9. Smoke from Wildland Fire: Just Hanging Around?

Lesson Overview: From a lab demonstration or video, students learn how smoke disperses (or doesn't), depending on atmospheric conditions. They learn how smoke affects visibility and human health, especially if it sticks around for days or weeks instead of dispersing into the upper atmosphere. Finally, they apply health guidelines regarding smoke to the issue of protecting students' breathing while planning athletic events on smoky days.

Lesson Goal: Increase students' understanding of smoke from wildland fires, how it disperses, its effects on human health, and how we can protect ourselves from its effects.

Subjects: Science, Mathematics, Reading, Writing, Speaking and Listening, Social Studies, Health Enhancement

Duration: 2-3 half-hour sessions

Group size: Entire class

Setting: Classroom

Vocabulary: *inversion, normal atmospheric conditions, particulate/particulate matter, PM2.5, smoke, stable/unstable conditions, thermal belt*

Objectives:

- Students can interpret data on inversions and air quality during a wildland fire.
- Students can make a decision about how to protect respiratory health during sports events.

Standards:		6th	7th	8th
CCSS	Reading Informational Text	1, 2, 4, 7, 10	1, 2, 4, 10	1, 2, 4, 10
	Writing	2, 4, 7, 10	2, 4, 7, 10	2, 4, 7, 10
	Speaking/Listening	1, 2, 4, 6	1, 2, 4, 6	1, 2, 4, 6
	Language	1, 2, 3, 4, 6	1, 2, 3, 4, 6	1, 2, 3, 4, 6
	Reading Standards Science/Tech	1, 2, 3, 4, 7, 10	1, 2, 3, 4, 7, 10	1, 2, 3, 4, 7, 10
	Writing Standards Science/Tech	1, 2, 4, 7, 10	1, 2, 4, 7, 10	1, 2, 4, 7, 10
NGSS	Earth's Systems	ESS2.D		
	Earth and Human Activity	ESS3.A, ESS3.B, ESS3.C		
	Matter and Its Interactions	PS1.A, ETS1.B		
EEEGL	Strand 1	A, B, C, E, F, G		

Teacher Background: There's no wildland fire without smoke, but the amount of smoke produced and the way in which it disperses differ from one fire to another and from one time to another on a single fire. If the smoke disperses upward rapidly, high-altitude winds will scatter it downwind, and the only result we notice may be the beautiful, orange-tinged sunrise and sunset colors produced by particles in the air. However, if the smoke is trapped near the fire by an inversion, it can make the air difficult to breathe and even difficult to see through. These conditions may be hazardous, especially for anyone who has asthma or other respiratory illness and for those who engage in strenuous exercise.

In this activity, students learn about smoke dispersal. From a demonstration, they learn that air – and the smoke it may contain - can disperse readily into the atmosphere under *normal* conditions or be trapped near the ground during *inversions*. Then they compare data on particulate matter during a wildfire in 2017 with guidelines provided by the Montana Department of Environmental Quality to decide if smoke from a wildland fire may be hazardous to students' health during athletic events.

Summary of content: On most summer days, sunlight warms the earth's surface and the layer of air lying on the earth's surface. The warming air rises due to convection. As it rises, it expands and cools. If the air is dry, the temperature falls about 1°C for every 100-meter rise in altitude (about 5° F for every 1000 ft)[1]. As a result of this natural cooling, mountain tops tend to remain much cooler than valleys even on hot summer days. Because the air is constantly moving and mixing under these normal day-time circumstances, we call the air unstable.

Every night, when the sun is no longer warming and stirring up the atmosphere, cold air from the mountain tops – which is more dense than warm air - flows downhill into the valleys. Sometimes the sun doesn't warm the surface air back up in the morning. Perhaps clouds are blocking the incoming light… or smoke is blocking it… or (in winter) snow is reflecting the light rather than absorbing it. When this happens, the cold air is stuck on the ground. It is not expanding, therefore not rising, and therefore "trapped" on the ground until something stirs up the atmosphere. This is called an inversion because the normal daytime pattern (warm air on the bottom, rising into cooler air on top) is upside-down. The blanket of warm air that lies on top of the cold air is called a thermal belt. During an inversion, the cold surface air is very stable. It cannot be dislodged until it is heated or stirred up by wind.

During an inversion, dust and other particulates in the air are trapped in the cold air at the earth's surface. Inversions during wildland fires trap smoke, which may be so dense that you can't see very far and the city streetlights come on in the middle of the day. When seeds of some plants are exposed to dense smoke, it becomes easier for them to germinate. But when people are exposed to dense smoke, it becomes harder to breathe. Dense smoke is especially dangerous for babies, older adults, and anyone with respiratory illnesses (such as asthma) or heart disease. It is a good idea for people to stay indoors (provided the indoor air is clean) or limit aerobic activities until the air quality improves.

[1] Although metric units of measure are used in most of this curriculum, we used "standard" units of measure in parts of this lesson because fire managers still use mostly standard units. This is because they rely on fire behavior models developed in the 1960s, which use standard units of measure.

For further background, see the readings and presentations included in this lesson and in Activity H11 in the High School curriculum.

Materials and preparation:

1. Download 2 presentations:
   - ***M09_SmokeDispersion.pptx*** (just 3 slides – to be used at the start of the activity)
   - ***M09_InversionsAndMeasuringSmoke.pptx*** (used right after the lab. Introduces the **Assessment**)
2. **OPTIONAL: You may want students to hear a 7:49-minute feature from a 2017 broadcast on Montana Public Radio.** If you want to use it, make sure you can access it at https://www.mtpr.org/post/summer-smoke-exposes-need-clean-indoor-air-montana.
3. Decide how to make "Recommendations for Outdoor Activities Based on Air Quality for Schools and Child Care Facilities" (**M09_ActivityGuidelinesForWildfireSmoke.pdf** or http://4cleanair.org/sites/default/files/Documents/Montana-ActivityGuidelinesforWildfireSmokeEvents.pdf) available to students – on a printout or electronically.
4. Decide how to demonstrate atmospheric inversions in **Step 6** below: by viewing an online video (https://www.youtube.com/watch?v=LPvn9qhVFbM), creating the same demonstration in class, or creating a demonstration that compares temperatures and air circulation above ice vs. boiling water (described in **M09_InversionDemonstration_Boiling-vs-Ice.pdf**).

Procedures:

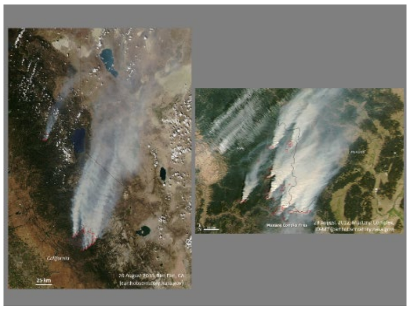
1. **Hook:** Select 3-4 students to sit in a circle around a prop (box, book, stool, other object) that represents a campfire. Have them pantomime some fun things to do. Maybe they'll start a song, roast marshmallows, add sticks to the fire, etc. Then have another student be wind and circulate around the fire or back and forth, blowing on the smoke. Ask those sitting around the fire to pantomime their reactions. As they cough and hack or move to a different spot, ask what the problem is. SMOKE BOTHERS US!
2. **OPTIONAL:** Listen with the class to the 7:49-minute radio broadcast on smoke from wildland fires in western Montana during the summer and fall of 2017: https://www.mtpr.org/post/summer-smoke-exposes-need-clean-indoor-air-montana.
3. Ask: What is smoke? Smoke consists of water, gases, and tiny particles of unburned and partially burned fuels. These are called particulates or particulate matter. The particulates are light enough to circulate in the atmosphere instead of settling immediately to earth, as larger particles do.
4. Explain: In this activity, we'll learn about where the smoke from wildland fires goes and how we can protect ourselves from its harmful effects.

5. Go through the 1st presentation (***M1_SmokeDispersion.pptx***):

Slide 1

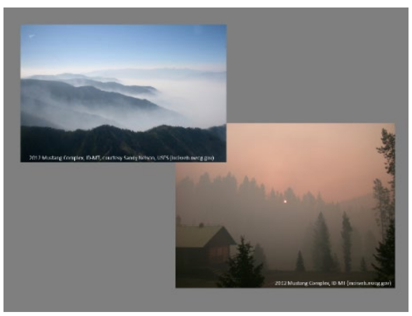
Where does the smoke from wildland fires go? You can make some guesses from these photos. It usually goes up, just like heat does. It cools off as it rises. When its temperature is about the same as that of the surrounding air, it stops rising and just travels wherever the wind takes it.

Slide 2



Satellite photos show that smoke can travel a long way. Use the 25-km scale on the photos to estimate the width of these smoke plumes: 50-75 km on the Rim Fire (left) and 100-200 km on the Mustang Complex (right). About how far has the smoke traveled? 300 km or so. What are some towns or other landmarks that far from our location?

Slide 3



But smoke doesn't always move up and away. Sometimes it settles near the ground and stays there for days or even weeks. This might be smoke from a fire nearby, or it could be smoke from fires hundreds of miles away. This thick, messy, hazardous air is often caused by a weather pattern called an inversion.

5. Explain: A demonstration will help us understand inversions better.

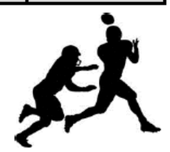
6. Choose one of these options:
   a. View the 2:49-minute video about inversions from "Steve Spangler Science" (https://www.youtube.com/watch?v=LPvn9qhVFbM).
   b. Create the demonstration described above in class.
   c. Create the demonstration described in **InversionDemonstration_Boiling-vs-Ice.pdf**, which compares temperatures and air circulation above ice vs. boiling water. The file shows the data table you'll need to put on the board. The trunk contains the supplies needed for this demonstration.

7. Give each student a copy of - or electronic access to - "Recommendations for Outdoor Activities Based on Air Quality for Schools and Child Care Facilities" **(M09_ActivityGuidelinesForWildfireSmoke.pdf** or http://4cleanair.org/sites/default/files/Documents/Montana-ActivityGuidelinesforWildfireSmokeEvents.pdf - shown on the next page). Explain that they'll use it at the end of the presentation:

Recommendations for Outdoor Activities Based on Air Quality for Schools and Child Care Facilities

Health Effect Category	Good	Moderate	Unhealthy for sensitive groups*	Unhealthy	Very Unhealthy/ Hazardous
Visibility (miles)	13+	9-13	5-9	2-5	Less than 2
NowCast Concentration (μg/m^3)	≤ 12	12 - 35	35 - 55	55 - 150	150 +
Recess or Other Outdoor Activity (15 minutes)	No limitations	No limitations	Make indoor space available for all children to be active, especially young children. If outdoors, limit vigorous activities and people with chronic conditions should be medically managing their condition.	Keep all children indoors.	Keep all children indoors.
Physical Education Class (1 hour)	No limitations	Monitor sensitive groups and limit their vigorous activities.	Make indoor space available for all children to be active, especially young children. If outdoors, limit vigorous activities and people with chronic conditions should be medically managing their condition.	Conduct P.E. indoors. If outdoors, only allow light activities for all participants. People with chronic conditions should be medically managing their condition.	Conduct P.E. in a safe (good air quality) indoor environment.
Athletic Practice, Training (2-4 hours)	No limitations	Monitor sensitive groups and limit their vigorous activities.	People with chronic conditions should be medically managing their condition. Increase rest periods and substitutions for all participants to lower breathing rates.	Conduct practice and trainings indoors. If outdoors, allow only light activities for all participants. Add rest breaks or substitutions to lower breathing rates. People with chronic conditions should be medically managing their condition.	Conduct practice and trainings in a safe (good air quality) indoor environment.
Scheduled Sporting Events (2-4 hours)	No limitations	Monitor sensitive groups and limit their vigorous activities.	People with chronic conditions should be medically managing their condition. Increase rest periods and substitutions for all participants to lower breathing rates.	Consider rescheduling or relocating event. If outdoor event is held, have emergency medical support immediately available. Add rest breaks or substitutions to lower breathing rates. People with chronic conditions should be medically managing their condition.	Reschedule or relocate event.
Examples of light activities: Walking slowly on level ground; Carrying school books; Hanging out with friends			Examples of moderate activities: Skateboarding; Slow pitch softball; Shooting basketballs	Examples of vigorous activities: Running, jogging; Playing football, soccer, and basketball	Please note that the intensity of an activity can vary by person and ability

See the back of this document for suggestions on how to use particulate concentration measurements and visibility guidelines to make a decision about poor outdoor air quality and your event. Visit www.todaysair.mt.gov for more information.



* For the purpose of this document, sensitive groups include:

- Young children (ages 0-5 years). Young children may be more sensitive to air pollution as their lungs are still developing and they may have an unknown underlying health condition.
- People who have a chronic condition, such as asthma or another respiratory disease, or cardiovascular disease. People with these conditions may be more sensitive to air pollution and should talk with their primary healthcare provider about managing their condition.

MONTANA DPHHS DEQ Montana Department of Environmental Quality Montana Office of Public Instruction Denise Juneau, State Superintendent opi.mt.gov

How To Use This Table And The Today's Air Website

- Start early. Well before your event, start monitoring the air quality by visiting the www.todaysair.mt.gov website.
    - Review the forecast on the today's air website: http://svc.mt.gov/deq/todaysair/smokereport/mostRecentUpdate.aspx.
    - Review the NowCast concentration measurements for your area. If your area is not near an air monitor, follow directions below for using the visibility guidelines.
    - Make adjustments to your plans depending on the forecast and the health effect category.
- Continue to monitor the air quality and the forecast in your area.
    - Make adjustments to your plans depending on the forecast and the health effect category.
    - Be sure to leave adequate time for decisions to be made before teams/participants begin travel.
    - Air quality can change rapidly. Regularly review the concentration levels before and throughout lengthy events to assess for deteriorating conditions.
    - If air quality readings are in the Unhealthy or Very Unhealthy/Hazardous levels follow those recommendations.

How to estimate air quality based on visibility:

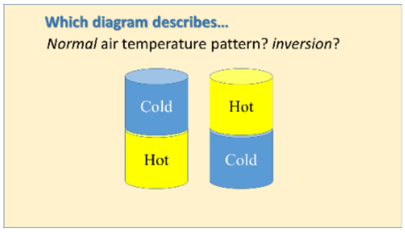
1. Use pre-determined landmarks that were established on a clear day for distances.
2. Face away from the sun.
3. Determine the limit of your visible range by looking for targets at known distances (miles).
4. Visible range is when an object you can easily see in the distance disappears.
5. Use the visibility values in the table to determine the local wildfire smoke category.

Items to Consider when Planning for Poor Air Quality during the School Year

- Is there an outdoor air quality section in the school's Emergency Plan? If so, do you know where it is located?
- How do you determine the air quality category in your area?
    - Which air quality monitor do you use or what geographic spot do you use for visibility guidelines?
- Who makes the recommendations to hold or cancel an outdoor event?
- How do you communicate what the decision was based on?
- How do you reschedule? Are there any rules about rescheduling?
- How do you get information out about your decision? If participants are already traveling, how do you notify them?
- What do you do with the students and parents that arrive to a postponed or canceled event? How do you make the announcement to them?
- What do you do for recess on school days?
- What are the plans if poor air quality affects the school/playground/track/swimming pool for a long period of time?
- How do you document what happened?
    - What went well? What can be done better?
    - What information did you needed that you did not have or were not trained to do?

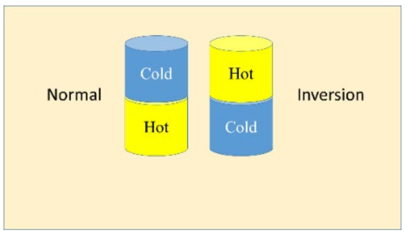
8. Use the 2nd presentation (***M09_InversionsAndMeasuringSmoke.pptx***) to further explain the concept of inversions and then help students interpret data on inversions, particulates, and the relationship of air quality to health:

Slide 1



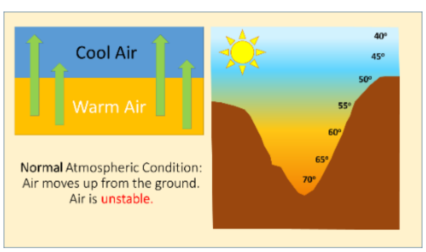
Ask: If the cylinders represent parcels of air, which diagram shows normal conditions and which one shows inversion conditions? Normal conditions are on the left, inversion conditions on the right.

Slide 2



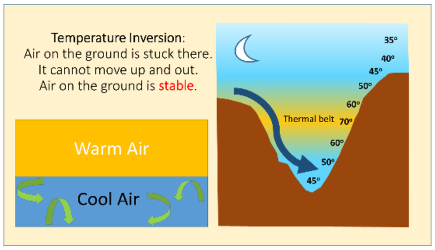
Discuss:
If you viewed or created the demonstration in the video: The demonstration with warm water on the bottom and cold water on top represents *normal* conditions. With warm water below cold water, the liquids were *unstable*; the warm water was expanding, the liquids were circulating – moving - and the colors were mixing. With cold water below warm water, the liquids were *stable* – not moving, not circulating - and the colors were not mixing. These stable conditions represent an *inversion*.
If you used the ice/boiling water demonstration: The air above boiling water showed *normal* conditions because the air was *unstable*, even turbulent; the hot air and water vapor were rising rapidly, and any pollutants in the air would be dispersing upward. The air above ice showed an *inversion* because the air was very *stable* – too dense to rise into the warm air above; any pollutants in the cold layer of air would be trapped and would not disperse.

Slide 3



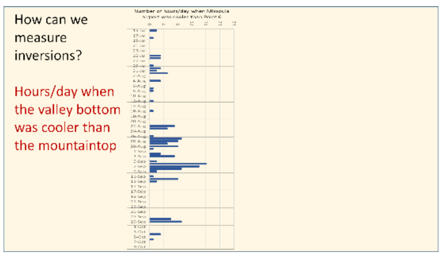
Review: *Normal* atmospheric conditions occur when sunlight warms the earth's surface in the morning, and this warms the air on the ground. The warming air expands and therefore rises. As it rises, it gradually cools off. If the air is dry, the temperature falls about 1°C for every 100-meter rise in altitude (about 5° F for every 1000 ft). As a result of this natural cooling, mountain tops are usually cooler than valleys on hot summer days. Due to all the air movement, these conditions are described as *unstable*.

Slide 4



Review: Inversions occur when air at the earth's surface is cold. It is not getting warmed by the sun, so it is not expanding and rising. It is stuck on the ground. It cannot be dislodged until it is heated or stirred up by wind. We say the cold, surface air is very *stable.* Inversions often occur at night. The cool air on the mountain tops is denser than the warm air in the valleys. When the sun goes down and stops stirring up the surface air, the cool, dense mountaintop air flows downhill into the valley bottoms and pushes the warm surface air uphill. This blanket of warm air at middle elevations is called the *thermal belt.*

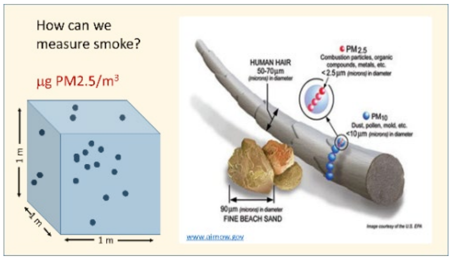
Slide 5



Explain: We're going to make some decisions about high school sports events based on data about inversions and air quality. We'll take on the roles of the school nurse and a sports coach while the 2017 Lolo Peak Fire was burning in western Montana. (We studied this fire in **Activity M08.**) To make informed decisions, we need some measurements. First, how can we measure inversions? We have records of the temperature every hour of every day during the fire. The records are from two weather stations that are located about 15 miles from the fire. One station is in a valley - at the Missoula Airport. The other station is on a mountain top called "Point 6." The blue bars on this graph show the days when inversion conditions existed in the Missoula valley. The length of the bar shows how many hours those conditions existed. Try some examples: On the first day of the fire, July 15, was there any time when the Missoula airport (valley bottom), was cooler than Point 6 (mountain top)? Yes, and those conditions lasted just 2 hours. What about the end of that week (after July 18) - were there any inversions? No, Point 6 was cooler than the airport – or at the same temperature – all of the time from July 19 through July 24. What was the day with the longest-lasting inversion? September 6, when the valley bottom was cooler than the mountain top for 16 hours. When would you expect the worst air quality? During the long period from the end of August through early September, when inversions occurred almost every day and lasted many hours. When might you expect good air quality? The weeks of Sept. 17 and Aug. 13 are both good candidates, since the weather data from those periods shows almost no sign of inversions. (Write these hypotheses on the board.)

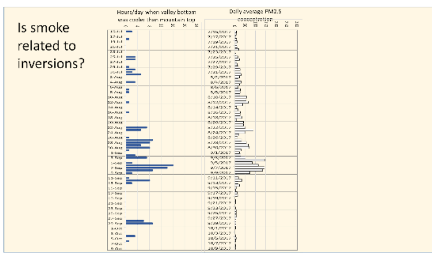
This graph shows measurements of inversion conditions. Now we need a way to measure smoke.

Slide 6



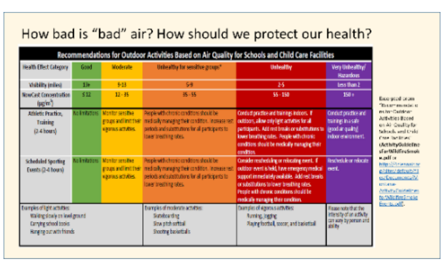
Explain: We'll use a measurement based on the <u>weight</u> of tiny particles in the air, which are the most common health hazard in smoke. Smoke monitoring equipment determines the weight of particles less than 2.5 microns (that is the same as micrometers) in diameter that are found in 1 cubic meter of air. We call the measurement "PM2.5" for short. So we're measuring the micrograms of PM2.5 per cubic meter of air. The drawing on the right shows just how tiny those 2.5-micron particles are, relative to the diameters of a particle of sand and a human hair; they are smaller than 1/20th the width of a human hair!

Slide 7



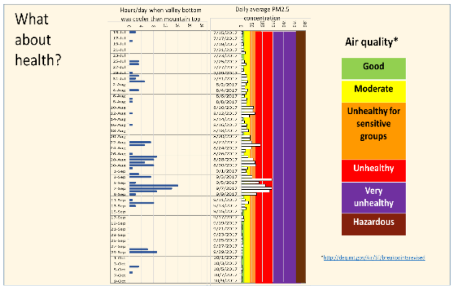
Explain: The graph with blue bars on the left, which we've already looked at, shows the record of inversions during the Lolo Peak Fire. The graph with white bars on the right shows the record of PM2.5 in the Missoula valley during that same time. How well did we predict the smoke pollution from inversion data? Students probably predicted the smoky and clean air episodes pretty well. However, there are a lot of periods without inversions that had fairly high levels of particulates. Why? The mountain top weather station could have been above the thermal belt, so the air above the inversion had cooled before it reached the mountain top sensors. Also, meteorologists have described a high pressure "ridge" that stayed in the upper atmosphere over the region during much of the summer; this made the surface air hot and reduced circulation even without inversion conditions. Finally, keep in mind that the smoke in the Missoula valley was not all from the Lolo Peak Fire. There were dozens of large fires burning in the West that summer.

Slide 8



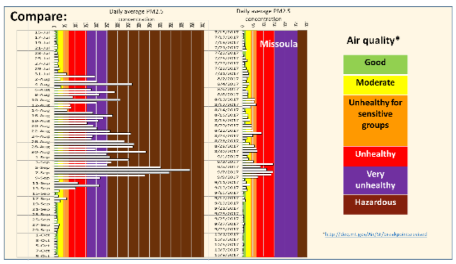
Explain/ask: For us to make good decisions on sports events during the 2017 fire season, we will use recommendations from the Montana Department of Environmental Quality. This slide is taken from your "Recommendations" handout, but it shows only the rows that apply to athletic practice and sports events. (Go through the Health Effect Categories and recommendations with students so they know how to use the table. Ask them to notice or describe how the limitations are cumulative – that is, activities are more and more limited – and more and more people are affected – with each step to the right, as air quality worsens.)

Slide 9



Ask: When particulate levels were high, how bad was the air quality… and what were the recommendations for limiting activity to protect health? Have students refer to their copies of the "Recommendations" to discuss. Air quality was UNHEALTHY for several days in early September. Who are "sensitive groups"? They can find this at the bottom of Page 1 of the "Recommendations." How are recommendations for sensitive groups different from general recommendations? Have them use the handout.

Slide 10



Explain: The Missoula air was unhealthy for several days during the summer of 2017, but it could have been worse. The Rice Ridge Fire, about 40 miles northeast of the Lolo Peak Fire, burned 3 times as much area as the Lolo Peak Fire. Smoke in the little town of Seeley Lake, on the edge of the fire, had much MUCH worse air than Missoula did. Both of these graphs are on the same scale. Compare the air quality in Seeley Lake with that in Missoula. Compare the recommended limitations for people in the Seeley Lake area. Keep this slide on display as you introduce the **Assessment.**

Assessment:

1. Have the students work in pairs.
2. Explain the assignment. As you do, note key information on the board:
   a. One person in each pair should be the school nurse, and the other should be a coach for a sports team. You pick the sport. You know that 2 members of your sports team have asthma.
   b. It is the morning of Friday, September 8, 2017 in Missoula, Montana. About 10 miles from your school, the Lolo Peak Fire has been burning for nearly 2 months. Your team has a big game/meet scheduled for tonight. A rival team is planning to come from 150 miles away. They plan to leave school around noon.
   c. But your area is surrounded by fires: To the southwest, the Lolo Peak Fire has already burned 49,000 acres. To the east, the Rice Ridge Fire has burned more than 120,000 acres so far. For the past week, the air in your valley has been smoky. (Refer to the final slide in the presentation above.) You have been smelling smoke from the fire throughout the school as well. Yesterday, the valley you live in was under a strong inversion. Visibility was limited outside, and the classrooms, cafeteria, and gym smelled smoky. What was the concentration of PM2.5 in your area yesterday? From the final slide in the presentation, estimate the PM2.5 concentration for September 7. Be sure to

use the Missoula data rather than the Seeley Lake data. The actual concentration was 143.9 $\mu g/m^3$. What was the air quality? UNHEALTHY, in the red range on the graph. Today, the forecast says that the inversion will weaken a little, but the concentration of PM2.5 will probably not change much. (The actual measurement for September 8 was 135.4 $\mu g/m^3$.)

d. Talk the situation over together. Use “Recommendations for Outdoor Activities Based on Air Quality for Schools and Child Care Facilities” to help you decide whether to hold the event as scheduled, cancel it, or hold it with some limitations - and specify what those limitations would be. You have to decide by noon so the visiting team can cancel their travel plans if you will not be playing.

e. Together, you will report to the class:

- what sport you discussed
- what the choices “Recommendations for Outdoor Activities” suggest for the amount of smoke predicted
- what you decided to do and why.

3. Have the teams for each sport report together.

Evaluation: Excellent	Good	Poor
- The team identified the sport they discussed. - The team correctly identified the forecast air quality as being UNHEALTHY. -The team made an appropriate decision: --- For indoor sports, students found out if indoor air quality has been degraded because of the previous week(s) of smoke pollution. If indoor air is OK, hold the event as planned. --- For outdoor sports, students chose 1 of these 2 options: (1) Reschedule or relocate the event. (2) Hold the event, but have emergency medical support immediately available. Add rest breaks or substitutions to lower breathing rates. Have the 2 asthmatic students careful to medically manage their condition.	- The team identified the sport they discussed. -The team correctly identified the forecast air quality as being UNHEALTHY. -The team made an appropriate decision: --- For indoor sports, hold the event as planned. The team did not consider the possibility of indoor air pollution. --- For outdoor sports, the team chose to hold the event as planned, but they did not make plans for emergency medical support and/or adding rest breaks or substitutions and/or gave inappropriate plans for the asthmatic students.	- The team identified the sport they discussed. - The team did not correctly identify the forecast air quality as UNHEALTHY. - The team’s decision did not indicate understanding of relationships between sports activity, smoke levels, and health.