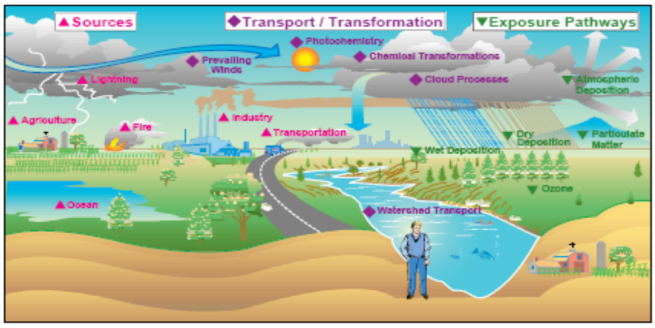
Name: _____ Date: _____

1.3 Sherlock NOx: The Mystery of Unnatural Pollution in Natural Places – Student Investigation Guide

Background:
The natural resources of Rocky Mountain National Park (RMNP), including its majestic vistas, are vulnerable to the harmful effects of air pollution. Ground level ozone, particulate matter and the deposition of air pollutants impact surface water, wildlife, vegetation, and visibility in the park.



One of the major air pollution threats to aquatic (water) and terrestrial (land) resources in RMNP is nitrogen deposition (depositing of nitrogen compounds on the Earth's surface). Nitrogen pollutants (mainly ammonia and nitrogen oxides) that are released into the air along the Colorado Front Range and beyond are transported upslope into the park by weather systems and deposited by rain and snow (wet deposition) onto lakes, streams, soils, and vegetation at RMNP. (Image: CDPHE)

The higher in the park are at a greater risk because they receive more precipitation and nitrogen deposition and are more sensitive to the excess nitrogen than lower elevations. Scientific research in RMNP reveals the effects of increased nitrogen deposition include:

- Nitrogen saturation of soils, which leaks into alpine lakes and streams changing the water chemistry
- Changes in the amounts and types of microscopic organisms called diatoms in alpine lake aquatic communities in high-elevation watersheds.
- Intensified activity of soil microbes, which then creates more available nitrogen in ecosystems
- Increased nitrogen levels in soils act as a fertilizer changing the composition of alpine plant communities by increasing grasses and sedges and reducing biodiversity, and potentially wildflowers, in this fragile ecosystem
- Increased nitrogen levels in lichens (organisms that grow on trees & rocks).
- Potential elevated levels of nitrogen in spruce needles, that may cause trees to be more susceptible to forest disease, drought, or insect infestations
- Potential increase in the risk of exotic invasive plant infestations (weeds)
- Potential increase in the risk of algal blooms in high mountain lakes

The National Park Service, the State of Colorado, and the Environmental Protection Agency are currently coordinating efforts to reduce the levels of nitrogen deposition in Rocky Mountain National Park through the Nitrogen Deposition Reduction Plan.
Source:
http://www.nature.nps.gov/air/permits/aris/romo/impacts.cfm?tab=0#TabbedPanels1

Day 1
Engage

Surveying the Scene:
Our National Park Service aims to protect vital natural resources for wildlife, their habitats, and visitors alike. Do our national parks have good or poor air quality?

This video provides an introduction the National Park Services' air quality research program. As you watch the video, complete the "fast facts" to gather initial clues about air quality in our national parks. After watching the video, share your responses during a class discussion to complete or correct any responses, if needed.

Video: "On the Air: Air Quality" (5 min. 34 sec.)
http://www.nature.nps.gov/air/multimedia/podcast/OnTheAir/AirPodCast.cfm

1. National Parks are pristine (unspoiled) places. True or False

2. The visibility (clarity of the air) in National Parks is increasing / decreasing. (circle the correct choice).

3. Name the top five air pollutants that are a concern in our National Parks:
   a) _____
   b) _____
   c) _____
   d) _____
   e) _____

4. List the most common sources of air pollution that affect our National Parks:
   a) _____
   b) _____
   c) _____
   d) _____

5. Greenhouse gases are recognized as air pollutants by the National Park Service, which is making efforts to understand and respond to the effects of climate change. True or False

a) National Parks are raising public awareness about air quality issues and reducing their own contributions to air pollution by:
   a) _____
   b) _____

Explore

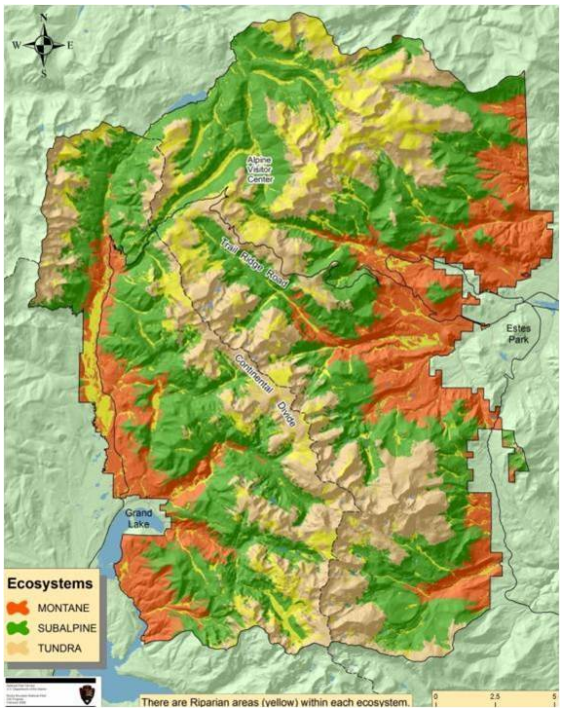
Tracing the Tracks of Air Pollution in the Park:

Take a virtual field trip to Rocky Mountain National Park to learn how national park staff and scientists conduct air quality research in the park and complete the table below.

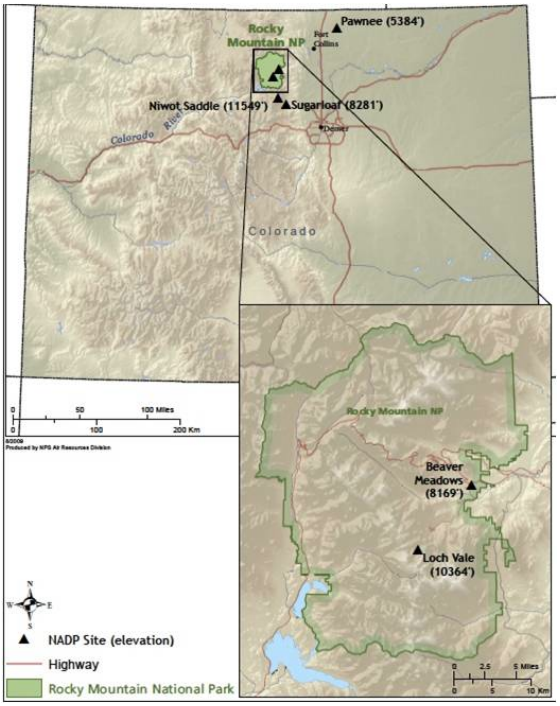
Video: "Rocky Mountain National Park Science Behind the Scenes – Air Quality" (10 min. 2 sec.)

https://www.youtube.com/watch?v=rFIq01sLIpc

Air Monitoring System	What is Measured?
1.	
2.	
3.	



RMNP Ecosystem Types



RMNP National Atmospheric Deposition Program (NADP) Air Monitoring Locations

Images: NPS

Review the maps to identify the ecosystems and locations of the nitrogen deposition air monitoring stations in Rocky Mountain National Park:

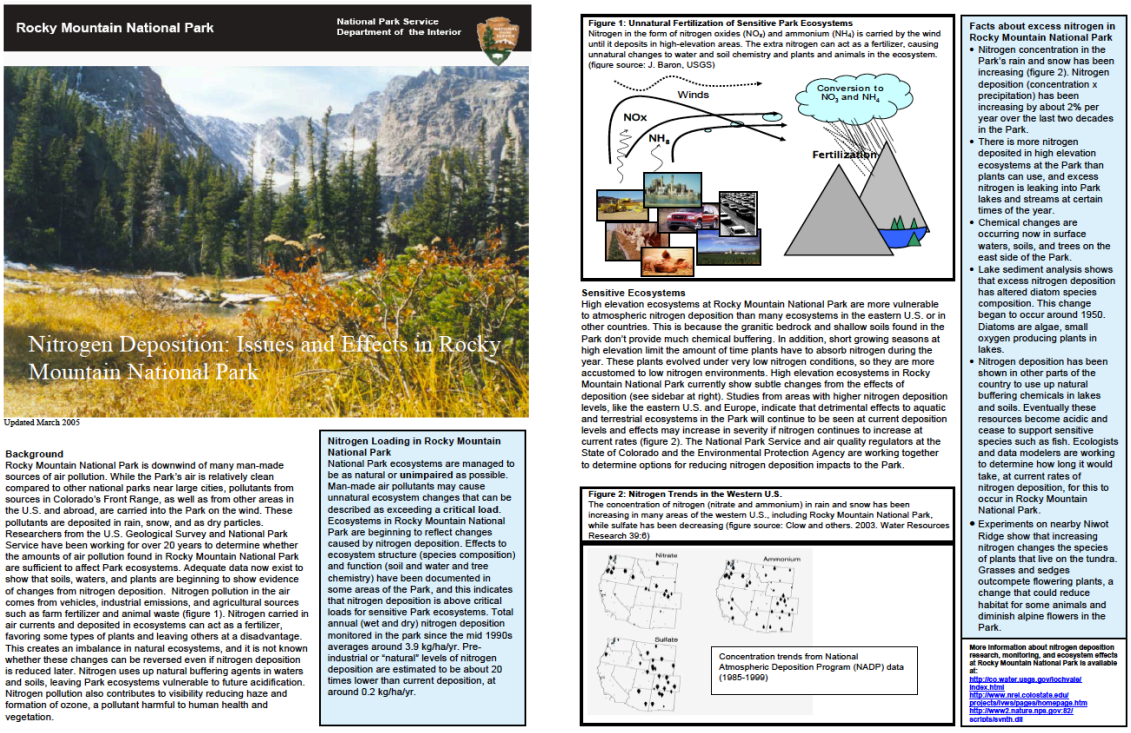
1. Which ecosystem is the Beaver Meadows NADP monitoring site located?
   Montane Subalpine Tundra (circle one correct choice)

2. Which ecosystem is the Loch Vale NADP monitoring site located?
   Montane Subalpine Tundra (circle one correct choice)

Explain

Identifying and Interpreting N-Dep. Evidence:

Read the "Nitrogen Deposition: Issues and Effects in Rocky Mountain National Park" National Park Service brochure for an overview of the causes and effects of nitrogen deposition in the park.



Rocky Mountain National Park

National Park Service
Department of the Interior

Nitrogen Deposition: Issues and Effects in Rocky Mountain National Park

Updated March 2005

Background
Rocky Mountain National Park is downwind of many man-made sources of air pollution. While the Park's air is relatively clean compared to other national parks near large cities, pollutants from sources in Colorado's Front Range, as well as from other areas in the U.S. and abroad, are carried into the Park on the wind. These pollutants are deposited in rain, snow, and as dry particles. Researchers from the U.S. Geological Survey and National Park Service have been working for over 20 years to determine whether the amounts of air pollution found in Rocky Mountain National Park are sufficient to affect Park ecosystems. Adequate data now exist to show that soils, waters, and plants are beginning to show evidence of changes from nitrogen deposition. Nitrogen pollution in the air comes from vehicles, industrial emissions, and agricultural sources such as farm fertilizer and animal waste (figure 1). Nitrogen carried in air currents and deposited in ecosystems can act as a fertilizer, favoring some types of plants and leaving others at a disadvantage. This creates an imbalance in natural ecosystems, and it is not known whether these changes can be reversed even if nitrogen deposition is reduced later. Nitrogen uses up natural buffering agents in waters and soils, leaving Park ecosystems vulnerable to future acidification. Nitrogen pollution also contributes to visibility reducing haze and formation of ozone, a pollutant harmful to human health and vegetation.

Nitrogen Loading in Rocky Mountain National Park
National Park ecosystems are managed to be as natural or **unimpaired** as possible. Man-made air pollutants may cause unnatural ecosystem changes that can be described as exceeding a **critical load**. Ecosystems in Rocky Mountain National Park are beginning to reflect changes caused by nitrogen deposition. Effects to ecosystem structure (species composition) and function (soil and water and tree chemistry) have been documented in some areas of the Park, and this indicates that nitrogen deposition is above critical loads for sensitive Park ecosystems. Total annual (wet and dry) nitrogen deposition monitored in the park since the mid 1990s averages around 3.9 kg/ha/yr. Pre-industrial or "natural" levels of nitrogen deposition are estimated to be about 20 times lower than current deposition, at around 0.2 kg/ha/yr.

Figure 1: Unnatural Fertilization of Sensitive Park Ecosystems
Nitrogen in the form of nitrogen oxides (NO_x) and ammonium (NH_4) is carried by the wind until it deposits in high-elevation areas. The extra nitrogen can act as a fertilizer, causing unnatural changes to water and soil chemistry and plants and animals in the ecosystem. (figure source: J. Baron, USGS)

Sensitive Ecosystems
High elevation ecosystems at Rocky Mountain National Park are more vulnerable to atmospheric nitrogen deposition than many ecosystems in the eastern U.S. or in other countries. This is because the granitic bedrock and shallow soils found in the Park don't provide much chemical buffering. In addition, short growing seasons at high elevation limit the amount of time plants have to absorb nitrogen during the year. These plants evolved under very low nitrogen conditions, so they are more accustomed to low nitrogen environments. High elevation ecosystems in Rocky Mountain National Park currently show subtle changes from the effects of deposition (see sidebar at right). Studies from areas with higher nitrogen deposition levels, like the eastern U.S. and Europe, indicate that detrimental effects to aquatic and terrestrial ecosystems in the Park will continue to be seen at current deposition levels and effects may increase in severity if nitrogen continues to increase at current rates (figure 2). The National Park Service and air quality regulators at the State of Colorado and the Environmental Protection Agency are working together to determine options for reducing nitrogen deposition impacts to the Park.

Figure 2: Nitrogen Trends in the Western U.S.
The concentration of nitrogen (nitrate and ammonium) in rain and snow has been increasing in many areas of the western U.S., including Rocky Mountain National Park, while sulfate has been decreasing (figure source: Clow and others. 2003. Water Resources Research 39:6)

Facts about excess nitrogen in Rocky Mountain National Park

- Nitrogen concentration in the Park's rain and snow has been increasing (figure 2). Nitrogen deposition (concentration x precipitation) has been increasing by about 2% per year over the last two decades in the Park.
- There is more nitrogen deposited in high elevation ecosystems at the Park than plants can use, and excess nitrogen is leaking into Park lakes and streams at certain times of the year.
- Chemical changes are occurring now in surface waters, soils, and trees on the east side of the Park.
- Lake sediment analysis shows that excess nitrogen deposition has altered diatom species composition. This change began to occur around 1950. Diatoms are algae, small oxygen producing plants in lakes.
- Nitrogen deposition has been shown in other parts of the country to use up natural buffering chemicals in lakes and soils. Eventually these resources become acidic and cease to support sensitive species such as fish. Ecologists and data modelers are working to determine how long it would take, at current rates of nitrogen deposition, for this to occur in Rocky Mountain National Park.
- Experiments on nearby Niwot Ridge show that increasing nitrogen changes the species of plants that live on the tundra. Grasses and sedges outcompete flowering plants, a change that could reduce habitat for some animals and diminish alpine flowers in the Park.

More information about nitrogen deposition research, monitoring, and ecosystem effects at Rocky Mountain National Park is available at:
http://co.water.usgs.gov/noc/nvalar/index.html
http://www.nrel.colostate.edu/projects/lter/pages/homepage.htm
http://www2.nature.nps.gov/ard/scripts/smith.dll

What are the impacts of nitrogen on RMNP ecosystems?

When air pollutants such as nitrogen are deposited into ecosystems it can cause acidification of surface water and soils, enrichment of soils (fertilization) that can change plant species diversity and leach into water, leading to eutrophication (succession of an aquatic habitat to a terrestrial habitat). Ecosystems in RMNP that are particularly sensitive and vulnerable to the effects of nitrogen deposition are the park's high elevation lakes and streams, subalpine forests, and alpine meadows. The National Park Service conducts and sponsors research and monitoring studies designed to answer specific questions about the effects of air pollutants on natural resources and the sources of air pollutants contributing to these impacts. These research projects provide valuable scientific information to State and Federal air regulators to help determine where pollution reductions are most needed in order to maintain healthy ecosystems in our national parks and beyond.
Source: http://www.nature.nps.gov/air/aqbasics/compounds.cfm

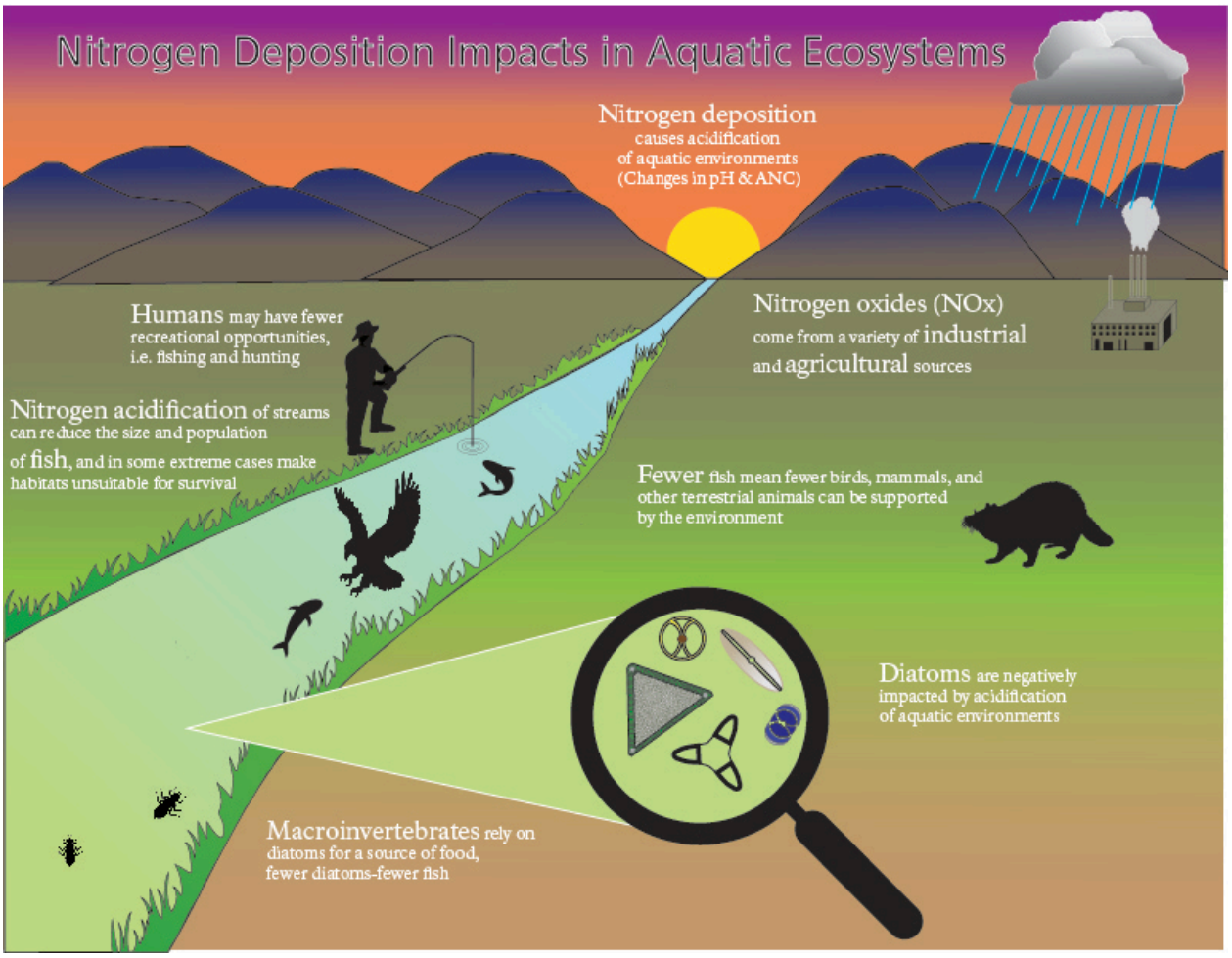
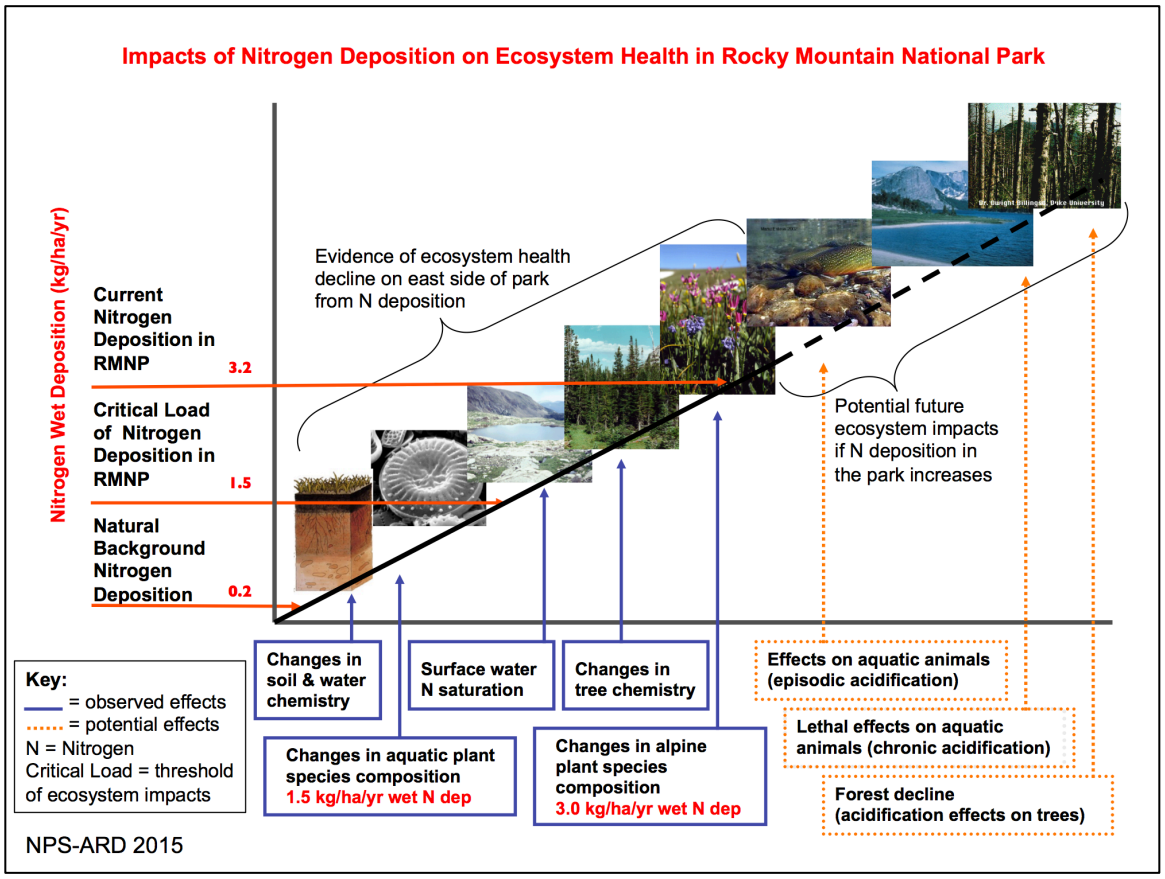


Image: NPS

What is the nitrogen deposition level in RMNP?
The natural background level of nitrogen in the park is 0.2 kilograms per hectare per year (kg/ha/yr). Scientists determined that changes to alpine lake aquatic communities began in the 1950's when nitrogen wet deposition rates in the park increased to about 1.5 kg/ha/yr. This value has been defined as the "critical load", which is the threshold where ecosystem impacts are first observed. If nitrogen levels are below this threshold level it is unlikely that significant negative effects would occur. The current rate of nitrogen wet deposition rates in the park is approximately 3.2 kg/ha/yr. To give an idea of how much nitrogen this adds to an ecosystem, this amount is equal to about 775,000 20-lb. bags of nitrogen fertilizer!



1. What is the natural background level of wet nitrogen deposition? What is the current nitrogen deposition level:

2. The critical load level (threshold of minimal ecosystem impacts) is 1.5 kg/ha/yr. What are the ecosystem effects at and below this value?

3. What ecosystem effects have been observed above the critical load value?

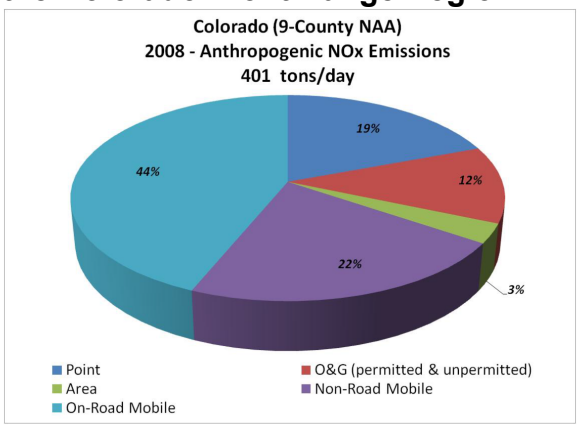
4. The annual wet deposition rate in 2013 (above 4.5 kg/ha/yr.) was the highest ever recorded. What future potential effects will likely occur if this trend continues?

5. Approximately how many times greater was the 2013 annual wet deposition rate than the average of 3.2 kg/ha/yr.?

Day 2
Elaborate

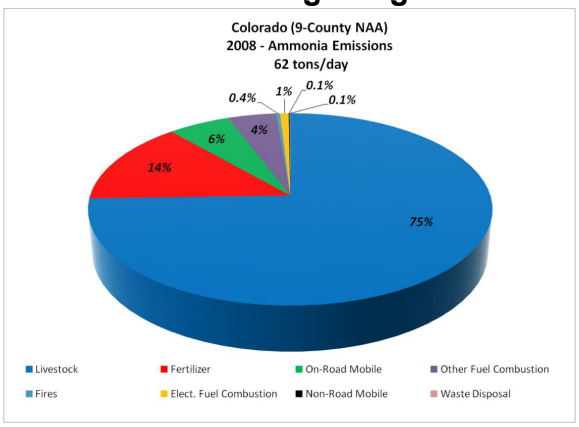
Connecting the N-Dep. Dots:
Nitrogen deposition is one the biggest air quality concerns in Rocky Mountain National Park. However, there are not significant sources of human caused nitrogen emissions in the park so where does it come from? Study the two graphs below for evidence of the key sources of nitrogen from the Denver metropolitan area (also known as the 9-County Nonattainment area (NAA)) that contribute to nitrogen deposition air pollution in the park.

Sources of Nitrogen Oxides (NOx) in the Colorado Front Range Region



1. What is the greatest source of nitrogen oxide emisions?
   a) Fertilizer (plant growth promoting chemicals)
   b) Mobile Sources (cars, trucks, trains, planes, etc.)
   c) Point Sources (factories, industry, etc.)

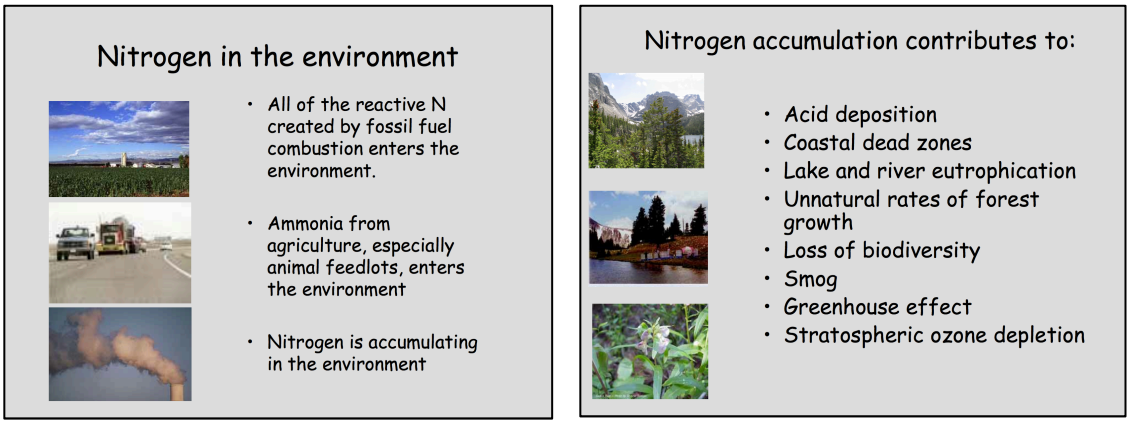
Sources of Ammonia (NH_3) in the Colorado Front Range Region



2. What is the greatest source of ammonia emissions?
   a) O&G (Oil & Gas wells)
   b) Mobile Sources (cars, trucks, trains, planes, etc.)
   c) Livestock (agricultural sources)

Images: CDPHE

What are the main sources of nitrogen deposition in RMNP?



Source: Jill Baron, USGS

First, watch the video to see how ammonia gas that is emitted from livestock and farming activities combines with nitrogen oxides emitted from cars and other combustion sources to create nitrogen particles (ammonium nitrate) in the air. These nitrogen particles are the forerunners to nitrogen deposition in Rocky Mountain National Park.

Video: "Ammonia Deposition in Rocky Mountain National Park: What Is the Role of Animal Agriculture?" (12 min. 47 sec.)
http://www.extension.org/pages/22686/ammonia-deposition-in-rocky-mountain-national-park:-what-is-the-role-of-animal-agriculture#.VJM-gV4tL40

Next, review the "Agricultural Best Management Practices" National Park Service brochure for an overview of how the National Park Service is working together with the agricultural community to reduce nitrogen deposition in RMNP:

Agricultural Best Management Practices:
Helping to Reduce Nitrogen Impacts at Rocky Mountain National Park

Rocky Mountain NP, Colorado

What is the issue and who is involved?	Nitrogen emissions from a variety of man-made sources, including ammonia from agricultural production, contribute to excess atmospheric nitrogen deposition at Rocky Mountain National Park (RMNP) in Colorado. In 2006, Colorado's crop and livestock producers and researchers at Colorado State University (CSU) began collaborating with the National Park Service (NPS), the Colorado Department of Public Health and Environment (State), and the U.S. Environmental Protection Agency, to address nitrogen deposition impacts at RMNP. With the help of Colorado agriculture, nitrogen deposition can be reduced and the nutrient balance can be improved.	
Why is excess nitrogen harmful to Rocky Mountain National Park?	Although nitrogen is an important part of the park's ecosystems, deposition of excess atmospheric nitrogen at twice the tolerable rate is impacting natural resources. Three-quarters of the park is above 9000 feet where high elevation ecosystems, developed under low nutrient conditions with thin, granitic soils are especially susceptible to excess nitrogen. Within these ecosystems, alpine tundra, aquatic plants, soil and water quality are	most affected. Scientists are also concerned that excess nitrogen may promote non-native plants and reduce forest health. The NPS monitors nitrogen deposition rates and impacts to protect RMNP resources for the enjoyment of this and future generations and because, as agricultural producers understand, proper nutrient management is the right and responsible course of action.
What are the sources of excess atmospheric nitrogen?	Nitrogen in the atmosphere comes from a variety of natural and man-made sources. Sources of man-made or excess atmospheric nitrogen include power plants, vehicle exhaust, oil and gas production, wastewater treatment plants, landfills, fertilized crops, and livestock production,	as well as municipal and residential activities such as lawn care and waste disposal. Research shows that excess nitrogen comes into RMNP from both urban and rural areas in Colorado as well as from other states.
How is atmospheric nitrogen transported into the park?	Winds blowing from the west regularly transport nitrogen and deposit it into RMNP. In addition, past weather data and recent research show that common spring and summer weather events, with upslope winds from the east, are transporting and	depositing nitrogen in the park. During these weather events, nitrogen is transported by wind, combined with moisture in the air, and then deposited in the park by rain or snow.

June 2014

What is being done about it?	State and federal agencies are working with industry to reduce significant sources of nitrogen emissions. The State is using nitrogen oxide reduction strategies including engine regulations, vehicle standards, and power plant controls to achieve a 37% reduction in statewide nitrogen oxide emissions by 2018. In addition, Colorado's crop and livestock producers are exploring ways to further reduce agriculture's contribution. Research at CSU is focused on identifying and refining voluntary best management practices (BMPs) for agriculture to improve efficiency and reduce ammonia emissions. Many agricultural producers already employ beneficial BMPs and broader use of science-based BMPs can help further reduce emissions. BMPs aim to reduce ammonia emissions by: 1) reducing nitrogen inputs, 2) keeping more nitrogen in the final product, or 3) preserving more nitrogen in the soil on the farm.	One promising BMP in development is an "early warning system," which would advise agricultural producers to avoid high nitrogen-emitting activities, such as certain methods of manure handling and crop fertilizing, during specific weather events that could readily transport nitrogen into RMNP. Other BMPs being evaluated by CSU include, reducing dietary crude protein and using animal feed additives and hormones. Together these techniques may help increase fed nitrogen retention to improve production or animal rate of gain, and reduce nitrogen lost to the environment. **More information on ammonia BMPs is available at ammoniabmp.colostate.edu.** Nitrogen use efficiency in crop production is also improving with advances in fertilizer application that optimize fertilization rates, timing, and placement. Conservation tillage techniques, precision watering, and crop technology are also important ways to improve nitrogen use efficiency.
Why should agricultural producers care about voluntary best management practices to reduce ammonia emissions?	Voluntary implementation of ammonia reducing BMPs will benefit agriculture by: •Lowering costs by using less nitrogen and keeping more on the farm for production. •Allowing agricultural producers the opportunity to refine BMPs that are culturally and operationally acceptable and economically viable.	•Reducing the need for mandatory BMPs or regulations in the future. •Extending land stewardship beyond the farm by helping to address current ecosystem impacts and avoid future impacts to Colorado's natural systems. •Reducing nitrogen deposition impacts and preserving RMNP and other lands for the enjoyment of future generations.
How can agricultural producers get involved?	**Implement BMPs for even greater nitrogen efficiency on the farm.** This will reduce the total amount of nitrogen lost from raw materials, decrease ammonia-related odor complaints, and result in more valuable products. **Sign up to participate in the warning system**	at **www.rmwarningsystem.com.** Signing-up will allow you to receive warnings in advance of weather events likely to carry nitrogen into RMNP from selected counties. Producer participation in this collaborative effort can help keep agriculture on a voluntary and successful path forward.
For more information:	**Contact:** Brock Faulkner, faulkner@tamu.edu Elizabeth Sapio, elizabeth.sapio@state.co.us Jim Cheatham, jim_cheatham@nps.gov	**RMNP air quality websites:** www.colorado.gov/cdphe/rmnpinitiative www.nature.nps.gov/air/Permits/aris/romo http://nadp.sws.uiuc.edu

Now, answer the following questions to make a case about the causes, effects, and solutions to help reduce nitrogen deposition in RMNP. Write in complete sentences using correct capitalization, punctuation, spelling and grammar.

1 Name two specific agricultural practices that create ammonia emissions and contribute to the nitrogen deposition concern in Rocky Mountain National Park?

2 How do the nitrogen particles emitted (released) in the Front Range end up in the mountains of Rocky Mountain National Park?

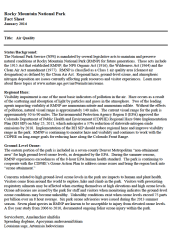
3 List three environmental impacts on ecosystems caused by increased nitrogen deposition in Rocky Mountain National Park.

4 How are ranchers and farmers reducing the amount of ammonia gas they release into the air? How do these actions benefit both the agricultural community and Rocky Mountain National Park?

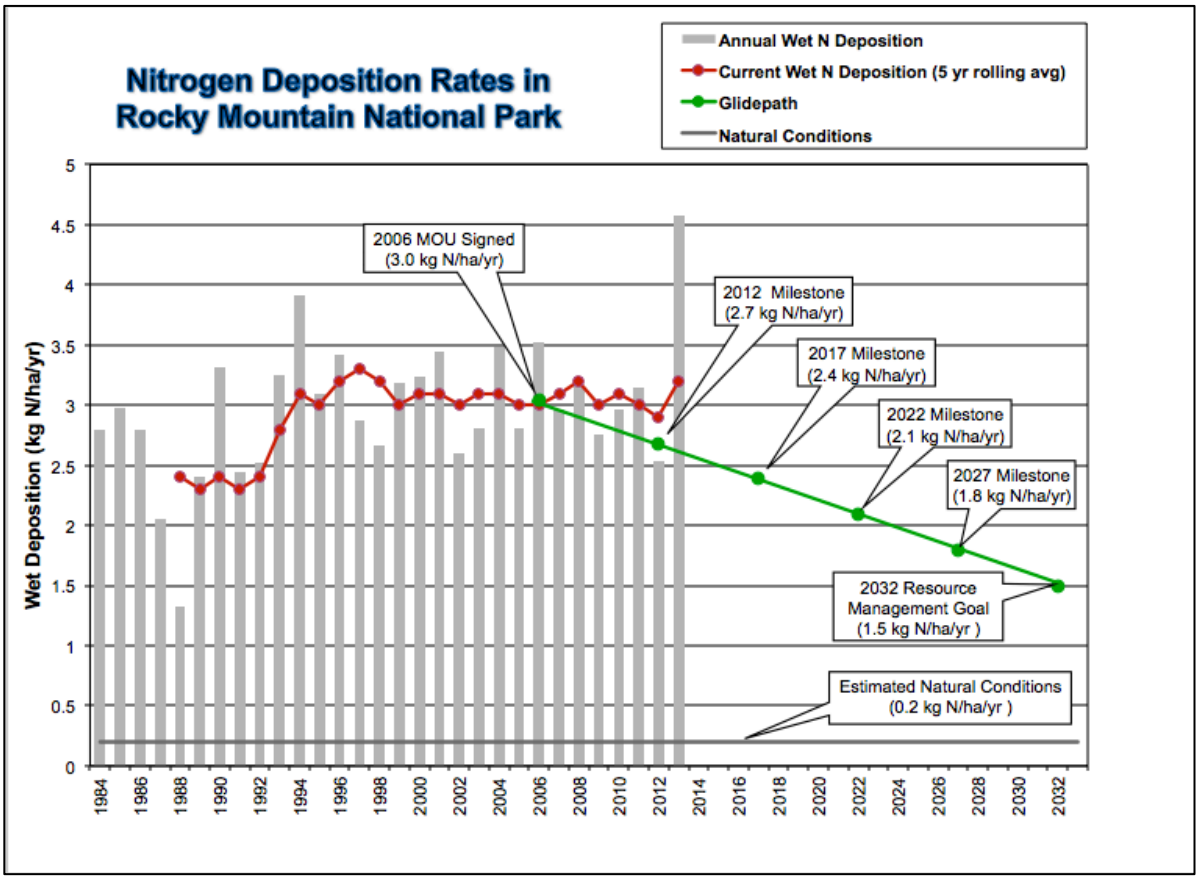
Evaluate

What is the pattern of past, present & potential nitrogen deposition in RMNP?
Nitrogen emissions from human-made sources, including ammonia from agricultural production and nitrogen oxides from fuel combustion, contribute to excess nitrogen deposition at Rocky Mountain National Park. In 2007, a voluntary, collaborative partnership was made between Colorado's crop and livestock producers, researchers at Colorado State University, the National Park Service, the Colorado Department of Public Health and Environment, and the U.S. Environmental Protection Agency to reduce the effects of nitrogen deposition in the park. The resulting Nitrogen Deposition Reduction Plan has a 25-year goal to reduce the current levels of nitrogen deposition back to the critical load threshold level of 1.5 kg/ha/yr by the year 2032.

Final Deductions:



Assess the graph below that combines NADP wet deposition data and the Nitrogen Deposition Reduction Plan milestone goals. Then briefly review the "RMNP Air Quality" fact sheet nitrogen deposition sections. Evaluate the evidence and predict the outcome of nitrogen deposition in Rocky Mountain National Park:



Source: NPS

N-Dep. Reflection - State Your Case:

1. Which year was the nitrogen deposition rate the lowest?

2. Which year was the nitrogen deposition rate the highest?

3. Is the overall nitrogen deposition rate increasing, decreasing, or stable?

4. Between which years was the increase in the 5-year average rate of nitrogen deposition the greatest?

5. Between which years was the 5-year average rate of nitrogen deposition approximately 3.0 kg/ha/yr?

6. The critical load (the threshold where ecosystem impacts are observed) of the annual nitrogen deposition rate is 1.5 kg/ha/yr. How many times greater is the current level nitrogen deposition than the critical load? Than natural background nitrogen levels?

7. The Nitrogen Deposition Reduction Plan was adopted in 2007. The plan's first milestone goal was in 2012. Between these two dates was the rate of nitrogen deposition increasing, decreasing, or stable?

8. Based on past actual annual wet nitrogen deposition levels, make a prediction as to whether future Nitrogen Deposition Reduction Plan milestones between 2017 and 2032 will be reached. Explain your prediction.

Scientist Snapshot:
Meet the scientists who conduct groundbreaking research to understand and find solutions to improve air quality for people, places, and all living things!

Jim Cheatham, National Park Service
Environmental Protection Specialist – Park Planning & Technical Assistance
Jim Cheatham works for the National Park Services' Air Resources Division where he assists parks with air and scenic resources management. From 2008 to August 2014, Jim was a Biologist at Rocky Mountain National Park, managing the park's air, water, and vegetation programs. He played an instrumental role in helping develop and implement the Nitrogen Deposition Reduction Plan. Jim has 19 years of natural resources experience working in national parks (NP) including:

- Big Bend NP, Texas
- Lake Mead National Recreation Area, Nevada
- Guadalupe Mountains NP, Texas
- Catoctin Mountain Park, Maryland
- Devils Tower National Monument, Wyoming

From 1994 to 1996, Jim served in the U.S. Peace Corps to help increase sustainable agroforestry practices in The Gambia, West Africa. He is a graduate of James Madison University with a Bachelor of Science degree in Biology.