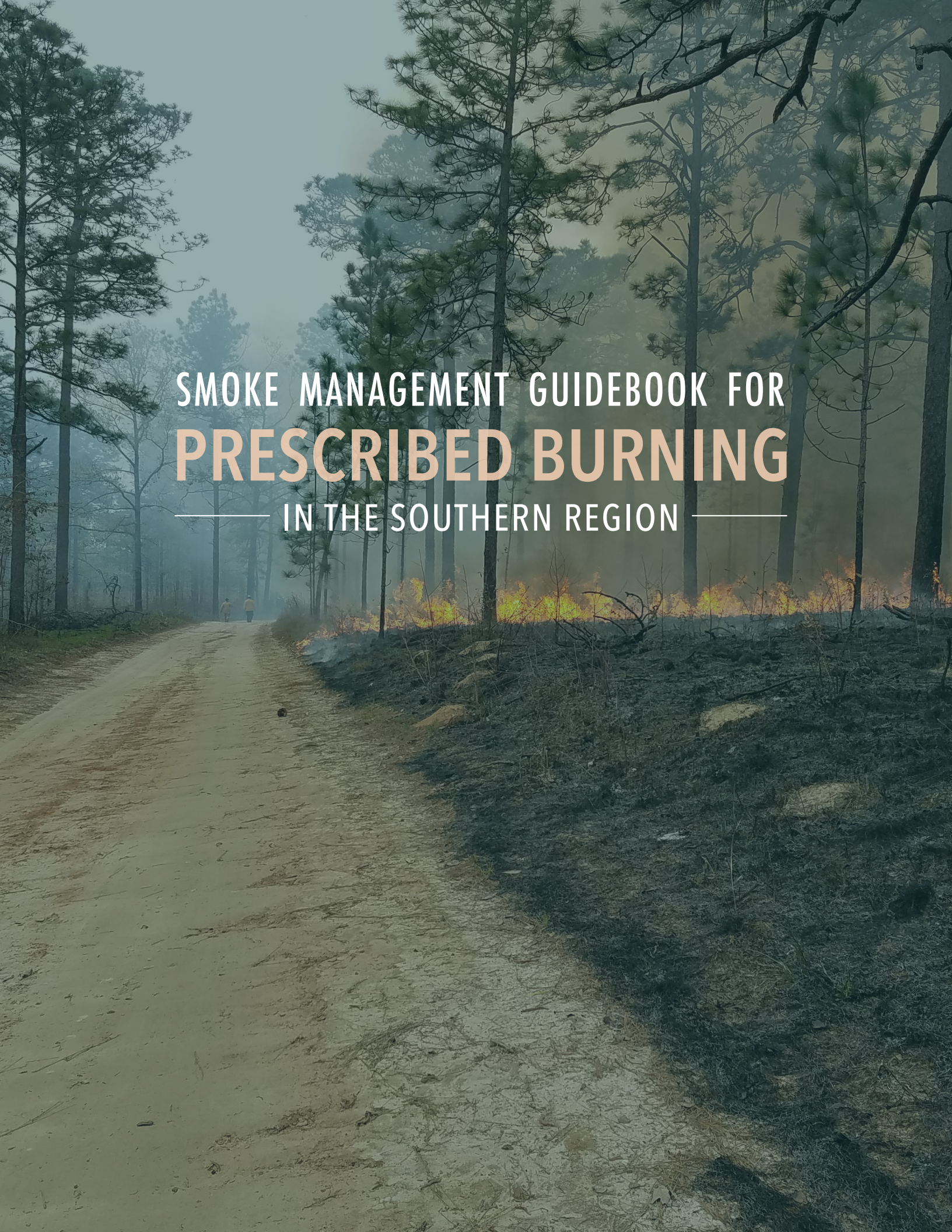

SMOKE MANAGEMENT GUIDEBOOK FOR PRESCRIBED BURNING IN THE SOUTHERN REGION

This landowner smoke management guidebook was created through a collaboration between the Environmental Protection Agency (EPA), North Carolina State University, Southern Fire Exchange, Southern Regional Extension Forestry (SREF), and the University of Georgia Warnell School of Forestry and Natural Resources. The goal of the guidebook is to help southeastern U.S. landowners understand smoke management for prescribed burning and various techniques that can be used to help manage the smoke that is created by prescribed fire.

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Design, graphics, and layout by Laura Costa and Melanie Quinton, of Southern Regional Extension Forestry.

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INDEX

INTRODUCTION

The *Smoke Management Guidebook for Prescribed Burning in the Southern Region* is helpful in planning for and addressing smoke when conducting ***prescribed fires***. The guidebook will be most useful to private landowners and other practitioners who currently use prescribed fire, are new to burning, and are not required to complete national training requirements from the National Wildfire Coordinating Group (NWCG). This guidebook, however, can augment NWCG, state agency, and other training. Experienced burners can benefit from the guidebook as a refresher on basic ***smoke management*** practices, a source of regional resources and online modelling tools, and a simplified explanation of the science and rules behind smoke management. For more in-depth information, consult the NWCG *Smoke Management Guide for Prescribed Fire* (NWCG, 2020).

This guidebook contains information on prescribed fire smoke management techniques and tools, air quality regulations, smoke monitoring, modeling, communication, and the public perception of prescribed fire and smoke. Through straightforward explanations, diagrams, and step-by-step methods, the guidebook serves to simplify the process of safely managing smoke. The content is based on federal, state, tribal, and local air quality laws, basic smoke management practices, and smoke management plans. The guidebook is intended to be used as a companion manual to *A Prescribed Burning Guidebook for the Southern Region* by Boby et al., in review. It can also be used to supplement information from resources such as the NWCG *Smoke Management Guide for Prescribed Fire* (NWCG, 2020), *Conducting Prescribed Fires*: A *Comprehensive Manual* (Weir, 2009), and to the *Introduction to Prescribed Fire in Southern Ecosystems* (Waldrop and Goodrick, 2012), which all provide basic information needed to help you become technically proficient in the proper planning and use of prescribed fire.

It should be noted that this guidebook is intended to supplement information provided by your state, tribal, and federal forestry agency, as they are excellent sources of information and can provide critical guidance on burn conditions specific to a location, as well as required state and local rules and regulations to follow. Many of these agencies provide periodic training in prescribed burning, including smoke management. This guidebook is not intended to meet any NWCG or other federal training requirements.

The guidebook contains three main sections: (1) a smoke management overview, (2) a step-by-step guidebook for implementing smoke management on a prescribed burn, and (3) Appendices A-C containing key contacts, resources, and tools, respectively. All ***bold, italicized*** words in the guidebook are defined in Appendix D.

IMPORTANCE OF SMOKE MANAGEMENT

Why is Smoke Management Important?

Prescribed fire, or controlled burning, is a planned fire used to meet land management objectives. The term "prescribed" is used because specific conditions (i.e., weather, location, safety measures, etc.) must be met during the course of the burn to protect public and fire personnel safety, to follow rules and regulations relating to ***smoke dispersion***, and to meet land management and burn objectives.

There are many benefits of prescribed burning, including:

- reduced ***fuel*** loads
- improved wildlife habitat
- increased diversity of plant and animal species
- management of vegetation (including some invasive species)
- increased availability of plant nutrients

Prescribed burning can also present challenges, with smoke being a major concern. Smoke can negatively affect human and animal health, decrease driving visibility, obscure scenic views, and be a nuisance. When a burn plan is not carefully developed and followed or unexpected weather conditions arise, smoke-related challenges are magnified (and can create negative public perception and tolerance of prescribed fire). Continued utilization and public acceptance of prescribed fire, in part, relies on burn practitioners following best practices to manage smoke.

Prescribed fires are planned and conducted under conditions that are most suitable for reducing smoke production and for transporting smoke away from communities, sensitive populations, and roadways. A wildfire, on the other hand, is an unplanned event that can vary considerably in size and smoke ***emissions***. As a result, impacts from wildfires can be significant. Wildfire smoke may also contain smoke from burning structures, vehicles, and other man-made objects, in addition to smoke from natural fuel sources. Prescribed fire smoke, in comparison, solely consists of emissions from natural fuel sources.

Defining Smoke

Smoke is comprised of tiny particles, water vapor, and trace gases in the air that occur when a substance (fuel) is burned, or ***combusted***. Fire

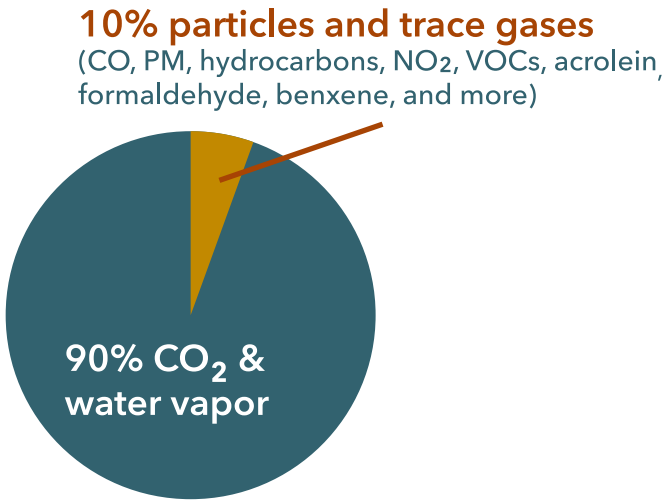


Figure 1: Emissions typically found in wildland fire smoke, by percentage. It should be noted that greater than 70% of the particulate matter (PM) found in smoke is less than or equal to $PM_{2.5}$ (NWCG, 2020).

managers and air quality regulators often refer to the products of combustion as emissions. Common prescribed fire emissions can be found in Figure 1. Of all smoke emissions, carbon monoxide (CO), ***particulate matter*** (PM), and ozone have the greatest impact on human health, visibility, and air quality. However, other emissions also have negative impacts. For example, carbon dioxide (CO_2) is a greenhouse gas and water vapor decreases visibility (Weir and Carlson, 2008). This will be discussed in more detail in the Health and Safety section.

There are four main phases of combustion: ***pre-ignition***, ***flaming***, ***smoldering***, and ***glowing*** (Fig. 2). Theoretically, the stages occur in progressive order (pre-ignition to glowing), but in reality, they occur simultaneously across the landscape throughout the course of a burn. Why is it

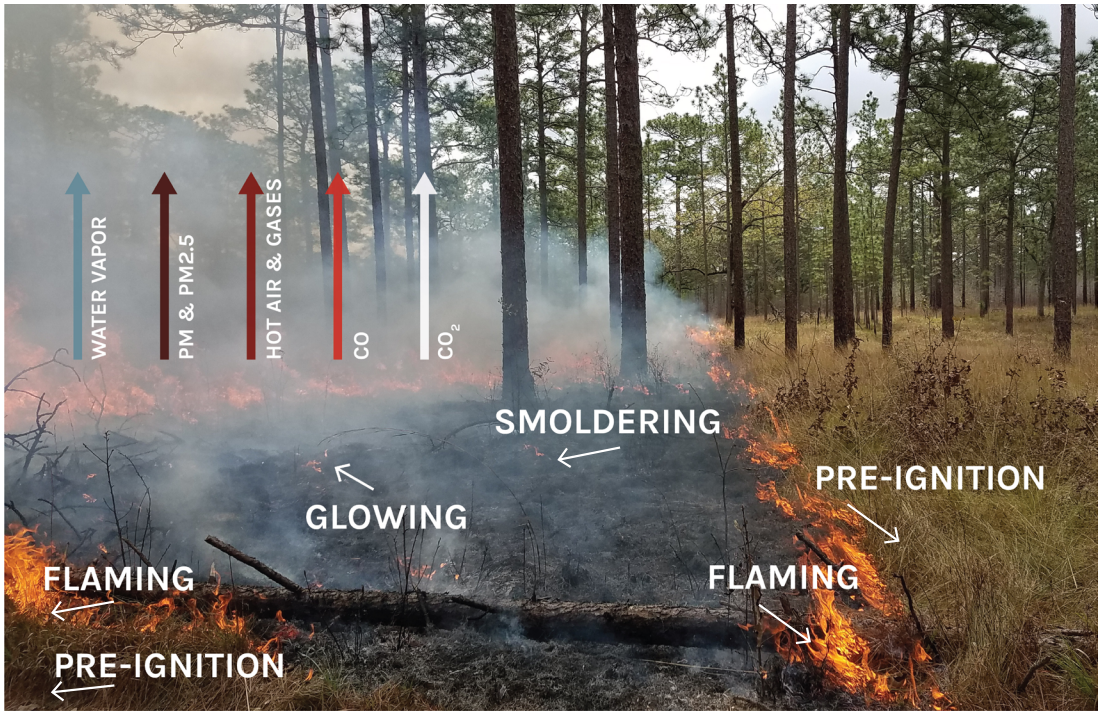


Figure 2: This image of a prescribed fire provides a visual representation of the four phases of combustion (pre-ignition, flaming, smoldering, glowing) and their emissions. Credit: Holly Campbell

important to know the stages of combustion? Each stage produces different emissions, some more harmful to human health and safety than others.

Generally, during the pre-ignition and flaming stages, combustion efficiency is higher and produces comparatively lower amounts of PM. Smoke production is typically highest in the smoldering phase. Certain fuels, such as decayed logs, forest floor duff, and organic soils can lead to increased and longer duration smoke production (Weir and Carlson, 2008). For this reason, it is often suggested that prescribed burners employ methods that maximize combustion efficiency during a burn when possible. For example, most combustion that occurs in ***backing fires*** is in the flaming stage ***(complete combustion)***. Burning under specific weather and fuel moisture conditions can support more complete combustion.

Factors that Affect Smoke

Prescribed burners should manage their fires to reduce smoke impacts on the public. Typical smoke management goals are to (1) minimize the amount of smoke produced, (2) transport smoke away from sensitive populations and other sensitive areas, (3) disperse smoke to reduce its concentration, and (4) mitigate smoke issues if they arise.

Good smoke management requires an understanding of how several factors influence smoke behavior, such as atmospheric and weather conditions, topography, and fuel (Fig. 3). These factors directly impact smoke production, dispersion, and direction of movement.

Figure 3: Prescribed burning factors that affect smoke (Waldrop and Goodrick 2012).

ATMOSPHERIC & WEATHER CONDITIONS

When smoke enters the atmosphere, its concentration in any one place or time is dependent on the weather and atmospheric factors that transport and disperse it. Smoke moves horizontally and vertically. Its vertical movement is influenced by smoke ***plume*** buoyancy (ability to lift into the atmosphere) and atmospheric stability and its horizontal movement is influenced by the wind (NWCG, 2020). Depending on the stage of combustion, atmospheric and weather conditions may have a greater or lesser effect on smoke. Good ***smoke dispersion*** or the scattering and dilution of smoke is essential in a prescribed burn.

Figure 4 illustrates several important atmospheric and weather factors that influence smoke behavior and are used to develop smoke management plans for most southeastern U.S. states. Daily values for these factors are readily available through a ***fire weather forecast*** on the National Weather Service's website, Fire Weather Dashboard (www.weather.gov/dlh/firepoker), or from your state forestry agency (See Appendix A). It should be noted that some of the following atmospheric and weather factors may not be used in all states and the preferred range of values may vary state to state. During planning, verify which factors and ranges are appropriate for your location.

Atmospheric Dispersion Index (ADI)- indicates how rapidly smoke will be dispersed and is based on ***mixing height***, ***transport wind***, and other variables. The morning forecast provides the ADI for the current day, nighttime, and following day, whereas the afternoon forecast provides the nighttime and following day ADI values (Table 1).

Atmospheric Stability- indicates how rapidly air is vertically mixed and, therefore, influences smoke dispersion. Unstable conditions are most common during the afternoon. Stable conditions are more likely to occur in the morning, evening, and through the night, but this depends on several variables. A slightly unstable atmosphere is preferable for good smoke dispersion (Table 2).

Category Day- is a smoke screening method used by some southeastern U.S. states. Category Day uses a rating of 1-5, with days 2 to 5 being the best days for reducing smoke impacts. See Appendix B for more information and detailed steps for using Category Day.

High and Low-Pressure Systems- are created by air pressure in the Earth's atmosphere and the unequal heating of the Earth's surface by the sun. High and low-pressure systems may affect mixing height, wind direction and speed, and atmospheric stability.

Inversions- affect the vertical movement of smoke. Typically, inversions are lower in the atmosphere in the morning, evening, and through the night and higher in the atmosphere in the afternoon, but this varies depending on several factors (Table 3). Inversions lower in the atmosphere trap smoke close to the ground surface. For this reason, upper atmospheric inversions (higher inversion height) are more favorable for smoke dispersion. Inversions can be difficult for smoke to penetrate because they are a stable air mass. Though rarely encountered on prescribed fires, if the smoke produced from a prescribed fire has enough heat and lift, it can break through the inversion and disperse higher in the atmosphere.

Keetch-Byram Drought Index (KBDI)- is an indicator of soil and duff dryness on a scale from 0-800. KBDI can provide an indication of vegetative fuel moisture and potential fire behavior (Table 4).

Low Visibility Occurrence Risk Index (LVORI)- indicates the potential for smoke or fog to negatively affect visibility in the nighttime. It is rated on a scale from 1-10, where 10 is the highest likeliness of smoke (or fog) contributing to an accident and 1 is the lowest (Table 5).

Mixing Height- is the height at which smoke will be diluted and dispersed. Low mixing heights keep smoke close to the ground surface. High mixing heights allow smoke to rise higher in the atmosphere and be vigorously diluted and dispersed by transport winds. Mixing heights are typically lowest in the morning and evening, and highest during the middle of the day. However, this varies due to weather and other factors, such as coastal influences on temperature, season, and high and low-pressure systems.

Precipitation & Soil Moisture- These factors affect soil, duff, and fuel moisture and, thus, the amount of smoke produced. A rain gauge is the most reliable way to determine how much rain a location has received. Soil and duff moisture can be evaluated by touching the duff and soil layers to evaluate their relative moisture content. Alternatively, more sophisticated electronic moisture meters can be used to measure soil and duff moisture content (Klaus, 2016).

Precipitation impacts fuel moisture. Smaller fuels such as pine needles and small branches absorb and lose water content rapidly. Larger and more dense fuels gain and lose moisture much more slowly. During periods of drought, larger fuels lose moisture and can produce more smoke due to burning a higher quantity of fuel, while organic soils can smolder for weeks.

Relative Humidity (RH)– indicates how much water vapor is in the air compared to how much it could hold at the same temperature. Relative humidity influences smoke production by lowering fuel moisture because drier fuels produce less smoke (Waldrop and Goodrick, 2012). Short-term changes in RH will affect the moisture content in smaller fuels, however, larger fuels are affected more by changes in RH over longer periods of time. Low RH dries fuels while high RH can make fuels too moist to efficiently burn, leading to higher smoke production or an inability to burn some fuels at all because they are too moist. This can be an advantage with some fuels that the burner does not wish to burn, such as larger downed woody debris or organic soils (that can smolder for long durations if fuel moisture is low enough for them to burn). In some cases, prescribed fire managers will plan the burn when the RH is low enough to dry out fine fuels (i.e., pine needles, grass), but conditions are not so dry that larger fuels, duff layers, or organic soils ignite. Lastly, RH can influence fog conditions.

Ventilation Rate/ Index- indicates how well smoke will be diluted and dispersed on a given day and is used to calculate Category Day for smoke screening. This index is usually calculated using the mixing height and transport wind speed. See Appendix B for more information on using Category Day.

Wind– Transport winds are an average of the horizontal wind speed and direction from the Earth's surface to the mixing height. Surface winds are measured at a height of 30 feet above the Earth's surface. Winds affect the movement and dispersion of smoke, as well as influence the rate of fuel drying. Steady wind speed and direction leads to more predictable smoke management. Wind is strongly influenced by several variables, including changes in temperature, weather fronts,

storm systems, topography, surface friction, and breezes from water bodies. Despite several influences on wind speed and direction, a fire weather forecast by the National Weather Service provides a good indication of expected wind conditions and your state agency may provide additional information to consider.

DURATION

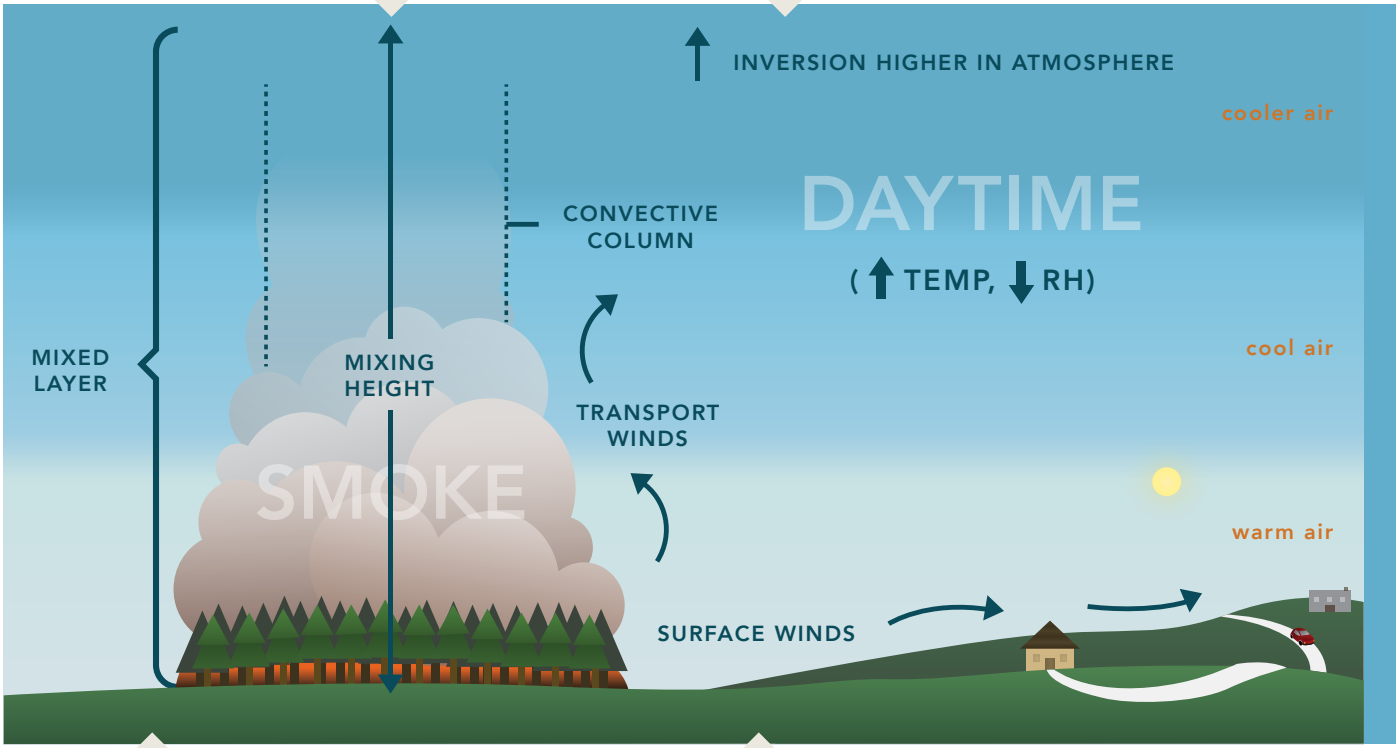
Burns occurring over a shorter time can create less smoke than burns occurring over a longer period, but this does not necessarily relate to the size of the area to be burned. For example, high fuel moisture and RH can lead to a longer burn, even over a small area. Another consideration for fire duration is that the weather can unexpectedly change during a longer burn. It is generally recommended to start and conduct a burn in as short a time as possible.

FIRING TECHNIQUE

Methods used to start and ignite a prescribed fire, referred to as firing techniques, can affect smoke in different ways. Typical firing techniques include backing fires, ***heading fires***, ***point-source fires***, ***ring fires***, and ***pile and windrow fires***. Backing fires consume more fuel in the flaming stage than other firing techniques, meaning they have more complete combustion and produce less smoke over the course of the burn. Backing fires, however, move slowly and may limit how much acreage can be burned based on the burn plan. Heading and point-source fires often burn with a faster rate of spread than backing fires which can result in lower smoke production (NWCG, 2020). Ring fires involve igniting the perimeter of the burn unit and one or more spot fires in the center of the unit. Convection from the interior fire pulls the flames of the perimeter fire towards the center of the burn unit, often creating a fast rate of spread and strong vertical lift of smoke. Pile and windrow burning, if not carefully planned, can result in significant and long-duration smoke production (especially if heavy fuels are mixed with soil, the pile is not stacked well, or woody debris is not sufficiently dry) (Waldrop and Goodrick, 2012).

Mixing Height - is the thickness of the lower atmosphere layer where wind vigorously mixes the air and, thus, is the height where smoke will be diluted and dispersed, It is measured from the ground surface to the base of the inversion layer. A lower mixing height keeps smoke close to the surface, wehereas a higher mixing height lifts smoke up and away from the burn.

Inversions - are stable atmospheric layers than can restrict vertical movement of smoke. Inversions often serve as a cap over mixed layers, or at the top of the mixing height, and are typically closer to the ground surface in the morning and evening and higher in the atmosphere in the afternoon, though this depends on several other factors.



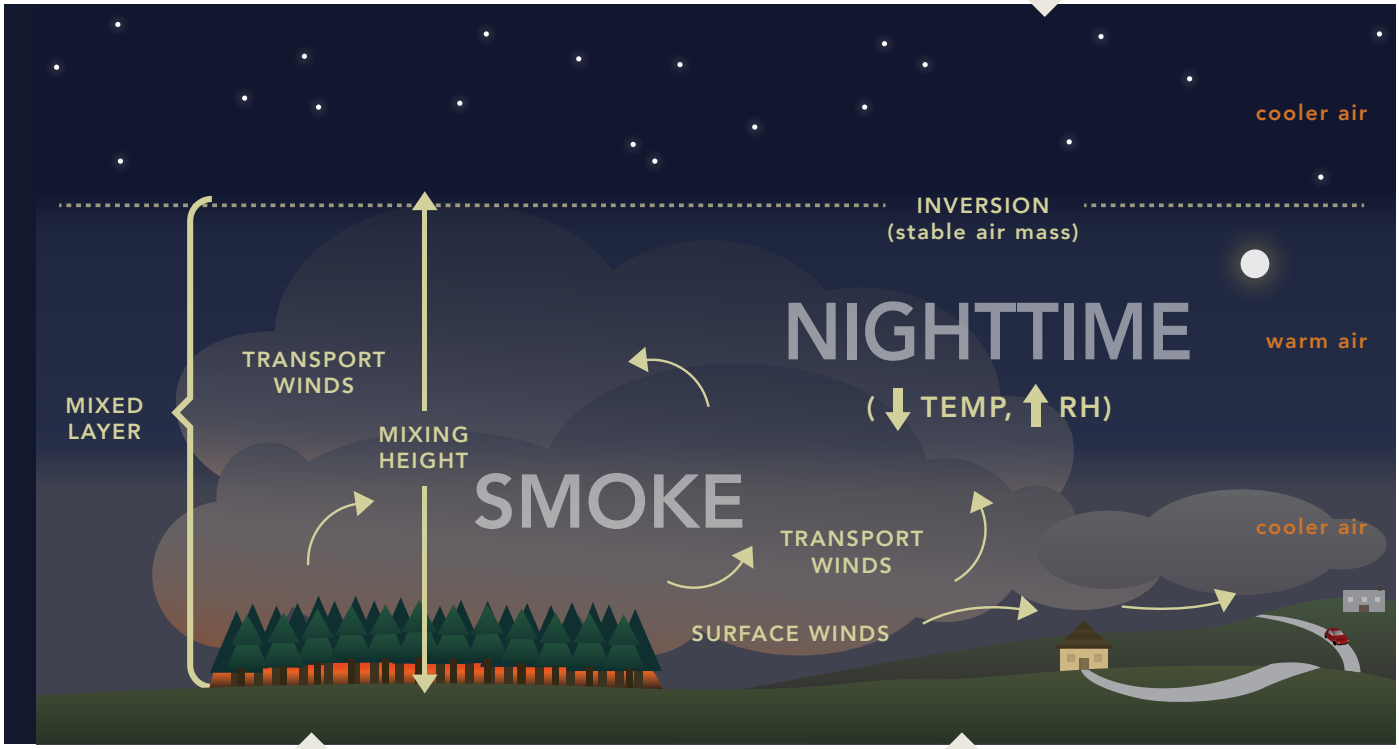
Mixing Layer - is the layer of air in which vigorous mixing of smoke takes place.

Surface Wind - is the wind blowing near the Earth's surface. It is measured by an anemometer (for wind speed) or wind vane (for wind direction) at a standard height of 10 m (32.8 ft) above ground.

Figure 4: Atmospheric and weather conditions and how they may influence smoke behavior during the day (page 12) and night (page 13). Credit: Laura Costa, Southern Regional Extension Forestry

Precipitation - is any product of the condensation of atmospheric water vapor that falls under gravity. The main forms of precipitation include drizzle, rain, sleet, snow, and hail. Precipitation affects soil moisture. Soil moisture protects soil organic matter and plants' roots from burning. Precipitation also influences fuel moisture.

Relative Humidity (RH) - is the ratio of the amount of moisture (water vapor) in the air to the amount the air can hold when saturated at the same air temperature. It is expressed as a percentage. Relative humidity influences fuel moisture which influences the amount of smoke produced.



Transport Wind - is the average speed or direction of all winds between the ground surface and the mixing height, or the mixing layer. Strong winds lead to greater smoke dispersion and transport, whereas light to variable winds lead to poor smoke dispersion and transport.

Temperature - is the degree or intensity of heat present in the atmosphere. Temperature affects fuel moisture levels which, in turn, influences burn efficiency and the amount of smoke produced.

Table 1: Atmospheric Dispersion Index (ADI) values for daytime and nighttime burns (Lavdas, 1986; Lavdas & Achtemeier, 1995; Wade & Mobley, 2007; NWCG, 2020).

Daytime ADI* (sunrise to sunset)	Smoke Dispersion	Burn Conditions Description
>70	Excellent	**Hazardous burning conditions.** All prescribed or wildfires present control problems. Reassess decision to burn unless mitigation measures have been used.
60 – 69	Very Good	Single fire smoke issues seem unlikely but be aware of multiple fires in the surrounding area. Fire behavior often results in control problems. Reassess decision to burn.
50 – 59	Good	Weather conditions are at upper end of prescribed fire windows. This can often play one burn variable against another to achieve acceptable results.
41 - 49	Generally Good	Generally good dispersion, especially for prescribed fires less than 50 acres.
21 – 40	Fair	Any residual smoke likely to result in problems if ***surface wind*** speed is < 3 mph. Reassess decision to burn especially if burn is within wildland-urban interface (WUI).
7 - 20	Generally Poor – Poor	**DO NOT BURN-** Prescribed fires are permissible if other criteria are used to support decisions (i.e. dispersion models, air monitors, or other metrics (light fuels, small acreage, burn within daytime dispersion window, etc.) are utilized to evaluate smoke impacts on sensitive areas.
1 - 6	Very Poor	**DO NOT BURN-** Prescribed fire smoke at these levels does not disperse adequately
Nighttime ADI* (sunset to sunrise)	**Smoke Dispersion**	**Burn Conditions Description**
13 - 20	Good	Nighttime Smoke Dispersion "GOOD" with surface wind speeds greater than 12 mph but beware of the influence of combustion rate. Roadway visibility can be reduced but surface circulation keeps visibility acceptable. Deployment of smoke signs and monitors need to be considered.
8 - 12	Fair – Poor	Nighttime Smoke Dispersion "FAIR" with surface wind speeds 9 to 12 mph. Surface wind speeds of 9 mph usually result in acceptable mid-flame wind speeds. Roadway visibility can be reduced but air movement allows motorists to adjust to driving conditions. Smoke signs and monitors should be deployed.
5-7	Poor	**DO NOT BURN**.** Nighttime Smoke Dispersion "POOR" with surface wind speed 5 to 8 mph.
1-4	Very Poor	**DO NOT BURN**.** Nighttime Smoke Dispersion "VERY POOR" surface wind speed 2 to 4 mph or Nighttime Smoke Dispersion "STAGNANT" surface wind speed < 2 mph.

* This table is best used for prescribed burning fuels less than 1 inch in diameter. Larger fuels will result in a longer combustion time period and so the burner should consider other metrics for burn planning.

**** DO NOT BURN** unless dynamic dispersion or smoke tracking models (PC-HYSPLIT, PBPiedmont, etc.), air monitors or other metrics are used and coupled with evaluation of smoke impacts on smoke sensitive areas. If roadway visibility is reduced, mitigating actions need to be ready to be implemented.

Table 2: Atmospheric stability rating (unstable, neutral, stable), its effect on smoke dispersion, and the positive and negative aspects of atmospheric stability ratings. An unstable atmosphere is preferable for smoke dispersion compared to neutral or stable atmospheres (Waldrop and Goodrick, 2012; NWCG, 2020).

Atmospheric Stability	Effect on Smoke Dispersion	Benefits	Negatives
Unstable	Very Good	Can significantly increase the height that smoke rises in the atmosphere and increases the strength of smoke dispersion	If highly unstable, can make smoke behavior difficult to predict
Neutral	Average	Smoke dispersion is adequate with a sufficiently high wind speed	Without a higher wind speed, smoke dispersion may be inadequate
Stable	Poor	n/a	Restricts smoke dispersion, with smoke remaining lower in atmosphere or smoke initially rising then moving back to ground-level downwind of the fire

Table 3: Weather factors and landscape features that influence inversion height in the atmosphere. Inversions that are higher in the atmosphere are preferable for smoke dispersion since inversions lower in the atmosphere can trap smoke close to the ground (NWCG, 2020).

Inversion Height in Atmosphere	Weather Factors and/ or Landscape Features Influencing Inversion Height
High	Daytime heating
High	Warming fronts
Low	Over valleys and basins during clear night
Low	Near lakes and oceans during the afternoon
Low	In mountain gaps during the winter months
Low	With high pressure fronts (can occur at any time during the day or night)

Table 4: Keetch-Byram Drought Index (KBDI) values, conditions, and fire intensity associated with each range of values (Keetch and Byram, 1968).

KBDI Value	Condition
0 - 200	Soil moisture and large class fuel moistures are high and do not contribute much to fire intensity.
200 - 400	Lower litter and duff layers are drying and beginning to contribute to fire intensity.
400 - 600	Lower litter and duff layers actively contribute to fire intensity and will burn actively.
600 - 800	Often associated with more severe drought with increased wildfire occurrence. Intense, deep burning fires with significant downwind spotting can be expected.

Table 5: Low Visibility Occurrence Risk Index (LVORI) values and their associated accident potential (Lavdas, 1996).

LVORI Category	Accident Potential
1	Lowest proportion of accidents with smoke and/or fog reported (130 of 127,604 accidents, or just over 0.0010 accidents).
2	Physical or statistical reasons for not including in category 1, but proportion of accidents not significantly higher.
3	Higher proportion of accidents than category 1, by about 30% to 50%, but of marginal significance (1%-5%).
4	Significantly higher than category 1, by a factor of 2.
5	Significantly higher than category 1, by a factor of 3 to 10.
6	Significantly higher than category 1, by a factor of 10 to 20.
7	Significantly higher than category 1, by a factor of 20 to 40.
8	Significantly higher than category 1, by a factor of 40 to 75.
9	Significantly higher than category 1, by a factor of 75 to 125.
10	Significantly higher than category 1, by a factor of 150.

FUEL LOAD AND TYPE

Fuel load and type has a strong influence on the amount of smoke produced during a prescribed fire. The following fuel factors influence smoke production:

Moisture content and size - Fuels can respond quickly to changes in temperature, RH, rainfall, wind speed, and soil moisture. The drier the fuel the quicker it ignites, leading to increased fire behavior, more complete combustion, and lower smoke production. Wet fuels will either not burn at all or tend to smolder and produce higher quantities of smoke. Fuels are classified by size (Table 6). As mentioned earlier, fine fuels such as pine needles (1-hour fuels) and small branches (10-hour fuels) absorb and lose water content rapidly, whereas larger and more dense fuels such as larger fallen limbs and stems (100 to 10,000-hour fuels) gain and lose moisture much more slowly. Elevation can influence fuel moisture. With every 1000-foot increase in elevation there is a four to five and a half degree decrease in temperature and increase in RH, leading to increased fuel moisture potential at higher elevations versus lower elevations.

There are several techniques available to test fuel moisture, including evaluating by touch (using your hands to feel and bend fuels), using fuel moisture meters and scales, utilizing ***fuel moisture sticks***, and using RH from a weather forecast (See Appendix C for forecasted fuel moisture for your area, keeping in mind that fuel moisture is very site specific).

Amount- Fuel loading varies depending on the type of fuel, the site's management activities, and fuel moisture. The amount of fuel on the site to be burned will directly influence the amount of smoke produced. If a site contains a large amount of fuel yet most of the fuel is too wet to burn, then less smoke will be produced. On the other hand, if 100 – 10,000-hour fuels are dry enough to burn and are abundant on the site, more smoke will be produced. Simple techniques such as the Fuel Calculator exist to estimate the amount of fuel on a proposed burn site. (See Fuel Calculator, Appendix C)

Type- Smoke production will vary depending on fuel type and composition. For example, fuels that contain aromatic compounds, such as pine needles, produce different types of emissions.

Soils- Soils with large amounts of organic matter (soils that contain less than 10% mineral soil) that are dry enough to burn can smolder for weeks. When organic soils burn, they produce

Table 6: Fuel size classes and their associated diameter ranges, response to changes in weather, and fuel examples.

Fuel Class Size	Fuel Diameter	Response to Changes in Atmospheric Moisture/ RH/ Precipitation	Examples
1-hour	< ¼ inch	Quickly	Grass, pine needles
10-hr	¼ -1 in	Quickly-moderately	Small branches
100-hr	1 - 3 in	Moderately	Medium branches
1,000-hr	3 - 8 in	Moderately-slowly	Large branches/ small trees
10,000-hr	8+ in	Slowly	Stems/ trunks (on ground)

high quantities of smoke that can remain close to the ground surface. Organic soils usually occur in swamps, wetlands, pocosins, or mineral soils with thick duff or organic surface layers. Burners are advised to consult with fire professionals if conducting a burn in an area containing organic soils.

LOCATION/ GEOGRAPHY

Across the southeastern states, a wide variety of climates, vegetation, and soils occur, as well as differences in laws, regulations, and public acceptance of smoke. Smoke management will differ on several levels depending on your location.

MOP-UP

Mop-up is the process of extinguishing remaining flames or smoldering fuels after the prescribed fire is complete (Fig. 5). Residual smoke problems usually arise from smoldering logs, stumps, brush piles, organic soils or peat, and snags (standing dead trees). Mop-up can be an important step for mitigating smoke related problems.

PROXIMITY TO URBAN AND SUBURBAN AREAS

Be aware of rules governing prescribed burns near urban and suburban areas. Some states may have burn bans in counties surrounding major metropolitan areas. Contact your state forestry agency, air quality regulatory agency, or local fire department for rules and laws governing prescribed burning near urban and suburban areas.

SIZE

The amount of acreage, or area burned, greatly influences the amount of smoke produced. Even if a large burn appears to produce less smoke and a certain firing technique is used to increase burn efficiency, it still produces more smoke than a similar burn over a smaller area.

Figure 5: Mopping-up after a prescribed burn is important to minimize residual smoke from smoldering fuels, such as from this smoldering 10,000-hour fuel. Credit: Holly Campbell.

TIME OF DAY

Temperature and RH can dramatically change from sunrise to sunset, as do the height of inversions. Across the southeast, temperature typically peaks during the afternoon with RH decreasing during that same period. Solar radiation over the course of the day causes dew to evaporate, morning inversions to lift higher into the atmosphere, and fuels (especially fine fuels) to dry out (NWCG, 2020). It is generally recommended to complete a burn (from ignition to extinguishing all flames and smoke) after the morning inversion lifts and before the evening inversion forms, however the optimal time to burn is dependent on a number of variables.

TIME OF YEAR

In the Southeast, dormant (winter to early spring) and growing season (late spring to summer) burns are common. Dormant season burns tend to burn more uniformly in comparison to growing season burns, which can result in patchier burns.

TOPOGRAPHY

Topography influences where smoke moves. For example, smoke tends to move from higher points on the landscape, such as ridges, and collect in lower points on the landscape, such as valleys, drainages and along roadways (NWCG, 2020).

Health and Safety

Smoke impacts human health and reduces visibility in transportation corridors (roads, airports, waterways, etc.). All prescribed burners should keep in mind that smoke originating from their burn is entirely their responsibility, even after it leaves the property.

HEALTH CONCERNS

As mentioned earlier, smoke emissions of greatest concern to human (and animal) health are particulate matter (PM), CO, ozone, and other smoke emissions (Table 7). The concentration of these emissions, combined with exposure time, can influence the severity of human health effects. Some individuals will be more sensitive than others and therefore react more strongly to the type, concentration, and exposure time of smoke emissions. The following information describes how certain emissions influence human health (EPA, 2019).

Particulate matter (PM)- Smoke contains tiny particles of solids and liquids known as PM. The PM sizes of greatest concern in wildland fire smoke are those less than or equal to 10 and

Table 7: Common smoke emissions, their influence on human and environmental health, and their approximate proportion of smoke (NWCG, 2016; Cascio, 2018; NWCG, 2020).

Smoke Emission	Negative Effects	Relative Proportion of Smoke
Carbon dioxide (CO_2)	Global climate change	Major
Water vapor	Visibility impairment	Major
Carbon monoxide (CO)	Human health	Moderate
Particulate matter (PM)	Human health and visibility	Moderate
Hydrocarbons	Human health and visibility	Minor
Nitrogen oxides	Human health and visibility	Minor
Organics (volatile organic compounds, benzene)	Human health	Minor
Ozone (secondary emission)	Human health	Minor
Acrolein, formaldehyde, acetaldehyde	Human health	Very Minor

2.5 microns (written as PM_{10} and $PM_{2.5}$) (Fig. 6). PM_{10} and $PM_{2.5}$ travel great distances, sometimes remaining aloft in the atmosphere over 30 days and travelling over 100 miles (Hinnant, 2012). Approximately 90% of particulates from burning woody and vegetative debris in a wildland fire are less than or equal to PM_{10}, with over 70% of this amount less than or equal to $PM_{2.5}$ (NWCG, 2020), which are in greatest quantity during smoldering.

High concentrations of PM_{10} and $PM_{2.5}$ are an indication of poor air quality and are closely monitored by air quality regulators to protect human health and well-being (NWCG, 2020). The human respiratory system has a difficult time filtering and expelling $PM_{2.5}$. As a result, the particles can lodge deeply in the lungs where the body's defense mechanisms are ineffective at removing them (NWCG, 2020). $PM_{2.5}$ can cause a range of minor to severe health effects (EPA, 2019).

Potential PM Health Effects: eye and respiratory tract irritation, reduced lung function, bronchitis, exacerbation of asthma, heart failure, and premature death.

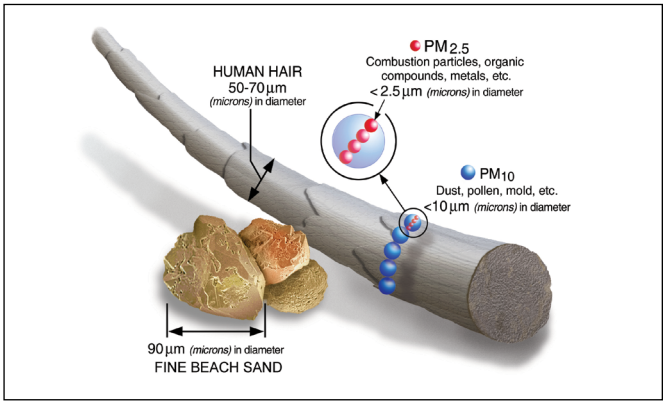


Figure 6: Particulate matter (PM) size compared to the diameter of human hair and fine beach sand. Credit: Environmental Protection Agency

Carbon monoxide (CO)- Carbon monoxide is primarily released in the glowing combustion phase. Exposure to this colorless, odorless gas increases when in close proximity to burning fuels. Carbon monoxide limits the delivery of oxygen to tissues and organs in the body and is especially damaging at low concentrations to people suffering from cardiovascular diseases (EPA, 2019).

Potential CO Health Effects: headache, weakness, dizziness, confusion, nausea, disorientation, visual impairment, coma, and death.

Ground-level Ozone- When the combination of smoke emissions, nitrogen oxides (NO_x) and volatile organic compounds (VOCs) are exposed to sunlight, they can form ozone. Ozone is typically thought of as a protective layer in the upper atmosphere that shields the planet from harmful ultraviolet light, but ozone can also form near the surface of the earth and negatively impact humans, animals, and plants. Though ground-level ozone is a rare occurrence in small prescribed fires (in comparison to larger wildfires), some of its potential health effects are included here for your knowledge and awareness (EPA, 2019).

Ground-level Ozone Health Effects: coughing, wheezing, shortness of breath, pain with deep breathing, inflammation of the airways, reduced lung function, premature mortality, and potential for changes in heart rate variability and systemic inflammation.

Prior to burning, prescribed burners should check the AQI forecast for their area (https://airnow.gov) to ensure that there are no "Air Quality Alerts" for high levels of ozone being caused by other emissions sources in the area, which would typically only occur near large metropolitan areas such as Atlanta and during the hot summer months.

Figure 7: Prescribed burner exposed to smoke on a fireline. Credit: Holly Campbell

Other smoke emissions of concern- Smoke is also composed of several emissions in minute concentrations, such as acrolein, formaldehyde, acetaldehyde, and benzene. These minor emissions can be carcinogenic (Whalen et al., 2003) and have harmful effects on human health (especially infants and children) depending on the concentration and length of exposure (EPA, 2019). These emissions can affect the eyes, respiratory tract, hematologic system, and immune system (OEHHA, 2019).

Those most affected by smoke- Smoke has the greatest impact on individuals who are most vulnerable to it, those who reside in locations downwind of the burn, and prescribed burners or firefighters (Fig. 7). Vulnerable, or sensitive populations include infants, children, older adults, pregnant women (and their unborn child), people of low socio-economic status, outdoor workers, those recreating out-of-doors, and health-impaired individuals; especially individuals who are asthmatic, have heart, liver or lung disease or have an infectious respiratory disease like pneumonia (EPA, 2019). For this reason, it is important to limit or plan to prevent smoke reaching ***Smoke Sensitive Areas*** (SSAs) such as schools, daycares, nursing homes, and hospitals. Health effects from smoke are also influenced by the length of exposure someone has, from short-term exposure (few days to a few weeks) to long-term or cumulative exposure over months to years, such as may occur with wildland firefighters (EPA, 2019). It should also be noted that not all individuals exposed to smoke will experience adverse health effects.

Prescribed burn plans require an important planning stage called ***smoke screening***, which involves mapping the potential direction of smoke based on several weather variables. If SSAs are determined to be impacted by the smoke from a proposed fire through smoke screening, then a different wind direction must be chosen, or the burn plan must be altered in other ways that will not impact sensitive populations. For more information, please read the Mitigation section below. Contact your state forestry agency or local air quality regulatory agency for questions regarding safe smoke screening.

Burners should take measures to avoid smoke intrusion in Class 1 areas and near transportation corridors (see more information in the Air Quality section below) and must take measures to avoid smoke intrusion in non-attainment areas. If other burns are scheduled to occur at the same time, the burner must also consider the collective impact multiple burns will have on sensitive populations.

Individuals conducting the prescribed burn typically receive the greatest exposure to harmful smoke emissions. There are specific tasks during the burn that lead to high exposure, including holding a prescribed fire line and mop-up. In general, limiting smoke exposure and seeking

RECOMMENDATION

- Wear respirator (or masks rated for PM) and other Personal Protective Equipment (PPE)
- Limit smoke exposure time
- Rotate crew members out of high smoke areas
- Reduce mop-up time
- Hold meetings in smoke-free areas

Figure 8: Safety recommendations for prescribed burners to reduce health impacts they may encounter from smoke exposure. (Hinnant, 2012; NWCG, 2020).

Figure 9: Smoke from a prescribed burn crossing a road. Credit: Scott Goodrick, USDA Forest Service

fresh air whenever possible lessens the negative effects of smoke on health. Burners can follow several safety recommendations to protect themselves (Fig. 8).

Though it is imperative to protect SSAs, all populations should be considered in smoke management plans.

TRANSPORTATION SAFETY

Smoke movement and collection in and around transportation corridors (roadways, airports, railways) is a major public safety issue (Fig. 9). The burner must ensure that smoke does not limit visibility on roadways and airports (NWCG, 2020). Valleys, drainages, roadways, and other low-lying areas on the landscape are where smoke typically settles at night, reducing visibility and safety in these locations. Smoke can move rapidly into transportation corridors, providing minimal time to warn motorists or transportation authorities. As a result, there are multiple tragic examples of motorists killed in accidents associated with smoke-enhanced fog on roadways (NWCG, 2020).

Particulate matter and other smoke emissions scatter light, leading to reduced visibility. When smoke and fog combine, however, a phenomenon called ***superfog*** can develop (Fig. 10). Superfog is a dangerous combination of smoke and fog that creates hazardous transportation conditions in the southeast (NWCG, 2020). Superfog can create "white-out" conditions during the day or night, limiting visibility down to approximately six feet (Achtemeier, 2003). Some states, like North Carolina, have a superfog warning on the National Weather Service Fire Weather Forecast for the state. Check with your state forestry agency to determine if your state weather forecast has a superfog warning.

Figure 10: This image displays visibility conditions ninety minutes after a 2008 North Carolina motor vehicle accident due to superfog. Credit: NIOSH, 2008

Air Quality Regulation

Prescribed fire smoke can affect air quality, which impacts human and animal health. Understanding and following air quality rules and regulations leads to responsible prescribed burning.

United States air quality regulation was first established in the mid-twentieth century by the federal government to protect human and environmental health. States work to protect air quality by monitoring and regulating the amount and type of air pollutants known to cause health problems. All levels of government are involved in air quality regulation, from the federal to the state and local levels, including tribal governments.

The federal Clean Air Act (CAA), passed in 1963, is the foundation for air quality regulation. The CAA instructs the United States Environmental Protection Agency (EPA) to develop policies, rules, and standards that the states, tribes, and local governments implement and enforce. While there are no federal regulations that specifically limit or prohibit the use of prescribed fire, there are aspects of some regulations that can affect how and when prescribed fire is used in specific areas. All prescribed fire practitioners should understand how the CAA impacts development and implementation of their burn plans. The following are policies, rules, and standards every burner should understand. For updated information, contact your state or local air quality regulator, or state forestry agency (See Appendix A).

The EPA establishes National Ambient Air Quality Standards (NAAQS) that seek to limit the concentration of primary air pollutants such as ozone, $PM_{2.5}$, CO, sulfur dioxide and more; all of which can be found in smoke from prescribed fires. States are required to develop State Implementation Plans, which detail how they will maintain air quality by following NAAQS. The EPA approves and monitors progress of these plans. NAAQS are updated periodically and may develop more stringent regulations on certain prescribed fire pollutants like PM and ozone. It is important to note that prescribed fire rarely leads to a NAAQS violation.

State, local, and tribal agencies operate a network of air quality monitors across the country to determine if they are meeting NAAQS. Areas in compliance are labelled Attainment Areas. Those not in compliance are called Nonattainment Areas and those that have been re-designated from nonattainment to attainment are termed Maintenance Areas. It is important that a proposed prescribed fire's smoke does not impact Nonattainment or Maintenance areas. Visit the EPA Nonattainment Areas for Criteria Pollutants webpage (www.epa.gov/green-book) and contact your state forestry or air quality agency to learn more.

The ***Air Quality Index*** (AQI) is a color-coded index to help the public understand how daily

levels of air pollution in their local area may affect their health. The EPA calculates the AQI for ground-level ozone, $PM_{2.5}$, CO, sulfur dioxide, and nitrogen dioxide. AQI values below 100 are generally considered satisfactory. When AQI values are above 100, air quality is unhealthy—at first for certain sensitive groups of people, then for everyone as AQI values get higher. You can find the AQI for your area on EPA's AIRNOW website (https://airnow.gov/). Many state and local agencies prepare and publish an AQI forecast on the AIRNOW website for the following day (by the afternoon of the previous day). In some areas AQI forecasts can impact burn permit allocations. Contact your forestry agency for local regulations. In general, you should avoid conducting a prescribed burn on days for which the local AQI forecast is above 100.

Smoke Management Programs (SMPs) have been developed in several states where prescribed fire can have a significant impact on air quality. The SMPs were developed through a collaboration between land managers and air quality regulators in certain states. Their purpose is to reduce smoke in populated areas and transportation corridors, prevent significant air quality deterioration and NAAQS violations, reduce impacts on Class 1 areas (described below), and reduce or avoid ***nuisance smoke*** (Whalen et al., 2003). As well, SMPs establish procedures for managing prescribed fire smoke, provide approval for burn plans and administer burn permits, make burners aware of local regulations and other burners in their area, and provide a plan for long term minimization of negative smoke impacts (Whalen et al., 2003). Some southeastern states require SMPs, whereas other states are voluntary. Contact your state forestry agency or air quality agent for a copy of your state's SMP.

The U.S. Congress has designated Class 1 Areas, which are certain wilderness and national parks that have special significance and public value. These areas receive the highest level of air quality regulation and have additional air quality rules to limit human-caused air pollutants. Explore Class I Areas in the Southeast at www.epa.gov/visibility/regional-haze-program. The Regional Haze Rule seeks to limit impairment of visibility to Class 1 areas and general reduction of human-caused pollutants nationwide. When developing a burn plan, learn the location of all Class 1 areas and avoid dispersing smoke towards them. Contact your state or local air regulatory agency to locate Class 1 Areas, and check with your state's SMP for information on limiting smoke impacts to these areas.

Isolated events can sometimes lead to a temporary reduction in air quality, leading to a violation of NAAQS. The Exceptional Event Rule (EER) was created by the EPA to govern how these isolated events can be reviewed and potentially excluded from what otherwise could lead to a Nonattainment Area designation and reduced state and local support for prescribed fire use. Though prescribed fire rarely leads to a NAAQS violation, the 2016 EER contains provisions that allow prescribed fires to qualify as exceptional events if burners document use of basic smoke management practices and comply with any state required SMPs.

Nuisance Smoke

When smoke interferes with activities, privileges, and rights of the public, it is considered nuisance smoke (NWCG, 2016). Nuisance smoke can impact one or more individuals or an entire city and can have long or short-term effects (Whalen et al., 2003). Smoke becomes a nuisance when it affects views of natural areas, disrupts recreational

experiences, or affects other day-to-day activities. Burners can successfully manage for nuisance smoke through recommendations outlined in Figure 11. Though no federal regulations on nuisance smoke exist, it is regulated by state and local laws based on complaints and highway accidents (Whalen et al., 2003). Some states, such as Georgia, protect prescribed burners from nuisance smoke complaints if a burn plan is followed and gross negligence does not occur. Though state dependent, it is important for the burner to understand that a prescribed burn can be terminated with just a few nuisance smoke complaints. Following basic smoke management practices and using smoke screening can mitigate nuisance smoke from prescribed fires.

Mitigation

Smoke mitigation is reducing the severity or impact of smoke from the area you are burning, or the burn unit. Though best considered during the planning stages and incorporated into a burn plan, smoke mitigation techniques (Fig. 12) may also be employed during or after the burn. Mitigation techniques are important in both daytime and nighttime burns.

- **Have sufficient burn crew members on hand to monitor smoke beyond the immediate burn unit**
- **Monitor smoke on roads**
- **Document smoke behavior through images and descriptions**
- **Patrol smoke sensitive areas**

Figure 11: Smoke management recommendations to reduce nuisance smoke (Whalen et al., 2003).

BEFORE THE BURN

- Use a smoke screening tool to select a better smoke direction or dispersion (see Appendix C)
- Prepare multiple burn units, so you can match the best conditions to the best unit
- Understand how temperature changes affect smoke behavior (very important in nighttime burns)
- Burn over a longer period to reduce peak hourly emissions
- Burn at a higher fuel moisture level (less fuel is consumed, so a lower quantity of smoke is produced)
- Burn in smaller units
- Use a different firing technique
- Use other fuel reduction techniques (i.e., herbicides, mowing, grazing)
- Place signage on the roadway to alert drivers, if needed
- Alert neighbors or communities, especially SSAs
- Do not burn (if conditions are not ideal)

DURING OR AFTER THE BURN

- Contact emergency management if smoke encroaches on roadways or causes other hazardous conditions (i.e., additional signage, directing traffic)
- Mop-up to reduce smoldering
- Shut down burn (if necessary)

Figure 12: Smoke mitigation techniques for daytime and nighttime burns (Goodrick, 2014; J. Wimberley, personal communication, June 20, 2020).

Liability

Liability concerns related to smoke on roads and escapes are one of the greatest barriers to private landowners using prescribed fire. Smoke can play a major role in liability related to prescribed fire. For this reason, all prescribed burners should understand local and state laws regarding prescribed fire liability, since it varies from state to state.

Liability is defined as the state of being responsible for something, specifically by law. If the prescribed burner is burning within the laws and regulations of their state, then the burner's liability is generally reduced. There are three types of liability related to prescribed burning: strict liability, simple negligence, and gross negligence. In brief, strict liability places the burden of any damages caused by a burn on the burner, regardless of actions to minimize potential damages. Simple negligence requires that a person simply prove that the damages caused by a prescribed fire were due to a burner being negligent. Gross negligence requires a person to prove that "the damage resulted from the burner having a conscious and voluntary disregard for the need to use even reasonable care" (Weir et al., 2020). Any state where the proof of gross negligence is applied requires burners to follow strict burn guidelines and may require certification or training to burn under this type of liability.

The best way to reduce prescribed fire liability is to practice safe burning that follows the laws and regulations in your state, while aiming to eliminate escaped fires and minimize smoke problems. Contact your state forestry agency for more information and read *Prescribed Fire: Understanding Laws, Liability, and Risk* (Weir et al., 2020). (See Appendix C)

SMOKE MANAGEMENT: A STEP-BY-STEP GUIDE

Getting Started: Understanding & Using Basic Smoke Management Practices

The very first step in planning your prescribed burn is to learn Basic Smoke Management Practices (BSMPs). Reducing the air quality and safety impacts of prescribed fire can be achieved by following BSMPs. These practices help burners achieve three crucial smoke management goals: (1) reducing the amount of smoke produced, (2) transporting smoke away from sensitive populations and other target areas, and (3) dispersing smoke to reduce its concentration (Weir, 2009; Hinnant, 2012; NWCG, 2020). Though use of BSMPs are required by most federal, state, and local agencies using prescribed fire, use by private landowners is not required by all states but highly recommended for safety and liability reasons. In addition to following these BSMPs, some states require that landowners use state-specific Smoke Management Plans (SMPs). Your state forestry agency can provide more information on BSMPs and SMPs.

The 12 BSMPs listed were developed by the Southeast Regional Partnership for Planning and Sustainability (SERPPAS) Prescribed Fire Work Group and the Coalition of Prescribed Fire Councils. The second section of this book will focus on specific actions recommended to implement the 12 BSMPs when planning, conducting, and evaluating a prescribed burn for smoke management.

12 BASIC SMOKE MANAGEMENT PRACTICES:

1. Identify, map, and avoid impacting smoke sensitive areas
2. Match appropriate smoke impact screening tools to burn complexity
3. Use test fire to verify expected smoke dispersion
4. Only burn when smoke dispersion conditions are favorable
5. Monitor changing weather conditions and respond to unintended smoke impacts
6. Understand and follow local, state, federal, and tribal prescribed fire and air quality laws and regulations
7. Notify appropriate parties (neighbors, public agencies, authorities) of intent to burn
8. When feasible, use ignition patterns and methods which minimize smoke production
9. Minimize impacts from smoldering smoke
10. In high smoke risk areas, explore alternative methods to burning
11. Enhance smoke management skills through training and experience
12. Be aware of other burning activity and sources of pollution in your area

Smoke Management Timeline for Prescribed Burning

(Though not all recommendations on this timeline are required, following them will improve smoke management.)

6 MONTHS- 1 YEAR BEFORE BURN (NEW SITE)

- ☐ Learn about laws & regulations governing prescribed burns in your area
- ☐ Contact state forestry agency for advice on smoke management (new burn sites)

1-3 MONTHS BEFORE BURN (NEW SITE)

- ☐ Monitor weather
- ☐ Smoke screen practice
- ☐ Assess fuel load

2 WEEKS BEFORE BURN

- ☐ Communicate with necessary parties
- ☐ Monitor weather
- ☐ Communicate with neighbors

2 DAYS BEFORE BURN

- ☐ Monitor weather
- ☐ Measure weather conditions onsite. If differ greatly from forecast, request a spot forecast
- ☐ Communicate again with neighbors

DAY BEFORE BURN

- ☐ Monitor weather
- ☐ Communicate with necessary parties
- ☐ Contact state forestry agency for permission to burn (some states)

MORNING OF BURN

- ☐ Obtain weather forecast & record on burn plan
- ☐ Determine firing technique based on forecast and observed fuel conditions
- ☐ Determine fuel moisture
- ☐ Smoke screen
- ☐ Contact state forestry agency for permission to burn (some states)
- ☐ Contact public safety & transportation authorities
- ☐ Place signage on roadways, as needed

IMMEDIATELY BEFORE BURN

- ☐ Evaluate smoke dispersion with test fire

DURING BURN

- ☐ Monitor & record weather several times during burn
- ☐ Update public safety & transportation authorities several times during burn
- ☐ Patrol neighborhoods impacted by smoke

AFTER BURN

- ☐ Mop-up
- ☐ Inform public safety & transportation authorities of burn termination
- ☐ Monitor residual smoke

DAY AFTER BURN

- ☐ Assess if smoke objectives met
- ☐ Determine if smoke management plan followed
- ☐ Evaluate how to improve smoke management next time

WEEKS AFTER BURN

- ☐ Evaluate if you were successful in avoiding SSAs

MONTHS TO YEAR AFTER BURN

- ☐ Determine if you received public comments for or against burning program based on smoke complaints

SMOKE MANAGEMENT CHECKLIST FOR PLANNING YOUR PRESCRIBED BURN

Understand and follow prescribed fire plans, laws, and regulations

- ☐ Follow your state's Smoke Management Plan (obtain through state forestry agency)
- ☐ Obtain information on burn bans, air quality alerts, and state and local air quality regulations

Notify appropriate parties of intent to burn

- ☐ Contact state forestry agency and public safety representatives (police, fire departments)
- ☐ Communicate with all potential affected populations

Be aware of other burning activity and sources of pollution in your area

- ☐ Inquire with state agencies about other upcoming burns

Use methods to minimize smoke production

- ☐ Consider burning a smaller area or using a burning technique that reduces smoke
- ☐ Observe and record fuel type, fuel moisture and fuel load at the burn site
- ☐ Select ignition technique and pattern that will reduce smoke production

Monitor changing weather conditions for favorable smoke dispersion

- ☐ Check fire weather forecasts and/or measure weather conditions on site
- ☐ Request a spot forecast, if necessary
- ☐ Understand atmospheric dispersion trends (from fire weather forecast) near burn site

Smoke screening

- ☐ Practice screening. Understand ideal conditions and screening distance
- ☐ Identify where smoke sensitive populations are located near the burn site

Consider alternative methods to burning

- ☐ Consider alternatives to burning if safe smoke management is unlikely

Smoke management training and experience

- ☐ Contact your state forestry agency, Prescribed Fire Council, or other prescribed burn organization for opportunities to increase your skills

Smoke management plans should be developed well in advance of the proposed burn date, even up to a year in advance, but at least a few weeks to a few days prior. Of course, the degree of advanced planning will depend on a landowner or land manager's burn experience and familiarity with the burn site, local weather conditions, topography, and Smoke Sensitive Areas (SSAs). Planning provides the opportunity to understand local and state laws and regulations, alert local authorities and surrounding communities of the proposed burn, and investigate optimal weather conditions, firing techniques, and fuel moisture at a proposed burn site, and much more. The planning stage is one of the most important steps for implementing a successful burn and smoke management plan. Based on the 12 BMSPs, the following tasks will assist in planning a smoke management plan. With experience and familiarity with a burn site, several of these steps may not need to be reviewed. This section begins with the planning checklist above, followed by more detailed instructions below.

Planning Your Burn with Smoke Management in Mind

FOLLOW STATE AGENCY RULES AND PROGRAMS

Contact your state forestry agency. (See Appendix C)

- Notify agency of your intent to burn.
- Obtain and follow any required/ recommended burn plan template and Smoke Management Program (SMP) guidelines or other guidance on smoke management.
- Inquire about other state and local laws and regulations affecting smoke management.
- Find out if prescribed fire permitting is impacted by local air quality (i.e., ozone, $PM_{2.5}$) or when several other burns are occurring on the same day.
- Document any air quality ratings or other sources of pollution in your area. Keep this with your burn plan.

OBSERVE AND RECORD OBSERVATIONS OF FUEL TYPE AND FUEL MOISTURE AT THE BURN SITE

Understand what type of fuels are on the burn site and develop objectives for what you want to burn (i.e., 1-hr vs. 10-hr fuels). For example, 1-hr hour fuels like pine straw will produce less smoke than 10-hr fuels like branches.

Measure your site's fuel moisture:

- Higher fuel moisture can produce more smoke due to ***incomplete combustion***, but higher fuel moisture also limits what can burn (producing less smoke because less fuel is available to burn since it is too moist). Your burn objectives will outline what fuels you want to burn on a site.
- Use fuel moisture sticks, estimation tables or other methods to calculate or estimate fuel moisture. (See Appendix C)
- Consult with your state forestry agency for advice on measuring fuel moisture or the fuel moisture required to burn certain fuels.

ESTIMATE FUEL LOAD ON THE PROPOSED BURN SITE

Refer to Table 8 or Appendix C for additional methods for estimating fuel load.

Table 8: Fuel load (tons per acre) estimations in four natural landscapes. Data reprinted with permission from Introduction to Prescribed Fire in Southern Ecosystems by Waldrop and Goodrick, 2012

Description	Fuel Load (tons/ acre)	Estimated Fuel Consumption (tons/acre)		
		Moist	Moderate	Dry
Grass-dominated				
Short grass (≤ 1 feet)	0.74	0.5	0.6	0.7
Timber with grass understory	4	1.8	2.6	3.2
Tall grass (> 2.5 feet)	3	2	2.3	2.4
Chaparral & Shrubs				
Chaparral	16	10	12.1	13.0
Brush	3.5	2.2	2.6	2.9
Dormant brush	6	3.8	4.5	5
Southern rough	4.87	2.6	3.4	4
Timber Litter				
Closed timber litter	5	2.6	3	3.3
Timber litter	3.48	2	2.4	2.7
Timber (litter and understory)	12	5.2	6.5	7.1
Slash				
Light logging slash	11.5	8	9.7	10.5
Medium logging slash	34	23.6	28.8	31
Heavy logging slash	58	40	49	52.8

Note: Consumption estimates calculated using FEPS v 1.1.0 and default fuel moisture scenarios as named above. These numbers are provided as a rough estimate and may not match a particular site or fuel moisture conditions.

SELECT AN IGNITION TECHNIQUE AND PATTERN THAT WILL REDUCE SMOKE PRODUCTION

Weather conditions on the day of the burn will dictate the best firing technique(s) to use, but consider the following in advance of the burn to reduce smoke:

- Use a backing fire (though slower moving, produces less smoke) or a heading fire (moves fast, but depending on fuel moisture, may produce less smoke). You may even consider using a combination of both techniques.
- Burn using fuel moisture conditions that consume only the targeted fuels on the site and minimize smoldering.
- Burn smaller areas.

For burning piles and windrows, see Appendix B.

OBTAIN FIRE WEATHER FORECAST AND OBSERVE WEATHER

Check with your state forestry agency for the ranges of atmospheric and weather factors to burn, if required in your state.

Optimal smoke management requires that specific atmospheric and weather factors be within a known, defined range of values (i.e., wind direction and speed) to support safe burning conditions and have minimal impact to Smoke Sensitive Areas for

a particular burn site. If burning a new site, begin monitoring weather conditions well in advance of the burn. These observations, along with smoke screening, help inform the best wind direction and other factors needed to burn a site with as little smoke production and impact as possible. Overall, a site should be burned during ideal weather conditions based on smoke screening and other factors.

Check weather (regional and on-site):

- Obtain daytime and nighttime fire-weather forecasts at https://www.weather.gov/dlh/firepoker and record your observations, filling in necessary weather information on your burn plan. The weather variables (and their recommended/ required value ranges) related to smoke management that need to be included on your burn plan will vary from state to state. Be sure to check with your state forestry agency for more information or recommended values. Note: do not burn if conditions are not within prescription on your burn plan.
- If available, measure weather conditions on site using a handheld weather meter (Fig. 13) or belt weather kit and sling psychrometer. (See Appendix C)
- (Optional) If on-site weather conditions vary from fire-weather forecast, in some areas, a spot forecast may be requested on the fire weather forecast site. Contact your nearest weather service to find out if a spot weather forecast is available for your site (See Appendix D or https://www.weather.gov/dlh/firepoker) and request wind speed and direction, RH forecast, and possible shifts in weather.
- Record all observations (written and photos).

Figure 13: Using a handheld weather meter to record conditions during a prescribed fire. Credit: David Godwin

SMOKE SCREEN FOR SMOKE SENSITIVE AREAS

Begin the smoke screening process one or more days prior to (burning new sites) or the morning of a burn (previously burned sites).

Using Google Maps, knowledge of your community, or other information, locate SSAs in an approximate 20-mile radius around the burn site. Note these locations on a map.

Obtain the National Weather Service Fire Weather Forecast for your area for both day and night.

Use an online smoke screening modelling tool, ***VSmoke-Web***, or other modelling tool (See Appendix C) to plot the potential path of smoke from the burn.

- Access VSmoke-Web at: http://weather.gfc.state.ga.us/GoogleVsmoke/vsmoke-Good2.html.
- Input the following information into VSmoke-Web for the site you are going burn: location (latitude-longitude), fire size (acres), fuel load, fuel consumption, and weather (Fig. 14). Note that VSmoke-Web assumes a constant wind

direction, though a constant wind direction is less common. Contact your state forestry agency for guidance on using VSmoke-Web or refer to the VSmoke-Web instructional video in Appendix C.

- VSmoke-Web will provide an output that maps potential predicted air quality for specified distances from the burn. Keep in mind that no SSAs should be within the minimum smoke screening distance. If they are, additional screening must be used (using a different wind direction and speed) and a different burn day must be selected.
- Take a screen shot of the output and save/print for your records.
- Add any necessary information from the VSmoke-Web output to your burn plan.

If your screening identifies a problem, plan to burn under different atmospheric and weather conditions or use other mitigation techniques.

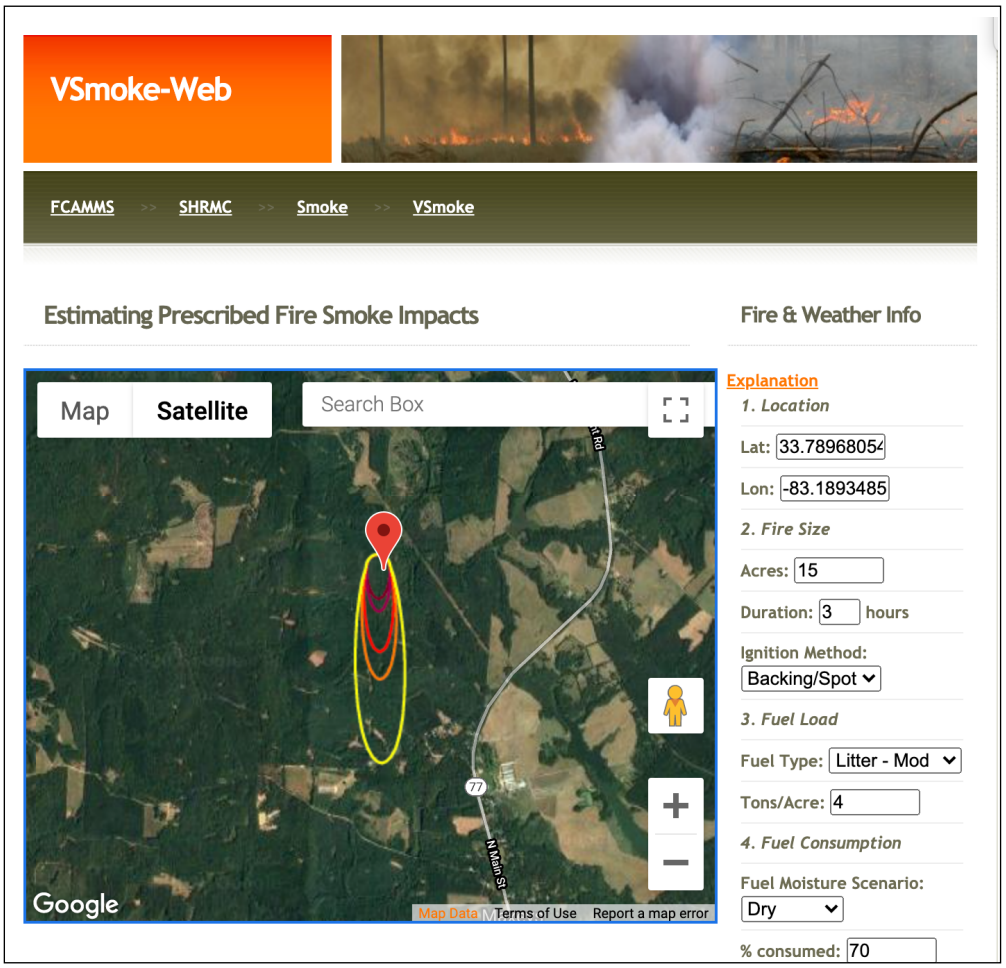


Figure 14: Smoke screening using VSmoke-Web. Input parameters specific to your burn site (Lavdas, 1996).

NOTIFY APPROPRIATE PARTIES OF INTENT TO BURN

Communicate with neighbors, health agencies, public safety and transportation authorities (police), fire departments, and sensitive populations downwind through door hanger pamphlets, flyers, newspaper, email, phone calls, and/ or in person.

(Optional) Provide education or outreach to local communities and authorities about why prescribed fire is a valuable land management practice. This can lead to greater public support and tolerance of smoke when its output is within prescription.

Record when and how you contacted appropriate parties for your records and burn plan, if required. Also, record any relevant local air quality ratings or other sources of pollution you are aware of.

OTHER CONSIDERATIONS RELATED TO SMOKE MANAGEMENT

In high smoke risk areas, explore alternative methods of fuel management to reduce smoke while burning or as an alternative to burning:

- Herbicides
- Mechanical treatments (i.e., mowing, discing, and brush and understory vegetation removal)
- Timber sales
- Grazing

Enhance smoke management skills through training and experience:

- Contact your state forestry agency to learn about smoke management training or mentoring opportunities in your area or take the online FRAMES course. (See Appendix C)
- Explore other online training opportunities available. (See Appendix C)

SMOKE MANAGEMENT CHECKLIST FOR CONDUCTING YOUR PRESCRIBED BURN

Use methods to minimize smoke production, especially to smoke sensitive areas

- ☐ Obtain fire weather forecast night prior to, the day of, and the night following the burn to ensure good dispersion
- ☐ Measure fuel moisture night before and morning of the burn
- ☐ Determine best firing technique for dispersion based on current conditions
- ☐ Smoke screen
- ☐ If burn conditions do not align with your prescription, use one or more mitigation techniques

Notify appropriate parties of intent to burn and be aware of other burning activity

- ☐ Contact your state forestry agency for permission to proceed with burn
- ☐ Contact public safety and transportation authorities (police)
- ☐ Contact fire departments
- ☐ Ensure signs posted along all affected roads if roads are impacted
- ☐ Communicate again with neighbors, health agencies, and sensitive populations downwind
- ☐ Be sure to follow what you have proposed to do on your Smoke Management Plan

Use test fire to verify expected smoke dispersion

- ☐ Light a test fire prior to the burn to test smoke behavior

Monitor changing weather conditions and respond to unintended smoke impacts

- ☐ Monitor weather conditions throughout the burn
- ☐ Monitor transportation areas
- ☐ Update transportation authorities as needed
- ☐ Monitor neighborhoods and communities downwind of the burn
- ☐ Record all observations
- ☐ Monitor residual smoke issues downwind of the burn and continue to monitor after burn

Minimize impacts from smoldering smoke

- ☐ Extinguish snags, smoldering logs, and any other smoldering debris

Conducting Your Burn with Smoke Management in Mind

OBTAIN FIRE WEATHER FORECASTS FOR THE NIGHT PRIOR TO, THE DAY OF, AND THE NIGHT FOLLOWING THE BURN

- Only burn if atmospheric and weather conditions (especially dispersion) meet the burn objectives on the burn plan (based on smoke screening). If not, plan to burn on another day.
- Record atmospheric and weather variables on your burn plan.

MEASURE FUEL MOISTURE (NIGHT BEFORE AND MORNING OF BURN)

SMOKE SCREEN USING VSMOKE-WEB OR OTHER SMOKE SCREENING TOOLS (MORNING OF BURN)

- Ensure VSmoke-Web output (smoke screening) does not impact SSAs.
- Save/ print the VSmoke-Web output.
- Screen for potential nighttime smoke impacts using PBPiedmont. (See Appendix B)

IF BURN CONDITIONS DO NOT ALIGN WITH YOUR PRESCRIPTION, USE ONE OR MORE OF THE MITIGATION TECHNIQUES OUTLINED IN FIGURE 12.

CONTACT YOUR STATE AGENCY FOR A PERMIT/ PERMISSION TO BURN (MORNING OF BURN), IF REQUIRED

- Ensure smoke dispersion conditions are favorable.
- Inquire about other restrictions on the burn day that may impact smoke management, such as other air quality impacts or several burns occurring simultaneously.

NOTIFY APPROPRIATE PARTIES OF INTENT TO BURN (MORNING OF BURN)

- Contact public safety and transportation authorities (police) and fire departments again and arrange to have signs posted along all affected roads, if roadways will be impacted.
- Communicate again with neighbors, health agencies, and sensitive populations downwind.

START A TEST FIRE TO EVALUATE SMOKE DISPERSION (IMMEDIATELY BEFORE BURN)

- Locate a small plot within the burn area that is easily extinguishable (usually at your ***anchor point***).
- This plot will be used to test smoke behavior before initiating the actual burn. If conditions are not favorable, you should not burn.

MONITOR WEATHER DURING BURN

- Check weather. Record and save all data collected for your records.

MONITOR SMOKE DISPERSION DURING BURN

- Direct extra helpers to monitor transportation areas (roads, highways, waterways, etc.).
- In more complex burns, consider updating local authorities about the progress of the burn.
- Request assistance from local authorities (police) to direct traffic or distribute more road signs if smoke encroaching on road becomes a problem.

- Direct extra helpers to drive through neighborhoods and communities downwind of the burn to monitor smoke dispersion. Having a fire department vehicle and staff member on hand has been shown to reduce public anxieties concerning smoke.
- Record all observations (written and photos), including any nuisance complaints.

MINIMIZE SMOLDERING (DURING AND AFTER BURN)

- After the fire has moved through parts of the area burned, began extinguishing snags, smoldering logs, and any other smoldering debris.
- After the burn, quickly extinguish any remaining smoldering fuels through mop-up.

AT THE END OF THE BURN, CONTACT APPROPRIATE PARTIES AGAIN

- Contact police and fire departments, if necessary, to inform them that the burn has concluded, but that you will monitor the burn throughout the evening to ensure any residual smoke does not cause road hazards.

CONTINUE TO MONITOR WEATHER AFTER THE BURN

- After the burn, address any residual smoke issues following the fire, throughout the evening and downwind of the burn, if necessary.
- This especially applies to pile and windrow burns.

Evaluating Smoke Management After a Burn

Evaluating the success of your smoke management plan occurs at three different intervals, immediately following the burn and two separate evaluations a period of time after the burn. You can combine evaluation information with data you gathered during the actual burn to improve future smoke management plans. Be sure to record and save all evaluation information for your records. More evaluation information can be located at e-Fire: https://efire.cnr.ncsu.edu/efire/evaluating/

IMMEDIATE EVALUATION (DAY OF OR DAYS FOLLOWING BURN):

- Was pre-burn preparation properly done and adequate for the burn?
- Were smoke objectives met?
- Was the smoke management plan followed? Were changes made and documented?
- Were weather conditions, fuel conditions, fire behavior, and smoke dispersion within planned limits? Were any deviations documented?
- Was the burning technique used ideal for smoke management under the weather conditions?
- What could be done to improve similar smoke management plans next time?

SHORT-TERM EVALUATION:

- What degree of success did you have in avoiding smoke-sensitive features?
- Any adverse public comment or reaction prior to, during, or immediately after the burn?

LONG-TERM EVALUATION:

- Have you received public comments either for or against the burning program based on smoke complaints?

Conclusion

Prescribed fire is an important land management tool utilized to meet several landowner objectives. Every year, numerous landowners across the southeast effectively and safely conduct prescribed burns, following the appropriate rules and regulations. Prescribed burners, however, have a responsibility to protect their communities' health and also preserve the ability to keep burning as populations change and public opinion shifts in the region. As you learned through this guidebook, smoke from prescribed fires can negatively contribute to air quality, health, transportation safety, and public enjoyment of the outdoors if smoke management is not carefully planned and executed. Through ongoing training, planning, preparation, and practice, prescribed burners can support the continued responsible use of this land management practice.

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APPENDIX A: STATE AND REGIONAL CONTACTS

STATE	AGENCY/ ORGANIZATION	INFORMATION	WEBSITE
AL	Alabama Forestry Commission	Prescribed Burn Information	https://www.forestry.state.al.us/Default.aspx Search under "Protect" menu item for info on prescribed fire.
	Alabama Department of Environmental Management	Air Quality Information	http://adem.alabama.gov/programs/air/airquality.cnt
	Alabama Prescribed Fire Council	Information and Contacts	http://www.alpfc.org/
AR	Arkansas Forestry Commission	Prescribed Burn Information	https://www.aad.arkansas.gov/arkansas-forestry-commission Search for "prescribed fire" information in search bar on home page
	Arkansas Department of Environmental Quality	Air Quality Information	https://www.adeq.state.ar.us/
	Arkansas Prescribed Fire Network	Information and Contacts	https://www.facebook.com/ArPrescribedFireCouncil/
FL	Florida Forest Service	Prescribed Burn Information	https://www.fdacs.gov/Divisions-Offices/Florida-Forest-Service/Wildland-Fire
	Florida Department of Environmental Protection	Information, Contacts, and Air Quality Data	https://floridadep.gov/air-topics
	Florida Prescribed Fire Councils	Information and Contacts	https://www.fdacs.gov/Contact-Us/Regional-Contacts
GA	Georgia Forestry Commission	Prescribed Burn Information	https://gatrees.org/fire-prevention-suppression/prescribed-burn/
	Georgia Environmental Protection Division	Air Quality Information	https://epd.georgia.gov/air-protection-branch
	Georgia Prescribed Fire Council	Information and Contacts	https://www.garxfire.com

KY	Kentucky Division of Forestry	Prescribed Fire Information	https://eec.ky.gov/Natural-Resources/Forestry/wildland-fire-management/Pages/default.aspx
	Kentucky Division for Air Quality	Air Quality Information	https://eec.ky.gov/Environmental-Protection/Air/Pages/default.aspx
	Kentucky Prescribed Fire Council	Information and Contacts	https://www.kyfire.org
LA	Louisiana Department of Agriculture and Forestry	Prescribed Fire Information	https://www.ldaf.state.la.us/forestry/protection/
	Louisiana Department of Air Quality	Air Quality Information	http://deq.louisiana.gov/subhome/air
	Louisiana Prescribed Fire Council	Information	https://www.facebook.com/louisianaprescribedfirecouncil/
MS	Mississippi Forestry Commission	Prescribed Fire Information	https://www.mfc.ms.gov/burning-info/prescribed-burning/
	Mississippi Department of Environmental Quality	Air Quality Information	https://www.mdeq.ms.gov/air/
	Mississippi Prescribed Fire Council	Information	https://mspfc.wordpress.com
NC	North Carolina Forest Service	Prescribed Fire Information	https://www.ncforestservice.gov/goodfire/index.htm
	North Carolina Environmental Quality	Air Quality Information	https://deq.nc.gov/about/divisions/air-quality/air-quality-rules/rules/open-burning
	North Carolina Prescribed Fire Council	Information and Contacts	https://www.ncprescribedfirecouncil.org
OK	Oklahoma Forestry Services	Prescribed Fire Information	https://forestry.ok.gov/rxfire
	Oklahoma Department of Environmental Quality	Air Quality Information	http://www.deq.ok.gov/divisions/aqd/
	Oklahoma Prescribed Fire Council	Information and Contacts	https://www.oklahomaprescribedfirecouncil.okstate.edu

SC	South Carolina Forestry Commission	Prescribed Fire Information	https://www.state.sc.us/forest/fire.htm
	South Carolina Department of Health and Environmental Control	Air Quality Information	https://scdhec.gov/environment/your-air
	South Carolina Prescribed Fire Council	Information and Contacts	http://scpfc.weebly.com
TN	Tennessee Department of Agriculture: Division of Forestry	Prescribed Fire Information	https://www.tn.gov/agriculture/forests.html Search on this page for burn permits and prescribed fire information
	Tennessee Department of Environment and Conservation	Air Quality Information	https://www.tn.gov/environment/program-areas/apc-air-pollution-control-home.html
	Tennessee Prescribed Fire Council	Information and Contacts	https://www.tn.gov/agriculture/forests.html
TX	Texas A&M Forest Service	Prescribed Fire Information	https://tfsweb.tamu.edu/prescribedburns/
	Texas Commission on Environmental Air Quality	Air Quality Information	https://www.tceq.texas.gov/agency/air_main.html
	Prescribed Burn Alliance of Texas	Information and Contacts	http://pbatexas.org/
VA	Virginia Department of Forestry	Prescribed Fire Information	https://www.dof.virginia.gov/fire/prescribed/index.htm
	Virginia Department of Environmental Quality	Air Quality Information	https://www.deq.virginia.gov/Programs/Air.aspx
	Virginia Prescribed Fire Council	Information and Contacts	https://www.vafirecouncil.com

SE REGION	Southern Fire Exchange	Information and Events	https://southernfireexchange.org/
	Consortium of Appalachian Fire Managers and Scientists	Information and Events	https://www.appalachianfire.org
	Oak Woodlands and Forests Fire Consortium	Information and Events	https://oakfirescience.com
	Great Plains Fire Exchange	Information and Events	https://www.gpfirescience.org
	North Carolina State University	Information and Events	https://research.cnr.ncsu.edu/blogs/southeast-fire-update/smoke-management/
	e-FIRE	Information	https://efire.cnr.ncsu.edu/efire/
FEDERAL	Natural Resources Conservation Service (NRCS)	Information	https://www.nrcs.usda.gov/

APPENDIX B: ADDITIONAL MODELS AND TOOLS

Steps for hand-drawn smoke screening using the Category Day method.

Category Day is a smoke screening method utilized by some southeastern states to determine the distance required for smoke screening. Category Day is rated from 1-5, with days 2 to 5 being the best days for reducing smoke impacts. No burning should occur on Category 1 days because the smoke will not sufficiently disperse. Caution should be used on Category 2 days because only marginal smoke dispersion will occur (Weir, 2009). While Category 5 days may lead to the best smoke dispersion, caution also must be used when burning on these days because they are the days most likely to produce potentially dangerous fire behavior and have potentially hazardous weather such as thunderstorms (Weir, 2009). Category Days are not a universal element of fire weather or spot forecasts and may not be used in all southeastern states.

1. Obtain values for transport wind speed (convert to meters per second), mixing height (convert to meters), and transport wind direction the morning of the proposed burn date through a fire weather forecast. Note that morning weather reports are predictions for same-day afternoon weather conditions and depending on the weather report type (fire or spot forecast), most weather predictions report conditions near or on the burn site.
2. Determine the Category Day, which is based on the ventilation rate (Fig. 15). Calculate ventilation rate (m*m/s) by multiplying mixing height (meters) by transport wind speed (meters/ second).
3. Determine minimum smoke screening distance (in miles) by using your Category Day value and the type of firing/ ignition technique you plan to use (Fig. 16). Note that any firing technique not listed should be included as head fire if under 1,000 acres.
4. Obtain a large print map that includes the proposed burn site and a distance greater than 30 miles in all directions from the proposed site. All roads should be clearly outlined on the map. Add a scale to the map, noting the number miles per inch.
5. Draw an outline around the exact acreage that will be burned.
6. Mark on the map locations of ALL smoke sensitive areas (airports, hospitals, schools, nursing homes, Class 1 areas, recreation areas, residences, and certain industries). Note locations of major roads and highways, especially in drainage areas.
7. Draw a smoke plume trajectory map (Fig. 17). Using the predicted wind direction and a ruler, draw a line through the middle of the burn unit in the direction of the wind. Next, draw two lines at a 30-degree angle from the wind direction. (Note: if wind direction is variable and not constant, forty-five-degree angles from the centerline should be used to increase the screening width). Ideally, all lines should be extended 20 miles from the burn unit and marked at 5, 10, 15, and 20 miles, or at least to the minimum screening distance. No smoke sensitive areas should be within the minimum smoke screening distance and, if so, additional screening must be used (using a different wind direction, speed, or higher Category Day).
8. Record observations and add necessary information to your burn plan.

Screening for nighttime smoke impacts using online software PBPiedmont

1. Access PBPiedmont at: https://piedmont.dri.edu/
2. Contact your state forestry agency for

more information on evening burns or if smoldering is expected to persist from daytime burns.

3. If significant smoldering for a daytime burn is anticipated to extend through the evening (which can be possible in pile or windrow burning), in areas with pronounced topographic relief or drainages, the online smoke screening software PBPiedmont can be used to predict potential smoke movement downslope and into drainage areas at night.
4. Keep in mind that several states do not allow evening burns.

Burning piles and windrows

The following steps can be used to reduce smoke in piles and windrows (NWCG, 2020).

1. Following tree harvest, allow scattered slash to dry before stacking.
2. After drying, stack debris with a tined or forked front-end loader to pile wood. Little to no soil should be added to the pile and the wood should be stacked carefully for sufficient air flow.
3. Check dispersion conditions, including LVORI predictions. Piles and windrows can smolder throughout the evening, causing dangerous visibility conditions on roadways and low areas on the landscape.
4. Alternatively, logging slash does not have to be stacked, limiting soil disturbance. Broadcast burning is conducted with logging slash remaining in place.
5. (Optional) Use an air curtain incinerator. For more information visit: https://www.fs.fed.us/eng/pubs/html/02511317/02511317.htm

CATEGORY DAY SMOKE MANAGEMENT GUIDELINES

Category Day	Guidelines	Ventilation Rate (m*m/s)
1	**NO BURNING!**	less than 2,000
2	No burning until after 11:00 am and not before surface inversion has lifted. **Fire should be substantially completed by 4:00 pm.**	2,000-4,000
3	Daytime burning only but not before surface inversion has lifted.	4,000-8,000
4	Burning anytime. **For night burns, use backing fires with surface wind speeds greater than 4 mph and a Relative Humidity less than 80%.**	8,000-16,000
5	"Unstable" and windy, Excellent smoke dispersal. **BURN WITH CAUTION.**	greater than 16,000

Figure 15: Category Day rating based on ventilation rate. Ventilation rate can can be calculated or obtained from your fire weather forecast (Weir, 2009). Category Day ventilation rates vary from state to state. Check with your state forestry agency for more information. Not all states and NWS offices will provide the Category Day or the ventilation rate in their fire weather forecast.

MINIMUM SMOKE SCREENING DISTANCE (MILES)

Type of Burn	Category Day 1	2	3	4	5
Backing Fire less than 1,000 acs.	NO BURNING	10	5	2.5	.75
Head Fire less than 1,000 acs.		20	10	5	.75
More than 1,000 acs.		20	10	5	.75
Piles/Windrows		30	15	8	.75

Figure 16: Before the burn, determine minimum smoke screening distance (in miles) using Category Day (Weir, 2009).

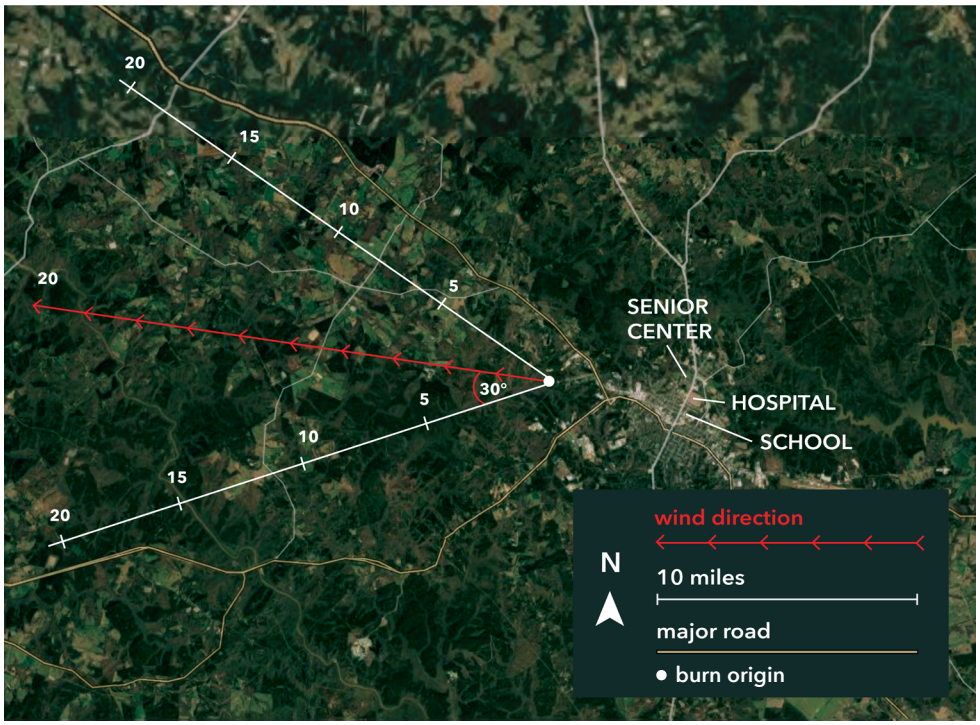

Figure 17: Example of smoke screening using the Category Day method.

APPENDIX C: ONLINE RESOURCES

TITLE	WEBSITE
GENERAL PRESCRIBED FIRE SMOKE MANAGEMENT INFORMATION	
Air Curtain Destructors/ Incinerators (for slash or pile burns)	https://www.fs.fed.us/eng/pubs/html/02511317/02511317.htm
Basic Smoke Management Practices for Prescribed Burning	https://southernfireexchange.org/publications/
Introduction to Prescribed Fire in Southern Ecosystems	http://treesearch.fs.fed.us/pubs/41316
Managing Smoke at the Wildland-Urban Interface	https://www.fs.usda.gov/treesearch/pubs/28550
NIFC National Smoke Management Resources	http://www.nifc.gov/smoke
NRCS Basic Smoke Management Practices	https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1046311.pdf
NWCG Smoke Committee Emissions & Smoke Portal: Air Quality Library	https://www.frames.gov/partner-sites/emissions-and-smoke/educational-resources/air-quality-library/
NWCG Smoke Management Guide for Prescribed Fire	https://www.nwcg.gov/publications/420-3
NWCG Smoke and Roadway Safety Guide	https://www.nwcg.gov/publications/477
Prescribed Fire: Understanding Laws, Liability, and Risk (Oklahoma State University)	https://extension.okstate.edu/fact-sheets/prescribed-fire-understanding-liability-laws-and-risk.html
Situational Awareness: Nighttime Smoke and Fog on Prescribed Burns	https://southernfireexchange.org/publications/
Smoke Management for Prescribed Burning (Oklahoma)	http://www.forestry.ok.gov/wildlandfire-publications

Smoke Management Photographic Guide: A Visual Aid for Communicating Impacts	https://www.fs.usda.gov/treesearch/pubs/50985
Smoke Management Publications from the Southern Fire Exchange	https://southernfireexchange.org/publications/
Smoke Prediction with V-Smoke Web	https://southernfireexchange.org/publications/
Superfog: State of the Science	https://southernfireexchange.org/publications/
Wildland Fire Smoke Effects on Public Health What Does the Research Say?	https://southernfireexchange.org/publications/
WEATHER FORECAST & MONITORING TOOLS	
Fire Weather Intelligence Portal	https://climate.ncsu.edu/fwip/
Handheld weather instrument (Disclaimer: This is not an endorsement but an example of one type of weather instrument).	https://kestrelmeters.com/
Measuring wind speed and direction at a site	https://www.wcc.nrcs.usda.gov/climate/windrose.html
NWS Enhanced Data Display	https://preview.weather.gov/edd/
NWS Fire Weather Forecast (and requesting spot forecast)	https://www.weather.gov/dlh/firepoker
SMOKE SCREENING/ SMOKE MODELING TOOLS	
PBPiedmont	https://piedmont.dri.edu/
Simple Smoke Screening Tool	http://fireweather.fdacs.gov/Simple-Smoke/
Smoke Management Model Forecast, on Oklahoma Mesonet (Oklahoma only)	http://www.mesonet.org/index.php/okfire/home
VSmoke-Web	http://weather.gfc.state.ga.us/GoogleVsmoke/vsmoke-Good2.html

SMOKE MANAGEMENT ONLINE TOOLS	
Prescribed Fire Smoke Management Pocket Guide (includes a fuel calculator)	http://smokeapp.serppas.org/
AIR QUALITY ONLINE TOOLS	
AirNow- national air quality measurement provided by the EPA	https://www.airnow.gov
Current wildfires and associated air quality (through EPA-AirNow)	https://fire.airnow.gov
WinHaze- downloadable software that helps you visualize air quality differences	https://www.air-resource.com/resources/downloads.html
FUEL MOISTURE PREDICTIONS	
Fire Weather Intelligence Portal (Establish your area of interest. Next, click on drop down menu for "Point Data." Scroll to bottom where Predicted 1 to 1000-hr Fuel moisture forecasts are listed and select your choice.Select "update point data." Number results on map correspond to the legend below map for predicted % fuel moisture.)	http://climate.ncsu.edu/fwip/index.php
USDA Forest Service Wildland Fire Assessment System (Select Current or Forecast for your area corresponding to the fuel size listed.)	http://www.wfas.net/index.php/dead-fuel-moisture-moisture--drought-38

FUEL LOAD ESTIMATIONS	
Digital Fuel Loads Photo Series (Click on dots on map near your location)	https://depts.washington.edu/nwfire/dps/
Fuel Calculator: Online Prescribed Fire Smoke Management Pocket Guide	http://smokeapp.serppas.org/available-fuel-calculator.html
Fuel Load Estimations for South Carolina (South Carolina Forestry Commission)	https://www.state.sc.us/forest/fuelloads.pdf
Fuel Treatments in Pine Flatwoods: A Photo Series Guide (assists with fuel load estimates in this forest type)	https://southernfireexchange.org/wp-content/uploads/Fuel_Treatments_Photo_Guide.pdf
ONLINE EDUCATIONAL COURSES	
Basic Prescribed Fire Training (Under "courses," click on "Energy and Environment" and then "Rangeland". You may need to create a log in and password (free) before gaining access to the course.)	http://campus.extension.org/
e-FIRE	https://go.distance.ncsu.edu/efire/
FRAMES: Smoke Management and Air Quality for Land Managers: An Online Training Resource (create a log in and password for free)	https://www.frames.gov/smoke/tutorial/overview
Introduction to Southeastern Prescribed Fire (Under "courses," click on "Energy and Environment" and then "Forestry". You may need to create a log in and password (free) before gaining access to the course.)	http://campus.extension.org/
Public perception and tolerance of smoke from wildland fires	https://www.frames.gov/partner-sites/emissions-and-smoke/research/perceptions/

OTHER ONLINE RESOURCES	
Instructional webinar for how to use VSmoke-Web	https://www.youtube.com/watch?v=-8OirOp0BCc&feature=youtu.be
National Interagency Fire Center: Smoke Management	https://www.nifc.gov/smoke/
National Wildfire Coordinating Group	https://www.nwcg.gov/
NOAA Hazard Mapping System Fire and Smoke Product (can obtain GIS and KML files and satellite imagery)	http://www.ospo.noaa.gov/Products/land/hms.html
NWCG Smoke: Knowing the Risks Video	https://www.youtube.com/watch?v=0gqTbJSQL_U&feature=youtu.be
NWCG Smoke, Roads and Safety: Check Before They Wreck	https://www.youtube.com/watch?v=hklDp38xE14
APPS/ MOBILE APPLICATIONS FOR PHONES AND TABLETS	
AIRNow	Apple/ IOS Devices: https://itunes.apple.com/us/app/epa-airnow/id467653238?mt=8 Androids: https://play.google.com/store/apps/details?id=com.saic.airnow&hl=en
Prescribed Fire Smoke Management Pocket Guide	http://smokeapp.serppas.org
Weather Underground (establish prescribed burning as a "Hobby" and the App will predict the weather when suitable burning conditions are available)	https://www.wunderground.com/download

APPENDIX D: DEFINITIONS

Words that are italicized and bold throughout the text of the guidebook are defined below. Many of the following definitions were obtained from the National Wildfire Coordinating Group's Glossary of Wildland Fire (https://www.nwcg.gov/about-the-nwcg-glossary-of-wildland-fire) and USDA Forest Service.

For more smoke management and air quality terms, consult the Smokepedia at: http://smokeapp.serppas.org/smokepedia.html

Air Quality Index — The Air Quality Index (AQI) is an index for reporting daily air quality. It tells how clean or polluted the air is, and what associated health effects might be a concern. The AQI focuses on health effects that might be experienced within a few hours or days after breathing polluted air. EPA calculates the AQI for five major air pollutants regulated by the Clean Air Act: ground-level ozone, PM, carbon monoxide, sulfur dioxide, and nitrogen dioxide.

Anchor point — An advantageous location, usually a barrier to fire spread, from which to start constructing a fireline. The anchor point is used to minimize the chance of being flanked by the fire while the line is being constructed.

Atmospheric Dispersion Index — The Atmospheric Dispersion Index (ADI) is a numerical indicator of how rapidly smoke will be dispersed based on atmospheric stability, mixing height, and transport wind speed.

Atmospheric stability — The atmosphere contains both vertical and horizontal motion, which is caused by several factors such as wind and heating of the Earth's surface. Stability is an indication of how rapidly vertical mixing is taking place. In the case of smoke, the more unstable the atmosphere, the more vigorously smoke is mixed, or lifted and dispersed into the atmosphere. Stable atmospheres disperse smoke less efficiently and can result in higher concentrations of smoke moving back to the ground some distance downwind.

Backing fire — A type of ignition technique where fire moves against the predominant wind direction. Flames during a backing fire tilt away from direction of spread. Less smoke is produced during a backing fire because most fuel is consumed during the flaming stage, a stage of combustion where primary smoke products include water vapor and carbon dioxide.

Category Day — A rating of weather factors (determined by calculating the ventilation rate) that helps prescribed burners minimize smoke impacts and assist with smoke screening. Category Day is rated from 1-5, with days 2 to 5 being the best days for reducing smoke impacts. Not all states utilize the Category Day method.

Combustion	The rapid oxidation of fuel in which heat and usually flame are produced. Combustion can be divided into four phases: preignition, flaming, smoldering, and glowing.
Complete combustion	Occurs when oxygen reacts with a fuel (vegetation, in the case of prescribed fire) to produce water and carbon dioxide. Combustion releases energy in the form of heat and light. Complete combustion leads to the maximum amount of energy released (heat) and is usually characterized by a blue flame.
Emissions	The production and discharge of greenhouse gas and other combustion byproducts.
Fire weather forecast	A weather prediction specially prepared for use in wildland fire operations and prescribed fire.
Flaming phase	The stage of combustion when the ignition temperature of the fuel is reached, and light emitting visible combustion begins.
Fuel	Any combustible material. Fuel carries a fire across the landscape. Surface fuels include dead or dry grass, agriculture residue, forest litter, slash, logs, brush, and standing dead trees. Ground fuels include duff, organic soil, and roots.
Fuel moisture sticks	Used to estimate moisture content of small forest fuels for prescribed burning operations and to determine forest fire danger.
Glowing phase	A stage of combustion that follows the smoldering combustion phase and continues until the temperature drops below the combustion threshold value, or until only non-combustible ash remains.
Heading fire	A type of ignition technique where fire moves in the direction of the wind and flames tilt in the direction of the fire spread. Heading fires lead to more intense fires compared to backing fires.
Incomplete combustion	Occurs when oxygen reacts with a fuel (vegetation, in the case of prescribed fire) to produce carbon monoxide, water, carbon, and other products. Incomplete combustion occurs when there is an insufficient amount of oxygen for the fuel to react with and, therefore, releases less energy (heat). Incomplete combustion is characterized by an orange flame.
Inversion	Very stable layers in the atmosphere that severely limit vertical motion within that layer.
Keetch-Byram Drought Index	A measure of meteorological drought based on soil moisture gain or loss.

Low Visibility Occurrence Risk Index	The Low Visibility Occurrence Risk Index (LVORI) indicates the potential for smoke or fog to negatively affect visibility.
Mixing height	Mixing height is the height to which relatively vigorous mixing occurs due to convection.
Mop-up	To reduce residual smoke after the fire has been controlled by extinguishing or removing burning material within the burn unit or along or near the control line. Mop-up is often considered an essential practice for securing a burn unit following a fire.
Nuisance smoke	When smoke interferes with activities, privileges, and rights of the public.
Particulate matter	Smoke contains tiny particles of solids and liquids known as particulate matter (PM), which are particles smaller than 100 microns. The PM sizes of greatest concern in smoke management are those less than or equal to 10 and 2.5 microns (written as PM_{10} and $PM_{2.5}$)
Pile/windrow fire	Following a forestry or agricultural harvest, debris (slash) is scattered across the landscape. To prepare for planting, slash is often pushed into piles or long rows (windrow) and burned. Piles and windrows, if not carefully planned, can lead to prolonged smoldering which affects transportation safety and creates nuisance smoke.
Plume	A convection column generated by combustion (of wildland fuel).
Point-source fire	An ignition technique using a grid or spacing of spot/dot ignitions.
Pre-ignition phase	The stage of combustion when volatile materials in the fuel are vaporized.
Prescribed fire	A wildland fire originating from a planned ignition in accordance with applicable laws, policies, and regulations to meet specific objectives.
Relative Humidity	Relative humidity (RH) is the ratio of the amount of moisture (water vapor) in the air to the amount the air can hold when saturated at the same air temperature. It is expressed as a percentage.
Ring fire	A fire started by igniting the full perimeter of the intended burn area so that the ensuing fire fronts converge toward the center of the burn. Set around the outer perimeter of a resource to establish a protective black-line-buffer.

Smoke screening	The distance and area to examine downwind of a burn site for potential, sensitive targets.
Smoke Sensitive Areas	Smoke Sensitive Areas (SSAs) are locations where individuals, groups of people, or other areas can be adversely affected by smoke and ash. SSA examples include airports, major highways, communities, recreation areas, schools, hospitals, nursing homes, subdivisions, residences, factories, individuals with respiratory conditions, livestock operations, etc.
Sling psychrometer	An instrument that contains a wet and dry bulb thermometer used to measure relative humidity.
Smoke Management Program	Smoke Management Programs (SMPs) are developed through a collaboration between land managers and air quality regulators in certain states to reduce smoke in populated areas and transportation corridors, prevent significant air quality deterioration and NAAQS violations, reduce impacts on Class 1 areas, and reduce or avoid nuisance smoke. As well, SMPs establish procedures for managing prescribed fire smoke, provide approval for burn plans and administer burn permits, make burners aware of local regulations and other burners in their area, and provide a plan for long term minimization of negative smoke impacts.
Smoldering phase	Phase of combustion immediately following flaming combustion. Emissions are at twice that of the flaming combustion phase.
Smoke dispersion	The decrease in concentration of airborne pollutants as they spread throughout an increasing volume of atmosphere.
Smoke management	Conducting a prescribed burn under specific field and meteorological conditions and with burning techniques that keep the effects of smoke and ash on the environment within acceptable limits.
Spot forecast	A special forecast issued to fit the time, topography, and weather of a specific incident. These forecasts are issued upon request of the user agency and are more detailed, timely, and specific than zone forecasts. Usually, on-site weather observations or a close, representative observation is required for a forecast to be issued.
Superfog	An extremely dense surface fog (water droplets suspended in the atmosphere) that reduces visibility to less than three meters (approximately ten feet).
Surface wind	Wind measured at a surface observing station, customarily at some distance (usually 30 feet) above the average vegetative surface to minimize the distorting effects of local obstacles and terrain.

Transport wind	The average speed or direction of all winds between the ground surface and the mixing height, or the mixing layer.
VSmoke-Web	A web browser based Gaussian smoke dispersal model that is commonly used in smoke screening.
Ventilation Rate	Calculated by multiplying the afternoon mixing height by the transport wind speed. Ventilation rate is used to calculate the Category Day.