From Emission to Deposition
Flows of Nitrogen Along the Front Range

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0:01:00 - Overview, definitions, and acronyms

0:05:00 - Air movement near RMNP

0:15:00 - Sources of N along the Front Range

0:20:00 - Atmospheric deposition of N in RMNP

0:35:00 - Ecological effects of N enrichment in RMNP

0:45:00 - The RMNP “glidepath” - an outsider’s view

0:52:00 - Questions and responses
A Few Acronyms

- RNS - reactive nitrogen species (biggies: NH\textsubscript{x}, NO\textsubscript{x})
- TIN - total inorganic nitrogen (TIN = NH\textsubscript{4}-N+ NO\textsubscript{3}-N)
- NADP - National Atmospheric Deposition Program
- CASTNET - Clean Air Status and Trends Network
- RMNP(I) - Rocky Mountain National Park (Initiative)
- RoMANS - Rocky Mountain Atmospheric Nitrogen and Sulfur study
The Basic Idea

• Pristine RMNP ecosystems evolved with low nutrient inputs

• These ecosystems now exhibit signs of ecological shifts

• The shifts are consistent with nutrient enrichment (primarily N)

• Wet deposition of N appears to have increased in the Park over the past couple of decades

• Hypothesis: Increased wet deposition of N is responsible for irreversible shifts in high alpine ecosystems

• Corollary: Reducing wet deposition of N would head off those ecological shifts
Air Movement Near RMNP
What is a Wind Rose?

- Does not necessarily represent the motion of the airmass as a whole
- Shows wind frequency × speed × direction
- Prevailing (~60%) winds at RMNP have a westerly (downslope) component
- Data may be disaggregated to show seasonality or diurnality
RMNP Wind Rose - Daytime

- Prevailing (~50%) tends to be moderate to strong, downslope (W-N) winds
- Significant component (~25%) is dominated by relatively light, upslope (SSE-SE) winds
• Downslope (sinking, warming) winds present ~70%

• Almost no upslope (E) component at night
Chinooks predominate and can be very strong.
• Strong downslope component
• Significant upslope, moderate speeds
• Downslope component predominates, but wind speeds are not as great

• Upslope winds are light
• Chinooks dominant
Greeley Wind Roses

Greeley GLY03: Hourly Surface Data for 2004

Greeley GLY03: Hourly Surface Data for 2006
Kersey Wind Roses

2004

Kersey KSY01: Hourly Surface Data for 2004

Kersey KSY01: Hourly Surface Data for 2006

2006
So What?

Air masses over RMNP generally come from the W and NW, depending on the season; BUT

Air masses *that generate significant precipitation* tend to come from the E and SE

Wind direction in RMNP does not necessarily point directly back at the source of the air mass!
Sources of N Along the Front Range
Sources

Nitrogen compounds (e.g., NO\textsubscript{x}, ammonia) and sulfur compounds are emitted into the atmosphere from a variety of air pollution sources, including automobiles, power plants, industry, agriculture, and fires. Colorado’s Front Range is an area of rapid population growth, escalating urbanization, oil and gas development, and agricultural production. Increases in these activities result in corresponding increases in nitrogen deposition in mountain ecosystems.

Facts

♦ 2/3 of the state's population lives along the Front Range.
♦ Ammonium nitrate is a common crop fertilizer and results in emissions of ammonia.
♦ Some chemical transport models suggest that 25-30% of nitrate and 45-50% of sulfate is associated with emissions from within Colorado.

Source: Rocky Mountain Atmospheric Nitrogen and Sulfur (RoMANS) Brochure
What Happens to Emitted NH$_3$?

- Atmospheric residence time of NH$_3$ gas is fairly short (<7 days) due to its high reactivity with surfaces, with water, and with acid gases.
- NH$_3$ sources tend to be at ground level (i.e., not stack emissions).
- Dry deposition of gaseous NH$_3$ dominates near sources.
- Wet deposition of particle-phase NH$_4^+$ dominates away from sources.

Source: Asman et al. (1998)
Watson et al. (1996)

- Northern Front Range Air Quality Study (NFRAQS)
- Seasonality, composition, and distribution of PM along the I-25 and US85 corridors
- Major conclusion: Study area is relatively enriched with respect to NH$_3$ as compared to SO$_x$ and NO$_x$
- Would changes in NH$_3$ concentration give rise to changes in secondary fine particles (sulfates and nitrates)?
More NFRAQS Conclusions

- Virtually all of the sulfate and nitrate in the NFR can be accounted for as secondary ammonium salts (PM$_{2.5}$)

- If NH$_3$ levels were reduced by 50%...
  - ...most of the available HNO$_3$ would be neutralized
  - ...particle NO$_3$ would be reduced by only 15%

- Beyond 50% reduction in NH$_3$, particle NO$_3$ would decrease proportionately with NH$_3$
Atmospheric Deposition in RMNP
Two Kinds of Deposition

- **WET deposition** - rainfall, snowfall, fog
  - Gases and particles dissolve into liquid phase to form solution
  - Solution deposits on surfaces (canopies, vegetation, soils, surface water) as fog, dew or precipitation

- **DRY deposition** - gases and particles impact or settle onto surfaces without assistance from condensing water
Anatomy of an NADP Site

Deposition (kg/ha/yr) = Precipitation (mm/wk) * Concentration (mg/l) * 0.52
Rain Gauge
Rainfall Sampler
NADP Sites in Rocky Mountain National Park

CO19 “Beaver Meadows”

CO98 “Loch Vale”
Deposition and Precipitation, CO19
Seasonality of Wet Deposition and Precipitation, Loch Vale
Seasonal Proportion of NO$_3$-N and NH$_4$-N in Wet Deposition
Loch Vale, 1996-2006
"An analysis of 1995 through 1998 CASTNET data shows no trend in dry nitrogen or sulfur deposition at the park.” (RMNP, 2008)

\[ \frac{dN}{dt} = -0.01 \text{ (kg/ha/yr)/yr} \]

Baron et al. (2005)
So Who’s Responsible?

This is a question known as “source apportionment”

Source apportionment requires modeling:

Assumptions

Discretized domains (grid sizes >4 km)

Accepted algorithms

Tracers within the source domains

GIGO - results can be no more accurate than the input data
RoMANS: A Source-Apportionment Study

Two models required

- MM5 (wind fields, precipitation)
- CAMx (chemical transport)

Tracer sources inside and outside of CO

Interim finding: 33% of NH$_3$ and 50% of NO$_x$ affecting RMNP are from CO sources

Source: Barna et al. (2007)
NH$_4^+$ ion concentrations, 2004
Ammonia Emissions in Colorado

Facts

- Northeastern Colorado is a highly productive agricultural region.
- Colorado ranks 4th in the United States for confined-fed cattle, sheep, and lamb production.
- Colorado ranks 11th in the United States for pig production.

Regional Ammonia Emissions

Source: Rocky Mountain Atmospheric Nitrogen and Sulfur (RoMANS) Brochure
Wet Deposition Can Increase If:

- Precipitation increases*; OR
- Emissions of compounds or precursors increase within the source footprint*; OR
- Frequency of upslope conditions increases*; OR
- Any two or more of the above coincide*

*All other influences remaining equal
Ecological Effects of N Deposition in RMNP
Ecological Effects of Alpine N Enrichment

- Water quality: increased N concentrations in streams and lakes
- Eutrophication
- Change in microbial flora (diatoms)
- Vegetation: From wildflowers to grasses and sedges
- Soil acidification as NH₄ oxidized to NO₃

Source: Baron et al. (2005)
The RMNP “Glidepath”
Major Glidepath Components

- Historical background deposition in RMNP estimated at 0.2 kg N/ha/yr
- “Critical load” (at which ecosystem shifts thought to begin) estimated at 1.5 kg N/ha/yr
- The resource-management goal established by NPS and agreed by CDPHE and EPA is 1.5 kg/ha/yr by 2032
- Interim goal of 2.7 kg/ha/yr by 2012
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These are the areas where mitigation strategies focus.
Two thirds (65%) of the NH$_3$ under consideration originates outside CO?
Cold (Beef) Carcass Weights at Slaughter
Annual Means, National, 1989-2006

Source: CattleFax

5.27 lb/yr increase (0.73%/yr)
Estes Valley Traffic Projection:

>50% increase over 20 years
Q&R