Name: _____ Date: _____

1.1 Air Quality: More than Meets the Eye – Student Investigation Guide

Background:

Air quality is a measure of how clean the air is. As air pollution increases air quality decreases. Polluted air causes health problems in humans, damages plants and crops, affects animals and ecosystems, pollutes water, corrodes infrastructure, and reduces visibility. Air pollution contributes to smog, acid rain, and climate change. Pollutants in the atmosphere can be carried long distances so air quality is not just a local concern but also a regional, national, and global concern.

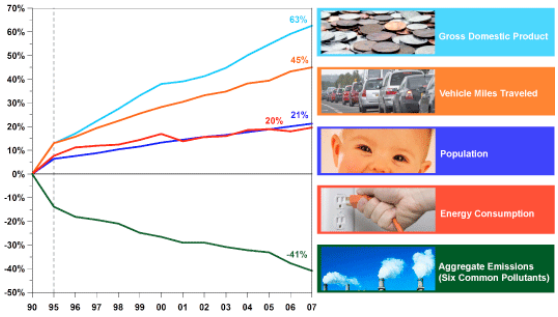


Image: EPA

Sources of air pollution can be natural, like wildfires and windblown dust, or human-made, such as fossil fuel powered vehicles and electricity generating power plants. Air pollutants are classified as either “primary pollutants” that are directly emitted (released) into the air, like nitrogen oxides, or as “secondary pollutants”, like ozone, which are formed from other pollutants in the air.

Thanks to Congress passing the Clean Air Act in 1970, the air quality is better now than it was in the 1960s even though there are more people, cars, and energy used today. The Air Quality Index (AQI) is a daily report of how clean or polluted the air is and what health related effects might be a concern from breathing polluted air. The EPA sets national air quality standards and calculates the AQI for five major air pollutants regulated by the Clean Air Act: ground-level ozone, particulate matter (also known as aerosols or particle pollution), carbon monoxide, sulfur dioxide, and nitrogen dioxide. Ground-level ozone and particulate matter are the two pollutants that pose the greatest threat to human health in the US.

The Northern Front Range of Colorado currently exceeds air quality standards for ground-level ozone pollution – a harmful air pollutant that can negatively affect our health and environment. Agencies like the US Environmental Protection Agency (EPA), the Colorado Department of Public Health & Environment (CDPHE), and the Regional Air Quality Council (RAQC) are looking out for the lungs, gills, and leaves of living things that require clean air. Each of us can make changes in our own actions to help reduce air pollution and improve air quality, too!

Source: http://www2.epa.gov/nutrientpollution/sources-and-solutions-fossil-fuels
http://airnow.gov/index.cfm?action=aqibasics.aqi

Day 1
Engage
Now You See It, Now You Don't:

1) Observe the images below of Denver. Predict the air quality (AQ) of each photo:
   Image 1: good air quality ☐ poor air quality ☐
   Image 2: good air quality ☐ poor air quality ☐

2) Share your observations of the images that support your AQ predictions with the class. (Note: the images were taken on different days but at the same time of day.)

3) Your teacher will now share the AQ data for each image with the class. Indicate the actual air quality of each image. Write the Visibility Standard Index (VSI) rating and the ozone (O_3) values and rating data that supports the actual air quality:
   Image 1: good air quality ☐ poor air quality ☐
   VSI: _____ O_3: _____
   Image 2: good air quality ☐ poor air quality ☐
   VSI: _____ O_3: _____

Image 1

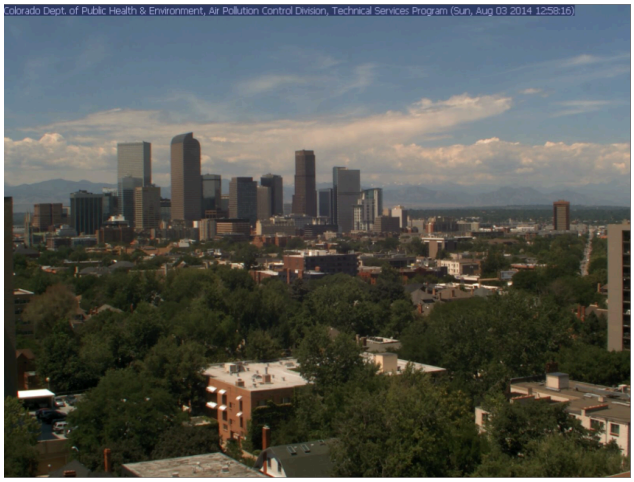
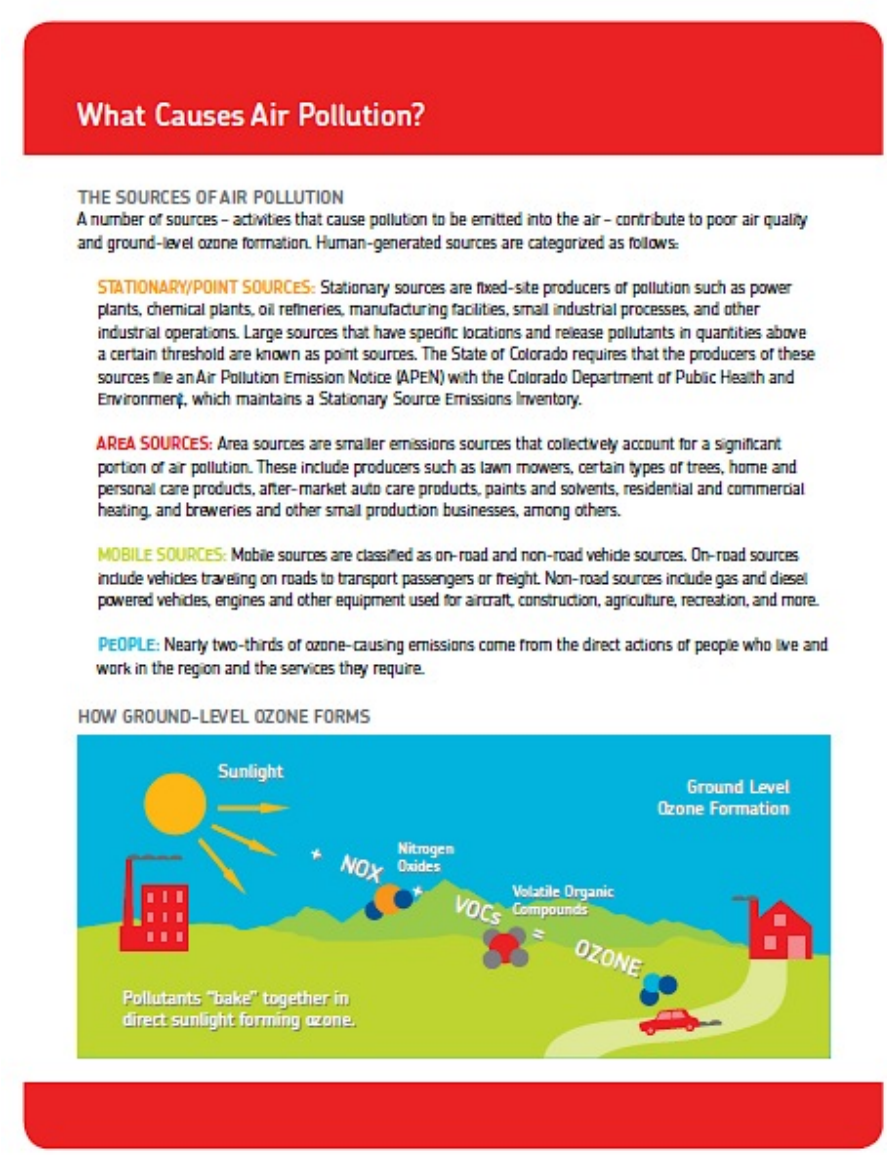


Image 2

Explore
Air Pollution 101 Introduction:
In this hands-on, visual demonstration, you will gain an understanding that everyone's actions directly, indirectly, and collectively contribute to the quality of our air. You will learn about the main pollutants and their sources that affect the air quality of Colorado's Northern Front Range. You will also learn about how you and your family can make simple changes to help reduce air pollution and improve the air quality in Colorado and beyond!

Review the "Causes of Air Pollution" fact sheet:



What Causes Air Pollution?

THE SOURCES OF AIR POLLUTION

A number of sources – activities that cause pollution to be emitted into the air – contribute to poor air quality and ground-level ozone formation. Human-generated sources are categorized as follows:

STATIONARY/POINT SOURCES: Stationary sources are fixed-site producers of pollution such as power plants, chemical plants, oil refineries, manufacturing facilities, small industrial processes, and other industrial operations. Large sources that have specific locations and release pollutants in quantities above a certain threshold are known as point sources. The State of Colorado requires that the producers of these sources file an Air Pollution Emission Notice (APEN) with the Colorado Department of Public Health and Environment, which maintains a Stationary Source Emissions Inventory.

AREA SOURCES: Area sources are smaller emissions sources that collectively account for a significant portion of air pollution. These include producers such as lawn mowers, certain types of trees, home and personal care products, after-market auto care products, paints and solvents, residential and commercial heating, and breweries and other small production businesses, among others.

MOBILE SOURCES: Mobile sources are classified as on-road and non-road vehicle sources. On-road sources include vehicles traveling on roads to transport passengers or freight. Non-road sources include gas and diesel powered vehicles, engines and other equipment used for aircraft, construction, agriculture, recreation, and more.

PEOPLE: Nearly two-thirds of ozone-causing emissions come from the direct actions of people who live and work in the region and the services they require.

HOW GROUND-LEVEL OZONE FORMS

Source: Regional Air Quality Council/OzoneAware.org

Materials & Equipment:

- Clear plastic cup filled ¾ full with water (one per student)
- "Pollutants" – shared set of 4 liquid food colors (labeled as CO, NOx, VOC, and O_3), cocoa mix (PM2.5), coffee grounds (PM10), (4-6 students per set)
- Large clear container filled ½ full with water (shared with class)

Ingredient	Air Pollutant	Pollutant Sources
Green food color	**Carbon Monoxide (CO)** Primary pollutant	Fossil fuel powered vehicle combustion engines (e.g. cars, trucks, trains, planes), home/industrial heating sources, fires (natural, human-caused)
Red food color	**Nitrogen Oxide (NOx)** Primary pollutant	Fossil fuel powered vehicle emissions (e.g. cars, trucks, buses, off-road equipment), fuel combustion for generating electricity & heat (e.g. power plants, propane tanks, boilers), industrial processes (e.g. oil & gas production, petroleum refining, mining, cement and chemical manufacturing)
Blue food color	**Volatile Organic Compounds (VOCs)** Primary pollutant	Solvents (e.g. paints, stains, paint removers, nail polish remover, dry cleaning chemicals, degreasers, etc.)
Yellow food color	**Ozone (O_3)** Secondary pollutant	Formed in the atmosphere when NOx and VOCs combine in the presence of sunlight
Cocoa mix	**Fine Particulate Matter – (PM2.5)** Primary pollutant or Secondary pollutant	Inhalable fine particles 2.5 micrometers or less in diameter from wildfire smoke, haze formed from vehicle & power plant emissions, etc.
Coffee grounds	**Coarse Particulate Matter –(PM10)** Primary pollutant or Secondary pollutant	Inhalable coarse particles between 2.5 and 10 micrometers in diameter from dust (e.g. dirt/gravel roads, construction sites), fires (e.g. wildfires, agricultural & prescribed burns), etc.

Air Pollution 101 Demonstration Part 1:
As a class, briefly review the activity instructions, the types and sources of each pollutant, and the ingredients that represent each pollutant, as described in the table.

The cup of water represents the air and the ingredients represent air pollutants that you will add to the air depending on your actions over the past week. Your teacher will read the following series of actions aloud. If you participated in the action within the past week then add one drop/pinch of the corresponding pollutants into your cup of water. Remember, not all of the following actions may apply to you (e.g. staining the house or mowing the lawn).

1. You drove in a gas-powered vehicle (car, truck, bus, etc.):
   - 1 drop **Carbon Monoxide** from motor vehicle exhaust
   - 1 drop **VOC** produced by the engine when gasoline or oil is burned
   - 1 drop **Nitrogen Oxide** from vehicle exhaust

2. You traveled down a dirt or gravel road:
   - 1 pinch **PM2.5** from fine dust particles
   - 1 pinch **PM10** from larger dust particles

3. You enjoyed indoor heat or air conditioning:
   - 1 drop **Nitrogen Oxide** emitted by combustion to generate electricity and heat water
   - 1 pinch **PM2.5** created from combustion processes from power generation
   - 1 pinch **PM10** resulting from power plants burning coal to produce electricity

4. You got ready for school and used hair or body care products (hairspray, body spray, nail polish, etc.):
   - 1 drop **VOC** emitted from some personal care products

5. You used a computer, tablet, cell phone, iPod, or TV at home or school:
   - 1 pinch **PM10** resulting from power plants burning coal to produce electricity
   - 1 drop **Nitrogen Oxide** emitted by combustion used to generate electricity
   - 1 pinch **PM2.5** created from combustion processes from power generation

6. Your family burned firewood (fireplace, campfire) or yard debris (leaves, grass):
   - 1 drop **CO** in wood burning
   - 1 pinch **PM2.5** from fine particulates in wood burning
   - 1 pinch **PM10** from larger particulates in wood burning

7. Your family used paint or stain on your home:
   - 1 drop **VOC** when chemicals evaporate
   - 1 drop **Ozone** from evaporation

8. Your family filled a vehicle with gasoline at a gas station:
   - 1 drop **Ozone** from evaporation while filling the tank
   - 1 drop **VOC** when chemicals evaporate

9. Your family used gasoline-powered equipment to mow the lawn, blow yard clippings/leaves, trim weeds, or blow snow:
   - 1 drop **VOC** in exhaust and gas vapors
   - 1 drop **Nitrogen Oxide** in exhaust from burning fuel
   - 1 drop **Ozone** from fuel combustion and evaporation

10. Your family had clothes dry-cleaned:
    - 1 drop **VOC** when chemicals evaporate

11. You used a computer printer or a copy machine:
    - 1 drop **Ozone** from evaporation

12. Your family used paint or stain on your home:
    - 1 drop **VOC** when chemicals evaporate
    - 1 drop **Ozone** from evaporation

13. You enjoyed a warm shower:
    - 1 drop **Nitrogen Oxide** emitted by combustion to generate electricity and heat water
    - 1 pinch **PM 2.5** created from combustion processes from power generation
    - 1 pinch **PM 10** resulting from power plants burning coal to produce electricity

14. You washed & dried clothes, or cooked food:
    - 1 drop **Nitrogen Oxide** emitted by combustion to generate electricity and heat water
    - 1 pinch **PM 2.5** created from combustion processes from power generation
    - 1 pinch **PM 10** resulting from power plants burning coal to produce electricity

Discussion Questions:

a. Compare and contrast how the "air" (water) looked before and after you added pollutants based on your actions that contribute to air pollution:

- "Air" (water) before "pollutants" added:

- "Air" (water) after "pollutants" added:

b. Name another source of air pollution that you think affects air quality.

Explain
Air Pollution 101 Demonstration Part 2:

1. Predict what you think will happen if each individual's cup of colored water (polluted air) is added to the jar of water (atmosphere).

2. When asked, pour your cup of "polluted air" (colored water) into the "atmosphere" (jar of water). After each individual has added their water to the jar, observe the jar and describe the effect individual contributions of air pollution have on the overall air quality of the atmosphere.

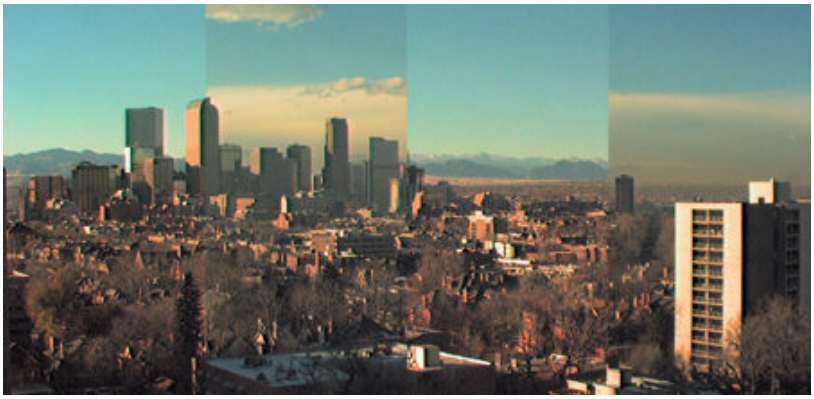
3. As a class, view the AirNow.gov website. Discuss the following ways to reduce air pollution. Choose two or more ways you and your family can help to reduce air pollution and improve air quality:

   - Check the AirNow.gov website for current air quality conditions and forecasts.
   - Drive less - walk, bike, carpool, or take public transportation when possible.
   - Save energy – turn off lights, electronics (TVs, computers, etc.), and unplug chargers when not in use.
   - On hot, sunny days, mow after 5pm and delay mowing on severe ozone level days
   - Tell adults to avoid car idling and combine errands into one trip.
   - Ask adults to refuel vehicles after 5pm on hot, sunny days, stop filling the tank at the "click", and tighten the gas cap to reduce ozone-forming pollutants.
   - Ask adults to turn home thermostat temperatures down in winter (68 F, 10 degrees lower when not home) and up in summer (78 F, 10 degrees higher when not home).
   - Let adults know that solvent-based products have air-polluting chemicals and to use water-based paints, stains, sealants, and cleaners instead.
   - Avoid painting and staining projects in the heat of the day
   - Reduce, reuse & recycle!

Day 2
Elaborate
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!

Roya Bahreini, UC-Riverside
Assistant Professor of Atmospheric Science
Professor Roya Bahreini and her graduate students, Kennedy Vu (left) and Justin Dingle (right), from UC- Riverside came to Colorado in the summer of 2014 to measure particulate matter (PM) composition and haze levels in the Northern Front Range and the Western Slope. Along with a dozen other scientists, they installed their instruments on the National Science Foundation's C-130 aircraft and went on to explore the skies, probing the air from Earth's surface up to 15,000 ft. (4572 m) in the atmosphere. Their research goal was to understand what the sources of PM in the area are and how these sources impact regional air quality and visibility. Because of the summertime air turbulence that is common in the Front Range, the research flights were occasionally very bumpy, but it was all worth it because of the interesting dataset that was collected!

Visibility and Air Quality Analysis Introduction:
Have you noticed that on some days in the Front Range the views of the Rocky Mountains look crisp and clear and on other days the views look hazy and blurred?



Visibility is a measure of how well an observer can view a scene. This includes how far one can see in the atmosphere as well as the ability to see the details of scene such as textures and colors. Haze affects visibility. Where does haze-forming pollution come from? While some haze-forming pollutants such as particulate matter (PM) are directly emitted to the air (primary pollutants), other particles such as sulfate and nitrate are created from gases emitted to the air (secondary pollutants). These particles will either scatter or absorb light, impacting peoples' views of objects, such as our views of the Rocky Mountains.

Air pollutants come from a variety of natural and anthropogenic (human-made) sources. Natural sources can include windblown dust and soot from wildfires. Human-made sources can include vehicle exhaust and electricity generated from fuel burning. Particulate matter pollution is the major cause of reduced visibility in parts of the United States. Colorado is one of a few states that monitors and protects its clear skies.

How is visibility measured? The Visibility Standard Index (VSI) is a measure of the visual air quality. The VSI corresponds to how clear or hazy the air is.

Scale - Visibility Standard Index	
0 - 50	GOOD
51 - 100	MODERATE
101 - 200	POOR
201 - 300	EXTREMELY POOR
	WEATHER LIMITED
	NOT AVAILABLE

Air Pollution Control staff at the Colorado Department of Public Health & Environment use an instrument called a transmissometer, situated atop a building near Cheesman Park in Denver, to measure the clarity of the air through a complicated process. In simple terms, the transmissometer measures the amount of light that is able to pass through the atmosphere - the more light that is allowed to pass, the clearer the air; the less light that is allowed to pass, the hazier the air. Data from the transmissometer are converted to a Visibility Standard Index based on a scale much like the AQI scale. The lower the VSI value the clearer the air, the greater the VSI value the hazier the air.

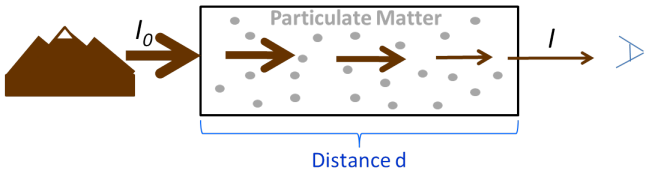
Source: http://www.colorado.gov/airquality/brochure.aspx

Kinesthetic Visibility & PM Activity:
Pollutants in the atmosphere cause haze and reduce visibility by absorbing or scattering the light between the observer and an object at distance. When the intensity of the light that reaches the observer is reduced (I compared to I_0 in the diagrams below), this results in a "fuzzier image" of the object as seen by the observer. Scattering of light by particulate matter pollution (PM) is an important factor contributing to visibility reduction. The following factors affect the amount of light scattered by PM:

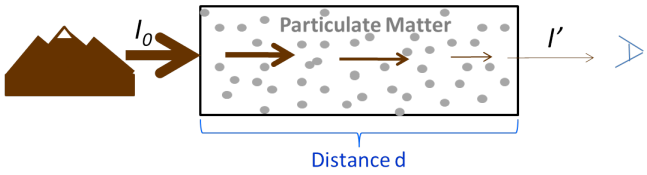
Procedure:
As a class, carry out the following two scenarios on PM pollution. First, read the description and review its corresponding diagram. Next, conduct the related kinesthetic activity to reinforce the concept being presented.

A. Particulate Matter (PM) concentration: When PM concentration is higher the visibility is lower (hazier views). When the PM concentration is lower the visibility is higher (clearer views)

Lower PM concentration, higher visibility:



Higher PM concentration, lower visibility:

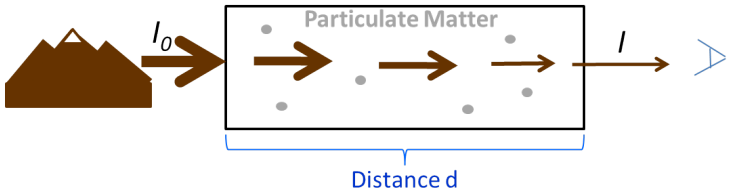


Kinesthetic Activity A.:

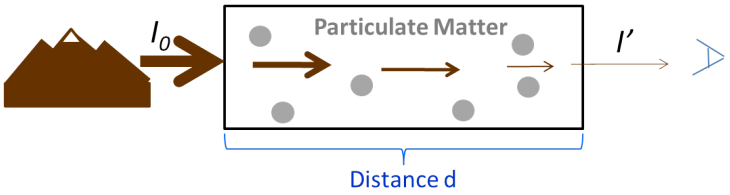
- Choose one end of the classroom to be the "view".
- Select 3 students to be the "observers" and have them stand at the opposite end of the classroom facing the view.
- Ask the "observers" to describe the visibility (details) of the "view".
- Select 6 students to act as "particulate matter" particles, which "flow" around the room between the "observers" and the "view" (lower PM concentration).
- Ask the "observers" to describe how the visibility (details) of the "view" is affected when the "particles" flowing through the air and creating "haze".
- Select another 6 students to act as additional "particulate matter" particles (higher PM concentration), which "flow" around the room creating more "haze" between the "observers" and the "view".
- Ask the "observers" to now describe how the visibility (details) of the "view" is affected with a higher concentration of "particles" flowing through the air.

B. Particulate Matter (PM) Size: Given similar PM concentrations, the larger the PM size the lower the visibility (hazier views) and the smaller the PM size the higher the visibility (clearer views).

Smaller PM, higher visibility:



Larger PM, lower visibility:



Kinesthetic Activity B.:

- Choose one end of the classroom to be the “view”.
- Select 3 of students to be the “observers” and have them stand at the opposite end of the classroom facing the view.
- Ask the “observers” to describe the visibility (details) of the “view”.
- Select 6 students to act as “fine particulate matter” particles, which “flow” around the room between the “observers” and the “view” (fine PM).
- Ask the “observers” to describe how the visibility (details) of the “view” is affected when the “fine particles” flowing through the air and creating “haze”.
- Now, ask the same 6 student “particles” to outstretch their arms and act as larger “coarse particulate matter” particles (coarse PM), which “flow” around the room creating more haze between the “observers” and the “view”.
- Ask the “observers” to now describe how the visibility (details) of the “view” is affected with larger “coarse particles” flowing through the air.

How do the percent of relative humidity (RH) and the ratio of organic particulate matter to inorganic particulate matter (PM) relate with the measured haze levels of visibility? As a class, read the description of the following two scenarios and discuss their main concepts in relation to PM pollution.

C. Relative humidity (RH), the amount of water vapor in the atmosphere, and the types of particulate matter (PM) can also affect visibility:

- Relative humidity (RH): Typically when the RH is higher, PM tends to scatter more light, resulting in hazier views (lower visibility). When the RH is lower, PM tends to scatter less light and the visibility is better (higher visibility).

- PM composition: In the Front Range, at low RH conditions, when there is a higher ratio of organic PM (e.g., organic acid) compared to inorganic PM (e.g., ammonium nitrate or ammonium sulfate) mass, the views are hazier (the higher ratio value, the lower visibility). When there is a lower ratio of organic PM to inorganic PM, the views are clearer (the lower the ratio value, the higher the visibility).

D. Haze is the opposite of visibility – the more clear the visibility the lower the amount of haze and the less clear the visibility the higher the amount of haze. The inability to see a view is the Haze Level, which is measured in units of inverse mega meter (Mm^{-1}).

- The lower the haze level value, the clearer and more detailed the visibility.

- The higher the haze level value, the hazier and less detailed the visibility.

Visibility & PM Concept Application:
Compare and contrast the images of Denver in terms of visibility (high vs. low), the haze level (the lower the value, the less haze) and the organic/inorganic particulate mass ratio (comparison of the amount of organic PM to the amount of inorganic PM).

View of Downtown Denver 08/02/2014 10:00 AM

Higher visibility Day (30% RH)
Haze Level= 8 Mm^{-1}
Organic/inorganic PM mass= 2

View of Downtown Denver 08/12/2014 10:00 AM

Lower visibility Day (30% RH)
Haze Level= 25 Mm^{-1}
Organic/inorganic PM mass = 4.5

View of Downtown Denver 08/15/2014 10:00 AM

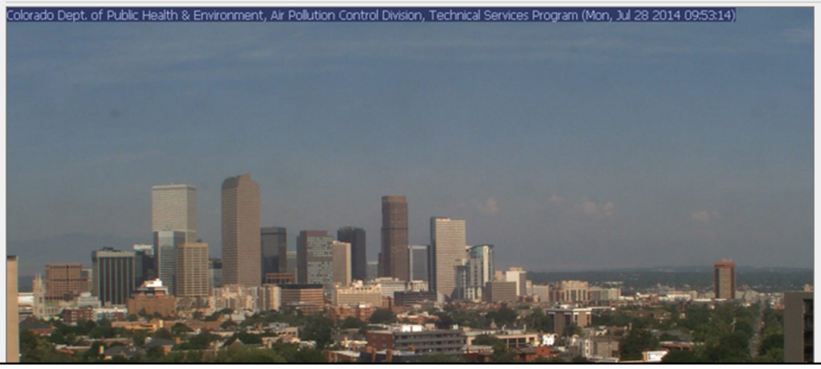
Higher visibility Day (34% RH)
Haze Level= 6 Mm^{-1}
Organic/inorganic PM mass= 1.7

View of Downtown Denver 08/03/2014 10:00 AM

Lower visibility Day (34% RH)
Haze Level= 10 Mm^{-1}
Organic/inorganic PM mass= 2.2

Scientist notes:
Higher haze level values on the low-visibility days shown above (8/12/14 and 8/3/14) corresponded to the higher organic PM mass ratio (higher ratio of organic to inorganic PM mass). Organic PM originate from incomplete combustion of fuel, for example, vehicle emissions or biomass burning.

View of Downtown Denver 07/28/2014 10:00 AM



Low visibility Day (62% RH)
Haze Level= 33 Mm^{-1}
Organic/inorganic PM mass = 1.3

Scientist notes:
On the very hazy day shown above (7/28/14), visibility was very low, and measured haze level was relatively high. On this day, organic PM mass fraction was not that high. Therefore, the low visibility on this day seemed to be driven by the inorganic components of aerosol (e.g., ammonium nitrate or ammonium sulfate) that were favorably formed under humid conditions (62% relative humidity). The precursors of the inorganic components of aerosol particles are found in emissions from vehicles, power plants, and dairy/feedlot facilities.

Visibility & PM Data Analysis:
Match the following air quality measurements with their correct air quality image below.

1) Circle the image that has the higher visibility (lower haze):

   Image 1 (top) 7/26/2014 Image 2 (bottom) 8/11/2014

2) Match and write the correct haze level value on the blanks below for Image 1 and Image 2:

a. 21 Mm^{-1}
b. 12 Mm^{-1}

3) Match and write the correct ratio of organic to inorganic PM mass on the blanks below for Image 1 and Image 2:

c. 3
d. 4

Image 1 (top) 7/26/2014
Relative Humidity: ~40%
Haze Level Value: _____
Ratio of Organic to Inorganic PM mass: _____

Image 2 (bottom) 8/11/2014
Relative Humidity: ~40%
Haze Level Value: _____
Ratio of Organic to Inorganic PM mass: _____

Image 1 (top) 7/26/2014

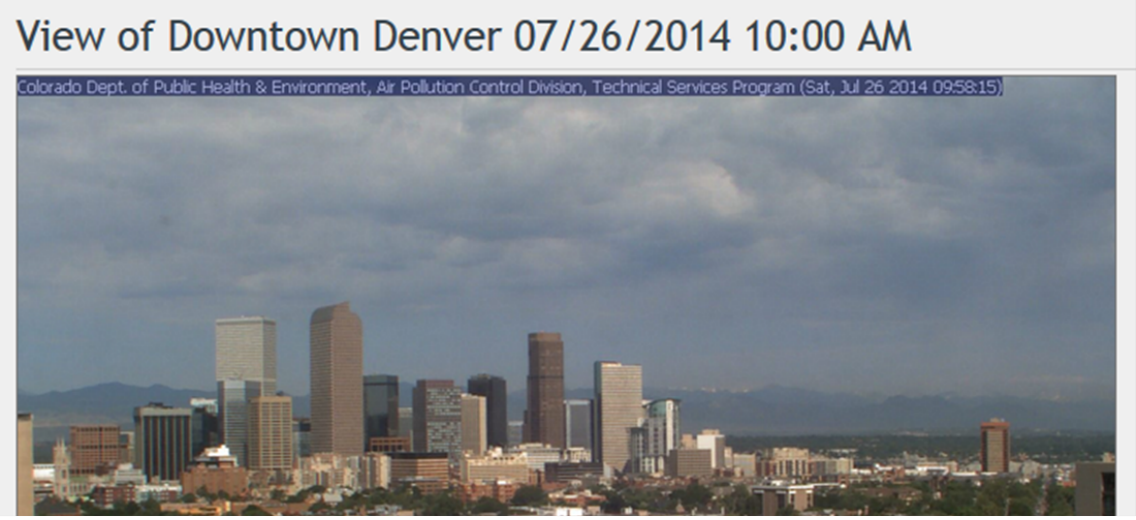


Image 2 (bottom) 8/11/2014

Image Source: http://www.colorado.gov/airquality/live_image.aspx

Evaluate
Air Quality 3-2-1 Exit Ticket:

Complete the exit ticket as you watch the two videos about the 2014 joint FRAPPÉ and DISCOVER-AQ air quality campaign:

- "Summertime Air Quality with FRAPPÉ" video: http://ucarconnect.ucar.edu/multimedia/videos/summertime-air-quality-frappé
- "The DISCOVER-AQ Mission" video: http://discover-aq.larc.nasa.gov

3-2-1 Exit Ticket: Evaluate student learning of the main causes of air pollution, methods of study, and primary concern regarding air quality in Colorado's Northern Front Range:

List **three** main sources of air pollution that affects air quality.

1.

2.

3.

What are **two** methods that scientists use to study air quality?

1.

2.

Circle the **one** air pollutant that is of most concern for the air quality of Colorado's Northern Front Range?

Particulate Matter (PM) Nitrogen Oxides (NOx) Ozone (O_3)