Smoke in the Ozark Highlands

Lesson 8

Subjects: Science, Geography, Health, Mathematics, Writing

Duration: 60 minutes (one class period)

Group Size: Individually or in small groups of 2-3

Setting: Classroom (students will need computers with internet access)

Vocabulary: Geographic information system [GIS], Smoke, Mitigation, Environmental hazard, Fire practitioner, Pre-ignition, Flaming, Smoldering, Glowing, Sulfur dioxide, Ambient Air Quality Standards, Particulate matter, Ozone, Carbon monoxide, Nitrogen dioxide, Lead, Risk Analysis

Lesson Overview In this activity, students use a **geographic information system** [**GIS**] model (VSmoke-Web) to map the extent of **smoke** impacts from a chosen prescribed fire case study. Students will determine possible impacts if the case study's burn were conducted. Students will decide if the burn should be conducted with the conditions presented in the case study. Students will discuss ways in which smoke impacts could be eliminated or **mitigated**.

Lesson Goal Students will increase their understanding of smoke production, the composition of smoke, smoke's effects on human health, and how smoke impacts resulting from prescribed fire can be managed. Students will also become familiar with how GIS can be used as a predictive tool.

Objectives

- ➔ Students can define smoke.
- ➔ Students list the primary components of smoke resulting from the combustion of vegetative matter.
- ➔ Students list the four stages of combustion and can describe each stage's characteristics.
- ➔ Students can determine possible health impacts from smoke using an air quality index (AQI).

- ➔ Students recognize the steps of risk analysis and their use in managing environmental hazards.
- ➔ Students can use a geographic information system [GIS] modelling tool to make predictions and to propose solutions.

Academic Standards

Table 1: Next Generation Science Standards - Science & Engineering Practices (SEP)

Developing and Using Models	Develop, revise, and/or use a model based on evidence to illustrate and/or predict the relationships between systems or between components of a system. Develop and/or use a model (including mathematical and computational) to generate data to support explanations, predict phenomena, analyze systems, and/or solve problems.
Analyzing and Interpreting Data	Analyze data using tools, technologies, and/or models(e.g., computational, mathematical) in order to make valid and reliable scientific claims or determine an optimal design solution.

Table 2: Next Generation Science Standards - Disciplinary Core Ideas (DCI)

HS-LS2 Ecosystems: Interactions, Energy, and Dynamics	HS-LS2-7: Design, evaluate, and refine a solution for reducing the impacts of human activities on the environment and biodiversity.
HS-ETS1 Engineering Design	HS-ETS1-4: Use a computer simulation to model the impact of a proposed solution to a complex real-world problem with numerous criteria and constraints on interactions within and between systems relevant to the problem.

Table 3: Next Generation Science Standards - Crosscutting Concepts (CC)

Cause and Effect: Mechanism and Explanation	Events have causes, sometimes simple, sometimes multi-faceted. Deciphering causal relationships, and the mechanisms by which they are mediated, is a major activity of science and engineering.

Scale, Proportion, and Quantity	In considering phenomena it is critical to recognize what is relevant at different size, time, and energy scales and the proportional relationships between different quantities as scales change.
Systems and System Models	A system is an organized group of related objects or components; models can be used for understanding and predicting the behavior of systems.

Teacher Background This lesson focuses on some of the **environmental hazards** associated with smoke and how such hazards can be managed. Smoke is made up of a complex mixture of gases and fine particles produced when trees, grasses, and other organic fuels burn. Smoke is a by-product of incomplete combustion resulting from an inefficient mixing of oxygen and the fuels mentioned previously (Weir and Carlson, OSU Extension Fact Sheet E-1008). Smoke presents many challenges for both **fire practitioners** and officials trying to minimize health impacts on populations.

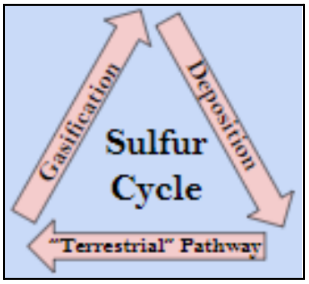
To understand smoke production, we must be familiar with the stages of combustion. There are four stages describing the progression of fire (Table 4). Each stage differs in the amount of fuel consumed and the amount of smoke that results. Smoke from the combustion of vegetative matter is composed primarily of water vapor and carbon dioxide (CO_2); water vapor and CO_2 make up 90% of smoke emissions (NWCG, 2018).

Table 4: The Four Stages of Combustion (Weir, 2009)

Stage	Characteristic(s)
Pre-ignition	Water vapor is expelled into the atmosphere.
Flaming	The efficiency of combustion is relatively high; this stage puts out the least amount of emissions in relation to the amount of fuel consumed.
Smoldering	The effectiveness of combustion is lower, resulting in greater particulate emissions. Studies show that the amount of particulate emissions produced per mass of fuel consumed during the smoldering stage is more than double that of the flaming stage.

Glowing	This stage is characterized by minimal smoke because all volatile material in the fuel has been driven out and oxygen can now easily reach the fuel particle, making combustion more efficient.

As an environmental hazard, smoke presents a variety of impacts that must be managed in order to reduce associated risks. Exposure to pollutants in smoke causes immediate responses in people, such as burning eyes, a runny nose, coughing, phlegm, wheezing and difficulty breathing (AirNow.gov). The younger and older segments of populations are usually affected most by smoke exposure, especially those with asthma, heart disease, or lung disease (AirNow.gov). Smoke also reduces visibility which can cause accidents. Traffic accidents are one of the most common causes of mortality related to smoke. Prescribed fire planners eliminate or reduce smoke effects by limiting the size of a burn and by burning only when the wind is from specified directions and when weather conditions allow for smoke to readily disperse (Weir and Carlson, OSU Extension Fact Sheet E-1008).



It is important to remember that not all impacts related to smoke are negative. Smoke components, many of which are categorized as pollutants, are part of biogeochemical cycles. **Sulfur dioxide** [SO_2], for example, is part of the sulfur cycle. Sulfur dioxide, a gas, allows sulfur to move rapidly in the environment. The smell of smoke triggers an instinctive "flight" response to flee or seek shelter in many species that have never been exposed to fire previously. Smoke also attracts species to fires, such as Swainson's hawks, since prey species may have lost concealing shelter or may have been disoriented, injured, or killed (Hovick, Torre J., et al., 2017).

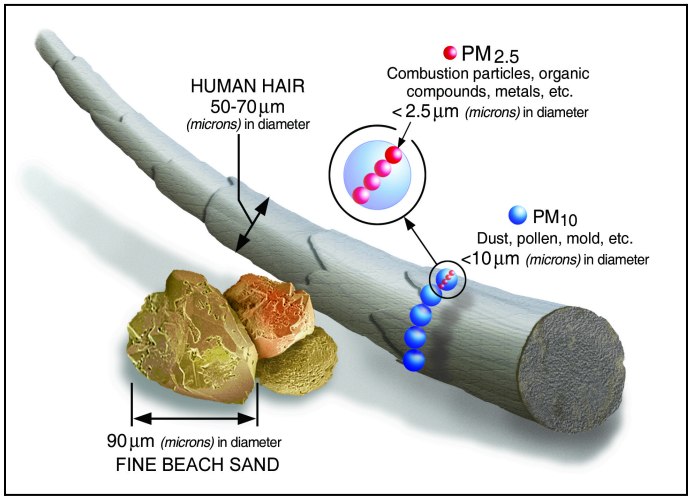
The Clean Air Act [CAA] is the primary law regulating smoke in the United States. One of the purposes of the CAA as described in its declaration is:

> to protect and enhance the quality of the Nation's air resources so as to promote the public health and welfare and the productive capacity of its population (Clean Air Act, 1970).

As part of its mission to protect public health and welfare, the CAA required the development of the **National Ambient Air Quality Standards** [NAAQS] for 6 criteria pollutants. These 6

pollutants, monitored by the Environmental Protection Agency [EPA], are: 1) **particulate matter** [PM]; 2) **ozone**; 3) **carbon monoxide**; 4) **nitrogen dioxide**; 5) sulfur dioxide; and 6) **lead**. These 6 criteria pollutants are used as standards for air quality decision making. Except for lead, these pollutants are present in smoke from vegetative fires.

Ozone and particulate matter [PM] are the two most problematic pollutants in smoke. Since the ozone from smoke is ground-level or tropospheric, its reactivity can result in human health issues (e.g., shortness of breath, sore throat, fatigue) as well as affecting other living things and nonliving materials (EPA, 2019 and National Park Service). $PM_{2.5}$ particles are of special concern because such particles are smaller than 2.5 microns (micrometers) in diameter. It would take at least 20 $PM_{2.5}$ particles placed side by side to equal the diameter of a human hair. Due to their small size, $PM_{2.5}$ particles can penetrate deep into the lungs and can even enter the circulatory system and impact organs such as the brain (EPA, 2020).



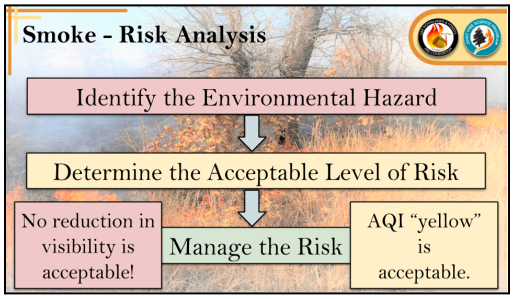
The EPA's AirNow program reports air quality using the official "Air Quality Index" [AQI] which is a color-coded index designed to communicate whether air quality is healthy or unhealthy. To calculate the value for AQI, a location's concentrations of 5 criteria air pollutants are used (lead is not included). All 5 of these pollutants are components of smoke from vegetative matter, so the AQI approach is useful for judging the impact of smoke on human health.

The color-coded categories used in AirNow's AQI (Table 5) provide statements that describe air quality in an area, which groups of people may be affected, and steps that can be taken to reduce exposure to air pollution and related health impacts. The GIS model, VSmoke-Web, used in this activity incorporates this color-coded system.

Table 5: Example of AirNow.gov's Air Quality Index [AQI]

Air Quality Index	Who Needs to be Concerned?	What Should I Do?
Good 0-50	It's a great day to be active outside.	
Moderate 51-100	Some people who may be unusually sensitive to particle pollution.	**Unusually sensitive people:** *Consider reducing* prolonged or heavy exertion. Watch for symptoms such as coughing or shortness of breath. These are signs to take it easier. **Everyone else:** It's a good day to be active outside.
Unhealthy for Sensitive Groups 101-150	Sensitive groups include **people with heart or lung disease, older adults, children and teenagers.**	**Sensitive groups:** *Reduce* prolonged or heavy exertion. It's OK to be active outside, but take more breaks and do less intense activities. Watch for symptoms such as coughing or shortness of breath. **People with asthma** should follow their asthma action plans and keep quick relief medicine handy. **If you have heart disease:** Symptoms such as palpitations, shortness of breath, or unusual fatigue may indicate a serious problem. If you have any of these, contact your heath care provider.
Unhealthy 151 to 200	**Everyone**	**Sensitive groups:** *Avoid* prolonged or heavy exertion. Move activities indoors or reschedule to a time when the air quality is better. **Everyone else:** *Reduce* prolonged or heavy exertion. Take more breaks during all outdoor activities.
Very Unhealthy 201-300	**Everyone**	**Sensitive groups:** *Avoid all* physical activity outdoors. Move activities indoors or reschedule to a time when air quality is better. **Everyone else:** *Avoid* prolonged or heavy exertion. Consider moving activities indoors or rescheduling to a time when air quality is better.
Hazardous 301-500	**Everyone**	**Everyone**: *Avoid all* physical activity outdoors. **Sensitive groups:** Remain indoors and keep activity levels low. Follow tips for keeping particle levels low indoors.

(AirNow.gov)



Risk analysis can help reduce or eliminate the environmental hazards associated with smoke. The first step in risk analysis involves identifying environmental hazards. For this activity, "pollutant exposure" and "reduced visibility" are the hazards. The next step in risk analysis is determining the acceptable level of risk. Finally, any acceptable risk must be managed. For this activity, no reduced visibility is acceptable, and air pollution should be managed so that exposure is limited to the yellow AQI category (see Table 5).

Smoke impacts should be avoided as much as possible. The two straightforward approaches to manage smoke impacts are: 1) to reduce the size of the burn; and 2) to pay attention to wind direction in relation to sensitive areas/"points of concern" (Table 6) (Oklahoma Cooperative Extension Service, 2006). The simplest way to reduce smoke impacts is to burn a smaller area; a reduced amount of fuel will produce less smoke (Weir and Carlson, OSU Extension Fact Sheet E-1008). **Smoke management** is a crucial component of planning a

prescribed burn. A burn's smoke management plan identifies sensitive areas/"points of concern" near a burn and states acceptable wind directions (The Samuel Roberts Noble Foundation, 2015).

This activity provides 4 case studies which students can use to investigate smoke impacts and smoke management. This activity's slideshow presents a sample case study that introduces "points of concern" or sensitive areas. Such "points of concern" have a greater risk of suffering smoke impacts. For example, busy highways with more traffic and vehicles travelling at greater speeds are more likely to have accidents resulting from reduced visibility than small roads in rural areas. Regarding human health, densely populated areas (e.g., towns, cities) will experience more health impacts than a few rural residences that are separated from each other. The locations of "points of concern" must be identified as part of a prescribed burn's smoke management plan.

Table 6: Partial List of "Points of Concern"/Sensitive Areas

	"Points of Concern"/Sensitive Areas
1)	Transportation Corridors (Highways; Streets/Roads With Heavy Traffic)
2)	Residences/Residential Areas
3)	Populated Areas (Cities; Towns)
4)	Outdoor Activities (Parks; Rivers; Athletic Fields; Campsites)
5)	Schools/Day Care Centers*
6)	Hospitals*
7)	Retirement Communities*

*People at Greater Risk to Health Related Smoke Impacts.

Table 7: Key Terms

Ambient Air Quality Standards	Maximum allowable concentrations of specific pollutants in the atmosphere as established by law (Art, 1993).
Carbon Monoxide	CO is an odorless, colorless gas produced by the incomplete combustion of hydrocarbons. It poisons by displacing the oxygen

	attached to hemoglobin in the blood which prevents cells and tissues from receiving oxygen (Art, 1993).
Environmental Hazard	A substance, process, or phenomenon found/occurring in the environment that poses a danger to human health or adversely impacts nature (Art, 1993).
Flaming	One of four stages of combustion in which the efficiency of combustion is relatively high; this stage puts out the least amount of emissions in relation to the amount of fuel consumed (Weir, 2009).
Fire Practitioner	An individual using accepted methods or practices to use the disturbance of fire to meet land management objectives (e.g., ranchers, national park personnel, etc.).
Geographic Information System [GIS]	A computer mapping system that links geographically referenced data with graphic map features. These systems allow for manipulation, analysis, and display of spatial information (Art, 1993).
Glowing	One of four stages of combustion which is characterized by minimal smoke because all volatile material in the fuel has been driven out and oxygen can now easily reach the fuel particle, making combustion more efficient (Weir, 2009).
Lead	Compounds made of lead (Pb) are toxic and will accumulate in the human body. Low-level or chronic lead poisoning may result in muscle cramps, abdominal pain, and eventual nervous system and brain damage (Art, 1993).
Mitigation	Reduction of harm or severity of impact (*Webster's Ninth New Collegiate Dictionary*).
Nitrogen Dioxide	NO_2 is a rust-colored gas that is a major air pollutant. It is a component of photochemical smog and, in the presence of sunlight, reacts with oxygen to form ozone (Art, 1993).
Ozone	O_3 (gas) occurs both in the Earth's upper atmosphere and at ground level. Tropospheric, ground-level, ozone is a harmful pollutant

	because of its effects on people and the environment.
Particulate Matter	A category of air pollutants that refers to small, solid particles or liquid droplets suspended in air (Art, 1993).
Pre-Ignition	One of four stages of combustion in which water vapor is expelled into the atmosphere (Weir, 2009).
Risk Analysis	Identifying hazards and evaluating the nature and severity (especially economic costs) of their associated risks. This information is used to determine options and to make decisions about reducing or eliminating risks and communicating information about risks to the public.
Smoke	Very fine particles of ash and/or partially burned or unburned fuel, suspended in the air as visible clouds. Smoke is often the result of the incomplete combustion of compounds or substances containing carbon (Art, 1993)
Smoldering	One of four stages of combustion in which the effectiveness of combustion is lower, resulting in greater particulate emissions. Studies show that the amount of particulate emissions produced per mass of fuel consumed during the smoldering stage is more than double that of the flaming stage (Weir, 2009).
Smoke Management	Defines the smoke sensitive areas near a burn and the acceptable range of wind direction(s) and atmospheric conditions for smoke management purposes (The Samuel Roberts Noble Foundation, 2015).
Sulfur Dioxide	SO_2 (gas) is a major air pollutant that is corrosive and harmful to plants and animals (Art, 1993).

Materials and Preparation This activity requires that students have access to computers/Chromebooks connected to the internet. There are no "physical" materials to prepare unless paper copies of the student worksheet will be used (discussed below). Students will run an online simulation using VSmoke-Web to predict smoke impacts from a prescribed

burn case study (video demonstration included in the "Procedures" below). There are numerous options for conducting this lesson. If instructors decide to develop the activity as an online lesson (e.g., JenksFERST "Smoke in the Ozark Highlands"), students could even use smartphones to interact with the slideshow, maps, case studies, and VSmoke-Web model.

The student worksheet is a great reference to become familiar with the progression of this activity. Links to the student worksheet as well as a worksheet "key" for instructors can be found in Table 8 (below).

Table 8: "Smoke in the Ozark Highlands" Resources for Teachers

"Smoke in the Cross Timbers" Resources
Student Worksheet (Word document)
Student Worksheet Key (Word document)

Links to the maps found in Table 9 (below) should be shared with students so they have an interactive experience (the links for student reference maps are included as active links on the student worksheet). Students will need to investigate the surroundings for each case study and will only be able to do so using Google Maps.

Table 9: Case Study Map Links

Case Study Map Links
Smoke in the Ozark Highlands - Case Studies
Smoke in the Ozark Highlands - Wilson's Creek National Battlefield

The case studies found in Table 10 may be printed, or the links may be copied and made available for online referencing. **Please note that there are two versions of each case study: one for students; and one for instructors with a correct simulation map to assist with verifying that case study parameters were entered into the VSmoke-Web model correctly. The instructor's versions also lists examples of "points of concern"/sensitive areas for each case study.** If an instructor decides to download, print, and distribute the case studies to students, a few copies of each will be sufficient.

Paper copies of the student worksheet can be made for each student or the link to the student worksheet (Table 8) can be copied and shared with students. The link given provides a download of the worksheet as a Word document that can be completed and submitted to instructors "electronically" (students can also convert the Word file into a Google document). If paper copies of the student worksheet will be used, instructors will need to decide if the resulting map will be: 1) reproduced by students on the worksheet; 2) printed; or 3) verified by the instructor on the VSmoke-Web site. Remember, correct maps are included on the "teacher version" for each case study. If it is preferred that students develop a map on a paper copy of the worksheet, be sure to provide "drawing space" below **Part D: The Simulation #13** on the worksheet before printing.

Table 10: Case Study Download Links

"Student Reference" Case Study Links (pdf)	**"Teacher Reference" Case Study Links (Word document)**
Chilton Creek Research and Demonstration Area (**Student**)	Chilton Creek Research and Demonstration Area (**Teacher**)
JT Nickel Family Nature and Wildlife Preserve (**Student**)	JT Nickel Family Nature and Wildlife Preserve (**Teacher**)
Optimus Glade and Woodland Restoration Area (**Student**)	Optimus Glade and Woodland Restoration Area (**Teacher**)
The Randolph Tract of Missouri's Pioneer Forest (**Student**)	The Randolph Tract of Missouri's Pioneer Forest (**Teacher**)

Procedure Instructors could use the online lesson provided at JenksFERST "Smoke in the Cross Timbers. If this option is chosen, instructors must be sure to provide submission instructions. Otherwise:

1. If paper copies of the student worksheet will be used, distribute them to students. If an "electronic" copy of the student worksheet will be used, be sure that students have used the link provided in "**Table 8**" to prepare their own document file.

2. Present the slideshow. Students should complete "Part A" and "Part B" of their worksheets during the presentation.
3. Leave the final slide (examples of "points of concern"/sensitive areas) as a reference for students.
4. At the conclusion of the slideshow, provide the case study map link to students so they can determine which one to investigate.
5. After students have decided upon the case study to be investigated, make the paper copies of or links for the case study parameter information available to students.
6. Once students transfer the case study parameters to their worksheets, they should conduct the simulation using the online simulation. Provide the VSmoke-Web internet address to students at this time. The link to the following demonstration video is also included on the student worksheet:

   VSmoke-Web Demonstration Using the JenksFERST Case Study from the Slideshow.

7. Once all worksheet prompts have been completed, the worksheet can be turned in. If students used paper copies of the worksheet, be sure to verify their VSmoke-Web maps using the "teacher versions" of the case studies if necessary. **Time permitting, class discussions could be conducted which compare the case studies and the results from each**.

Assessment

➔ Sample quiz/review questions for "Smoke in the Ozark Highlands"

1) Which stage of combustion is relatively efficient and has the least amount of emissions produced per amount of fuel consumed?

a) Pre-ignition

b) Flaming

c) Smoldering

d) Glowing

Answer: b

2) Which of the following is **NOT** caused by exposure to fine particulate matter ($PM_{2.5}$) and Ozone (O_3)?

a) Fatigue

b) Wheezing

c) Sunburn

d) Coughing

Answer: c

3) Which of the following pollutants is **NOT** present in smoke produced from burning vegetative matter?

a) Carbon monoxide

b) Particulate matter

c) Lead

d) Ozone

Answer: c

4) Which of the following is the correct order for the 3 steps of risk analysis?

a) Identify the environmental hazard; determine the acceptable level of risk; and manage the risk

b) Identify the environmental hazard; manage the risk: and determine the acceptable level of risk

c) Determine the acceptable level of risk; identify the environmental hazard; and manage the risk

d) Determine the acceptable level of risk; manage the risk; and identify the environmental hazard

Answer: a

5) Which of the following can be considered a "point of concern"/sensitive area when developing a smoke management plan?

a) Populated areas

b) Retirement communities

c) Transportation corridors

d) All of the above

Answer: d

Evaluation

Student Worksheet

A key for the student worksheet can be found as a separate document entitled "Student Worksheet - Key."

Sample quiz/review questions for the "Smoke in the Ozark Highlands"

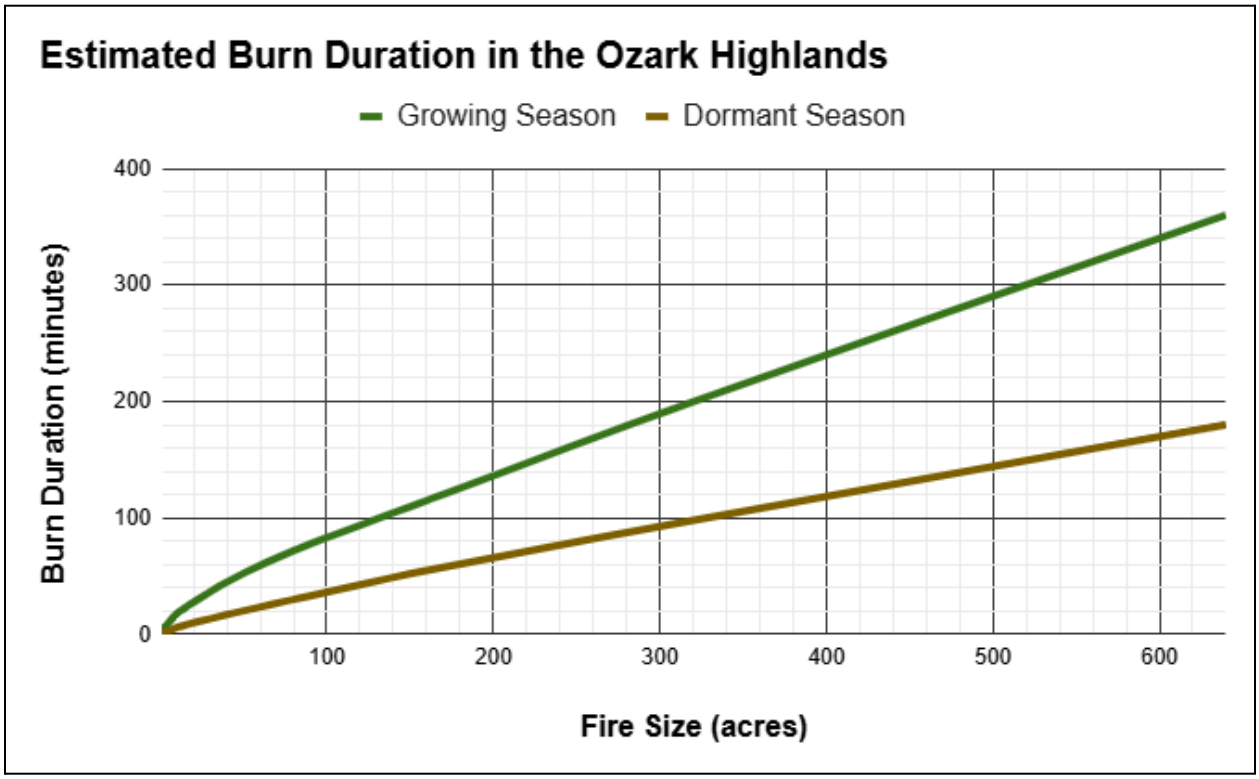
Answers provided with the questions in the **Assessment** section.

Extension

- The results of this activity could be used as the basis of class discussions about each case study's smoke management plan and whether or not the burns should have been conducted under the weather conditions described.
- Students could develop a smoke management plan for a prescribed burn of their choosing. Using Google Maps, students could develop their own case study by "visiting" a site of interest that could be managed with prescribed fire. Google Maps could be used to determine the area of the burn. Students would need to decide if their prescribed burns will be conducted during the growing season or dormant season and estimate "burn duration" using **Graph 1** (below). Students will also have the freedom to determine the other VSmoke-Web "Fire & Weather Info" for their case study. It is suggested that students only manipulate values for the parameters on the case study tables. If students want more information about the simulation and the other

parameters, here are links about the VSmoke-Web model: 1) "Smoke Prediction with VSMOKE;" and 2) "VSmoke-Web Explanation."

Graph 1: Burn Duration Estimates in the Ozark Highlands



References/Resources

Images and diagrams by Bryan Yockers unless cited/listed below or in the lesson materials.

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Additional Resources for Further Reading

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