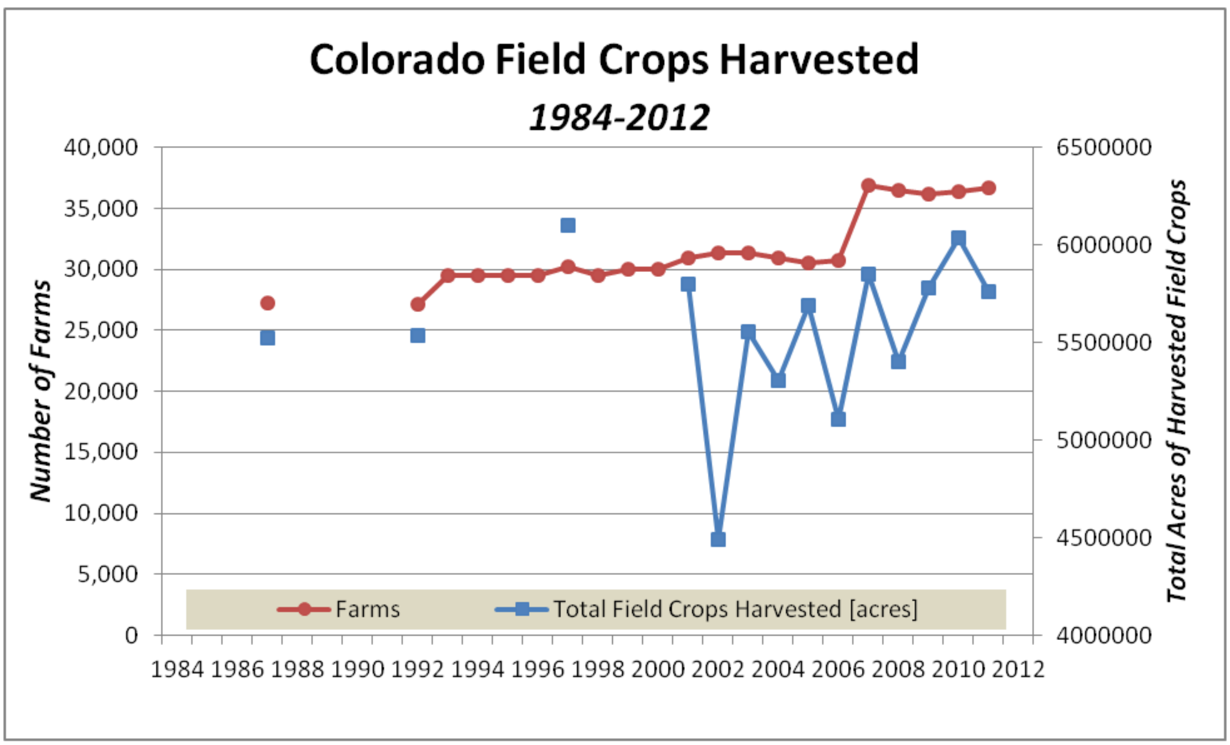

Figure 21: Colorado Field Crops Harvested (1984 - 2012)

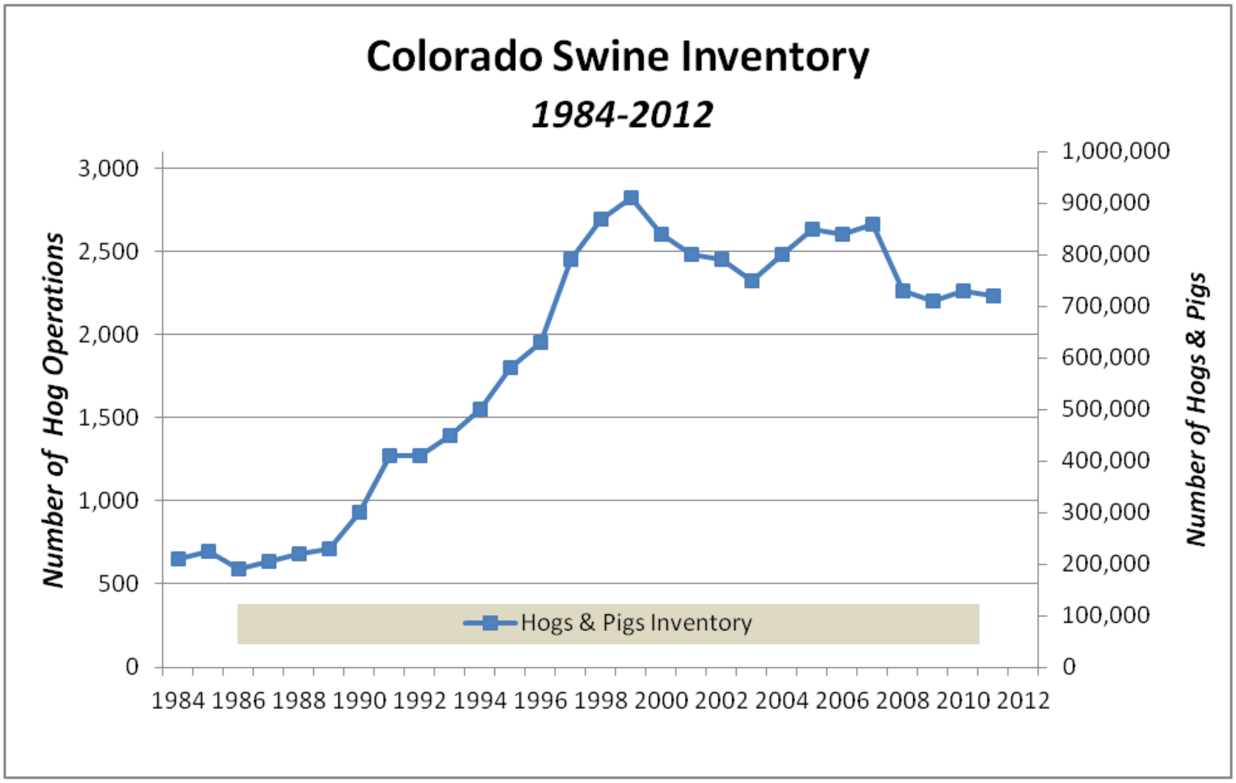

Figure 22: Colorado Swine Inventory (1984 - 2012)

Nationally, annual mean concentrations of nitrogen dioxide (NO_2), a common surrogate used to estimate NO_x emissions, decreased 52% between 1980 and 2010, with a 33% decrease occurring between 2001 and 2010, as shown in Figure 23. All recorded concentrations are well below the level of the annual human-health based standard (53 ppb). Downward trends in annual NO_2 are the result of various national emissions control programs, such as vehicle standards, New Source Performance Standards, State Implementation Plan requirements, and other emission control requirements. NO_2 continues to be tracked because of its' contribution to other air pollutants (e.g. ozone and $PM_{2.5}$), reduced visibility, and contribution to deposition.

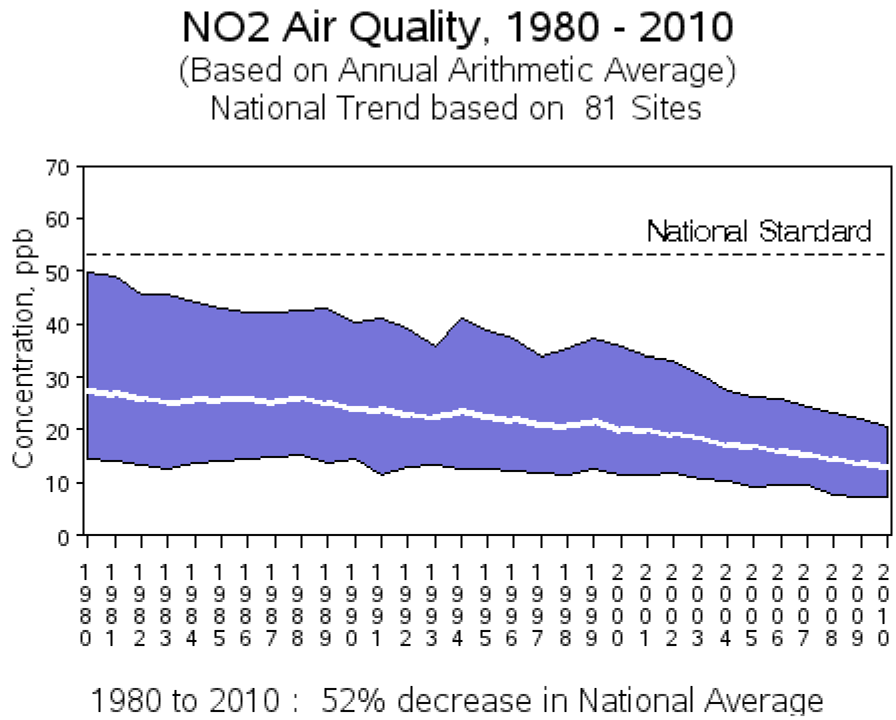

Figure 23: National Trends in Nitrogen Dioxide (NO_2) Levels

From a local perspective, the Denver/Front Range metropolitan area has seen a gradual decline in ambient NO_2 levels since 1991, with levels showing a 34% overall decrease in the 20 years between 1990 and 2010, illustrated in Figure 24.

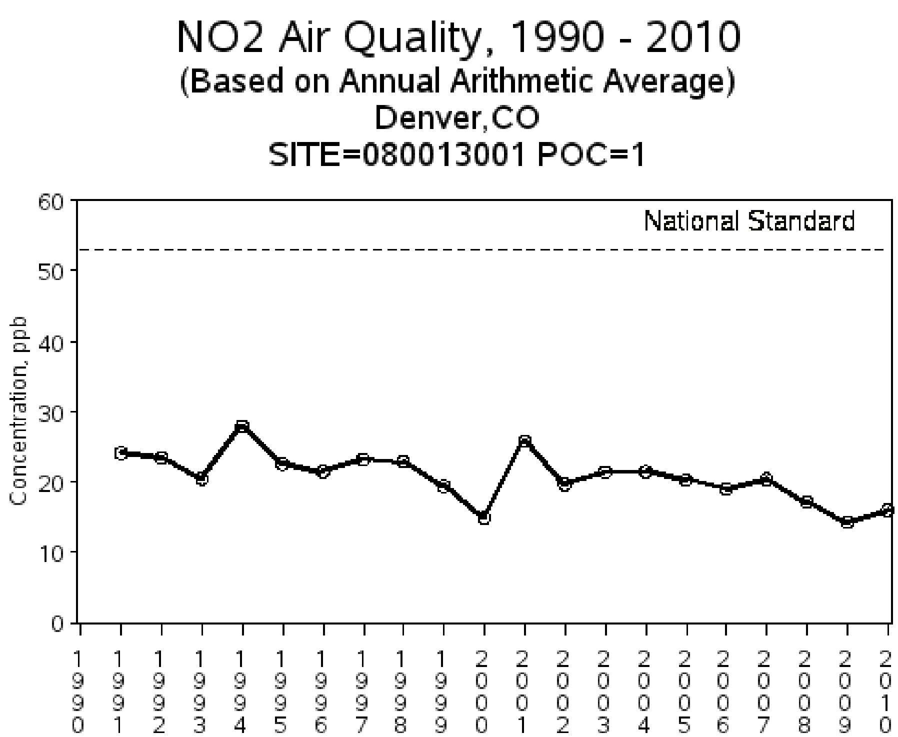

Figure 24: NO_2 Trends from Denver Metropolitan Site (1990 – 2010)

Using EPA's most recent 2008 NEI, Figure 25 demonstrates that nationally ammonia emissions have remained fairly stable since 2002. There was a slight increase in 2008 over the last 2005 NEI because of the addition of miscellaneous source categories, which include prescribed fires and waste disposal. Waste disposal increases are largely due to the addition of municipal and commercial composting in the 2008 NEI.

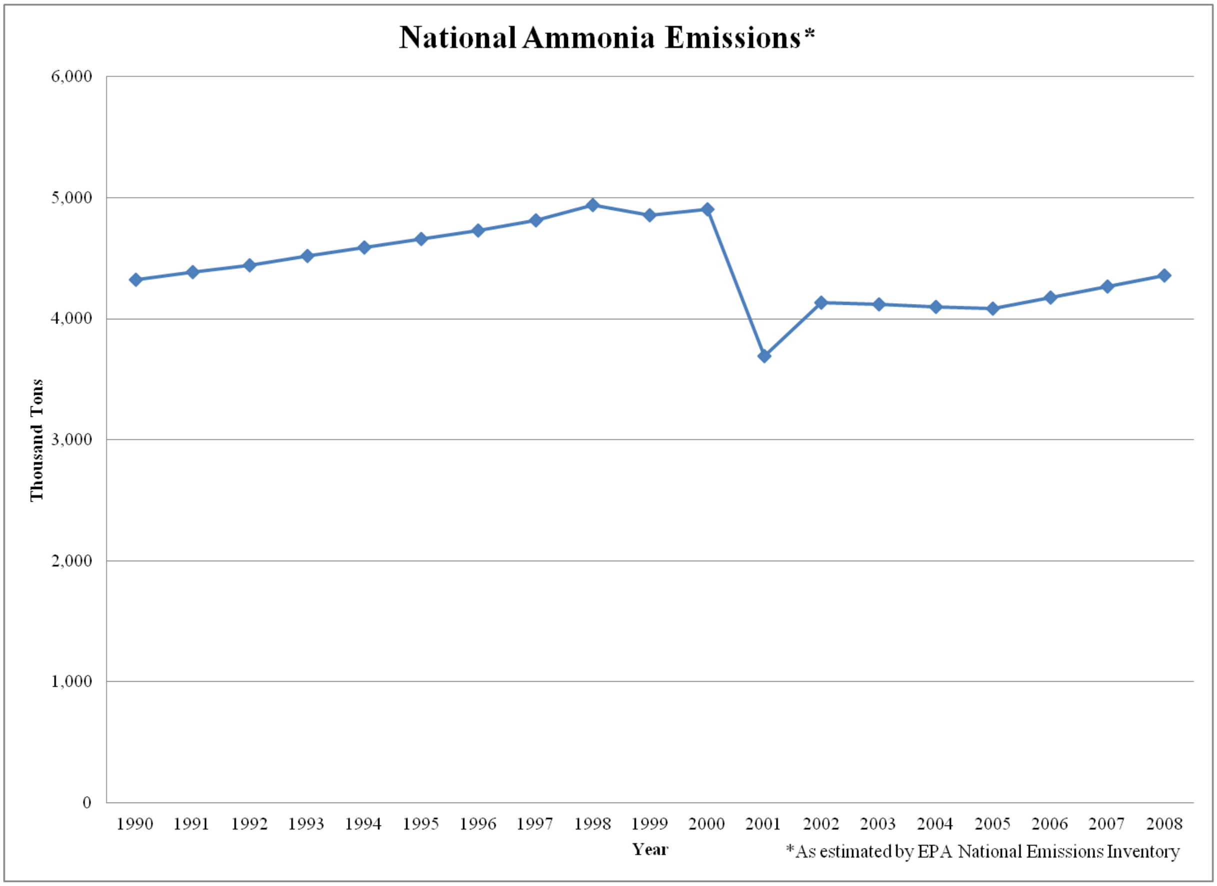

Figure 25: National Ammonia Emissions (1990 - 2008)

4.3. Statewide Emissions Inventories

Table 6 displays the 2008 NEI for the 64 counties of Colorado. Over the years, the NEI has evolved as source categories change, emission tracing improves and new sources emerge. The 2008 NEI does not include oil and gas exploration and production sources as this source category was not well characterized until more recently as inventories characterizing Rocky Mountain Region oil and natural gas production basins improved. The 2011 NEI, which should be released in 2014, will likely contain this category.

Table 6: 2008 NEI for Colorado Counties in tons per year (tpy)

County Name	*VOC [tpy]*	*NO_X [tpy]*	*CO [tpy]*	*SO_2 [tpy]*	*PM_{10} [tpy]*	*NH_3 [tpy]*
Adams	14,239	25,603	64,726	7,737	15,755	1,081
Alamosa	1,867	589	3,225	51	1,535	423
Arapahoe	13,489	11,884	80,521	258	14,904	467
Archuleta	1,581	535	7,193	32	1,706	227
Baca	707	1,569	2,085	14	7,279	1,590

County Name	VOC [tpy]	NO_X [tpy]	CO [tpy]	SO_2 [tpy]	PM_{10} [tpy]	NH_3 [tpy]
Bent	583	1,350	2,356	13	1,251	950
Boulder	7,698	10,458	43,695	917	5,431	600
Broomfield	1,423	1,344	7,859	20	2,218	28
Chaffee	1,366	609	6,315	18	1,638	130
Cheyenne	1,207	3,334	2,792	17	6,533	568
Clear Creek	1,303	1,874	11,267	17	2,656	58
Conejos	1,309	455	5,471	26	1,460	485
Costilla	1,119	324	3,814	19	1,691	220
Crowley	257	328	1,097	4	671	523
Custer	432	164	1,677	3	734	322
Delta	1,547	1,295	7,819	37	2,153	593
Denver	15,353	21,173	92,939	3,261	13,878	547
Dolores	851	422	2,567	9	1,729	103
Douglas	6,856	7,372	41,866	145	5,068	410
Eagle	2,602	3,453	18,517	50	3,780	310
Elbert	986	1,276	5,351	11	8,952	619
El Paso	20,514	22,341	117,226	12,701	21,880	1,073
Fremont	1,471	4,585	8,504	1,609	3,738	348
Garfield	12,940	7,856	24,365	127	4,707	375
Gilpin	275	506	1,683	6	478	19
Grand	2,333	1,782	10,674	86	3,366	261
Gunnison	3,356	1,117	14,340	68	2,737	343
Hinsdale	1,072	61	2,839	4	598	20
Huerfano	741	1,046	4,573	11	1,493	205
Jackson	1,401	307	4,190	21	770	264
Jefferson	14,597	14,450	82,383	2,897	10,408	510
Kiowa	579	483	1,586	5	8,139	427
Kit Carson	914	2,194	6,627	24	11,810	4,893
Lake	613	317	2,891	9	634	322
La Plata	3,451	2,111	17,669	71	3,884	404
Larimer	10,146	9,876	57,524	1,019	11,612	1,823
Las Animas	2,739	3,129	11,656	65	3,601	561
Lincoln	520	1,156	3,060	9	6,084	722
Logan	1,212	3,262	6,270	80	7,341	4,462
Mesa	6,393	7,191	30,883	2,823	5,759	1,120
Mineral	1,179	276	3,608	7	316	17
Moffat	3,624	18,327	8,190	3,959	7,919	597
Montezuma	1,795	1,387	8,174	55	2,663	342
Montrose	1,890	2,942	9,050	1,310	3,712	979
Morgan	1,641	8,671	8,471	13,466	6,880	5,765
Otero	927	1,581	4,601	18	1,920	1,450
Ouray	578	350	2,610	7	1,105	303
Park	1,743	643	8,148	29	2,229	310
Phillips	412	633	1,243	16	6,442	1,579
Pitkin	900	690	4,944	16	1,005	66
Prowers	814	2,047	4,004	26	4,897	2,886
Pueblo	6,255	12,312	32,747	11,024	11,168	734
Rio Blanco	3,860	3,467	6,646	52	5,132	403
Rio Grande	2,840	648	5,263	18	1,556	805
Routt	1,755	8,507	9,719	2,590	4,040	365

County Name	VOC [tpy]	NO_X [tpy]	CO [tpy]	SO_2 [tpy]	PM_{10} [tpy]	NH_3 [tpy]
Saguache	2,318	453	4,597	23	2,257	531
San Juan	1,193	130	3,212	2	261	2
San Miguel	1,026	836	3,797	9	1,424	108
Sedgwick	282	910	1,981	9	4,555	882
Summit	1,696	1,632	11,372	24	1,621	66
Teller	1,373	965	7,755	79	3,794	156
Washington	518	1,458	2,932	17	11,708	1,446
Weld	32,011	17,992	56,073	352	28,851	17,042
Yuma	1,305	2,540	3,708	26	11,606	8,938
Statewide Totals:	***233,976***	***268,576***	***1,034,940***	***67,429***	***337,120***	***74,180***
9-County Area Totals:	*115,813*	*120,152*	*527,586*	*16,607*	*108,123*	*22,507*

Notes: *Biogenic Emissions and Portable Sources Excluded*
Inventory Includes Point, Mobile and Area Sources
Oil & Gas Area Sources not included in 2008 NEI
Ozone Non-Attainment Area for 9-County area is shaded in blue

4.4. Denver Metro Area/North Front Range Emissions Inventories

Table 7 shows county-level source category detail for the DMA/NFR ozone nonattainment area from the 2008 NEI.

Table 7: 2008 NEI for 9-County Ozone Nonattainment Area in tons per year (tpy)

County Name	Source Category	VOC [tpy]	NO_X [tpy]	CO [tpy]	SO_2 [tpy]	PM_{10} [tpy]	NH_3 [tpy]
Adams	Fuel Comb. Electric Utilities	70	11,422	610	6,778	242	36
	Fuel Comb. Industrial	300	2,700	1,233	64	61	
	Fuel Comb. Other	325	686	1,894	85	264	114
	Chemical Product Mfg	7	3	2	58	5	
	Metals Processing	0				4	
	Petroleum Industries	408	523	518	629	365	
	Other Industrial Processes	469	8	48	0	1,564	
	Solvent Utilization	3,368	1	0	0	15	
	Storage & Transport	3,923	42	106	0	143	
	Waste Disposal & Recycling	113	14	70	6	721	2
	Highway Vehicles	3,482	7,059	38,215	63	404	175
	Off-Highway	1,740	3,140	21,865	53	247	3
	Miscellaneous	35	6	164	2	11,720	751
Arapahoe	Fuel Comb. Electric Utilities	10	125	53	4	1	
	Fuel Comb. Industrial	22	756	294	39	6	
	Fuel Comb. Other	327	833	2,130	15	280	161
	Metals Processing	1	1			4	
	Petroleum Industries	81	19	46	20	5	
	Other Industrial Processes	96	8	131	0	394	

County Name	Source Category	VOC [tpy]	NO_X [tpy]	CO [tpy]	SO_2 [tpy]	PM_{10} [tpy]	NH_3 [tpy]
	Solvent Utilization	3,570	0	0	0	3	
	Storage & Transport	2,729				34	
	Waste Disposal & Recycling	156	21	78	58	471	2
	Highway Vehicles	3,849	7,488	41,918	70	439	192
	Off-Highway	2,641	2,631	35,838	51	288	3
	Miscellaneous	7	2	33	1	12,980	108
Boulder	Fuel Comb. Electric Utilities	18	2,377	216	740	39	9
	Fuel Comb. Industrial	16	366	136	9	15	
	Fuel Comb. Other	313	539	2,052	12	285	104
	Chemical Product Mfg	63					
	Metals Processing	0	0	0	0	1	
	Petroleum Industries	23	31	69	27	25	
	Other Industrial Processes	86	1,309	388	57	947	
	Solvent Utilization	1,908				1	
	Storage & Transport	1,603	1	3		73	
	Waste Disposal & Recycling	28	3	6	1	3	1
	Highway Vehicles	2,085	4,001	22,289	37	234	102
	Off-Highway	1,533	1,827	18,437	32	166	2
	Miscellaneous	22	3	99	1	3,641	382
Broomfield	Fuel Comb. Electric Utilities	6	99	23	6	6	
	Fuel Comb. Industrial	10	1	3	0	2	
	Fuel Comb. Other	31	4	197	0	31	2
	Chemical Product Mfg	37				0	
	Other Industrial Processes	25	-	5	-	16	
	Solvent Utilization	432				1	
	Storage & Transport	229	0	0		2	
	Waste Disposal & Recycling	10	0	0	0	0	0
	Highway Vehicles	483	991	5,448	9	55	25
	Off-Highway	155	249	2,156	4	19	0
	Miscellaneous	6	1	27	0	2,086	0
Denver	Fuel Comb. Electric Utilities	26	3,047	212	2,615	155	11
	Fuel Comb. Industrial	34	492	312	13	24	
	Fuel Comb. Other	462	1,142	3,128	47	426	197
	Chemical Product Mfg	43			2	7	
	Metals Processing	4	0	42	0	0	
	Petroleum Industries	37	40	92	38	49	
	Other Industrial Processes	316	16	190	113	607	
	Solvent Utilization	4,258	0	0	0	16	
	Storage & Transport	2,416	0	2		20	
	Waste Disposal & Recycling	60	12	5	7	12	2
	Highway Vehicles	4,996	9,910	54,750	92	584	251
	Off-Highway	2,699	6,511	34,206	334	327	3
	Miscellaneous	1	1	0	0	11,652	82
Douglas	Fuel Comb. Electric Utilities	0	2	0	0	0	
	Fuel Comb. Industrial	1	55	11	3	2	
	Fuel Comb. Other	232	286	1,446	7	202	61
	Petroleum Industries	39	37	143	34	32	
	Other Industrial Processes	13	49	111	17	314	

County Name	Source Category	VOC [tpy]	NO_X [tpy]	CO [tpy]	SO_2 [tpy]	PM_{10} [tpy]	NH_3 [tpy]
	Solvent Utilization	1,694	0	0	0	2	
	Storage & Transport	1,300				7	
	Waste Disposal & Recycling	42	4	97	0	18	1
	Highway Vehicles	2,086	4,501	23,485	37	239	107
	Off-Highway	1,403	2,434	16,380	43	201	2
	Miscellaneous	46	4	193	2	4,050	238
Jefferson	Fuel Comb. Electric Utilities	3	11	9	2	2	
	Fuel Comb. Industrial	127	1,562	364	2,358	93	
	Fuel Comb. Other	567	897	3,785	18	536	195
	Metals Processing	0	0		0	3	
	Petroleum Industries	28	28	116	25	30	
	Other Industrial Processes	673	568	273	346	937	
	Solvent Utilization	3,589	1	1	1	26	
	Storage & Transport	2,514				130	
	Waste Disposal & Recycling	61	22	129	10	13	2
	Highway Vehicles	4,393	8,478	47,229	78	490	216
	Off-Highway	2,432	2,872	29,602	53	270	3
	Miscellaneous	211	11	875	6	7,878	94
Larimer	Fuel Comb. Electric Utilities	35	1,807	332	873	109	17
	Fuel Comb. Industrial	7	139	59	4	12	
	Fuel Comb. Other	547	552	3,479	26	496	101
	Metals Processing	0	1	1	0	0	
	Petroleum Industries	18	20	159	16	16	
	Other Industrial Processes	207	24	31	2	704	
	Solvent Utilization	2,003				7	
	Storage & Transport	1,585	7	8	0	143	
	Waste Disposal & Recycling	148	5	2	2	61	1
	Highway Vehicles	2,786	5,602	30,026	40	270	111
	Off-Highway	2,014	1,676	20,043	31	171	2
	Miscellaneous	796	43	3,384	24	9,621	1,591
Weld	Fuel Comb. Electric Utilities	173	1,106	1,188	43	300	105
	Fuel Comb. Industrial	1,916	6,733	4,997	26	206	
	Fuel Comb. Other	303	330	2,111	12	311	67
	Chemical Product Mfg	26				0	
	Metals Processing	75	9	7	0	40	
	Petroleum Industries	734	52	138	46	41	
	Other Industrial Processes	209	223	80	131	1,774	
	Solvent Utilization	2,916	17	21		26	
	Storage & Transport	21,304	292	633	1	281	
	Waste Disposal & Recycling	121	8	21	2	104	1
	Highway Vehicles	2,647	6,182	29,640	39	266	112
	Off-Highway	1,516	3,020	16,769	49	226	2
	Miscellaneous	71	19	468	4	25,276	16,755

Notes: *Biogenic Emissions and Portable Sources Excluded*
Inventory Includes Point, Mobile and Area Sources
Oil & Gas Area Sources not included in 2008 NEI

4.5. Ammonia Emissions Detail

Table 8 outlines county-level detail for ammonia emissions in Colorado. The miscellaneous source category outlined in the NEI comprises about 94% of the ammonia emissions statewide, which includes agriculture livestock (72.8%), fertilizer (19.6%) and fire sources (1.5%). The livestock waste emissions are based on the Carnegie Mellon University (CMU) Ammonia Model (version 3.6) using 2007 animal population data. The fertilizer emissions are based on the CMU Ammonia Model using county-level fertilizer consumption data for 2002 and 2007 from the Fertilizer Institute's Commercial Fertilizers Report.

Ammonia emissions from fires are determined using a combination of technical models[8] based on fire area burned and fuel consumed for both prescribed fires and wildfires. The WRAP Fire Emissions Joint Forum went through four distinct phases of fire emissions inventory development to continue improving fire emissions inventories as part of the WestJumpAQMS project. Fire emissions are classified as wildfires, prescribed burns, or agricultural burning. Overall fire source contributions are minor. Due to a potential increase in wildfires in Colorado and the West in the future, it is important to continue evaluating fire emissions and noting if this source category becomes significant in the future.

Highway vehicle ammonia emissions from the 2008 NEI estimate ammonia emissions to be about 54% lower than emissions reported in the 2005 NEI, which used an earlier model type. Fuel combustion ammonia emissions are based on fuel type and reported fuel burned.

Table 8: 2008 NEI - Colorado Ammonia Emissions

County	Livestock [tpy]	Fertilizer [tpy]	Fires [tpy]	Highway Vehicles [tpy]	Fuel Combustion [tpy]
Adams	294	457	2	175	128
Alamosa	126	283	2	7	4
Arapahoe	76	32	0	192	187
Archuleta	149	7	57	6	2
Baca	1,185	401	2	4	2
Bent	873	73	1	3	2
Boulder	249	133	1	102	112
Broomfield	-	-	0	25	4
Chaffee	83	11	15	8	5
Cheyenne	313	251	1	3	1
Clear Creek	8	2	8	32	3
Conejos	319	106	51	4	2
Costilla	81	103	31	3	0
Crowley	484	36	1	1	1
Custer	292	27	0	2	0
Delta	439	110	9	12	8
Denver	82	-	-	251	222
Dolores	67	20	12	2	0
Douglas	224	11	3	107	67
Eagle	232	8	0	37	13
Elbert	540	59	45	10	4

[8] Overall ammonia emissions fire model is termed SfV2; the model based on fire area burned is BlueSky, and the model based on fuel consumed is named CONSUME3.

County	Livestock [tpy]	Fertilizer [tpy]	Fires [tpy]	Highway Vehicles [tpy]	Fuel Combustion [tpy]
El Paso	299	50	0	204	195
Fremont	304	13	1	15	14
Garfield	215	32	50	37	16
Gilpin	12	-	-	3	1
Grand	149	26	64	11	4
Gunnison	183	10	129	9	4
Hinsdale	13	-	5	0	0
Huerfano	172	16	1	11	2
Jackson	172	59	30	2	0
Jefferson	53	27	14	216	202
Kiowa	227	195	2	3	1
Kit Carson	3,748	1,131	0	20	3
Lake	163	146	97	4	3
La Plata	265	-	3	23	12
Larimer	1,245	295	55	111	97
Las Animas	419	24	101	13	5
Lincoln	354	359	0	9	2
Logan	3,712	735	1	14	7
Mesa	708	238	51	55	48
Mineral	5	-	8	2	0
Moffat	444	21	24	8	4
Montezuma	259	41	11	15	6
Montrose	658	256	30	14	11
Morgan	4,902	816	0	18	8
Otero	1,224	205	3	8	8
Ouray	279	13	4	4	0
Park	226	20	45	8	2
Phillips	903	676	-	2	1
Pitkin	38	5	9	8	5
Prowers	2,532	344	4	6	5
Pueblo	443	99	2	67	56
Rio Blanco	325	50	19	4	2
Rio Grande	196	573	22	6	3
Routt	223	58	34	14	6
Saguache	152	335	36	4	1
San Juan	-	-	-	2	0
San Miguel	83	11	3	5	2
Sedgwick	459	417	1	5	1
Summit	16	6	2	23	7
Teller	112	2	18	8	5
Washington	633	808	0	7	1
Weld	14,579	2,209	3	112	65
Yuma	6,828	2,118	2	4	3

Statewide Totals:	***54,053 (74%)***	***14,568 (20%)***	***1,127 (2%)***	***2,099 (3%)***	***1,587 (2%)***
9-County Area Totals:	***16,802 (75%*)***	***3,163 (14%*)***	***80 (< 1%*)***	***1,291 (6%*)***	***1,084 (5%*)***

Blue Shaded rows denote 9-County Ozone Non Attainment Area

** 9-County Area % is percentage for 9-county area, not statewide total*

The WestJump Air Quality Modeling Study (WestJumpAQMS), described in further detail in Section 4.8.1, developed annual ammonia emissions by source category for national 2008 ammonia emissions, shown in Figure 26. The study concluded that livestock (58%) and fertilizer (28%) are by far the two biggest source categories, comprising 86% of national ammonia emissions. The next largest source category is fires, dominated by wildfires, at 5%. Although wildfire ammonia emission rates are uncertain, the locations and temporal variations of the emissions are fairly well characterized. Other area sources (4%) and on-road mobile (highway vehicle) sources (3%), whose emissions are based on the MOVES model, are the next two largest source categories.

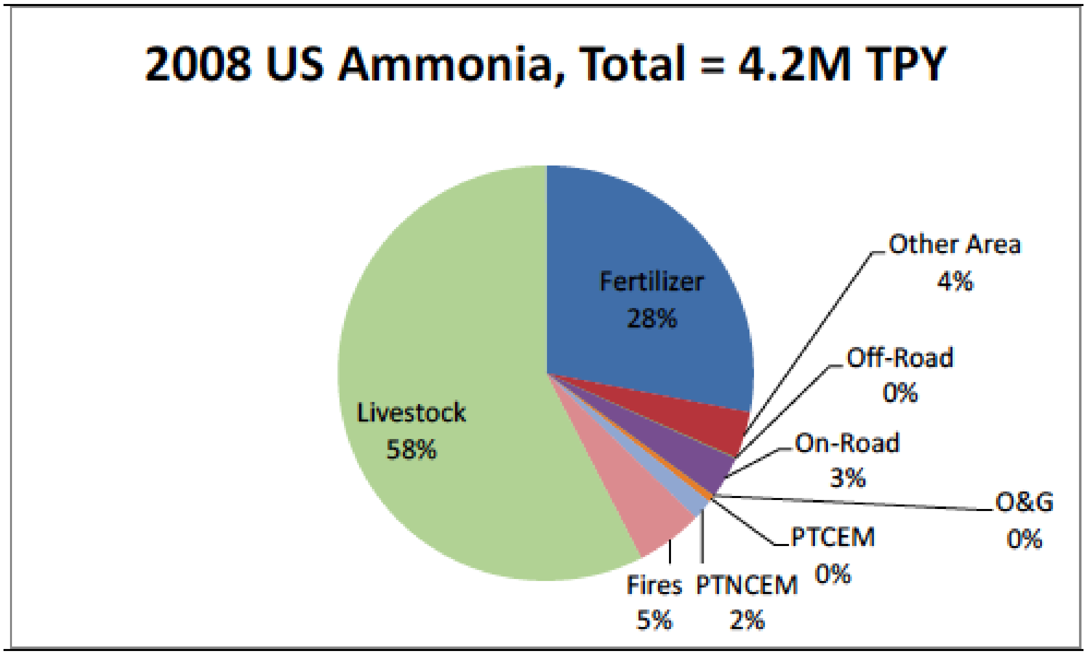

Figure 26: 2008 National Ammonia Emissions by Source Category from the WestJumpAQMS

4.6. NO_x Emissions Detail

Table 9 illustrates NO_x source categories for Colorado. Highway vehicle NO_x emissions were estimated in the 2008 NEI using a new model.[9] In addition, these MOVES-based mobile emissions have been compiled using hourly, gridded meteorology data for 2008 rather than monthly averages used in past approaches, and then summed to an annual value. The revised approach predicts higher NO_x and PM emissions than included in the 2005 NEI. For electric utility fuel combustion, NO_x emissions are predominantly based on Continuous Emissions Monitoring Systems data reported to the EPA Clean Air Markets Division. Off-Highway NO_x emissions are based on EPA default inputs.[10] The fuel combustion NO_x emissions for industrial and other sources are based on Colorado-specific Air Pollutant Emission Notices data.

[9] The 2008 NEI used the MOVES model instead of the previously used MOBILE6 model.
[10] These inputs are into the NONROAD model.

Since oil and gas activities can be a significant source of ozone precursors, CDPHE has historically inventoried oil and gas emissions to ensure accurate emission inventories are used in ozone State Implementation Plan development efforts. For 2008, CDPHE estimates that statewide, oil and gas point and area sources comprise about 56,909 tons per year (17.5%) of NO_x emissions. To put this in perspective, total 2008 NO_x emissions statewide are about 325,485 tons per year with this additional source category (268,576 tpy from Table 6 plus 56,909 tpy equals 325,485 tpy). In the 9-County DMA/NFR, the 2008 oil and gas NO_x emissions are about 17,111 tons per year. The total 2008 NO_x emissions in the 9-County DMA/NFR are about 137,263 tons per year, which mean oil and gas emissions are estimated to be about 12.5% of total NO_x emissions in the DMA/NFR and 5.3% of the statewide NO_x total. The oil and gas sector has experienced rapid growth in some areas of the state in recent years; these emission estimates should improve accordingly.

Table 9: 2008 NEI Colorado NO_x Emissions

County	Highway Vehicles [tpy]	Elect. Utility Fuel Combustion [tpy]	Off-Highway [tpy]	Industrial Fuel Combustion [tpy]	Other Fuel Combustion [tpy]
Adams	7,059	11,422	3,140	2,700	686
Alamosa	356	3	183	14	28
Arapahoe	7,488	125	2,631	756	833
Archuleta	358	-	84	19	31
Baca	304	-	946	303	11
Bent	254	1	878	147	62
Boulder	4,001	2,377	1,827	366	539
Broomfield	991	99	249	1	4
Chaffee	453	0	85	1	54
Cheyenne	255	97	426	2,498	46
Clear Creek	1,782	5	39	6	27
Conejos	241	-	156	8	20
Costilla	179	-	102	-	11
Crowley	104	-	150	64	7
Custer	109	-	43	-	12
Delta	634	6	567	-	79
Denver	9,910	3,047	6,511	492	1,142
Dolores	110	30	53	212	6
Douglas	4,501	2	2,434	55	286
Eagle	2,209	16	921	179	92
Elbert	877	-	275	33	92
El Paso	9,352	7,436	3,634	356	1,377
Fremont	810	939	138	124	99
Garfield	2,169	94	900	4,270	139
Gilpin	196	-	294	2	15
Grand	623	-	972	20	72
Gunnison	514	-	296	180	35
Hinsdale	26	-	29	-	3
Huerfano	719	-	296	7	22
Jackson	114	-	103	4	4
Jefferson	8,478	11	2,872	1,562	897
Kiowa	241	-	179	55	4
Kit Carson	1,570	37	566	4	15
Lake	258	-	35	1	21

County	Highway Vehicles [tpy]	Elect. Utility Fuel Combustion [tpy]	Off-Highway [tpy]	Industrial Fuel Combustion [tpy]	Other Fuel Combustion [tpy]
La Plata	1,198	1	425	304	99
Larimer	5,602	1,807	1,676	139	552
Las Animas	793	1	379	1,737	34
Lincoln	800	22	315	2	16
Logan	1,139	-	1,494	582	38
Mesa	2,869	1,207	1,539	1,125	272
Mineral	120	-	150	-	3
Moffat	436	16,581	263	816	35
Montezuma	796	17	160	317	77
Montrose	737	1,713	249	112	71
Morgan	1,379	4,754	1,201	1,232	91
Otero	585	72	795	50	47
Ouray	221	-	113	-	13
Park	457	-	103	-	43
Phillips	143	-	397	65	8
Pitkin	448	-	205	0	25
Prowers	493	11	770	728	26
Pueblo	3,540	5,380	1,778	386	425
Rio Blanco	251	29	194	2,757	136
Rio Grande	347	-	250	5	31
Routt	793	7,018	592	22	44
Saguache	242	-	159	-	16
San Juan	104	-	24	-	2
San Miguel	280	-	159	375	18
Sedgwick	433	-	468	0	6
Summit	1,324	-	246	0	55
Teller	441	-	90	31	61
Washington	554	-	795	97	11
Weld	6,182	1,106	3,020	6,733	330
Yuma	386	-	879	1,129	20
Statewide Totals:	***100,338 (39%)***	***65,466 (25%)***	***50,900 (20%)***	***33,185 (13%)***	***9,374 (4%)***
9-County Area Totals:	***54,213 (46%*)***	***19,996 (17%*)***	***24,360(21%*)***	***12,804 (11%*)***	***5,268 (5%*)***
Blue Shaded rows denote 9-County Ozone Non-Attainment Area					
** 9-County Area % is percentage for 9-county area, not statewide total*					

4.7. Significant Categories from NO_x and Ammonia Inventories

4.7.1. NO_x

Highway vehicles and electric utility fuel combustion represent over 60% of the NO_x emissions statewide. Off highway and industrial fuel combustion contribute about 30% of the NO_x emissions in Colorado. Similarly for the 9-County area, highway vehicles and electric utility fuel combustion represent over 60% of the NO_x emissions. Off highway and industrial fuel combustion sources contribute about 30% of the NO_x emissions in the 9-County area. Source category breakdowns are shown in Figure 27 andFigure 28. Note that these pie charts do not include CDPHE's estimate for oil and gas point and area sources.

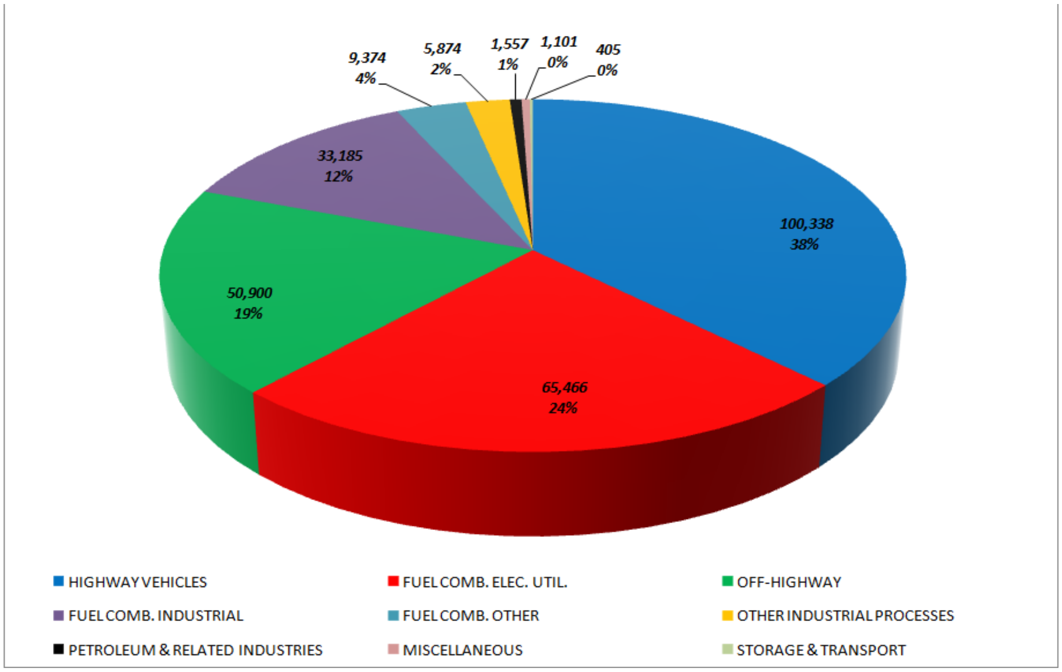

Figure 27: 2008 NEI Colorado NO_x Emissions by Source Category (%)

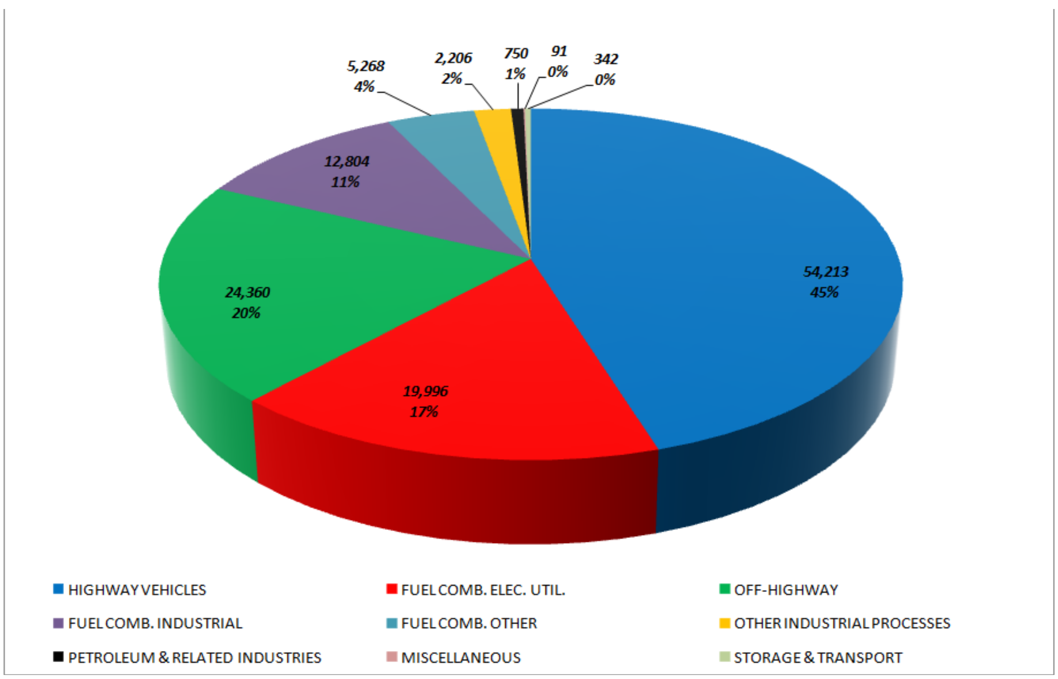

Figure 28: 2008 NEI DMA/NFR NO_x Emissions by Source Category (%)

4.7.2. Ammonia

Livestock are the dominant source of ammonia emissions in Colorado with some contribution from fertilizer, shown in Figure 29. Similarly for the 9-County area, livestock emissions are the largest source of ammonia with a smaller relative contribution from fertilizer, shown in Figure 30.

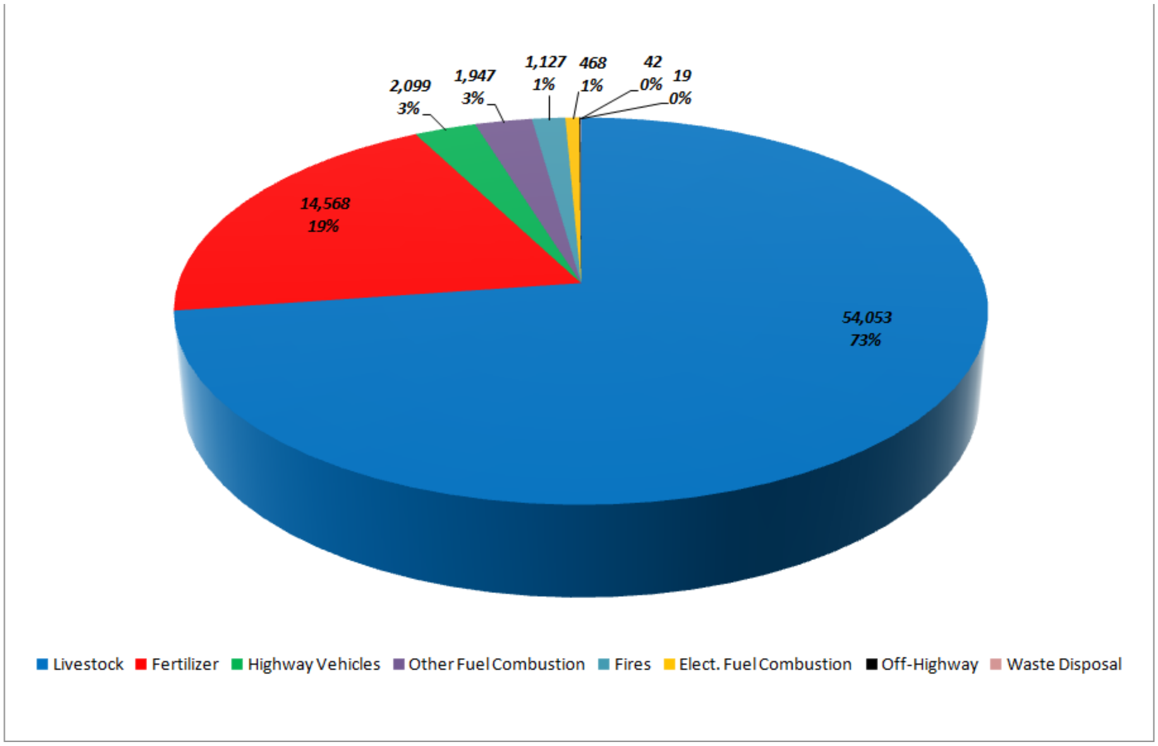

Figure 29: 2008 NEI Colorado Ammonia Emissions by Source Category (%)

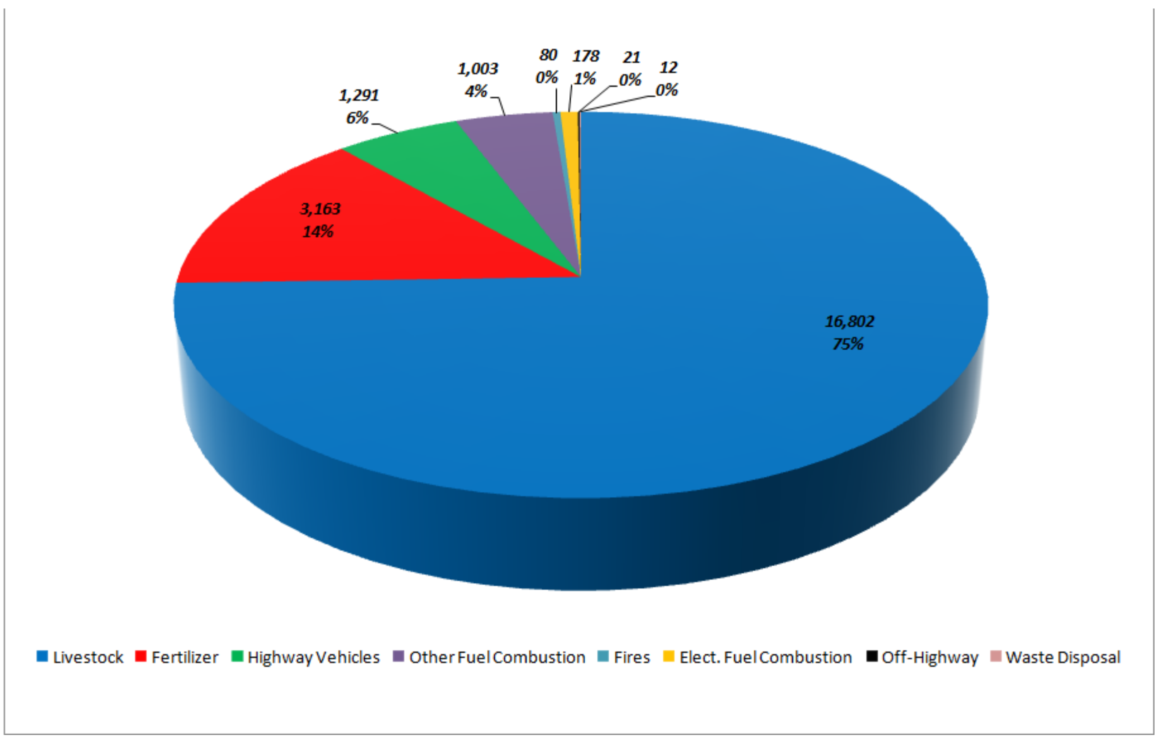

Figure 30: 2008 NEI 9-County DMA/NFR Ammonia Emissions by Source Category (%)

Scientists from Colorado State University measured ammonia in Northeast Colorado using Radiello passive ammonia samplers (Day et al., 2012). The results are consistent with emission inventories discussed earlier indicating that livestock is the dominant source category as shown in Figure 29 and Figure 30. This work revealed large spatial concentration gradients, or variations, in northeast Colorado ammonia concentrations. Average concentrations measured over a 10-week sampling period are shown in Figure 31. The lowest average ammonia concentrations, at 3.4 and 3.7 $\mu g/m^3$, respectively, were observed at the Ranch and Briggsdale sites. The Ranch site is native grassland and can be viewed as an estimate of a broad regional minimum concentration.

Average concentrations measured along the northern urban corridor (Loveland and Fort Collins sites) are about 0.8 $\mu g/m^3$ higher than at the Ranch site, indicating a small urban excess. The average ammonia concentration at a Loveland golf course location is about 0.7 $\mu g/m^3$ higher than at the Loveland and Fort Collins sites. This indicates that, on average, golf course emissions increase regional suburban concentrations by about 15%, despite intensive fertilization schemes in use to maintain golf course fairways and greens. The Ault and Greeley study sites are surrounded by concentrated large animal feeding operations (CAFOs). The concentrations at these two sites average 12.6 and 10.7 $\mu g/m^3$, respectively, or 3 – 4 times higher than concentrations at the background Ranch site and 2 – 3 times higher than the urban sites. The highest concentrations were measured at Kersey, which averaged 31.5 $\mu g/m^3$ and had a weekly high value of 41 $\mu g/m^3$. The Kersey monitoring site is located in an area of intense agricultural activity and within approximately a quarter of a mile from one of the largest CAFOs in Colorado. Altogether, these observations clearly reveal the important contributions of CAFOs to regional ammonia emissions and concentrations. Figure 31 also shows a spatial pattern of concentrations in Northeast Colorado measured on a single day using a continuous ammonia monitor in a mobile laboratory. The spatial patterns observed are qualitatively consistent with the longer-term average concentration pattern revealed in the fixed sampling network.

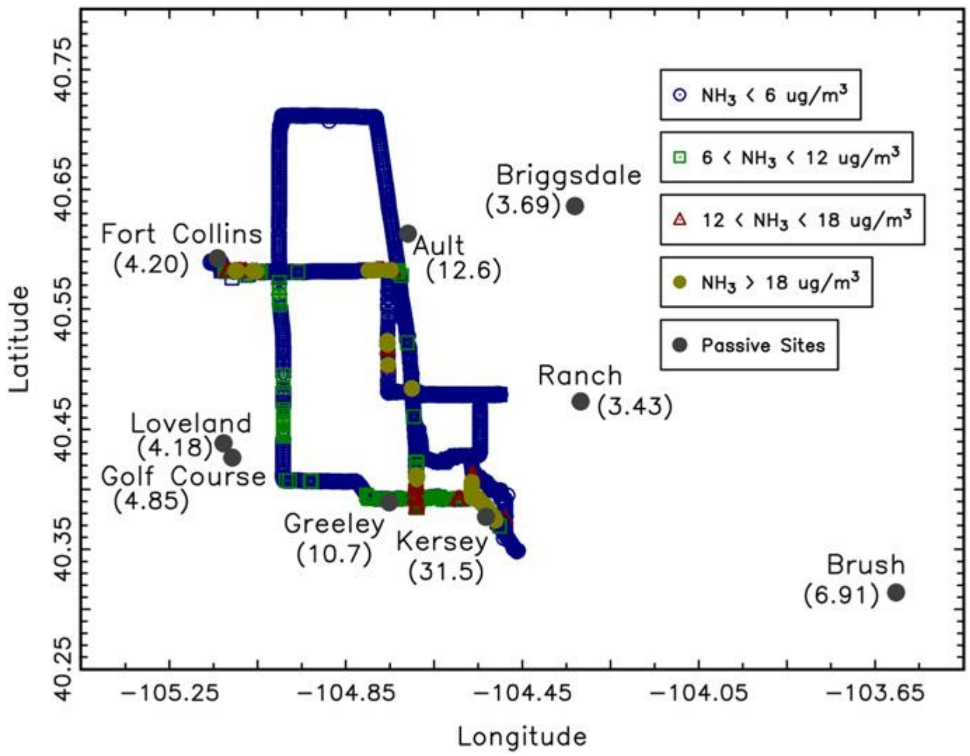

Figure 31: The spatial pattern of ammonia concentrations on the northeastern plains of Colorado obtained from mobile measurements and a passive ammonia monitoring network. The numbers in parentheses represent ammonia concentration averaged over the sampling period (May – Sept. 2010) using passive samplers. The trace of mobile measurements obtained May 3 and May 5, 2010 are represented by color coded ranges of values. All units are in µg/m^3.

4.8. Current Efforts to Improve Colorado Nitrogen Inventory Data

The NO_x and ammonia modeling and emission inventories outlined in previous sections are approximations and should only be used as predictors of major source categories for relevant pollutants. As noted in Section 4.1, inventory improvements are continually occurring by agencies and researchers. Current inventory improvement projects are described in the next two sections.

4.8.1. WestJump Air Quality Modeling Study (WestJumpAQMS)

During the WestJumpAQMS, completed in 2012, a number of emissions sources were comprehensively assessed to provide an updated modeling platform for the Western United States using a 2008 base year, and associated inventory improvements for key Western source categories. The Bureau of Land Management (BLM), the State of New Mexico, and industry funded WestJumpAQMS with input from a variety of stakeholders.

WestJumpAQMS provides a modeling framework for future air quality planning work. In addition, state-to-state source apportionments were performed that could be useful for state air quality planning in assessing transport. This source apportionment work was conducted for ozone and particulate matter, which can be useful in understanding both deposition and visibility in the Western United States.

One significant part of the WestJumpAQMS was to evaluate the NEI, which served as the starting point and identify source categories that might need to be updated or improved, such as ammonia emissions estimates from livestock operations and agricultural fertilizer application. A revised version of the Carnegie Mellon University (CMU) ammonia emissions model was applied and sources inventoried at the county level.[11]

A number of source categories for NO_x were also evaluated where most of the revisions were associated with oil and gas activities based on the Phase III inventories developed by the WRAP, discussed further in Section 4.8.3. In addition, those categories that are a part of the emissions modeling process like on-road mobile sources and biogenic sources, such as fire, were estimated as a part of the WestJumpAQMS instead of relying on the NEI.

4.8.2. Three-State Study Data Warehouse & Air Quality Study (Three-State Study)

The Three-State Study is a pilot project in Colorado, Utah, and Wyoming intended to develop a data warehouse to house photochemical modeling input and output files that can be used and reused as the starting point for air quality planning analyses by state, federal, and other interested parties. This study uses WestJumpAQMS data (2008 base year) as a starting point for the data warehouse and then plans to update the inventories parallel to the NEI timeframe. The BLM, EPA Region 8, NPS, the U.S. Forest Service, and the states of Colorado, Wyoming, and Utah funded this study with input from stakeholders.

The main source category of interest is oil and gas development in the three states. A base year is a year in the past for which modeling is performed such that ambient monitoring data can be used to evaluate results while a base case is an estimate of future air quality absent the adoption of new emissions control requirements. It is intended that the results of these modeling analyses will be made available through the data warehouse in addition to initial WestJumpAQMS data. Figure 32 shows the proposed pilot study area.

[11] The methodology and inputs into the CMU ammonia model are presented in a WestJumpAQMS technical memo that can be found at: http://www.wrapair2.org/pdf/Memo8_AmmoniaSources_Feb28_2013review_draft.pdf

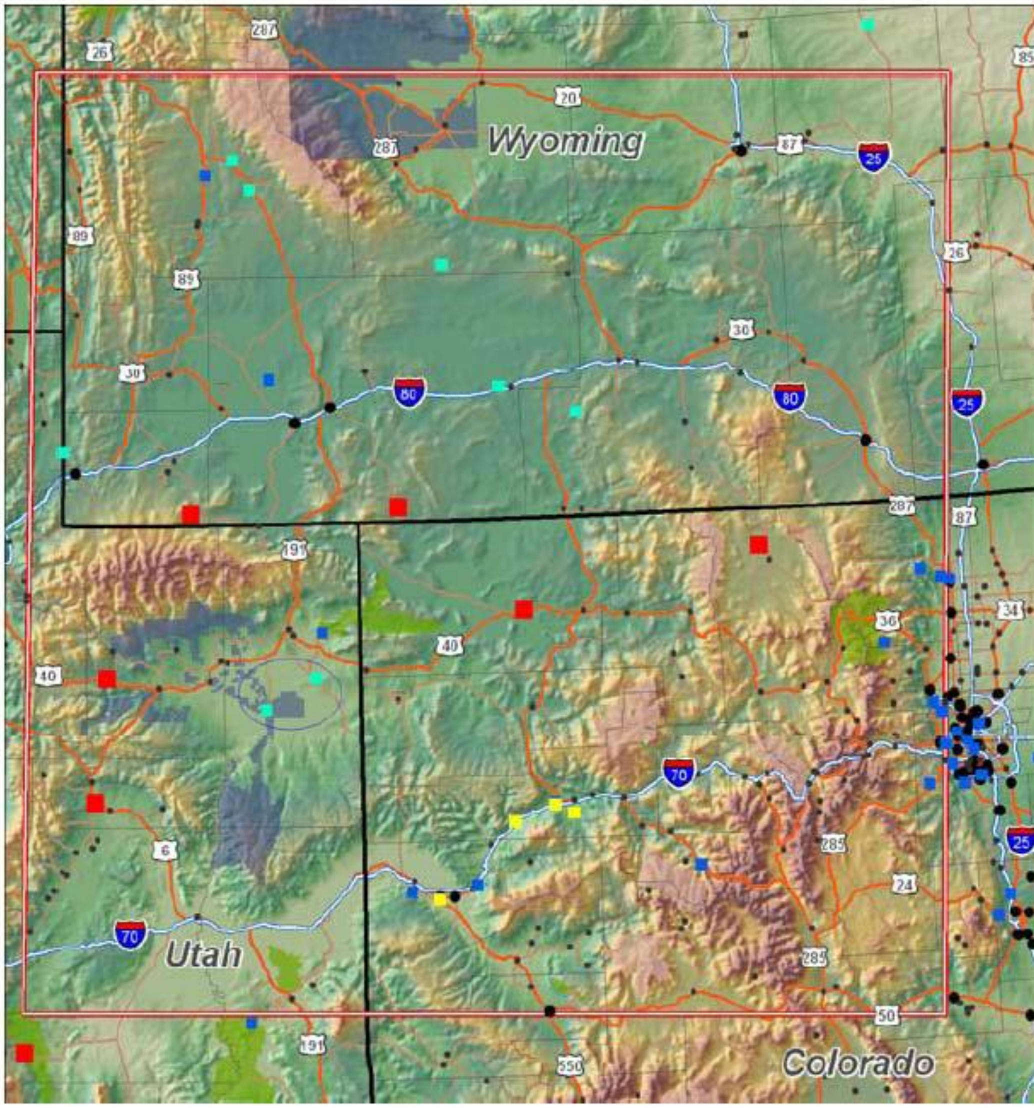

Figure 32: Proposed Three-State Study Pilot Area

Along with housing and storing the WestJumpAQMS data, the Three-State Study is also making improvements to the WestJumpAQMS work, especially to the chemical profiles and temporal and spatial allocations used in the emissions modeling. Emissions modeling is the process for characterizing emissions in a gridded and hourly format where many sources are initially estimated annually by county, so the emissions modeling distributes the emissions spatially and temporally for each grid cell for each hour. In Colorado, one of these improvements was updating the diurnal temporal profiles for livestock ammonia sources to be meteorology-based profiles. Another significant improvement was to spatially allocate livestock emissions to specific feedlot locations, rather than using a generic ‘agricultural’ land use surrogate. An emissions modeling expert hired by Three-State Study participants performed new 2008 base year modeling with these improvements. Next steps include inventory improvements with subsequent model runs and sensitivity analyses.

The Three-State Study participants plan to develop a full suite of inputs for performing photochemical modeling for the base year 2011. This includes meteorological modeling and emissions modeling using the 2011 NEI as the starting point as WestJumpAQMS did for 2008. In addition, estimates of future emissions will be developed. Once the emissions inventory and meteorological inputs are available, a photochemical model will be run for the 2011 base year and again in future years, likely for the same area shown in Figure 32. There will be modeling results for nitrogen deposition and visibility in addition to ozone. The full set of Three-State Study modeling results are targeted for completion in September 2014. Both the WestJumpAQMS and Three-State Study photochemical model inputs can be used in the future for a variety of analyses by participating agencies to assess current and future air quality conditions at RMNP.

4.8.3. NO_x

While significant strides have been made in reducing NO_x emissions from various sources in recent years, a number of entities continue to improve the NO_x emission inventory and learn about potential new NO_x sources in Colorado, such as expanded oil and gas development.

As part of the WestJumpAQMS, multiple technical memorandums that provided updated revised estimates regarding oil and gas emissions were produced. The most notable for this report is Memorandum 4a, which discusses 2008 oil and gas emissions for Colorado basins (Denver-Julesburg, Piceance, and North San Juan). The WRAP Phase III 2008[12] baseline oil and gas inventories that coincide with the WestJumpAQMS represent the results of a multiyear effort and are the most comprehensive and complete oil and gas inventory ever developed for the Rocky Mountain states.[13] Reductions in the scaled emissions resulting from controls required by on-the-books federal and state regulations are taken into account in the memoranda and resulting Phase III inventories.

It should be noted that statewide, industrial and other fuel combustion, including oil and gas, may comprise approximately 30% of the NO_x inventory. In the 9-county nonattainment area, this category is about 20% of the NO_x inventory. Figure 33 illustrates oil and gas sector NO_x emissions for 2008 (48 tons/day) and future 2018 (53 tons/day) for the Denver Metropolitan/North Front Range ozone nonattainment area. Additional modeling to supplement the analysis provided in Section 3.2.4 may be conducted to analyze how NO_x emission changes from the oil and gas category (and subcategories) may affect ozone levels and nitrogen deposition in the future. The MOU agencies will continue to monitor oil and gas NO_x emissions and their effect on nitrogen deposition in RMNP.

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[12] These projections use 2008 production statistics using 2006 survey data as a surrogate to scale emissions from the various source categories considered in Phase III, including drill rigs and some pneumatic devices.

[13] http://www.wrapair2.org/PhaseIII.aspx

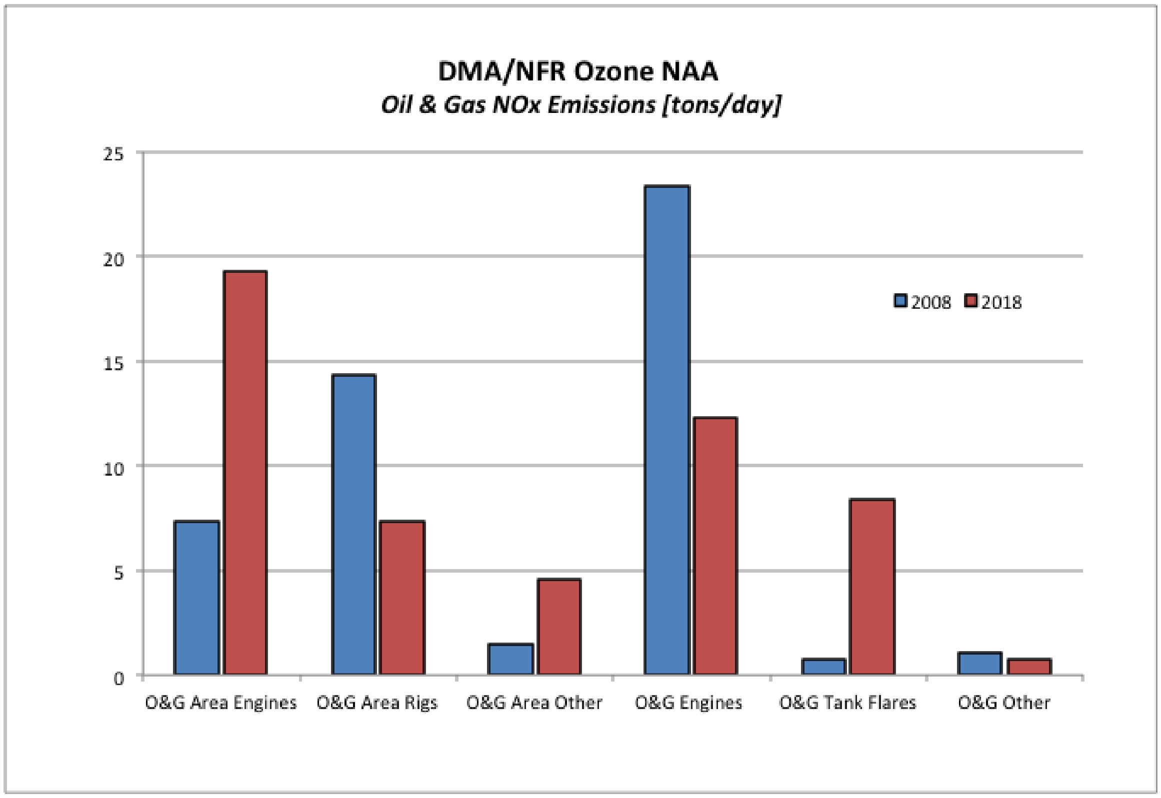

Figure 33: Estimated (2008) and future (2018) NO_x emissions (tons/day) for the Oil and Gas Sector in the DMA/NFR Ozone Nonattainment Area

4.8.4. Ammonia

Although ammonia has been heavily researched for over five decades, since EPA does not regulate this pollutant as a criteria pollutant or hazardous air pollutant under the Clean Air Act, inventories remain uncertain and modeling tools need fundamental improvement. The MOU agencies will continue to observe study results, conduct literature reviews, and conduct groundwork to improve ammonia emission knowledge.

CDPHE has investigated stakeholder inquiries regarding unknown or unrefined ammonia source categories, such as wastewater treatment facilities, biosolids, composting, industrial crop fertilizers, and other sources (i.e. urban fertilization, sod farms, golf courses) and continues to work to improve the ammonia inventory on a regular basis, both internally and in collaboration with external researchers and other interested parties. CDPHE has researched other national and international studies and emission factors to continue improving the inventory. Within CDPHE, there has been substantial cross-division coordination among the Air, Water, and Solid/Hazardous Waste Divisions to gather advanced data regarding wastewater treatment facilities, biosolids, and composting emissions. Through these efforts, a fact sheet regarding wastewater treatment facility ammonia emissions was produced and published for the AQCC and other interested stakeholders.[14] The Air

[14] http://www.colorado.gov/cs/Satellite?blobcol=urldata&blobheadername1=Content-Disposition&blobheadername2=Content-Type&blobheadervalue1=inline%3B+filename%3D%22AQCC+Nutrient+Standard+Impact+on+Ammonia+Emissions+from

Division continues to work on biosolids and composting emissions in conjunction with other efforts, such as those conducted by the Ag Subcommittee, discussed further in Section 5. Additionally, the Air Division continually works with other state agencies, including the Department of Agriculture and the Division of Wildlife to research more about bottom-up ammonia emissions and source category significance. CDPHE has also conducted outreach with the Rocky Mountain Agribusiness Association to obtain Colorado regional specific crop fertilizer application rates to create enhanced ammonia emission estimates from this source category.

4.8.5. Other Emissions Studies

The WRAP produced a memo outlining the key lessons learned during the collection, preparation, and modeling of ammonia data used during the WestJumpAQMS[15] that discusses potential for improvement in the emissions model, emission factors, animal population activity, spatial allocation, temporal allocation, and the air quality model(s). There will be an opportunity to revisit ammonia (and NO_x) emissions in the Three-State Study when the 2011 NEI becomes available.

CDPHE and NPS are currently involved in several upcoming research initiatives to be conducted in the Front Range in the near future. The first is the North Front Range Oil and Gas Air Pollutant Emission and Dispersion Study (2014-2017) being conducted by CSU that will examine small scale emissions from well pads and improve understanding of oil and gas emissions, specifically for VOCs and NO_x. The second study is a multiagency intensive air quality campaign, the Front Range Air Pollution and Photochemistry Experiment (FRAPPE), being spearheaded by the National Center for Atmospheric Research and will run parallel with the National Aeronautics and Space Administration's Deriving Information on Surface conditions from Column and Vertically Resolved Observations Relevant to Air Quality (DISCOVERAQ) campaign. EPA is also involved in this campaign. FRAPPE will occur in July and August of 2014 and involve research aircraft, multiple ground sites as well as mobile measurements and detailed high-resolution modeling. The FRAPPE study is expected to significantly enhance understanding of both oil and gas and agricultural emissions as well as greatly improve air quality modeling efforts in the Front Range area.

5. **Current and Future Emission Reduction Activities**

5.1. NO_x

There are numerous state and federal NO_x emission control programs that have been recently implemented or have been scheduled to be implemented over the next 20 years. These programs will reduce NO_x emissions and reduce nitrogen deposition at RMNP:

- Minor Source Best Available Control Technology (BACT) for natural gas compressor engines (greater than 100 hp): In 2006, the Colorado Air Quality Control Commission (AQCC) adopted emission performance standards for new and relocated engines that reduce the growth in NO_x emissions statewide. Colorado AQCC Regulation Number 7,[16] Section XVII.E.2 requires that all

+Wastewater+Treatment+Facilities.pdf%22&blobheadervalue2=application%2Fpdf&blobkey=id&blobtable=MungoBlobs&blobwhere=1251849624610&ssbinary=true

[15] http://www.wrapair2.org/pdf/Memo_NH3_Modeling_NextSteps_Aug29_2013.pdf

[16] Colorado Air Quality Control Commission Regulation 7 can be found at: www.colorado.gov/cdphe/aqcc-regs

new or relocated natural gas-fired reciprocating internal combustion engines (RICE) over 100 hp meet a NO_x standard of 1.0 grams per /horsepower-hour (g/hp-hr).

- Retrofit controls for existing RICE over 500 horsepower statewide: As of 2010, Colorado AQCC Regulation Number 7, Section XVII.E.3 requires all existing natural gas-fired rich burn (and lean burn, which just applies to VOCs) RICE over 500 hp to install emission controls if the retrofit control cost is below $5,000 per ton. CDPHE estimates NO_x reductions of about 5,800 tons per year starting with implementation.

- The Colorado Regional Haze SIP requires controls on specific sources that will result in significant NO_x emission reductions on or before 2018:
    - The Cherokee Power Plant in Adams County will shut down three coal-fired units and repower Unit 4 with natural gas, which results in NO_x emission reductions of about 8,528 tons per year.
    - The Valmont Power Plant in Boulder County will shut down a coal-fired unit and a cement manufacturer will add controls resulting in NO_x emission reductions of roughly 3,160 tons per year.
    - The Arapahoe Power Plant in Denver County will shut down a coal-fired unit and repower Unit 4 with natural gas, which results in NO_x emission reductions of about 2,018 tons per year.
    - The Colorado Energy Nations Company in Jefferson County has two industrial boilers that will install controls resulting in about 568 tons per year of NO_x emission reductions
    - The Rawhide Power Plant in Larimer County has one coal-fired boiler that will reduce NO_x emissions by about 448 tons per year.
    - Beyond the 9-county area, there are several sources, including Craig, Hayden, and Pawnee Power Plants that will achieve about 14,843 tons per year in NO_x emission reductions.

By 2018, a combined statewide approximate 37% NO_x reduction (based on 2009 inventory data) is expected to help reduce nitrate and overall nitrogen deposition in RMNP, as shown in Figure 34.

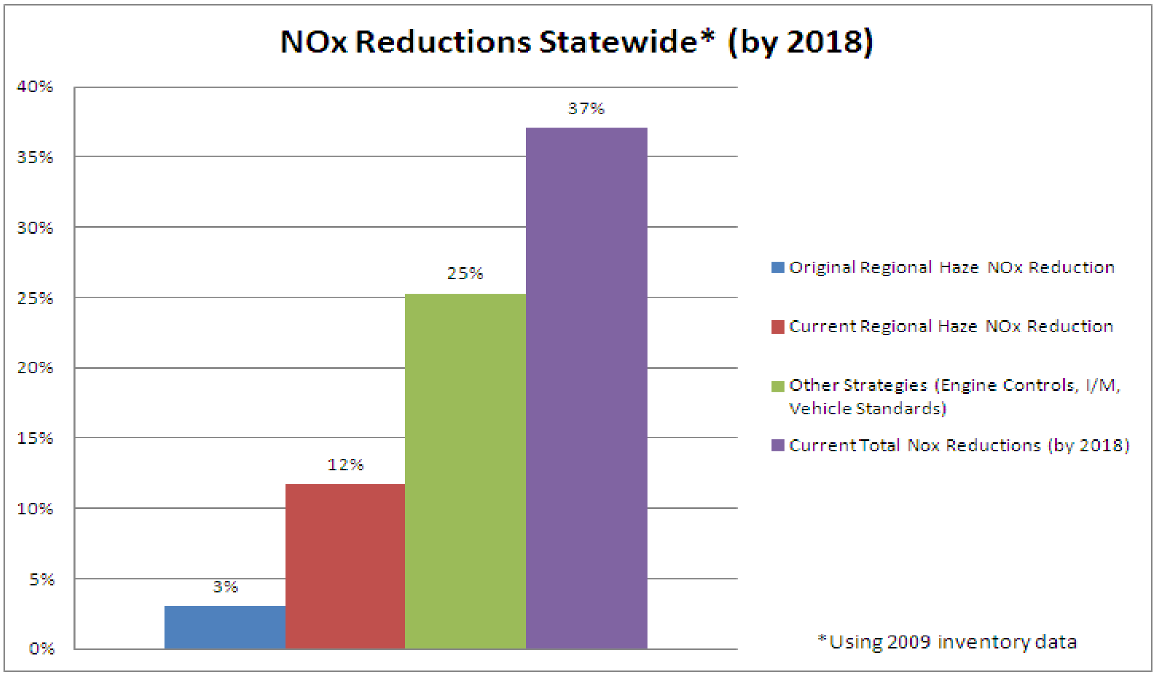

Figure 34: Projected NO_x Statewide Reductions by 2018 (2009 inventory data)

- Application of general air emission reporting and permitting requirements of the Air Quality Control Commission's Regulation 3,[17] and more specifically Reasonably Available Control Technology for NO_x stationary sources greater than five tons per year in the Front Range ozone nonattainment area, including oil and gas sources.

- Federal on-road vehicle TIER II, III and IV[18] gasoline and diesel exhaust standards, gasoline and diesel fuels standards, and federal off-road and small engine standards provide significant NO_x emission reductions. Generally, it should be noted that ammonia emissions from the gasoline fleet is and will continue to be much larger than that from the diesel fleet. The 2010 EPA fuel efficiency and vehicular gas emissions standards for medium- and heavy-duty trucks will be met using Diesel Exhaust Fluid combined with Selective Catalytic Reduction (SCR), resulting in nitrogen gas (N_2) and oxygen (O_2) emissions, as shown in Figure 35. SCR systems require periodic refilling of the Diesel Exhaust Fluid, and are commonly used in conjunction with other technologies, also shown in Figure 35, that reduce particulate matter emissions. SCR systems that use ammonia are equipped with Electronic Control Units that calculate the correct amount of ammonia needed, therefore reducing potential for ammonia slip, using various sensors[19] and contain On-Board Diagnostic systems that alert drivers of any potential problems with an indicator light.

[17] Colorado Air Quality Control Commission Regulation 3 can be found at: www.colorado.gov/cdphe/aqcc-regs
[18] For TIER IV diesel, urea is used to control NO_x emissions, but estimates are that very little ammonia will be released into the air. Other techniques may be deployed that do not utilize urea – this will be monitored.
[19] http://www.bowmannz.com/yahoo_site_admin/assets/docs/DieselEmissionTechnology.105104828.pdf

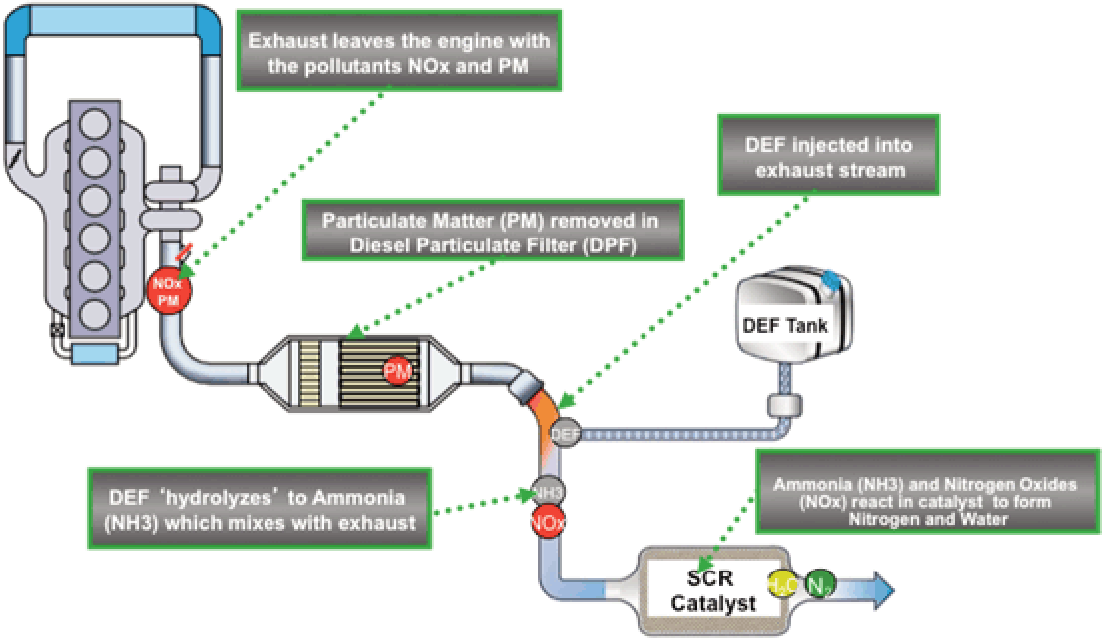

Figure 35: Diesel Exhaust Fluid and SCR Process in Diesel Vehicles[20]

- Implementation of an enhanced motor vehicle inspection and maintenance (I/M) program[21] in the more densely populated areas of Larimer and Weld Counties in November 2010.

- Regarding mobile source NO_x trends east of RMNP, the Fort Collins and Greeley areas are experiencing rapid urbanization and growth. Fortunately, the federal TIER II tailpipe and fuels standards along with I/M programs in the Denver Metro Area and North Front Range are countering this growth and significantly reducing projected emissions. Modeling results based on EPA's newest mobile source emissions model, MOVES, indicates that NO_x emissions from mobile sources will decrease approximately 54% (43.8 tons per summer day to 20.4 tons per summer day) between 2008 and 2018. It can be assumed that these future trends will also manifest themselves in the Estes Park and RMNP region, which are also experiencing dramatic mobile source activity and increases in vehicle miles traveled.

[20] http://www.reladyne.com/products/diesel-exhaust-fluid/meeting-new-epa-standards/

[21] The Automobile Inspection and Readjustment Program is a vehicle inspection and maintenance program currently operating in the Denver Metro Area and the North Front Range. Pursuant to the program, vehicles registered in the area must meet established criteria for emissions of excess carbon monoxide, NO_x, and hydrocarbons. To ensure compliance with these standards, vehicles are required to undergo periodic emissions testing at the time of their registration renewal. Vehicles that fail the tests must be repaired and pass a retest before they can be re-registered. The environmental benefit from the program is derived primarily from the emission reductions that occur when vehicles failing the initial test are repaired, with additional benefit derived from pre-inspection vehicle maintenance and repair performed to ensure compliance with program requirements. While most vehicles that are inspected pass the established standards, the vehicles that fail disproportionately contribute to the overall atmospheric emissions loading from the vehicle fleet.

- Pertaining to NO_x trends within RMNP, the NPS is taking various actions aimed at reducing fossil fuel (as well as greenhouse gas) pollutants, including seeking an energy audit to identify energy efficiency and renewable energy projects in RMNP, working towards replacing RMNP fleet with high efficiency vehicles, and expanding the shuttle system to reduce vehicle miles traveled within RMNP, discussed further in Section 6.1.

- Ozone planning in Colorado over the next 10 years will also focus on NO_x emission sources. EPA is currently conducting a periodic review of the ozone standard. If the standard becomes more stringent, it may drive new efforts to reduce both Colorado's and the nation's ozone precursor emissions. NO_x emission controls implemented for improving ozone levels are also anticipated to lower nitrogen deposition.

5.2. Ammonia

5.2.1. Agricultural Sector and Air Quality in the National Context

Significant consideration at the national level has been given to characterizing emissions and impacts of ammonia emissions in recent years. Under the Clean Air Act, ammonia is not a criteria pollutant and is, therefore, not directly regulated as part of the National Ambient Air Quality Standards (NAAQS) or New Source Performance Standards. However, ammonia is listed in Section 102 of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) of 1980 and, therefore, releases of ammonia must be reported as part of the Emergency Planning and Community Right to Know Act (EPCRA) of 1986. Debate over the applicability of each of these statutes to agricultural emissions of ammonia has brought attention to these sources in recent years, as have potential changes in ecosystems from nutrient imbalances, such as the changes in high-elevation ecosystems at RMNP from increased nitrogen deposition.

5.2.1.1. Animal Feeding Operation Emission Research

In January 2005, EPA announced a voluntary air quality compliance agreement to address air emissions from animal feeding operations (AFOs). Broiler, egg-layer, swine and dairy producers entered into the agreement and paid fees that funded the National Air Emissions Monitoring Study (NAEMS) while Purdue University researchers conducted the study with EPA oversight. The NAEMS was conducted by agricultural researchers and intensively measured particulate matter, volatile organic compound, hydrogen sulfide, and ammonia emissions. Monitoring began in late 2007 and was completed in early 2010. The world's largest agricultural emissions-oriented air quality monitoring database with more than 2.4 billion data points has recently been created by the NAEMS (Ni et al, 2011). Approximately 2,600 AFOs, representing nearly 14,000 facilities, are participating. Data from this study and other relevant studies has been used to develop draft emission-estimating methodologies (EEMs) to characterize emissions from the participating AFOs. The EEMs will be used to determine applicability of existing air quality regulations to these and similar operations. The EPA has analyzed NAEMS data and developed draft EEMs for broiler operations and liquid waste management systems at dairies and swine operations.

In 2012, the EPA released the draft EEMs for public review and also requested EPA's Science Advisory Board (SAB) to review the draft EEMs. On April 19, 2013, the SAB submitted its final report to EPA. As of November 2013, the EPA is reviewing SAB's recommendations and, where applicable, will use the recommendations to revise the draft EEMs. EPA is now examining all of this information as it works to develop EEMs for the AFO sectors that were monitored. Such methodologies are commonly used to estimate emissions from industries where site-specific monitoring data are not available.[22]

Many aspects of the beef feedlot system suggest a simplistic top-down model may have adequate accuracy for approximating emissions and doing inventory calculations. Research from Colorado State University (CSU), among others, shows that about 40% to 65% of the fed nitrogen is lost to the atmosphere as NH_3, regardless of location or manure management scheme (e.g., pen cleaning frequency). A sampling network has been in continuous operation at a 25,000 head feedlot near Fort Morgan, Colorado since October 2012. Ammonia concentrations at the downwind boundary typically ranged between 1,000 and 3,000 ppb with an overall average of 1,900 ppb. These data were then used in combination with data from a sonic anemometer to estimate emissions using the Flux Interpretation by Dispersion Exchange model. The fraction of fed nitrogen lost to the air as ammonia ranged from 70% in summer to 40% in January with an overall average of 53%. This fractional loss of fed nitrogen is very similar to data reported in other studies from Canada and Texas. Much progress was made on developing the passive conditional samplers deployed in a multi-nodal wireless network on the periphery of livestock operations. Using a weather-based sampling protocol allows these units to both identify ammonia hot spots within feedlots and help quantify emissions via inverse modeling. During the final phase of a current study, CSU plans to develop a semi-empirical model for predicting feedlot ammonia emissions that is driven strongly by crude protein in the diet with subtle adjustments based on seasonal weather conditions and management.[23]

5.2.1.2. CERCLA/EPCRA Reporting Requirements

The Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) reporting requirement serves as a trigger for informing the Federal government of a release so that Federal personnel can evaluate the need for a response in accordance with the National Contingency Plan and undertake any necessary response action in a timely fashion. The Emergency Planning and Community Right to Know Act (EPCRA) reporting requirement provides state and local officials with notification information so that they can assess whether a response action to the release is appropriate. In 2009, EPA issued a final rule entitled "CERCLA/EPCRA Administrative Reporting Exemption for Air Releases of Hazardous Substances from Animal Waste at Farms" that exempted farms from CERCLA reporting requirements for air releases of hazardous substances from animal waste and most from EPCRA reporting requirements for air releases of hazardous substances from animal waste. Those farms that are subject to EPCRA reporting requirements submit their release notifications to the State Emergency Response Commission of any state likely to be affected by the release and Local Emergency Planning Committee for any area likely to be affected by the release. EPA's rationale for the final rule was based on the purpose of notifying the National Response Center, State Emergency Response Commissions, and Local Emergency Planning Committees when a hazardous substance is released, and then the likelihood that a response to that notification would be taken by any government agency.

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[22] See: http://www.epa.gov/oecaagct/airmonitoringstudy.html for more information about NAEMS.
[23] Communication from Jay Ham, CSU Environmental Physics and Micrometeorology professor, via email to Elizabeth Sapio, Environmental Health and Sustainability Division, CDPHE on November 20, 2013.

Nothing in the final rule changed the notification requirements if hazardous substances are released to the air from any source other than animal waste at farms (e.g., ammonia tanks), or if any hazardous substances from animal waste are released to any other environmental media, (e.g., soil, ground water, or surface water) when the release of those hazardous substances is at or above its reportable quantity. Also, the administrative reporting exemption under section 103 of CERCLA, does not limit any of the Agency's other authorities under CERCLA sections 104 (response authorities), 106 (abatement actions), 107 (liability), or any other provisions of CERCLA or EPCRA. EPA's rationale for issuing exemptions from CERCLA and EPCRA is consistent with the Agency's goal to reduce reporting burden, particularly considering that federal, state or local response officials are unlikely to respond to notifications of air releases of hazardous substances from animal waste at farms.

5.2.1.3. Proposed Secondary NAAQS for NO_x/SO_x

In the most recent review of the NAAQS for oxidized forms of nitrogen, EPA considered adoption of a new, combined secondary standard for NO_x and SO_x in the form of an aquatic acidification index that would be based on effects of deposition of these constituents on acidification of sensitive ecosystems. Although EPA, in their 2012 final rule, declined to adopt such a standard, the discussion of the new approach included effects of ammonia emissions and deposition on these same ecosystems.

In the discussed approach, acidification from ammonia deposition would be considered when setting the allowable concentrations of NO_x and SO_x in the atmosphere that would be protective of aquatic ecosystems sensitive to acidification. Agricultural interests charged that the approach discussed in EPA's Policy Assessment formed a *de facto* standard for ammonia (i.e., attainment with a standard in the proposed form of an aquatic acidification index could be achieved through reductions in ammonia concentrations [and therefore deposition] in lieu of achieving reductions in NO_x or SO_x concentrations). EPA disagreed with the commentators that the aquatic acidification index would form a *de facto* standard, and noted that control of ammonia to allow more NO_x deposition would have been completely voluntary at the federal level.

5.2.1.4. Report from EPA's Integrated Nitrogen Committee

In 2011, EPA's Science Advisory Board Integrated Nitrogen Committee issued a report exploring the effects that reactive nitrogen, including ammonia, causes in the environment and assessing appropriate risk management actions to prevent undesirable outcomes due to human contributions to the nitrogen cycle. Among its recommendations, the committee suggested that livestock-derived ammonia emissions be reduced by 30 percent and that nitrogenous fertilizer use be reduced 20 percent (EPA, 2011). While the committee's report is not regulatory in nature, it is expected that this report will inform future actions by EPA in regards to regulation of reactive nitrogen.

5.2.2. Agriculture (Ag) Subcommittee

In 2006, in response to a request from the MOU agencies for agricultural input into the creation of the NDRP, a diverse group of stakeholders from Colorado's agricultural community along with other interested parties formed the Ag Subcommittee to assess the implications of the proposed plan and develop an action plan to address ammonia emissions affecting RMNP. Stakeholders involved in the Ag Subcommittee include livestock producers, crop producers, agricultural commodity associations, conservation districts, academia, local, state, and federal government, and non-governmental organizations (NGOs). Since their first meeting in October 2006, the Subcommittee has met quarterly to follow the progress of nitrogen deposition measurements in RMNP, help quantify ammonia emissions in the state, investigate ways to mitigate ammonia emissions from agriculture and other sources, develop plans for outreach activities to increase mitigation efforts across the industry, and dialogue with members of MOU agencies to improve understanding of the effects of nitrogen deposition in RMNP and the challenges and opportunities associated with reducing ammonia emissions from agricultural and other sources.

5.2.2.1. Research

Spurred by the NDRP, agricultural groups have supported research efforts to better understand sources of ammonia that may be affecting RMNP. Since 2007, when the NDRP was finalized, multiple research efforts in Colorado have sought to improve the understanding of ammonia emissions and their control.

Researchers at Colorado State University (CSU) have conducted surveys as a result of the NDRP to better understand current adoption of "best management practices" (BMPs) for ammonia and what factors affect the adoption of these BMPs by agricultural producers. Using two separate USDA Natural Resources Conservation Service (NRCS) grants, researchers from CSU have measured the effectiveness of a few BMPs at multiple livestock operations. Results of this research have produced some site-specific recommendations, but overarching recommendations are pending. Under grants from USDA's Agriculture and Food Research Initiative, EPA's Science to Achieve Results program, and the National Science Foundation Robotics program, researchers at CSU have improved tools for measuring ammonia emissions from feedlots and dairies and modeling the movement of those emissions along the Front Range and into the Rocky Mountains (Ham et. al, 2012 and Galles et. al, 2011).[24]

Researchers from CSU monitored trends in ammonia emissions from soil cores collected from RMNP to improve understanding of diurnal and seasonal trends in local ammonia emissions profiles.[25] CSU researchers conducted feeding trials to elucidate dietary regimens and feed additives that may reduce ammonia emissions from animal feeding operations without adversely affecting animal health, welfare, and growth. Led by faculty from CSU, a team of researchers, extension professionals, and agricultural producers from across Colorado and the United States have worked to improve the National Air Quality Site Assessment Tool, which was developed to help livestock producers assess their air quality management and identify opportunities to further reduce emissions.

Atmospheric scientists from CSU have partnered with the Colorado Livestock Association (CLA), USDA, NPS, CDPHE, and local producers to develop an Early Warning System (EWS) [26] to predict

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[24] As of November 2013, a paper has been written regarding isotope tracking from emissions sources and transport into RMNP. This manuscript is in internal review with a working title of "Assessing the Efficacy of Nitrogen Isotopes to Distinguish Colorado Front Range Ammonia Sources Affecting Rocky Mountain National Park". The paper is anticipated for submittal to the journal *Atmospheric Environments* in the near future.

[25] A paper has been written and submitted for publication entitled "Ammonia Emissions from Sub-Alpine Forest and Mountain Grassland Soils". As of November 2013, this paper is in-review for the journal *Atmospheric Environment*.

[26] http://www.rmwarningsystem.com

upslope conditions similar to those that precipitated large deposition events during the RoMANS studies. Prediction of these upslope conditions will form the basis for a warning system to generate notifications for agricultural producers to avoid practices that may lead to large releases of ammonia on days when these emissions have a high likelihood of being transported into RMNP. The body of research regarding emissions, transport, and mitigation of ammonia emissions from Colorado sources generated since 2007 is evidence of the proactive approach being taken by agricultural producers, researchers, and government organizations to try to better understand and reduce nitrogen deposition in RMNP.

5.2.2.2. USDA-NRCS Air Quality Initiative

Based on concerns about nitrogen deposition in RMNP, the U.S. Department of Agriculture – Natural Resources Conservation Service (USDA – NRCS) in Colorado added considerations of ammonia emissions and mitigation to its 2013 Air Quality Initiative, which makes reduction of ammonia emissions a priority resource concern for the agency. The effects of this decision include:

- Increased availability of technical and financial assistance to reduce ammonia emissions from Colorado sources of ammonia. Moving forward, $1.5 million in Air Quality Initiative funding will be available annually, considerably increasing the approximately $400,000 that was spent in the previous three years for nutrient management assistance on approximately 55,000 acres.

- Increased information and education resources to local NRCS personnel providing conservation guidance and technical assistance to producers.

- Colorado NRCS expanded the counties that are eligible for Environmental Quality Incentives Program Air Quality Initiative resources to include additional counties that may be contributing ammonia to RMNP deposition events but were not part of previous Air Quality Initiatives.

5.2.2.3. Outreach Efforts

Since 2007, significant efforts have been made to inform agricultural producers about the causes and impacts of nitrogen deposition in RMNP and promote practices that show promise for reducing ammonia emissions and transport into RMNP. Outreach efforts by the agricultural community include:

- Continued involvement by stakeholders in Ag Subcommittee meetings to keep producers abreast of the latest information regarding nitrogen deposition trends and opportunities for reducing impacts in RMNP.

- Development of numerous fact sheets[27] regarding sources and effects of ammonia emissions in agriculture, including means to reduce impacts of nitrogen emissions, strategies to manage fertilizer applications to minimize nitrogen volatilization, and more.

[27] Factsheets can be under the "Agriculture Subcommittee" section at: www.colorado.gov/cdphe/rmnpinitiative

- Development of web resources oriented towards agricultural producers and extension personnel with information about ammonia emissions, mitigation strategies, and the Early Warning System.[28]

- Hosting four Agricultural Air Quality Symposia (two in 2011; two in 2012) to reach producers in eastern Colorado. Symposia presenters included representatives from agricultural producer organizations, CSU, NPS, EPA, and CDPHE.

- Presentations to the Boards of Directors of CLA and Colorado Corn regarding the NDRP, BMPs, deposition trends in RMNP, and opportunities to reduce impacts on RMNP.

- Publication of several articles addressing nitrogen management and deposition in RMNP in CLA's *Vision Magazine* that is sent to over 1,400 livestock producers and associated businesses throughout the state.

- Tours of local livestock and crop farms and ranches for members of the Subcommittee and MOU agencies that do not have backgrounds in agricultural production.

Livestock producers, crop producers, CSU faculty, and representatives from MOU agencies have worked collaboratively to present a unified and effective message to the public and to agricultural stakeholders regarding the sources and impacts of nitrogen emissions and what can be done to mitigate the effects of these emissions. Since 2007, the general tone of many of these conversations has changed from one of skepticism to one of mutual understanding and cooperation. Moving beyond the 2012 milestone report, continued outreach efforts are already planned for 2014 and 2015 to continue to engage agricultural producers and other emitters of ammonia as well as to promote means of reducing impacts on RMNP.

5.2.2.4. Ag Subcommittee Future Plans

As a committed stakeholder group of the NDRP, the RMNP Ag Subcommittee is developing an adaptive 5-year plan to help achieve nitrogen reduction goals in RMNP. The plan contains details regarding the Early Warning System, research, monitoring, and outreach among other Subcommittee activities and plans.

The agricultural community plans to continue to support research and outreach efforts to reduce the impacts of ammonia emissions on RMNP for the next several years. Researchers, led by Jay Ham at CSU, will deploy improved on-site measurement tools to better characterize ammonia emissions from livestock production systems and pinpoint sources of ammonia within those systems that may provide the best opportunities for mitigation. Sampling will be conducted under a research agreement from the National Science Foundation that is funded through 2015. The main goal of this NSF research project is to develop a robotic air-quality management system for dairies and cattle feedlots that will help managers reduce ammonia emissions into the air. Currently, data are being collected at feedlots and dairies near Fort Morgan and Wellington.

[28] See: http://www.rmwarningsystem.com for more details.

A monitoring plan to improve quantification of the impacts of efforts by the agricultural community on reducing ammonia emissions and their impact on RMNP is being developed. Such a monitoring system may include highly time-resolved concentration data collected in RMNP along with a network of monitors located in eastern Colorado. No funding has yet been identified to support such monitoring, but members of the Ag Subcommittee are actively seeking such support.

A pilot Early Warning System (EWS) to inform producers of impending upslope weather events that are likely to transport ammonia emissions from eastern Colorado into RMNP will be deployed in 2014. During the pilot study, the reliability of the warning system will be evaluated both in terms of meteorological prediction and producer responses. Based on results from 2014, the system will be improved for 2015, and an implementation plan developed to scale-up to a fully functional regional warning system for 2016. This effort is being led by CLA in cooperation with atmospheric scientists at CSU, CLA, NPS (RMNP and the Air Resources Division), CDPHE (Air Pollution Control Division and Sustainability Program), CSU, and a USDA-NRCS Conservation Innovation Grant have provided funding for this effort.

Continued outreach to agricultural producers is planned, including meetings of livestock producers to discuss the EWS and address barriers to adoption (fall 2013), surveying crop producers to more fully engage this sector, and elucidating means to maximize the effectiveness of the EWS for this sector (2013-2014). Additional Air Quality Symposia are being planned for early 2015, once the pilot EWS has been active for a year and additional monitoring data are available from CSU's ongoing efforts. A communication plan is being developed by the Ag Subcommittee to expand awareness of nitrogen deposition in RMNP and the EWS within the agricultural community and to other sources of ammonia that may be contributing to nitrogen deposition in RMNP as well.

Members of the Ag Subcommittee are collaborating to identify additional partners and resources to further research and outreach efforts within and beyond the agricultural community in Colorado. As understanding of deposition trends, sources of ammonia emissions, and mitigation options grows, outreach plans will be augmented and adapted to better inform and educate the agriculture community and the general public.

5.3. Regulatory Background

One purpose of the Colorado Air Pollution Control Act (Act), is to "facilitate the enjoyment and use of the scenic and natural resources of the State," C.R.S. § 25-7-102. Rocky Mountain National Park is among the "scenic and natural resources" of the State. Additionally, broad authority is given to the AQCC to regulate any "air pollutant" and gives the AQCC "maximum flexibility in developing an effective air quality control program and [the AQCC] may promulgate such combination of regulations as may be necessary or desirable to carry out that program", C.R.S, §§ 25-7- 108, 109.

"Air pollutant" is defined in the Act as including "any fume, smoke, particulate matter, vapor, or gas or any combination thereof which is emitted into or otherwise enters to the atmosphere." "Nitrous oxide" is expressly regulated as one of the six ambient air quality pollutants necessary for a SIP and could potentially be regulated to protect "air quality related values (AQRV)" (see sections 1001-08 of the Act) in RMNP, as long as the source or category of sources is determined to be a major source or other source as discussed below whereas ammonia is not defined or regulated in the Act. See C.R.S. § 25-7-109(2)(c). The Act establishes a protocol for the AQCC to promulgate regulations for

Class I areas related to AQRV's that have been adversely impacted by air pollutants, C.R.S., § § 25-7-1001 to 1008.

5.3.1. Regulatory vs. Voluntary Approaches to Reducing Ammonia Emissions

Emission reduction options can be evaluated and implemented under two paradigms: mandatory regulations, such as incentive-based programs, or voluntary means such as pollution prevention and best management practices. Regulation-based controls traditionally have been sought to ensure emission reductions under an enforceable legal framework. The Colorado Air Quality Control Commission (AQCC) has authority under general and specific provisions of the Colorado Revised Statutes to adopt regulations that reduce emissions of air pollutants. Assuming that emission reductions are necessary to protect public health and welfare, the regulated community benefits because there are consistent requirements under which to operate.

During the RMNP Initiative process, questions have arisen regarding the state's authority to regulate sources of ammonia. Ammonia is a pollutant as defined in section 109 of the Colorado Air Pollution Prevention and Control Act ("Act"), C.R.S.§ 25-7-109(2)(c) because it is a "chemical substance," one of the categories in the definition of "pollutant" in that section. Therefore, as an air pollutant, it can be regulated by the Commission as provided in § 25-7-109(1)(a) if it is being emitted from a "significant source" or "category of sources" or from "each type of facility, process, or activity which produces or might produce significant emissions of [ammonia]." *Id.*

There is an exception from such regulation for certain types of facilities, sources, or categories of sources of ammonia emissions; specifically "agricultural, horticultural or floricultural production" such as "farming" and "animal feeding operations." *See* C.R.S. § 25-7-109(8)(a). However, there is an additional exception to this exception; that is, the following facilities or sources of ammonia emissions are subject to reasonable regulation even though they would otherwise fit into the above exceptions. These facilities or sources are "swine feeding operations as defined in section 25-8-501.1(2)(b)." Other exceptions to the exceptions are "'major stationary sources' as defined in 42 U.S.C. § 75602(j), sources required to be regulated by Part C (prevention of significant deterioration), Part D (nonattainment) or Title V (minimum elements of a permit program)", or which are participating in the "early reduction program of section 112 of the federal [Clean Air Act]. *Id.*

Otherwise, the statute makes no differentiation between types of agricultural operations; consequently the exemption applies to all types of operations, including family farms and large commercial farms. The statute also identifies specific operations that are not to be regulated including seasonal crop drying, animal feeding, and pesticide application. This means that all feedlots regardless of size and all pesticide applications are exempt from regulatory requirements (unless the feedlot or pesticide application qualifies as a major source). Ancillary activities not typically considered agricultural (*e.g.*, service stations located at a country cooperative) would still be regulated. Consequently, legislative action to revise state law to include agricultural activities would be necessary for air quality regulations to be imposed on this sector.

Some of the NO_x control options that reduce nitrogen deposition at RMNP have been adopted as regulations under other air quality programs such as regional haze, described in Section 5.1. Other potential control strategies and mitigation measures are considered voluntary mechanisms. As stated in the MOU, signatories are committed to bring NO_x control strategies to the AQCC that benefit RMNP. Also, some controls that begin as voluntary measures may become mandatory if consistency or equity issues arise.

Voluntary emission reductions, which will be important for improving conditions at RMNP, allow sources to reduce emissions in the manner and to the extent as they choose. This approach requires sincere commitments by sources to voluntarily reduce emission on an ongoing basis. Some voluntary measures could prove to be cost effective if efficiencies are gained or if the measures stave off future regulations that may be more costly. The MOU Agencies and Ag Subcommittee are discussing potential incentive opportunities, including participation in CDPHE's Environmental Leadership Program. A number of potential emission control options, including reducing agricultural emissions of ammonia using such mechanisms as the pilot Early Warning System, may be effective on a voluntary basis.

5.4. Emission Reduction Activities Summary

CDPHE tracks NO_x reduction strategies and resulting emission reductions achieved, outlined in Table 10. It should be noted that the reduction strategies are not implemented simultaneously and occur in different areas of the state over a number of years. This information is provided to illustrate approximate NO_x emission reductions that are occurring or will occur in the near future. It is apparent that Colorado will experience a significant decline in anthropogenic NO_x emissions through 2018.

Table 10: Statewide Estimated NOx Reductions

Statewide Reduction Strategies	**Estimated NO_x Reduction (TPY)**
Regional Haze requirements (by 2018)	34,774
Retrofit RICE > 500 HP (~2010)	5,800
Northern Front Range I/M (~2018)	575
Denver Metro Area I/M (~2018)	623
Phase-In of Federal On/Off-Road Vehicle Standards (2010 to 2018)	34,482 (on-road) 11,586 (non-road)
Total:	**87,840**
Statewide NO_x Emissions (2010)	**297,079**

Regarding ammonia, the agricultural community has been actively involved in research and outreach to reduce impacts of ammonia emissions since before the 2007 NDRP was promulgated. During this time, many stakeholders from diverse organizations and interests have worked collaboratively in an unparalleled effort to develop strategies for tackling nitrogen deposition in RMNP. This collaborative effort should serve as a model for industries and government agencies working together for a common goal. Since 2007, significant improvements have been made in understanding the factors that govern ammonia emissions and transport, and innovative solutions for reducing the impacts of the agricultural emissions on RMNP have been initiated. At this point, many of these ideas have not yet been developed to the degree that significant reductions in deposition contributions from agriculture could be expected, but tangible plans for these solutions are being developed and executed with the goal of reducing nitrogen deposition as future milestones approach and, in particular, the 2032 target of 1.5 kg N/ha/yr of wet nitrogen deposition.

The RMNP Initiative, including the NDRP, is a first-of-its-kind approach to nitrogen management in the United States and has been implemented within the context of increased awareness of reactive nitrogen and consideration of ammonia regulations at a national level. The agricultural community recognizes its contributions and responsibilities with regards to ammonia emissions and is working collaboratively with researchers, producers, academic institutions, government agencies, and non-governmental organizations to identify environmentally and financially sustainable solutions to nitrogen management.

6. RMNP (In-Park) Emissions and Controls

6.1. Mobile Sources

RMNP has approximately three million visitors per year who arrive at and tour RMNP and its surrounding areas primarily in gasoline and diesel powered vehicles. In addition, the community of Estes Park borders RMNP on the east side and attracts many visitors. These mobile sources contribute to NO_x emissions especially from June through October when visitation is highest. Some of these emissions contribute to nitrogen deposition in RMNP, although results from RoMANS I indicate that in-park NO_x emissions are minimal contributors, with less than 1% in the spring and roughly 8% in the summer, to the oxidized portion of total wet nitrogen deposition. Nearby Estes Park emissions were ascertained to make some contribution to oxidized nitrogen deposition, although RoMANS analyses did not allow for a quantitative measurement. Regardless, actions are in place to help reduce RMNP mobile source emissions including a visitor transportation system and increasing fleet efficiency.

From 2001 to present, RMNP has operated a visitor transportation system along the popular Bear Lake Corridor with two main routes. The Bear Lake Route moves visitors from RMNP's transportation hub, known as the Park & Ride, to Bear Lake with stops at popular trailheads. The Moraine Park Route connects RMNP's two main campgrounds to the Park & Ride. Riding the shuttle provides an opportunity for visitors to reduce their fuel consumption, reduce traffic and parking congestion, and lets them enjoy the ride and views without driving. Shuttles run from Memorial Day through Columbus Day with over 450,000 people riding these routes in an average year.

Beginning in 2006, RMNP, in conjunction with the Town of Estes Park, launched a pilot project to test an integrated visitor transportation system. This integrated system provides easy access from lodging establishments and the town's Fairgrounds Park and Ride to downtown shopping and RMNP access. The town of Estes Park provides four routes as part of their portion of the integrated system; two routes serve lodging establishments along Colorado Highway 34 and Colorado Highway 36, while the third is known as the "campground route" which serves private campgrounds in the Estes Park area. An additional shuttle provides access from the Town's Fairgrounds Park and Ride. RMNP added a connecting route known as the "Hiker Shuttle" which is an express route that runs from the Fairgrounds Park and Ride and Estes Park Visitor Center to RMNP's Beaver Meadows Visitor Center, and on to the Park & Ride. In 2012, over 53,000 people rode the Hiker Shuttle. The 2013 shuttle fleet, including more than ten diesel buses, was fitted with diesel particulate filters to remove much of the soot particulates from shuttle exhaust. The 2014 shuttle fleets will include two hybrid electric buses that will operate even more efficiently and with greater passenger capacity.

In addition, RMNP is increasing efficiency of its fleet by adopting hybrid electric technology, educating drivers on fuel saving practices, and optimizing fleet size and consumption. RMNP's 2013 fleet contains 219 vehicles including 19 hybrids (up from only four in 2007) and one full electric. In 2013, RMNP was awarded funding through the Department of Energy's Clean Cities National Parks Initiative. The Initiative supports transportation projects that educate RMNP staff and visitors on the benefits of reducing dependence on petroleum, cutting greenhouse gases, and easing traffic congestion. With support from the local Clean Cities coalition, Northern Colorado Clean Cities, RMNP purchased one Toyota Highlander Hybrid and two Chevy Volts, with plans to install two electric vehicle charging stations, and adopt idle-reduction programs as well as an education and outreach program for staff and visitors.

6.2. Stationary Sources

Two diesel-powered generators provide electricity to the Alpine Visitor Center and Trail Ridge Store during the summer months atop Trail Ridge Road at 11,796 feet elevation where electric service is otherwise not available. The Alpine Visitor Center is closed during the fall, winter and spring months. Energy efficient biodiesel powered electrical generators were installed in 2005 that reduced fuel consumption by approximately 45%. The administrative facilities within RMNP are powered and heated with electricity produced by local hydroelectric plants.

6.3. Natural Sources

Natural background nitrogen deposition for the western United States has been estimated at 0.2 kg N/ha/yr. Emission estimates include contributions from animal, plant, and fire sources. Nitrogen emissions to the atmosphere from natural sources in RMNP should be similar today as they were historically under natural conditions.

6.4. Climate Friendly Parks Program

Climate change and excess nitrogen deposition are threats to RMNP where the high elevation resources are especially susceptible to their impacts. To help address these challenges, RMNP became a part of the Climate Friendly Parks Program, which teams with the EPA as part of the NPS Green Parks Partnership Program. RMNP was the tenth NPS Park to become an official Climate Friendly Park in July of 2007. This title designated RMNP as part of a network of parks that place climate friendly behavior at the forefront of park planning and operations. The Climate Friendly Parks Program enables national parks to develop both short and long-term, comprehensive strategies to reduce their greenhouse gas and criteria air pollutant emissions. Also, the program includes a park commitment to educate the public about what actions RMNP is implementing to mitigate emissions, and to communicate why the issues of climate change and air pollution are so important.

As a result of the Climate Friendly Parks program, the RMNP Green Team was formed in the summer of 2007 with the mission of leading RMNP in implementing sustainable practices, promoting environmentally responsible behavior and to help RMNP serve as a role model of effective environmental stewardship for current and future generations. The Green Team consists of a group of interdisciplinary park employees who meet monthly to organize implementation of green ideas to help RMNP operations become more sustainable. The Green Team creates and promotes Energy & Waste Reduction Guidelines for RMNP employees and volunteers. These guidelines provide practical ways to reduce transportation, energy, and solid waste production, and promote a green culture during daily operation. By observing the guidelines, all employees and volunteers contribute to RMNP's commitment to environmental leadership, reduce operational costs and impacts to resources, and improve sustainability at RMNP as a Climate Friendly Park.

6.5. Environmental Management System

In 2011, RMNP began a comprehensive Environmental Management System (EMS) with goals to achieve 100% compliance with applicable environmental laws and regulations, and to further increase sustainability of all RMNP operations. Operational aspects with current EMS reduction/improvement goals include: energy, solid waste, water, green purchasing, sustainable buildings, greenhouse gas emissions, communication, and transportation.

Within the EMS, RMNP specifically commits to:

- Meet or exceed all applicable federal, state, and local environmental laws and regulations;
- Conduct operations in the most environmentally responsible manner possible while demonstrating the long term fiscal, social, and environmental benefits of green practices;
- Use the best available science and cost-effective technology to maximize sustainable facility design adaptations;
- Provide leadership when working with RMNP concessionaires, cooperating organizations, suppliers, vendors, and contractors;
- Continuously improve environmental performance, including areas not subject to regulations; and
- Educate RMNP staff, visitors, and other stakeholders about park sustainability, and the link between climate change, impacts on RMNP, and opportunities for environmental leadership.

The Energy Independence & Security Act of 2007 requires a 30% energy use reduction for RMNP buildings by 2015, using 2003 as the baseline year. Figure 36 shows RMNP reduction progress for annual British thermal units (BTUs) used by RMNP since 2003 with reduction goals achieved for 2011 and 2012. BTUs used include energy from electricity, natural gas, propane, and biodiesel.

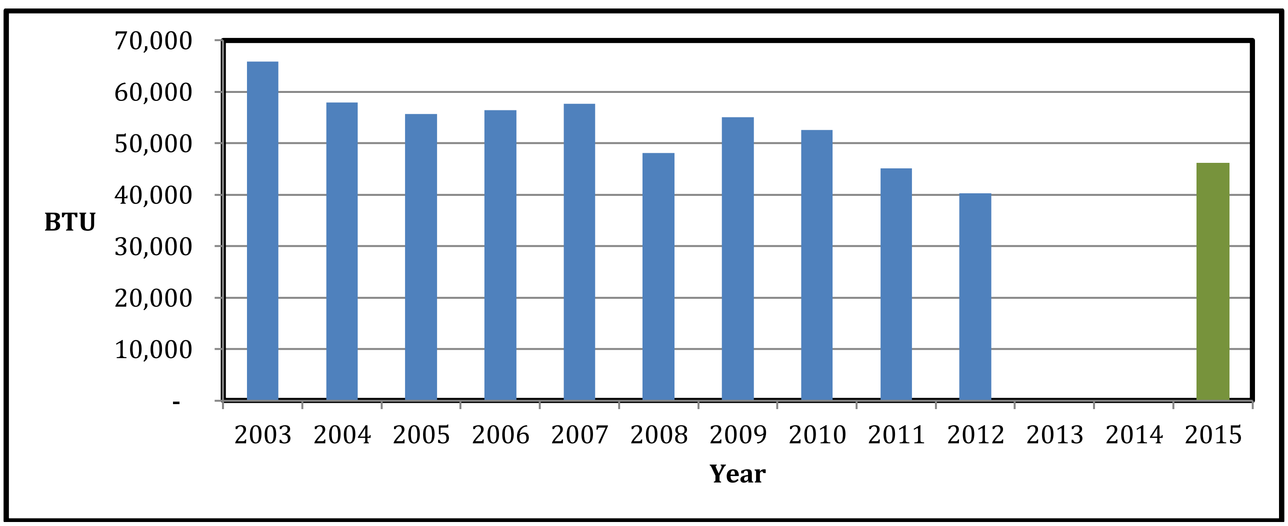

Figure 36: Annual British Thermal Units (BTU) per Square Foot used by RMNP (2003 - 2012) (blue bars), showing progress toward a 30% BTU reduction goal by 2015 (green bar)

7. Conclusions & Next Steps

RMNP has developed a resource management goal for nitrogen deposition that is supported by the MOU agencies. The resource management goal is expressed as a critical load of 1.5 kg N/ha/yr for wet nitrogen deposition (a 48% reduction from current wet deposition of 2.9 kg N/ha/yr).

Wet nitrogen deposition at Loch Vale in RMNP in 2012 was 2.9 kg N/ha/yr, which is above the glidepath. However, the long-term nitrogen deposition trend at Loch Vale (1984 – 2012) shifted from an increasing trend through 2009 year data, to being stable, or showing no significant trend, with the addition of 2010, 2011, and 2012 data. In contrast, at Beaver Meadows in RMNP wet nitrogen deposition increased over the long-term (1981-2012). Ammonium concentrations also increased significantly at four of the five sites in the region over the long-term. Recent trends (2006 – 2012) show that nitrate concentrations are decreasing at three out of five sites in the region while ammonium concentrations are stable.

Measurements and modeling analyses illustrate that anthropogenic NO_x (nitrogen oxides) and ammonia emissions from industrial, mobile, and agricultural sources appear to be significant contributors to particulate nitrate formation in RMNP during the spring and fall months. The Rocky Mountain Atmospheric Nitrogen and Sulfur Studies (RoMANs I and II), found that a substantial portion of deposited nitrogen originates from within the state of Colorado, with more than half of reduced nitrogen (ammonia/ammonium) originating from Colorado sources and less than half of oxidized nitrogen (nitric acid/nitrate) originating from Colorado sources.

Current demographic trends show population increases in the Denver Metropolitan Area averaging about 9% every four years while vehicle miles are predicted to increase roughly 12% over six years. Total cattle, farms, harvested crops, and hog counts have remained fairly stable over the past four years. Data shows substantial decreases in NO_x emissions over the past decade, both nationally and in the Denver area, while ammonia emissions have remained stable over the same time period.

Efforts continue to improve Colorado's nitrogen emission inventory data, including recent studies that estimate and identify source categories for improvement and updates, including livestock and fertilizer operations for ammonia and oil and gas activities for NO_x. The MOU agencies are involved in several collaborative inventory and research efforts that will improve both ammonia and NO_x inventories and real-time emission knowledge in the coming years.

Several significant upcoming NO_x reductions are noted, including natural gas compressor engine Best Available Control Technology (BACT) requirements, retrofit controls on larger engines, Regional Haze provisions, and federal on- and off-road standards. By 2018, a combined statewide approximate 37% NO_x reduction is anticipated, which is expected to reduce nitrogen deposition in RMNP.

The Ag Subcommittee has supported multiple ongoing research efforts, including several Colorado State University (CSU) studies evaluating best management practices (BMPs) and assessments of local ammonia emissions. A promising project coming out of this group's efforts was recently funded with the help of numerous partners, including the MOU agencies, to develop an Early Warning System (EWS), which will notify agricultural producers to avoid practices that may lead to large releases of ammonia on particular days where upslope weather conditions are predicted. Additionally, the Ag Subcommittee is developing an adaptive five-year plan to help achieve nitrogen reduction goals in

RMNP, which will include research, monitoring, and outreach plans. Other important efforts include EPA's draft ammonia emission-estimating methodologies (EEMs) for select animal feeding operation categories and CSU's continued research regarding monitoring and estimating ammonia emissions from feedlots.

Within RMNP, multiple projects are in place to help reduce mobile source emissions, including visitor transportation systems that connect popular destinations in the park and town of Estes Park. Additionally, RMNP is increasing the park's fleet efficiency by educating drivers on fuel saving practices and optimizing fleet size and composition. Biodiesel powered electrical generators were installed in 2005 at the Alpine Visitor Center. RMNP is designated a Climate Friendly Park and has a Green Team which organizes implementation of green ideas to help RMNP operations become more sustainable. An Environmental Management System is in place to achieve 100% compliance with applicable environmental laws and regulations, and to further increase sustainability of RMNP operations, including a goal to reduce energy usage 30% by the year 2015.

The two identified goals of this report are to address:

1. 2012 interim milestone determination
2. RMNP Nitrogen Deposition Contingency Plan triggering

Key goals of the NDRP are to reverse the trend of increasing nitrogen deposition in RMNP and, using a 25-year glidepath approach with an interim milestone of 2.7 kg N/ha/yr in 2012. Although the interim milestone was not achieved in 2012 and trends indicate that nitrogen deposition has not been reversed, the weight of the evidence demonstrates that nitrogen deposition is stabilizing, and has not been increasing in recent years. Many state and federal regulations being implemented in Colorado to reduce NO_x emissions are expected to reduce future nitrogen deposition in RMNP.

The Ag Subcommittee also continues to make progress by the development of an adaptive five-year plan that gives the MOU agencies confidence in future ammonia emission reductions. In particular, the EWS, planned research and outreach of best management practices, and ammonia monitoring highlight important steps to ensure future success. The Ag Subcommittee must continue to be adaptive to emerging issues and we anticipate continued close collaboration with their efforts. The agencies concur that allowing developing and current strategies adequate time to show effectiveness is prudent.

Therefore, the MOU agencies conclude that the 2012 interim milestone has not been achieved. However, the RMNP Nitrogen Deposition Contingency Plan shall not be triggered at this time. The MOU Agencies will complete the following steps to ensure progress continues during the next five-year period leading up to the 2017 Milestone Report evaluation.

The agencies will continue to monitor nitrogen deposition levels as strategies are implemented to determine whether additional steps are needed, in prior to 2017, to meet the next milestone. These MOU agency steps include:

- A review and update of the 2010 Contingency Plan that includes the latest information on deposition and research, and identifies the most effective contingency measures;

- Continued tracking of nitrogen deposition reduction through annual publications of Monitoring and Tracking Wet Deposition in RMNP[29];
- Continued collaboration with the Ag Subcommittee on EWS development, and other ways to reduce ammonia emissions from the agricultural community;
- Continued work with additional CDPHE programs (e.g. the Water Quality Control Division and Solid and Hazardous Waste Division), other state agencies (e.g. Department of Agriculture and Department of Parks and Wildlife), and other relevant agencies and stakeholders particularly on (ammonia and NO_x) inventory improvements;
- Continued collaboration with stakeholders, researchers, and other agencies regarding voluntary emission reductions including grant opportunities, graduate research projects, and others;
- Coordination with other states and initializing discussions regarding nitrogen deposition changes in the West;
- Additional monitoring research and modeling (as funding permits); and
- Education and outreach to interested stakeholders.

The MOU agencies will continue to assess the progress made in reducing nitrogen deposition impacts in RMNP, and commit to issue the next report for the 2017 milestone. Prior to 2017, and until nitrogen deposition approximates the glidepath at Loch Vale, the MOU agencies will use the weight of evidence approach to determine whether the 2017 milestone can be achieved with the current and anticipated emission reductions. Should the weight of evidence suggest the 2017 milestone cannot be achieved and there is greater departure from the glidepath and/or declining progress of partners, the MOU agencies may determine, with stakeholder input, whether the RMNP Nitrogen Deposition Contingency Plan may be triggered before the 2017 milestone evaluation.

[29] http://www.colorado.gov/cs/Satellite?c=Page&childpagename=CDPHE-AP%2FCBONLayout&cid=1251639300224&pagename=CBONWrapper

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ACRONYM LIST

Agriculture	Ag
Air Quality Related Values	AQRV
Ammonia	NH_3
Ammonium	NH_4
Ammonium Nitrate	NH_4NO_3
Animal Feeding Operations	AFOs
Best Available Control Technology	BACT
Best Management Practices	BMPs
British Thermal Units	BTUs
Bureau of Land Management	BLM
Carnegie Mellon University	CMU
Colorado Air Quality Control Commission	AQCC
Colorado Department of Public Health and Environment	CDPHE
Colorado Livestock Association	CLA
Colorado State University	CSU
Comprehensive Environmental Response, Compensation, and Liability Act of 1980	CERCLA
Concentrated Large Animal Feeding Operations	CAFOs
Denver Metropolitan Area	DMA
Denver Metropolitan Area/North Front Range	DMA/NFR
Early Warning System	EWS
Emergency Planning and Community Right to Know Act of 1986	EPCRA
Emission Estimating Methodologies	EEMs
Environmental Protection Agency	EPA

Front Range Air Pollution and Photochemistry Experiment	FRAPPE
Grand Teton National Park	GTNP
Grand Tetons Reactive Nitrogen Deposition Study	Grand TReNDS
Inspection and Maintenance	I/M
Kilograms of Nitrogen per hectare per year	kg N/ha/yr
Memorandum of Understanding	MOU
Motor Vehicle Emission Simulator Model	MOVES
National Air Emissions Monitoring Study	NAEMS
National Ambient Air Quality Standards	NAAQS
National Atmospheric Deposition Program Ammonia Monitoring Network *or* Ammonia Monitoring Network	AMoN
National Atmospheric Deposition Program/National Trends Network	NADP/NTN
National Emissions Inventory	NEI
National Park Service	NPS
Nitrate	NO_3
Nitrate and/or Ammonium Concentrations [measured in micro equivalents per liter]	µeq/L
Nitrate and/or Ammonium Concentrations [measured in micrograms per meter cubed]	µg/m3
Nitrogen	N
Nitrogen Deposition Reduction Plan	NDRP
Nitrogen Dioxide	NO2
Nitrogen Oxides	NO_X
Nitrous Oxide	N_2O
Particulate Matter	PM
Reciprocating Internal Combustion Engine	RICE
Rocky Mountain Atmospheric Nitrogen and Sulfur Studies I and II	RoMANs I and RoMANs II

Rocky Mountain National Park	RMNP
Rocky Mountain National Park Interagency Monitoring of Projected Visual Impairments	IMPROVE
Selective Catalytic Reduction	SCR
State Implementation Plans	SIPs
Sulfur Oxides	SO_X
Three-State Data Warehouse and Air Quality Study	Three-State Study
Tons Per Year	tpy
United States Department of Agriculture	USDA
United States Department of Agriculture Natural Resources Conservation Services	NRCS
Volatile Organic Compounds	VOCs
Western Regional Air Partnership	WRAP
WestJump Air Quality Modeling Study	WestJumpAQMS