Lesson Overview: In this activity, students learn about the composition of smoke from wildland fire, how it disperses, and its health impacts. They do a pre-class reading assignment and worksheet. During class, they discuss the pre-class reading, watch a video or demonstration of an inversion, and analyze Plumas county smoke data from two years when large wildland fires occurred.

Lesson Goal: Increase students’ understanding of how smoke from wildland fires disperses, how it may affect people’s health, and why smoke management is complicated.

Objectives:
- Students will understand the composition and health impacts of smoke from wildland fires.
- Students will understand how temperature inversions affect smoke dispersal.
- Students will analyze and interpret graphs of particulate matter concentrations.

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

Duration: pre-class reading plus 45 minutes

Group size: Entire class

Setting: Classroom

New FireWorks vocabulary: inversion, particulates/particulate matter, PM10/PM2.5, smoke, stable/unstable atmospheric conditions

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 even 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 benefit some plants by increasing seed germination. For humans, however,
they are hazardous, especially for anyone who has asthma or other respiratory illness and for those who engage in strenuous exercise.

In this activity, students learn that smoke can disperse readily or be trapped by an inversion. Then they consider who be harmed by smoke from wildland fires. Finally, they analyze air quality data to figure out when air quality is at its best and worst throughout the year and what effect wildfires have had on air quality.

On most summer days, sunlight warms the earth’s surface each morning, and the air lying on the earth’s surface is heated too. This warming, expanding air rises, and its temperature decreases due to the expansion. If the air is dry, the temperature falls about 1°C for every 100-meter rise in altitude. 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 circumstances, we call it unstable.

Sometimes the sun doesn’t warm the earth’s surface very much during the day. Clouds may block the incoming sunlight. In winter, the ground may be covered with snow that reflects sunlight instead of absorbing its energy. In summer, the smoke from a fire may be too dense to let sunlight through. When this happens, the cold air is stuck on the ground, and a warm layer of air rests on top of it. It is not expanding, therefore not rising, and therefore it is “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, cool air on top) is upside-down. The blanket of warm air lying on top of the cold air is called the inversion layer. 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 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 and anyone with asthma or other respiratory illness. It is a good idea for some types of seeds to be outdoors during a smoke-filled inversion, but it is a good idea for people to limit aerobic activities and even stay indoors until the air quality improves.

At the end of this activity, you will find an optional "extension" activity that contains two possibilities for technical reading assignments.

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**Materials and preparation:**

1. Decide how to demonstrate an inversion: You can use this 3-minute video (https://www.youtube.com/watch?v=LPvn9qhVFbM) or create the same demonstration yourself or use the demonstration with ice and boiling water that is described in the Middle School curriculum (M09).
2. Make 1 copy/student:
   - **Handout H11-1**: Reading and Questions from “Wildfire Smoke: A Guide for Public Health Officials” (3 pages)
   - **Handout H11-2**: Plumas Air Quality through the Year (2 pages)
3. Download *H11_Images.pptx*.

**Procedures:**

1. **Suggested homework**: Before doing this lesson, students should complete the reading/writing assignment on **Handout H11-1**.

2. **Hook**: Have students think of a time when they remember the air being really smoky. Ask some students to share their stories with the class. Tell students that this lesson is going to explore the composition of wildland fire smoke, how it moves through the atmosphere, the associated health impacts, and what precautions to take to avoid the health effects of smoke.

3. Discuss the reading/writing assignment (Handout H11-1) in small groups or as a class.

4. Explain: Now that we know what smoke is composed of and its associated health risks, we’re going to investigate how air moves above hot and cold surfaces, which will help us understand where smoke goes and how it impacts health.

5. **Demonstrate an inversion**: Use this video ([https://www.youtube.com/watch?v=LPvn9qhVFBM](https://www.youtube.com/watch?v=LPvn9qhVFBM)) or create the same demonstration yourself or use the demonstration with ice and boiling water that is described in the Middle School curriculum (M09).

6. **Diagrams and Discussion**: Start the PowerPoint *H11_Images.pptx*. Use the copy of slides and notes below, complete with notes for how to present the slides.

**Assessment**: Assign completion of **Handout H11-2**: Plumas Air Quality through the Year.

**Evaluation**: See Answer Key below.

**Technical Reading Extensions**: Assign students to read one of these two technical reports and write a 1-paragraph response to it, expressing any information in the report that they found surprising or alarming.

Ask: If the cylinders represent parcels of air, which diagram shows normal conditions and which one shows inversion conditions? The one on the left, with cold above hot, shows normal conditions. The one with hot above cold shows inversion conditions.

If you viewed the video demonstration: The demonstration with warm water on the bottom and cold water on top represented normal conditions because the liquids were circulating and pollutants were being dispersed. The demonstration with cold water on the bottom represented inversion conditions because the liquids were stable, not circulating.

If you used the ice/boiling water demonstration: The air above boiling water showed normal conditions because the air was unstable. The air above ice showed an inversion because the air was very stable.

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, and its temperature gradually falls due to the expansion. If the air is dry, the temperature falls about 1°C for every 100-meter rise in altitude. As a result of this natural cooling, mountain tops tend to be cooler than valleys even on hot summer days. Due to all the air movement, these conditions are described as *unstable*.
Inversions occur when the earth’s surface is cold and the sun doesn’t warm the earth’s surface enough to heat the air above it. The cold air is not warming, expanding, and rising. Therefore, it is stuck on the ground until something stirs up the atmosphere. The blanket of warm air lying on top of the cold air is called the inversion layer. During an inversion, the cold, surface air is very stable. It cannot be dislodged until it is heated or stirred up by wind. In winter, this may happen when it is cloudy or when the ground is covered with snow that reflects the sunlight instead of absorbing it.

Ask students to get into groups of 2-3 and discuss answers to this question. After a couple of minutes, go to the next slide to discuss answers.

Here are two diagrams that show how pollutants from a factory are dispersed (or not) under different atmospheric conditions. Smoke from wildland fires behaves in the same way.
Introduction: Smoke rolls into town, blanketing the city, turning on streetlights, creating an eerie and choking fog. Switchboards light up as people look for answers. Citizens want to know what they should do to protect themselves. Schools officials want to know if outdoor events should be cancelled. The news media want to know how dangerous the smoke really is. Smoke events often catch us off-guard. This handout is intended to provide you and local public health officials with the information you need when wildfire smoke is present so you can adequately communicate health risks and precautions to the public. It is the product of a collaborative effort by scientists, air quality specialists and public health professionals from Federal, state and local agencies.

Composition of Smoke: Smoke is composed primarily of carbon dioxide, water vapor, carbon monoxide, particulate matter, hydrocarbons and other organic chemicals, nitrogen oxides, trace minerals and several thousand other compounds. The actual composition of smoke depends on the fuel type, the temperature of the fire, and the wind conditions. Particulate matter is the principal pollutant of concern from wildfire smoke for the relatively short-term exposures (hours to weeks) typically experienced by the public.

Particulate Matter (PM): Particulate matter is a generic term for particles suspended in the air, typically as a mixture of both solid particles and liquid droplets. Particles from smoke tend to be very small - less than one micrometer in diameter. For purposes of comparison, a human hair is about 60 micrometers in diameter. Particulate matter in wood smoke has a size range near the wavelength of visible light (0.4 – 0.7 micrometers). Smoke particles efficiently scatter light and reduce visibility. Moreover, such small particles can be inhaled into the deepest recesses of the lung and are thought to represent a greater health concern than larger particles.

Health Effects of Particulate Matter: The effects of smoke range from eye and respiratory tract irritation to more serious disorders, including reduced lung function, bronchitis, exacerbation of asthma, and premature death. Studies have found that fine particles are linked (alone or with other pollutants) with increased mortality and aggravation of pre-existing respiratory and cardiovascular disease. In addition, particles are respiratory irritants, and exposures to high concentrations of particulate matter can cause persistent cough, phlegm, wheezing and difficulty breathing. Particles can also affect healthy people, causing respiratory symptoms, transient reductions in lung function,
and pulmonary inflammation. Particulate matter can also affect the body's immune system and make it more difficult to remove inhaled foreign materials from the lung, such as pollen and bacteria. The principal public health threat from short-term exposures to smoke is considered to come from exposure to particulate matter.

**Health Effects of Carbon Monoxide:** Another pollutant of concern during smoke events is carbon monoxide. Carbon monoxide is a colorless, odorless gas, produced by incomplete combustion of wood or other organic materials. Carbon monoxide levels are highest during the smoldering stages of a fire. Carbon monoxide (CO) enters the bloodstream through the lungs and reduces oxygen delivery to the body’s organs and tissues. The CO concentrations typical of population exposures related to wildfire smoke do not pose a significant hazard, except to some sensitive individuals and to firefighters very close to the fire line. Individuals who may experience health effects from lower levels of CO are those who have cardiovascular disease: they may experience chest pain and cardiac arrhythmias. At higher levels, as might be observed in a major structural fire, carbon monoxide exposure can cause headaches, dizziness, visual impairment, reduced work capacity, and reduced manual dexterity, even in otherwise healthy individuals. At even higher concentrations (seldom associated solely with a wildfire), carbon monoxide can be deadly.

**Health Effects of Other Air Pollutants:** Other air pollutants, such as acrolein, benzene, and formaldehyde, are present in smoke, but in much lower concentrations than particulate matter and carbon monoxide. Wildfire smoke also contains significant quantities of respiratory irritants. Formaldehyde and acrolein are two of the principal irritant chemicals that add to the cumulative irritant properties of smoke, even though the concentrations of these chemicals individually may be below levels of public health concern.

**Long-Term Effects:** One concern that may be raised by members of the general public is whether they run an increased risk of cancer or other long-term health impacts of exposure to wildfire smoke. People exposed to toxic air pollutants at sufficient concentrations and durations may have slightly increased risks of cancer or of experiencing other chronic health problems. However, in general, the long-term risk from short-term smoke exposure is quite low. Epidemiological studies have shown that urban firefighters exposed to smoke over an entire working lifetime have about a three-fold increased risk of developing lung cancer (Hansen 1990). This provides some perspective on the potential risks. The major carcinogenic components of smoke are polycyclic aromatic hydrocarbons (PAHs). Although the carcinogens benzene and formaldehyde are also present in smoke, they are thought to present a lesser risk.

**Overall:** Not everyone who is exposed to thick smoke will have health problems. The level and duration of exposure, age, individual susceptibility, including the presence or absence of pre-existing lung or heart disease, and other factors play significant roles in determining whether or not someone will experience smoke-related health problems.

Answer these on a separate sheet of paper. Keep the handout for the table at the bottom.
1. What groups are mentioned in the first paragraph and what questions do they have?
2. Think of another group that isn’t mentioned, what question do you suppose they’d have?
3. What is the purpose of this guide?
4. Of what is smoke composed?
5. Describe particulate matter.
6. Describe three health effects of smoke particulate matter?
7. What are two long-term effects of smoke exposure?
8. Now apply your knowledge to this problem:
   a) Access Air Now’s Air Quality Index chart, at this webpage: https://www.airnow.gov/index.cfm?action=airnow.mapcenter&mapcenter=1
   b) Click on “Current AQI” tab. AQI stands for Air Quality Index. It incorporates PM and O₃.
   c) Find the current unhealthiest area in your state. Use the color key at the bottom of the map to answer: What is the current AQI? Use the table below to describe associated health risks.
   d) In the table below, read the cautionary statements for “very unhealthy” air. Describe some challenges that would be associated with implementing the cautionary statements.

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<table>
<thead>
<tr>
<th>24-hr PM₂.₅ (µg/m³)</th>
<th>AQI Categories</th>
<th>AQI Values</th>
<th>AQI Cautionary Statements</th>
<th>AQI Health Effects Statements</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 - 12.0</td>
<td>Good</td>
<td>0 - 50</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>12.1 - 35.4</td>
<td>Moderate</td>
<td>51 - 100</td>
<td>Unusually sensitive people should consider reducing indoor or outdoor activities, including heavy exertion.</td>
<td>Respiratory symptoms possible in unusually sensitive individuals, possible aggravation of heart or lung disease in people with cardiopulmonary disease and older adults.</td>
</tr>
<tr>
<td>35.5 - 55.4</td>
<td>Unhealthy for Sensitive Groups</td>
<td>101 - 150</td>
<td>People with heart or lung disease, older adults, and children should reduce activity levels, including heavy exertion.</td>
<td>Increasing likelihood of respiratory symptoms in sensitive individuals, aggravation of heart or lung disease and premature mortality in people with cardiopulmonary disease and older adults.</td>
</tr>
<tr>
<td>55.5 - 150.4</td>
<td>Unhealthy</td>
<td>151 - 200</td>
<td>People with heart or lung disease, older adults, and children should avoid prolonged or heavy exertion; everyone else should reduce activity levels.</td>
<td>Increased aggravation of heart or lung disease and premature mortality in people with cardiopulmonary disease and older adults; increased respiratory effects in general population.</td>
</tr>
<tr>
<td>150.5 - 250.4</td>
<td>Very Unhealthy</td>
<td>201 - 300</td>
<td>People with heart or lung disease, older adults, and children should avoid prolonged or heavy exertion; everyone else should avoid prolonged or heavy exertion.</td>
<td>Significant aggravation of heart or lung disease and premature mortality in people with cardiopulmonary disease and older adults; significant increase in respiratory effects in general population.</td>
</tr>
<tr>
<td>Greater than 250.5</td>
<td>Hazardous</td>
<td>Over 300</td>
<td>Everyone should avoid all physical activity outdoors. Everyone else should avoid prolonged or heavy exertion.</td>
<td>Serious aggravation of heart or lung disease and premature mortality in people with cardiopulmonary disease and older adults; serious risk of respiratory effects in general population.</td>
</tr>
</tbody>
</table>
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Who is “SENSITIVE” to PM₂.₅? “People with heart or lung disease, older adults, children, and people of lower socioeconomic status are the groups most at risk.” See EPA’s Technical Assistance Document (link below). Also at higher risk: preterm infants, pregnant women, and people with respiratory or heart disease.

Sources:
- 2013 by Clean Air Fairbanks cleanairfairbanks@gmail.com http://cleanairfairbanks.wordpress.com
Answer Key for Handout H11-1: Reading and Questions from “Wildfire Smoke: A Guide for Public Health Officials”

1. What groups are mentioned in the first paragraph and what questions do they have?
   Citizens, school officials, and news media. They want to know what they should do to protect themselves, if outdoor events should be cancelled, and how dangerous the smoke really is.

2. Think of another group that isn’t mentioned, what question do you suppose they’d have?
   Examples: the elderly, individuals with infants, health care givers, coaches, outdoor educators. They may be asking how smoke will impact them, how long it will last, how they can keep it out of their homes, and even whether they should leave the area for a while.

3. What is the purpose of this guide? The purpose is to provide local public health officials with the information they need when wildfire smoke is present, so they can adequately communicate health risks and precautions to the public.

4. Of what is smoke composed? Smoke is composed primarily of carbon dioxide, water vapor, carbon monoxide, particulate matter, hydrocarbons and other organic chemicals, nitrogen oxides, trace minerals and several thousand other compounds.

5. Describe particulate matter. Particulate matter is a generic term for particles suspended in the air. They are typically a mixture of solid particles and liquid droplets. Particles from smoke tend to be very small - less than one micrometer in diameter.

6. Describe three health effects of smoke particulate matter? Answers may include: Eye and respiratory tract irritation, reduced lung function, bronchitis, exacerbation of asthma, and premature death. It can cause persistent cough, phlegm, wheezing and difficulty breathing. Particles can also cause respiratory symptoms, transient reductions in lung function, and inflammation in the lungs. These impacts reduce the ability of the lungs to resist irritation from allergens and infection from bacteria and viruses.

7. What are two long-term effects of smoke exposure? Slightly increased risks of cancer or of experiencing other chronic health problems. Epidemiological studies have shown that urban firefighters exposed to smoke over an entire working lifetime have about a three-fold increased risk of developing lung cancer.

8. Now apply your knowledge to this problem:
   a) Access Air Now’s Air Quality Index chart, at this webpage: https://www.airnow.gov/index.cfm?action=airnow.mapcenter&mapcenter=1
   b) Click on “Current AQI” tab. AQI stands for Air Quality Index. It incorporates PM and O₃.
c) Find the current unhealthiest area in your state. Use the color key at the bottom of the map to answer: What is the current AQI? Use the table below to describe associated health risks.

d) In the table below, read the cautionary statements for “very unhealthy” air. Describe some challenges that would be associated with implementing the cautionary statements. Challenges could be related to liability, costs, providing medical care or air purifiers, providing indoor locations for events that were planned outside, and possibly even paying for lodging if health-impaired people need to evacuate.
Handout H11-2: Plumas Air Quality through the Year

**Directions:** Answer these questions on a separate page. Use full sentences. The data you need are on the next page (the 2000 and 2012 air quality data from Plumas County, California) and at the bottom of Handout H11-1 (the EPA Air Quality Index table).

1. The 2000 air quality graph shows daily mean PM 2.5 data (µg/m³) from the Quincy and Portola air quality stations. What was the highest recorded level of the PM 2.5 in 2000? When was it recorded? What are the associated health risks?

2. The Storrie Fire, a large wildfire in Plumas County, began on August 17, 2000. A few days after the fire began, there was a spike in particulate matter. How high did the PM 2.5 measurement get? How long did the PM 2.5 measurement stay this high? What are the associated health risks?

3. The 2012 air quality graph shows the daily mean PM 2.5 measurement from the Quincy and Portola air quality stations. What was the highest recorded level in all of 2012? When was it recorded? What are the associated health risks?

4. The Chips Fire, a large wildland fire in Plumas County burned throughout August, 2012. How would you describe the daily particulate levels during the fire? What were the associated health risks while the fire was burning?

5. Based on particulate matter data from 2000 and 2012, which months seem most likely to have poor air quality? Which months generally have the best air quality?

6. Based on what you know about temperature inversions, what do you think causes the worst episodes of air quality?
1. The 2000 air quality graph shows daily mean PM 2.5 data ($\mu g/m^3$) from the Quincy and Portola air quality stations. What was the highest recorded level of the PM 2.5 in 2000? When was it recorded? What are the associated health risks? The highest recorded level of the daily mean PM 2.5 in 2000 was about 46. It occurred on 12/20/2000. 24-hour exposure to 46 PM 2.5 $\mu g/m^3$ is considered unhealthy for sensitive groups. There is increasing likelihood of respiratory symptoms in sensitive individuals.

2. The Storrie Fire, a large wildfire in Plumas County, began on August 17, 2000. A few days after the fire began, there was a spike in particulate matter. How high did the PM 2.5 measurement get? How long did the PM 2.5 measurement stay this high? What are the associated health risks? A few days after the Storrie Fire began, the daily mean PM 2.5 spiked at about 43. This lasted for only 1 day. 24-hour exposure to 43 PM 2.5 $\mu g/m^3$ is considered unhealthy for sensitive groups.

3. The 2012 air quality graph shows the daily mean PM 2.5 measurement from the Quincy and Portola air quality stations. What was the highest recorded level in all of 2012? When was it recorded? What are the associated health risks? The highest recorded level of the daily mean PM 2.5 $\mu g/m^3$ in 2012 was about 45. It occurred on 1/25/2012. 24-hour exposure to 45 PM 2.5 $\mu g/m^3$ is considered unhealthy for sensitive groups.

4. The Chips Fire, a large wildland fire in Plumas County burned throughout August, 2012. How would you describe the daily particulate levels during the fire? What were the associated health risks while the fire was burning? Throughout most of August, when the Chips fire was burning, the PM 2.5 levels mostly remained below 10 $\mu g/m^3$. This is good air quality. There were a few days of moderate air quality, when “unusually sensitive” people might be harmed.

5. Based on particulate matter data from 2000 and 2012, which months seem most likely to have poor air quality? Which months generally have the best air quality? The winter months tend to have the poorest air quality, while the summer months seem to have the best air quality – with occasional exceptions because of wildland fires.

6. Based on what you know about temperature inversions, what do you think causes the worst episodes of air quality? The air quality is poorest during the winter months. Inversions are typically more common in winter, when the air at the ground level doesn’t warm up during the day, keeping it trapped on the earth’s surface under a warmer layer of air. Any pollutants in the cold surface layer of air are also trapped – including particulates. In winter, the particulates probably come from wood-burning stoves, road dust, and possibly some industries.