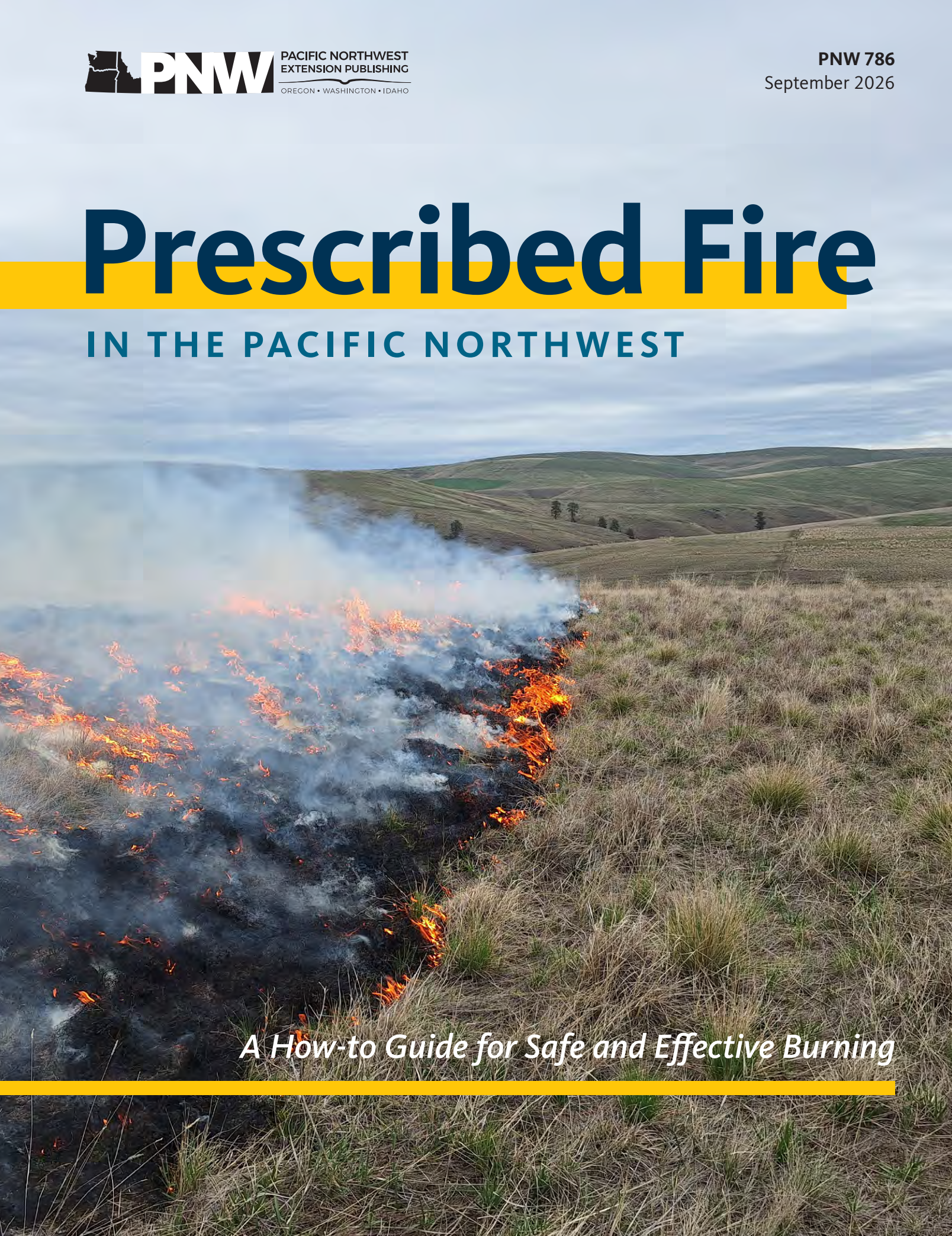
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Prescribed Fire

IN THE PACIFIC NORTHWEST



A How-to Guide for Safe and Effective Burning

AUTHORS

Carrie Berger (Editor), Manager, Oregon State University Extension Fire Program

Micah Schmidt, Northeast Regional Fire Specialist and Assistant Professor of Practice, Oregon State University Extension Fire Program

Heather Heward, Senior Instructor, University of Idaho

John Punches, Extension Forester and Associate Professor, Oregon State University Forestry and Natural Resources Extension

Chris Adlam, Southwest Regional Fire Specialist and Assistant Professor of Practice, Oregon State University Extension Fire Program

Aaron Groth, Coast Regional Fire Specialist and Assistant Professor of Practice, Oregon State University Extension Fire Program

Oregon State University Extension Service Fire Program

University of Idaho Extension

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SOUTHERN REGION GUIDEBOOK

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Image credit: Chris Adlam, © Oregon State University

WHY THIS GUIDEBOOK?

Prescribed fire is an essential tool for managing many habitat types and other natural areas in the Pacific Northwest. When carefully planned and implemented, it can improve wildlife habitat, reduce hazardous fuels to lower wildfire risk, promote ecosystem health and help maintain cultural traditions tied to fire. These benefits make prescribed burning a valuable practice for landowners and land managers across Washington, Oregon and Idaho.

However, learning to use prescribed fire safely and effectively can be challenging, especially for private landowners and others who have limited time, resources or access to training. Opportunities for education and hands-on experience vary widely by state and are not always available to everyone. This guidebook is not intended to replace existing programs or training but to serve as a practical reference and help fill gaps for those who cannot access other resources or want to deepen their understanding.

This guidebook is intended for readers who would like to gain an intermediate-level understanding of prescribed fire — those who have some familiarity with basic concepts but are not advanced burners. It is written primarily for private landowners, land managers and others who own or manage natural areas that could benefit from prescribed fire and who want to use fire safely and effectively as a land management tool. It is also suited for individuals interested in participating in or supporting burns through prescribed burn associations. While the content is not tailored to highly experienced practitioners, natural resource professionals and contractors who conduct burns as part of their work may find the information useful.

While this guidebook focuses on the Pacific Northwest, regulations and requirements differ by state. We provide general information to help you develop a burn plan and conduct a safe burn, but you should always confirm your state's specific regulations.

Pulling together all the information in this guidebook to plan and implement a burn may feel complex or challenging, but repeated burning with experienced individuals will help ground you in the principles of prescribed fire and build your confidence as a burner. We've included detailed information so you can use what's most relevant to your situation.



Image credit: Chris Adlam, © Oregon State University

HOW DO I USE THIS GUIDEBOOK?

This guidebook provides foundational information on fire-related topics and takes you step-by-step through the processes involved in planning, preparing for and conducting a prescribed fire. Each section is color-coded and includes checklists of activities to be completed, along with a timeline for each step. This guidebook will take you from the earliest planning stages to final evaluation of your burn.

This guide has two types of chapters: informational and action

Informational chapters provide more in-depth information on important fire-related topics. These chapters include helpful diagrams, descriptions and instructions for using prescribed fire.

Informational chapters:

- Weather
- Fuels
- Fire behavior
- Smoke management

Action chapters focus on the steps involved in prescribed fire from start to finish and include checklists of information to gather or actions to take. Each step in the checklist is described in enough detail so you can do what you need to do.

Action chapters:

- Getting started
- Planning
- Conducting
- Evaluating

Because pile burning is commonly used throughout the Pacific Northwest as a fuel-reduction tool, we included a dedicated chapter in the guidebook after the action chapters.

We strongly recommend that you seek guidance from your local state-prescribed fire program or agency, which can provide advice and recommendations tailored to your situation. A consulting forester, prescribed fire contractor, or an Extension fire or forest specialist may also provide helpful information.

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PRESCRIBED BURNING OVERVIEW

Section authors: Micah Schmidt and Chris Adlam

Image credit: Christina Friehauf

IN THIS SECTION

- ☐ What is prescribed fire?
- ☐ A historical overview
- ☐ Prescribed fire in the Pacific Northwest
- ☐ What is the purpose of prescribed fires?

What is prescribed fire?

Prescribed fire is the planned use of fire, applied under specified conditions to achieve land management objectives. This differs from wildfire, which is unplanned and can cause unwanted effects.

The main types of prescribed fire include broadcast burning and pile burning. Broadcast burning is igniting fire where it is intended to spread across the ground within a designated area. Broadcast burning under a forest canopy is typically called "understory burning" or "underburning."

Characteristics of prescribed burns

- ☑ Planned
- ☑ Applied in a set location, under specified weather conditions, and in a skillful manner
- ☑ Used to achieve specific objectives

Pile burning is igniting concentrated piles of woody debris ("slash") that were built by hand or with machinery. Pile burns generally aim to keep fire within the pile footprint, but fire may be allowed to "creep" outside of the pile footprint under some conditions. Broadcast and pile burning are both prescribed to meet specific land management objectives.

A historical overview

Native Americans have used fire in the Pacific Northwest for thousands of years to manage the land, sustain economies and resources, and as part of Indigenous lifeways. Their intentional ignitions created fire patterns and effects that differed from those that would have occurred if lightning were the only source of fire. For example, cultural burning helped clear travel routes along ridges and trails, kept woody species from filling in meadows and prairies, renewed forage for elk and deer, and enhanced the abundance and quality of food plants such as hazel, oaks, camas and huckleberries.

Patterns of fire over time, called fire regimes, were (and still are) diverse across the Pacific Northwest. In dry forests and river valleys, frequent, low-severity fires maintained widely spaced clumps and individuals of old, fire-resistant trees such as ponderosa pine, western larch, Douglas-fir and oaks. In moist uplands, with mixed conifer species, low- and moderate-severity fire maintained smaller "mosaic" patterns with diverse and shifting structure and composition. In wetter forests, such as the coastal Douglas-fir-dominated forests of the western Cascades and Coast Range, fire frequency and severity varied tremendously, resulting in a diverse landscape with forests of various ages, species compositions and structures. Grasslands and sagebrush ecosystems experienced periodic fires that maintained healthy bunchgrass and shrub communities with a diversity of forbs and helped limit juniper expansion.

Recommended video: *Fire Regimes*, https://www.youtube.com/watch?v=M97nw_3uKPQ

The displacement of Indigenous peoples, the suppression and prohibition of Indigenous burning, and the westward expansion of settlers and industry altered fire regimes across many parts of the Pacific Northwest. By the mid-1800s, in many settled valleys and prairies, ecosystems long influenced by Indigenous burning were experiencing fewer intentional fires, although lightning ignitions still occurred in some areas.

In 1910, wildfires burned 3 million acres in Montana, Idaho and Washington in only two days, devastating many newly established logging and mining communities. In response, the young (founded in 1905) U.S. Forest Service intensified a policy of aggressive wildfire suppression. By 1935, this approach was codified as the "10 a.m. rule," calling for all fires to be controlled by 10 a.m. the following day. Many state forestry and fire agencies soon followed.

These policies also greatly restricted the use of fire to manage lands for beneficial purposes, which had been adopted by many farmers, ranchers, forest landowners and timber companies. This caused heated debate between advocates of what was called "light burning" and people who favored total fire exclusion. In the decades that followed, agencies promoted the idea that all fire was destructive through extensive fire-prevention messaging, and the use of intentional fire on the landscape was drastically diminished.

Across much of the Pacific Northwest, ecosystems have shifted far from the diverse fire regimes described above, resulting in vegetation structures and species compositions to which many native plants are poorly adapted.

Wildfire suppression and the decline of prescribed fire have also altered the health and function of many forest and grassland ecosystems. Dry forests that were historically composed of widely spaced old trees are now crowded by dense thickets of young trees, increasing the risk of high-severity fire and contributing to the mortality of centuries-old trees. Large, sprawling oaks that once dominated oak savanna ecosystems are being overtopped and shaded out by conifers that were once kept at bay by fire. Grasslands that historically would have had few trees due to periodic fires are now encroached upon by junipers, shrubs and other conifers, leading to the decline of native grasses, shrubs and forbs.

Most of these changes, along with impacts from invasive species, past logging and grazing practices, climate change and urban development, have resulted in fire regimes that are drastically altered from those to which native vegetation adapted over thousands of years.

Prescribed fire in the Pacific Northwest

Today, we are relearning through a blend of Western science and Indigenous Traditional Ecological Knowledge that periodic fire plays an important role in most Pacific Northwest ecosystems. Fire helps restore landscapes while making communities safer by reducing the intensity of future wildfires.

Although much local burning knowledge and experience was lost, people in many parts of the Pacific Northwest are turning once again to the use of fire as an essential tool for land management. The declining vitality of fire-dependent ecosystems and the urgency of today's wildfire challenges are prompting the general public, landowners and managers, and decision-makers to reconsider the role of fire on the landscape.

What is the purpose of prescribed fires?

Prescribed fire is a multifaceted management tool for forests, grasslands and other ecosystems. In the Pacific Northwest, prescribed fire is commonly used to improve forest health and resilience, dispose of debris from logging or thinning, control invasive species and woody encroachment into pastures and prairies, and conserve biodiversity in fire-adapted ecosystems. A successful prescribed burn program strives to bring back a fire interval aligned with the historical fire regime in order to reap the ecological benefits of fire.

Prescribed fire can also be an economical way to manage vegetation that poses a wildfire hazard to timber resources, infrastructure and nearby communities. It removes small trees and shrubs, forest litter and dead wood, thereby reducing the intensity of any future wildfires.

Areas of recent prescribed burns that subsequently experience wildfire have shown greater resilience. As fire enters these forests, it transitions from crown fire to lower-severity surface fire, sparing overstory trees. Areas that are thinned but not treated with prescribed fire tend to be less resilient to severe wildfire.

Prescribed burning can also be used to promote non-timber forest products and habitat for wildlife in the understory. For example, frequent fire tends to favor understory plant species that provide good forage for herbivores. The regrowth of shrubs after fire is more palatable for deer and elk and contains a higher protein content that is especially needed during these animals' lactation period. Patches of understory regrowth of different ages also ensure the presence of productive berry- and nut-producing shrubs, which provide food for many species of birds and mammals. Landowners often report seeing more wildlife and a greater diversity of species after a burn.



Three areas affected by the 2021 Bootleg Fire show different responses to fire. At left, a section that had been thinned suffered significant loss, while some trees survived. The section in the center, which had been thinned and treated with prescribed fire, appears healthy. The section at right, which did not undergo thinning or prescribed fire, burned intensely, as evidenced by the blackened trees. Credit: Steve Rondeau

How plants have adapted to fire

Fire-adapted tree species in the Pacific Northwest include ponderosa and sugar pine (*Pinus ponderosa* and *P. lambertiana*), western larch (*Larix occidentalis*) and Oregon white oak (*Quercus garryana*). Adaptations to frequent fire include:

- Thick bark to protect vital tissues.
- Self-pruning lower limbs (common in pines) to reduce fire spread into the canopy.
- Dormant buds (seen in oaks) that allow regrowth after fire scorches the branches.

Fire-adapted understory plants also have a variety of protective traits. Most broadleaf shrubs resprout from the root crown, allowing them to quickly grow back if the above-ground parts of the plant are killed. Herbaceous perennial plants can regrow from underground roots, rhizomes or bulbs. Some species have seeds that germinate only through heat, smoke or when the seed coat is damaged in some way, as is the case for some manzanita and ceanothus species.

A few species that tend to grow in areas with less historic fire are fire-sensitive. But with proper planning, prescribed burns will benefit most species in some way.

Prescribed fire also maintains open habitat that is favored by sun-loving grass and wildflower species, which in turn provide the base of an entire food web of pollinators, songbirds and other wildlife. These open habitats include meadows, prairies, oak savannas and pine forests that are home to many species whose habitat has been drastically reduced by forest densification resulting from fire exclusion.

In some areas, ranchers commonly use fire to promote forage for livestock grazing. Burning eliminates competing woody vegetation and recycles important nutrients to enhance the next growth of forage species. Some introduced forage species, such as subterranean clover (*Trifolium subterraneum*), are promoted by fire and favored for their high protein content. Burning can also clear the ground to improve success when applying new seed. The resulting gains in productivity may reduce fertilizer costs and the need to use herbicides to control unwanted species.

Lastly, restoring land with prescribed fire can be rewarding and fun. Users often form trust, relationships and a community around their burning activities. In areas where prescribed burning is still a common practice, it is often a family and neighborhood affair.

Prescribed burn associations in particular embrace this community-oriented approach. PBAs bring people together to make the task of returning fire to the land safer and more accessible. Communities in wildfire-prone areas become empowered by learning about fire's role and working with others to secure its benefits.



Prescribed burn association members know that many hands make light work. Credit: Chris Adlam, © Oregon State University

Cultural burning and prescribed fire: Working together at Chaa-lamali

An interview with cultural fire practitioner Joe Scott, by Jessica Douglas (Confederated Tribes of Siletz Indians)

Long before prescribed fire became a management tool used by settler landowners and agencies, Indigenous communities across Oregon used cultural burning to sustain food systems, materials, medicines and the health of the land. Cultural burning is practiced in many different ways by different tribal nations and families across the state. At Chaa-lamali, a remnant oak savanna in the Long Tom watershed southwest of Eugene, cultural fire is used to promote youth leadership, ecological restoration and renewed relationships between Indigenous fire practitioners and prescribed fire partners.

The Traditional Ecological Inquiry Program was founded in 2017 by Joe Scott, a member of the Confederated Tribes of Siletz Indians, to support Native youth and families in inquiry-based ecological learning. Following projects rooted in fire ecology and Indigenous science, fire becomes not only a tool but a teacher.

> **"Youth get to explore fire with curiosity and healthy risk," Joe explains. "They're learning through the whole life cycle of the land — spring, summer, fall, winter. They're seeing the plants they burn in their fullness, not just on a burn day."**

It's a long relationship, not a quick one.

In early fall of 2025, the program and partners carried out a cultural burn at Chaa-lamali. It was the culmination of a partnership with the EcoStudies Institute, Oregon State University Extension, the Long Tom Watershed Council, Oregon Woods, McKenzie River Trust, the Oregon Department of Forestry, Lane Regional Air Protection Agency and many community volunteers supporting planning and logistics.

The most meaningful aspect of the burn, Joe notes, was the youth and cultural practitioners setting the pace, guiding ignition decisions, and leading with curiosity and knowledge of the land.

"Their curiosity [the youth] drove the day," Joe says, reflecting on the success of the burn.

On the day of the burn, prescribed fire practitioners and agencies stepped back, breaking with prescribed burn's typical focus on technical expertise, organizational hierarchy, and checking logistical and regulatory boxes. The collaboration upheld traditional approaches because partners instead offered support for the youths' experience and cultural mentorship.

"That's when I saw prescribed fire and cultural burning really supporting each other," Joe says.

For Joe, this was an example of prescribed fire supporting cultural burning rather than overshadowing it. Joe emphasizes that prescribed fire has a critical role in Oregon's fire-adapted landscapes, especially at large scales. But he also notes that cultural burning brings something prescribed fire often does not: Deep connection to place, food sovereignty and ongoing relational stewardship.

"If you're driving an engine through a camas meadow, you're not really connecting with the plants," he says.

Cultural burning is inseparable from tending foods, materials, medicines and ceremonies.

Partnerships work best, Joe notes, when prescribed fire practitioners recognize and defer to these community-held priorities. Meaningful allyship includes early communication, genuine consultation and respect for Indigenous leadership, not simply inviting a cultural practitioner to "say a few words" at the start of a burn. Partnerships also involve understanding whose land you are burning on, who has cultural responsibilities there, what plants or materials matter to tribal communities, and creating pathways for long-term access to culturally important sites.

Chaa-lamali is only one story, but it shows what becomes possible when prescribed fire practitioners support and honor cultural burning. While this guidebook is focused on prescribed fire, readers are encouraged to learn about fire's role in Oregon's cultural and ecological landscape. Through partnerships grounded in respect and reciprocity, prescribed and cultural fire practitioners can work together to restore the role of fire in supporting the communities and ecosystems that have depended on it for generations.



Image credit: Christina Friehauf

Informational chapters

LEARN THE BASICS

WEATHER 14
How weather conditions influence your burn and steps to minimize your risks

FUEL 30
How fuel types, loads, continuity and arrangement impact your burn

FIRE BEHAVIOR 50
Types of firing patterns, fire intensity and more

SMOKE MANAGEMENT 74
Minimizing the impact of smoke is a key component of your burn



WEATHER

Section author: Micah Schmidt

Image credit: Micah Schmidt, © Oregon State University

IN THIS SECTION

- Introduction to fire weather
- Weather factors
- Weather forecasts and monitoring resources
- Weather observations
- Fire indices and tools

Introduction to fire weather

Knowledge of weather conditions and their effects on fire behavior is crucial to conducting safe and effective prescribed burns. Understanding how weather factors affect fire starts with the most pertinent basic weather principles. While you can't manipulate or control the weather, being aware of its influence on prescribed fire will help set you up for success.

Weather conditions directly affect fire behavior, the likelihood of achieving management objectives and the amount of smoke produced, as well as how long the smoke lingers in the area and the direction it travels. Burning under unfavorable weather conditions could reduce the likelihood of achieving ecological objectives, raise the risk of escaped burns and leave lingering smoke that reduces road visibility or affects smoke sensitive communities. When burn prescriptions are developed, the range of values for different weather conditions is selected to meet prescribed burn objectives and to minimize smoke and the time it takes to disperse.

In preparation for burning, monitor weather forecasts in the days and weeks leading up to a likely burn day. Follow forecasts to watch for the right general set of weather conditions for your burn. If the general forecast conditions are suitable for your burn, obtain more accurate and specific fire weather forecasts and on-the-ground observations. This is important because weather conditions change from day to day and hour to hour. Monitoring these conditions is an ongoing task.

Generally, temperatures will rise and humidity levels will drop from morning to afternoon. Wind speed can increase or decrease, or change direction, and cloud cover can allow more or less sunlight to reach the burn unit. These fluctuations in daily and hourly weather conditions

will influence whether you can burn on a particular day, when you start your burn, your ignition techniques and fire behavior.

Weather forecasts provide general information and probabilities, but elements like temperature, wind speed and direction, and relative humidity must be measured and documented on-site before and throughout the burn to ensure you capture the actual weather on the burn unit. Fortunately, there are many tools for quantifying weather conditions and resources for accessing weather forecasts.

The National Weather Service and some state forestry agencies provide weather information specific to burning. On-the-ground observations can be captured with tools ranging from a basic thermometer and rain gauge to more sophisticated portable weather stations. The most common on-site weather tools are Kestrels and belt weather kits. This section provides information and a checklist on weather factors, weather observations and indices, smoke management, and fire behavior.

Weather factors

Temperature, relative humidity and wind are the three most important weather elements for prescribed fires. These elements influence each other and are also influenced by a range of other factors, including the season of the year, cloud cover, topography, vegetation, and more (Figure 1.1). See Table 1.1 for a more comprehensive list. Other weather elements to consider include atmospheric stability and cold and warm fronts. It is important to be familiar and comfortable with these essential weather elements when conducting a prescribed burn.

Recommended video: Introduction to Fire Weather, https://www.youtube.com/watch?v=1uk3gm-VUI8

TEMPERATURE

Atmospheric temperature (also referred to as "dry bulb temperature") is a measure of the hotness or coldness of the air and can be calculated with a standard thermometer on site. Burn prescriptions often start with selection of a desired range of values for temperature, as temperature influences the moisture of fuels. Higher air temperatures will dry fuels out faster, even if the relative humidity levels stay the same.

Exposure to direct sunlight can also contribute to drier and warmer fuels, which makes them easier to ignite. Water in fuels evaporates more rapidly when the air is warm, which means less heat energy from a fire is needed to reduce the fuel moisture and then preheat and ignite the fuel.

Air temperature also affects personal and crew safety — extreme temperatures can cause dehydration and heat exhaustion/stroke.



Figure 1.1. Topography can impact all weather variables. Burns in the mountains will differ from burns in valley bottoms. Credit: Micah Schmidt, © Oregon State University

Temperature: A measure of how hot or cold the air is.

Relative humidity: A value used to capture the amount of moisture content in the air and is recorded as a percentage of the total possible water that the air can hold at a given temperature. Complete saturation at a given temperature is equivalent to an RH of 100%.

Wind: The natural movement of any air of any speed or direction, caused by the earth's unequal heating.

Weather front: a boundary separating two masses of air with different densities.

Atmospheric stability: refers to how "active" weather patterns are a measure of how a parcel of air moves when it is pushed upwards by daytime heating or topography.

RELATIVE HUMIDITY

Relative humidity is a relative measure of the moisture content of the air as a percentage of the total possible amount of water vapor that the air can hold at a given air temperature. It is the single most important weather factor in the drying of fine fuels. The lower the relative humidity, the faster fuels will dry. The relative humidity is typically highest at daybreak and then decreases as the day warms. Since warm air can hold more moisture at saturation than cold air, the relative humidity of a given air parcel drops as its temperature rises (see Figure 1.2).

Recommended video: The Relationship Between Relative Humidity, Fuel Moisture, and Fire Behavior, https://www.youtube.com/watch?v=FUdPfKL8lXA&list=PLDqziABG8_L45o3y0h7qHBbsrqOUluim5&index=2&pp=iAQB

For every 20°F increase in temperature, the relative humidity will be reduced by approximately one-half. Conversely, the relative humidity roughly doubles with every 20°F decrease in temperature until the air becomes saturated. The minimum relative humidity is generally reached in the early afternoon and coincides with the maximum temperature.

The dew point is the temperature at which the air can no longer hold all its moisture, causing saturation (relative humidity = 100%). If the air continues to cool, moisture will change from a vapor to a liquid and heat will be released (called the heat of condensation). This is the process that causes dew to form. If the dew point is below freezing, then frost will form instead of dew. Clouds form when rising air cools and reaches the dew point temperature. Fog is simply a cloud in contact with the ground (Figure 1.3).

Fuel moisture depends in part on relative humidity and is an important factor in burning. Moist air has a cooling effect on fuels. As relative humidity increases, the fine fuel moisture also increases, since these fuels absorb water from the air. Moist fuels need more heat to burn than dry fuels. Heat from a fire is required to change liquid water (in the moist fuels) into vapor (heat of evaporation). Once the water in the fuels has evaporated, the fuels will ignite. Relative humidity can therefore be used to help regulate fuel consumption by affecting fuel moisture content.

Weather condition	What affects it?
Temperature	• Air mass • Shading vegetation • Wind • Humidity • Temperature inversions • Season of the year • Cloud cover • Topography • Aspect • Elevation • Proximity to large bodies of water • Inversions
Relative humidity	• Topography • Wind • Clouds • Vegetation • Air masses or fronts • Temperature • Water sources
Wind	• Topography and water • Diurnal variation • Vegetation • Eddies • Frontal boundary • Slope effect • Thunderstorms • Sea breezes

Table 1.1. The variables that affect each of the three main weather conditions. Adapted from John Weir (2009).

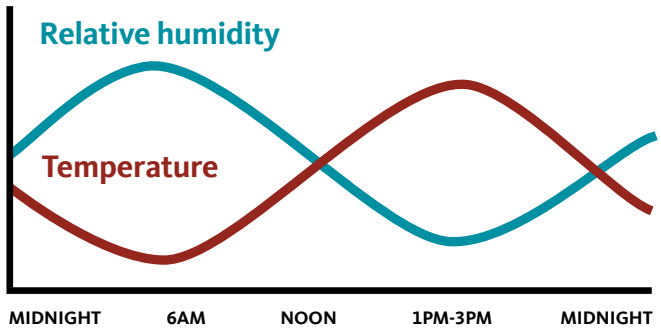
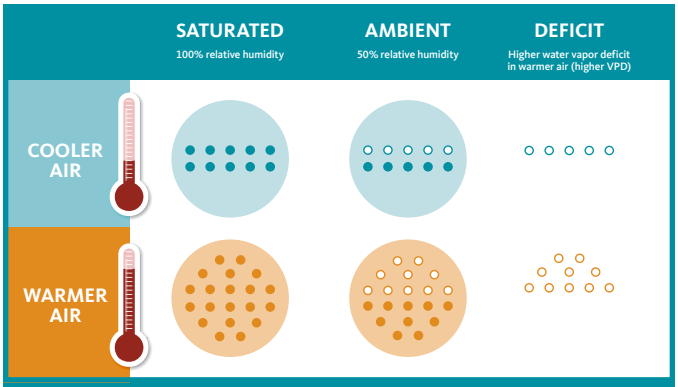


Figure 1.2. The relationship between relative humidity values and the temperature changes throughout the day and night.



Figure 1.3. Relative humidity is higher in the morning, which is why fog often forms at that time of day. Credit: Sarah McNair



Vapor pressure deficit is not a value reported in forecasts or weather observations for prescribed fires, but it is an increasingly important metric for understanding how "thirsty" the air is for moisture, which affects fuel moisture and fire behavior. Relative humidity gives a percentage, but that might not represent the actual space in the air. A low VPD (for example, 0.2 kPa) indicates that the air has little capacity to hold more water; thus, fuel moisture does not change. A high VPD (for example, 3.8 kPa) indicates that the air has a large capacity for more water, and that live and dead fuels dry faster.

VPD is most commonly used in greenhouse plant production to maximize growth. In nature, when the VPD is high, living plants will be stressed and dry and may be more likely to carry fire. For example, if you have had prolonged periods of time with high VPD, trees may be more likely to torch.

VPD graphic credit: © Oregon State University, adapted from Jeanette Roe, https://www.youtube.com/watch?v=Gq_ke7uqAVs.

As relative humidity rises, a patchy burn should be expected. On the other hand, under low relative humidity conditions, the air absorbs moisture in the fuel, rendering the fuels more flammable.

Recommended video: Temperature and Moisture Relationships, https://www.youtube.com/watch?v=Gq_ke7uqAVs&list=PLDqziABG8_L45o3y0h7qHBbsrqOUluim5&index=5

One-hour or fine fuels are fuels such as grass, pine needles, moss, twigs and slash less than ¼-inch in diameter. They dry out faster than other coarser fuels.

An increase in relative humidity results in an increase in fine fuel moisture. The lower the relative humidity level, the faster fuels dry.

In general, the lower the relative humidity, the better the burning conditions. However, spotting (where sparks or embers carried by the wind ignite a new fire outside the burn unit) can become a major problem when relative humidity drops too low. In part, this is because there is no longer enough moisture in the air to extinguish small firebrands. The main reason is because the top layer of litter becomes increasingly dry and receptive to ignition.

WIND

Wind is defined as the movement of air, the direction and speed of which is determined by the distribution of pressure centers and local topography. Wind direction is always expressed as the direction from which the wind is coming (Figure 1.4). For example, winds coming from the south and blowing toward the north are referred to as "south winds."

Wind direction is important, as it can help forecast what kind of conditions winds are bringing. West winds in Western coastal states tend to bring cool, moist air from the oceans, resulting in less extreme fire weather conditions, while east winds tend to bring warm, dry air that can dramatically increase fire behavior.

Like many weather factors, wind direction and speed can be difficult to forecast. The speed and direction of wind will influence fire behavior, including how quickly the fire

spreads, where it travels and the direction that smoke is transported. Wind also increases spotting potential and dries fuels more quickly.

To help meet your burn objectives, determine the desirable range of wind speeds and directions for your prescribed burn plan. Avoid unfavorable wind, which might cause challenges in your burn and for smoke management.

Wind is affected by topography, including slope and terrain features. Tall vegetation such as trees may lift the wind and shelter the area beneath them. Consult with experienced burners who are familiar with local wind patterns near your burn unit to help understand the typical winds that occur there.

Types of wind and measuring wind speed

There are two broad types of winds, — general and local — although in practice, it is difficult to separate them. General winds are those affecting a large area, such as an entire state. Winds form as air moves from high-pressure areas towards low-pressure areas, and then the direction is bent by the rotation of the Earth.

Local winds occur on a much smaller scale and are generated by local weather and terrain. Essentially, local winds are the ones that a person on the ground can measure or feel. These winds can also be caused by differing temperatures between land and water bodies. Some examples are a sea breeze or land breeze. Some local areas have consistent winds that fire managers need to be aware of, such as those that often blow at high speeds east or west through the Columbia River Gorge.

Wind speed is measured in miles per hour, and forecasts may include gusts, which are brief bursts of higher wind speed. At a burn site, wind is usually measured at eye level because that directly influences fire behavior. However, standard fire weather forecasts report wind speed at 20 feet above the tallest vegetation, known as the 20-foot wind. If you are burning in a forested area with a tree canopy that is 60 feet tall, the 20-winds represent the winds at 20 feet above the tree canopy, which would be 80 feet above the ground. These winds are generally stronger than eye-level winds in forested areas because vegetation and terrain reduce wind speed near the ground. In contrast, general weather forecasts often use 10-meter (33-foot) winds, the standard meteorological height. Local features such as trees, drainages, and slopes can further

Typical wind measurements used for prescribed fire
Measured in miles per hour

Wind speed	The speed of wind and the speed of gusts over 5 mph higher than the average wind speed in the forecast.
Wind direction	The prevailing direction the wind comes from. Wind direction may be a range, such as from north to northeast or south to southeast.
Surface wind (20-foot winds)	A measure of wind speed 20 feet above any vegetation, including the tree canopy. It is also called the surface wind speed.
Midflame wind (eye-level wind)	Measured at eye level in the burn unit. As wind becomes stronger (increases in speed), fire intensity also increases.
Canopy wind	Wind measured within a timber stand.

Table 1.2. Typical wind measurements used for prescribed fire.

Wind directions
The direction wind is blowing **from**.

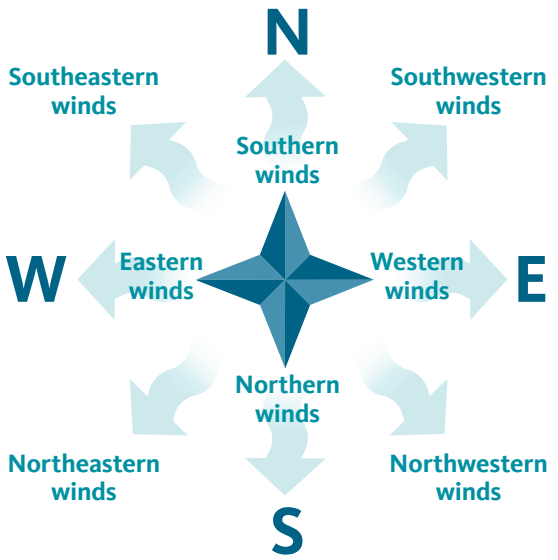


Figure 1.4. Wind direction is always expressed as the direction from which the wind is coming. Credit: Jessica Shaklee

alter wind speed and direction, so these effects should be considered when planning a prescribed burn. Always confirm which wind height your forecast represents, as this is critical for accurate fire behavior predictions. See Table 1.2 for a description of terms.

Wind and fire behavior

Wind speed and direction strongly affect how a fire behaves. Wind affects both the supply of oxygen to a fire, the dispersion of smoke and the rate at which exposed fuels dry. Sudden gusts or shifts in wind direction are the leading causes of escaped prescribed fires. High winds supply more oxygen, which can cause fires to behave erratically but also generally leads to better smoke dispersal. Conversely, low wind speed can cause smoke to linger. When winds are calm, particularly in flat areas, fire spread may become more unpredictable, as the fire spreads slowly and irregularly towards available fuels. In these conditions, ignition patterns or burning strategies that depend on specific wind directions may be ineffective.

Recommended video: Wind and Its Impact on Fire Behavior, https://www.youtube.com/watch?v=wp1oR-KQUss&list=PLDqziABG8_L45o3y0h7qHBbsrqOUluim5&index=6&pp=iAQB

It is imperative that the wind speed and direction on a prescribed burn fit within prescription parameters to maintain control of the burn, achieve the desired fire effects and satisfy smoke-management constraints. Local wind patterns should be considered when planning firebreaks and burn unit boundaries, and throughout the ignition and mop-up phases.

Factors that affect wind speed

Stand density and understory density can influence wind speed within a forest (Figure 1.5). Stand density refers to the density of canopy or midstory trees found within an area. Understory density refers to the density of the shrubs, small trees and herbaceous plants that make up the forest understory.

Wind tends to change direction and speed as it moves around and over ridges, swamps, lakes and rivers. Urban areas, large obstructions and constant heat sources such as airports or parking lots can also influence wind patterns. Confluences of canyons and drainages can also have erratic winds.

Potential airflow obstructions

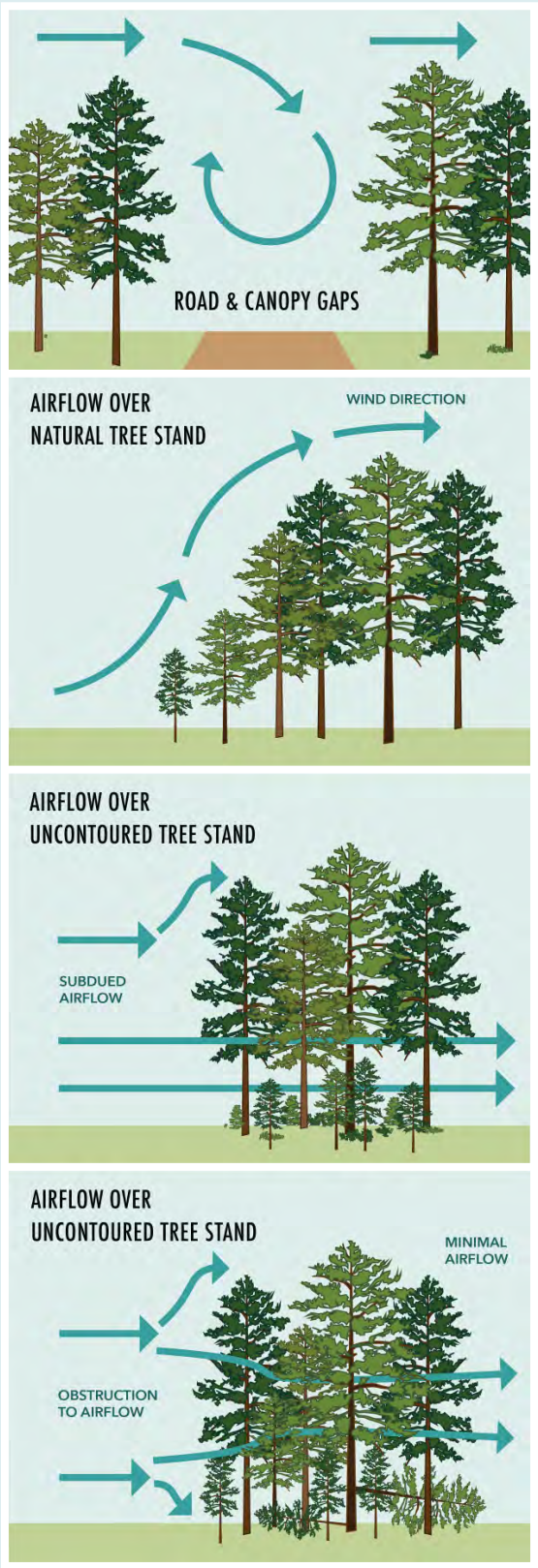


Figure 1.5. Airflow throughout and around stands is determined by stand structure and obstructions within the stand. Credit: Jessica Shaklee

Hilly or mountainous terrain also affects wind flow. Valleys channel wind and influence its direction. During the day, winds blow upslope as solar radiation heats the surface. At night, wind flow is generally downslope because of radiational cooling.

When burning in mountainous or hilly terrain, topography must be considered in the ignition plan. In calm conditions, slope orientation can effectively guide fire spread. For example, igniting a fire at the bottom of a slope will produce a head fire traveling upslope, whereas igniting a fire at the top of a slope will result in a backing fire moving down the slope (see "Fire behavior" for more information on head and backing fires).

Heading fire: Fire that moves with the wind
Backing fire: Fire that moves against the wind

ATMOSPHERIC STABILITY

The atmosphere is made up of several layers, including the troposphere, stratosphere, mesosphere, thermosphere and exosphere. The troposphere is the layer closest to the ground, and it's where weather happens. In this layer, the air usually gets colder as you go higher. This change in temperature allows air to move up and down, mixing the atmosphere.

The stability of the atmosphere describes how air behaves when it is pushed upward. During the day, the sun heats the ground, which warms the air near the surface. Warm air is lighter than cool air, so it rises. As it rises, it cools until it is the same temperature as the air around it.

In an unstable atmosphere, a rising parcel of air remains warmer than the surrounding air, allowing it to continue rising. In a stable atmosphere, a rising parcel of air becomes cooler and heavier than the air around it, causing it to stop or sink. Sunny days often warm the air near the ground more than the air above, creating unstable conditions that promote vertical movement, with warm air rising and cool air sinking. On sunlit slopes, this heating can also create upslope winds as the air moves upward along the terrain.

Recommended video: Atmospheric Stability and Wildland Fire, https://www.youtube.com/watch?v=1GXB26R6_Rg&list=PLDqziABG8_L45o3y0h7qHBbsrqOUluim5&index=7&pp=iAQB

The height at which vigorous mixing of the air occurs because of convection and turbulence is called the mixing height (Figure 1.6). Mixing height is important because it is the height at which smoke will be mixed with the surrounding air and dispersed by transport winds. In

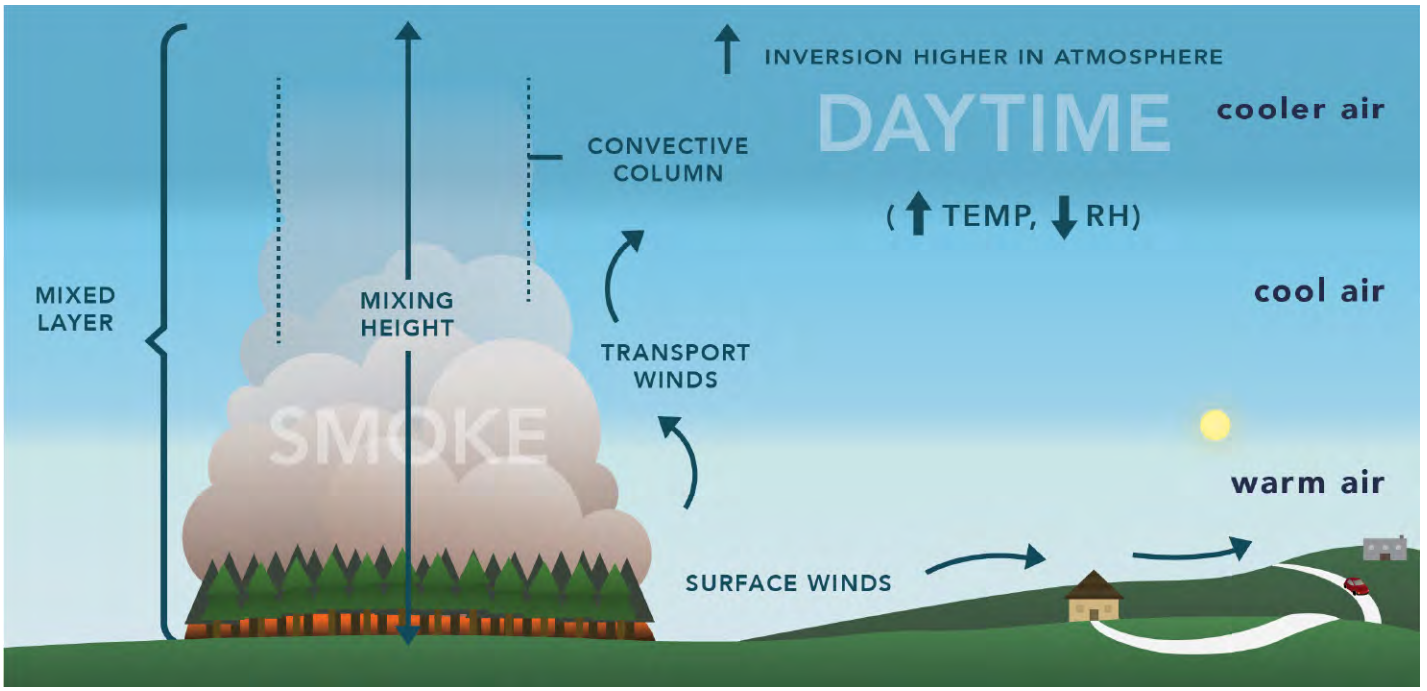
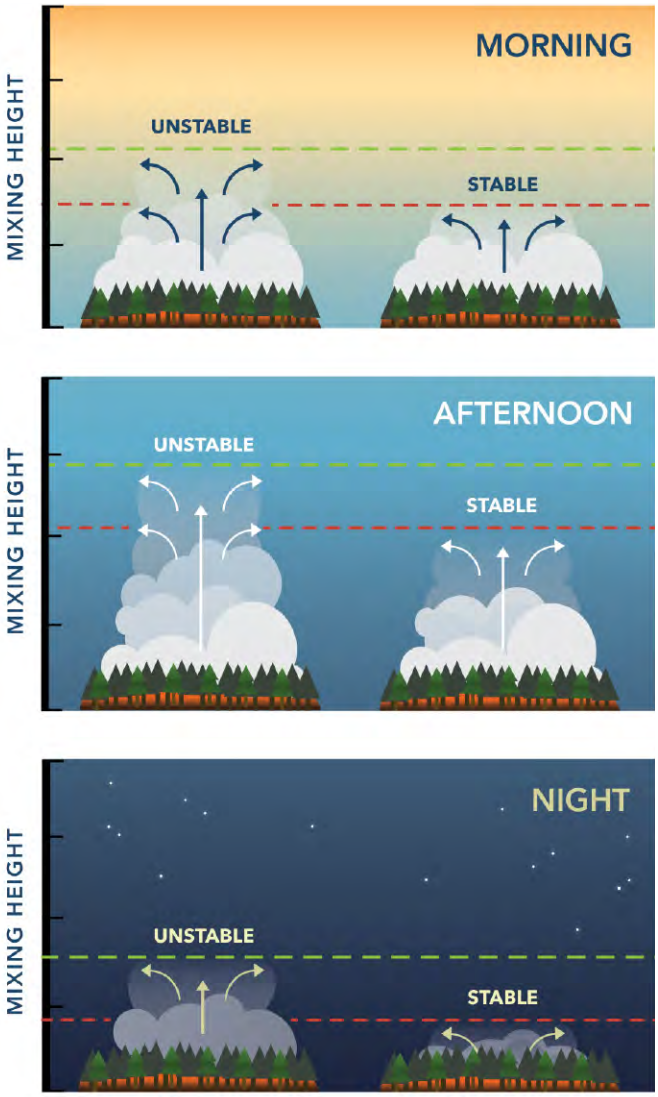


Figure 1.6. Atmospheric and weather conditions and how they may influence smoke behavior during the day. Credit: Laura Costa, Southern Regional Extension Forestry



general, the more unstable the atmosphere, the higher the mixing height. Higher mixing heights are common in summer, while lower mixing heights are common in winter. Mixing heights also change during the day, since solar heating raises the mixing height and lack of sunshine at night allows a more stable, lower mixing height overnight (Figure 1.7). This is why smoke settles in valleys overnight. Mixing heights vary dramatically, ranging from near the surface of the earth to thousands of feet up into the atmosphere.

Atmospheric stability strongly controls smoke dispersal and affects fire behavior (Table 1.3). An atmosphere that is more stable means that it is more resistant to air or smoke rising, whereas an unstable atmosphere is less resistant. An unstable atmosphere can be better for managing smoke from prescribed fires because smoke and combustion products can rise quickly, and the smoke tends to remain in a column. However, a well-defined smoke column can also affect fire behavior and make it more difficult to contain the fire. If atmospheric conditions are extremely unstable, there is a higher potential for extreme fire behavior.

Figure 1.7. Stable and unstable atmospheric conditions at different times of day and the corresponding changes in mixing height. Credit: Jessica Shaklee

	Unstable atmospheric conditions	Stable atmospheric conditions
Visual indicators	• Good visibility • Puffy clouds high in the sky • Gusty winds	• Poor visibility, smoke or haze • Fog, thick layers of heavy clouds • Inversion
Effects on fire behavior	• Smoke columns stay together, are tall and rising • Increased likelihood of fire whirls and dust devils • Gusty and erratic winds • The height and strength of convection and smoke columns often increase significantly during unstable atmospheric conditions • Increased likelihood of firebrands being lifted to great heights • Higher intensity fires due to increased vertical motion and high inflow wind feeding the fire new oxygenated air	• Poor smoke dispersion as the smoke column does not rise, but drifts apart • Decreased wind activity or air movement, which limits fire growth and intensity • Low intensity fires, as there is not much inflow of fresh air • Low wind speeds and fire spread rates (except in hilly terrain)

Table 1.3. Visual indicators of atmospheric stability and its effects on fire behavior. Adapted from *Guidebook for Prescribed Burning in the Southern Region*

As the sun sets, radiative cooling lowers the temperature of the Earth's surface and the adjacent air. This cooler air hugs the ground and flows downslope along drainages to lower elevations. These conditions can result in a layer of warm air that forms at a higher elevation. This is called an inversion. An inversion leads to stable atmospheric conditions and will trap smoke low in the atmosphere, potentially causing air quality issues. Inversions are often strongest during cold winter nights. As the sun heats the Earth's surface the following day, the air above it warms and rises, disrupting the nighttime temperature inversion, typically by midmorning.

FRONTS

A front is defined as the boundary or zone separating two air masses of contrasting density. An air mass is a broad region of air with uniform temperature and humidity. Fronts exist because the Earth does not heat evenly, and warm air moves towards the north and south poles, while cold air moves towards the equator or tropical areas. Fronts are described as warm or cold depending on the temperature of the air mass relative to the temperature of the air that it is replacing. Cold fronts develop when cold, denser air forces warm, moist air aloft. The cold air, which is denser, overtakes the warm air, moving forward by sliding beneath it and forcing the warm air mass upward off the ground (Figure 1.8). Table 1.4 shows how cold fronts may cause common weather changes.

Dry cold fronts can be a serious concern for fire managers in Oregon, Washington and Idaho. These weather systems don't always bring rain, but they often bring strong winds, low humidity, and unstable air — a mix that can quickly turn a safe prescribed burn into a dangerous situation. As a dry cold front approaches, the pressure difference in the atmosphere increases, causing wind speeds to rise.

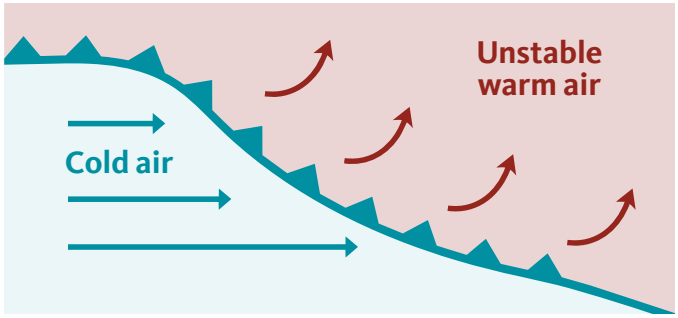


Figure 1.8. The heavier, cold air slides underneath the warm air, forcing it upward. Credit: Jessica Shaklee

These gusty winds can push flames beyond control lines. After the front passes, winds may shift direction suddenly, making fire behavior harder to predict and control. Dry air ahead of the front leads to a drop in relative humidity (RH), causing fuels to dry out.

The dry air also makes the atmosphere unstable. This instability helps smoke rise and spread out (which is good for air quality), but it also increases the risk of spotting and erratic fire behavior.

Unlike typical cold fronts, dry cold fronts bring little moisture. To stay safe, fire managers should avoid burning when a dry cold front is expected. If a burn must happen, conduct it early in the day before winds and instability increase. This timing can be challenging to forecast. Using smaller burn units, extra crews and real-time weather updates can help reduce risk.

Warm fronts, which are warmer than the air they displace, typically bring clouds and rain. Both types of fronts can occur year-round. Some fronts are stronger than others because of differences in humidity and temperature. Warm fronts are seldom associated with optimal prescribed burning weather.

Cold fronts may cause these common weather changes	
Weather factor	**Change**
Wind direction	Can change drastically throughout a burn
Wind speed	Increases up to 20 mph — higher speeds often occur at higher elevations
Temperature	Decreases of 5°F to 30°F as the front passes
Relative humidity	Decreases 10% to 30%
Rainfall / precipitation	May or may not be part of cold front, depending on amount of moisture present and density differences

Table 1.4. Cold fronts can cause changes in wind direction, temperature, relative humidity and other weather conditions.

ATMOSPHERIC PRESSURE SYSTEMS

Weather changes are caused by the different amounts of solar energy that regions of the planet receive at any time. Atmospheric pressure results from the weight or mass of the atmosphere, which is affected by the force of gravity. The distribution of atmospheric pressure is closely linked to weather patterns, especially because air moves in response to pressure differences.

Low-pressure centers are areas with lower pressure than the surrounding region. High-pressure centers are the opposite. Low-pressure systems have inward and rising air motion, spinning in a counterclockwise direction in the Northern Hemisphere, leading to cooling and increased relative humidity.

When the air flows into a low-pressure system from all sides, it is called convergence, as the air must move, and it can only rise because of the ground below. In high-pressure systems, air flows outward, spins clockwise in the Northern Hemisphere, and descends. Lines of low pressure are called troughs, while lines of high pressure are ridges.

In high-pressure systems, air flows down and out, and there are often clear skies and sunshine with few clouds. In low-pressure systems, the air flows in and up, and the water in the air condenses, forming clouds that can grow big enough to become a storm (Figure 1.9). Temperature differences and moisture content disparities generally produce more active fronts. Areas of low pressure are often associated with frontal weather.

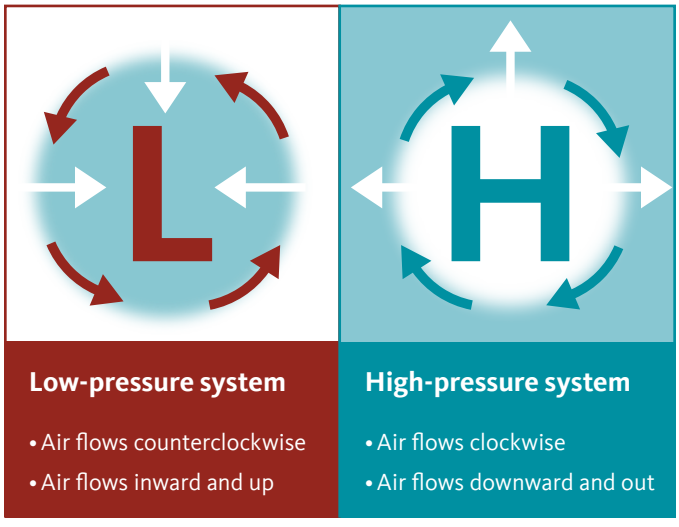


Figure 1.9. The formation of high- and low-pressure frontal systems.

Highs and lows are associated with different weather conditions that can also affect fire behavior. For example, when atmospheric pressure changes quickly, wind speed increases. Typically, higher wind speeds prevail in low-pressure systems, and strong wind speeds occur in the center of the lows. High-pressure systems have low wind speeds and weak pressure gradients near their centers. Areas with low pressure are associated with fronts, and the fronts tend to form in the troughs of lower pressure.

Weather forecasts and monitoring resources

National Weather Service fire weather forecast and fire weather dashboard

The National Weather Service produces an online fire weather forecast useful for burning (Figure 1.10). This forecast is more comprehensive than typical weather forecasts, as it also reports on the chance of wetting rain (CWR), humidity recovery, mixing height, transport winds and ventilation index. These forecasts are for fire weather zones that cover large geographical areas, so they are not specific to an area as small as a burn unit.

Recommend video: Guide to Fire Weather Forecasts, https://www.youtube.com/watch?v=cqiTwD8mn7w&list=PLDqziABG8_L45o3y0h7qHBbsrqOUluim5&index=1&pp=iAQB

The fire weather dashboard, https://www.weather.gov/dlh/fwd, is also helpful for forecasts across the U.S. on forecasted fronts and weekly, daily and hourly weather summaries.

National Weather Service hourly forecast

In addition to the fire weather forecast, you can view weather forecasts specific to an area by going to the seven-day forecast for the nearest town on the National Weather Service website and using the map on the right side to click on your location. A box will display the location and its detailed forecast. View the hourly weather forecast under the “Additional Forecasts and Information” section. This is helpful for monitoring temperature, relative humidity, wind and other parameters forecasted at different times during the day.

Fire Weather Discussion

```
NUS56 KPDT 091351
FWFPDT

Fire Weather Planning Forecast for NE Oregon and SE Washington
National Weather Service Pendleton OR
651 AM PDT Tue Sep 9 2025

.DISCUSSION...
A wet and cooler weather pattern is in store through much of this
week. Isolated thunderstorms are possible today and Wednesday. Wetting
rain is possible. Thunderstorm chances remain Thursday and Friday
but will be lower. Saturday looks mostly dry at this time.

***Thunderstorms imply strong gusty winds***
***Winds are 20 foot 10 minute averages***
***CWR-chance of wetting rain 0.10 or greater***
***Ventilation Index is derived from the
   transport wind multiplied by the mixing
   height in 100's of feet. Index categories
   are a generalized indicator and users are
   encourage to develop criteria that are
   suitable and representative of dispersion
   conditions in their local area of interest.***
     Note: Max transport winds may not occur
     at the same time as max mixing height.
```

Date and time the forecast is issued

Notes on the weather forecast for the next several days

Notes on how to interpret the forecast

Fire Weather Forecast for ORZ693

```
ORZ693-WAZ693-092330-
Canyon Grasslands of Wallowa County-
Southeast Washington Grande Ronde Valley-
651 AM PDT Tue Sep 9 2025

.TODAY...
* Sky/weather.........Mostly cloudy. A slight chance of showers and
  thunderstorms in the afternoon.
* Max temperature.....75-83...except 70-76 ridges.
* Min humidity........31-42 percent.
* 20-foot winds.......
*     Valleys/lwr slopes...Upslope less than 5 mph.
*     Ridges/upr slopes....light less than 5 mph.
* CWR.................0 percent.
* Chc of lightning....20 percent (slight chance).
* Mixing height.......11000 ft agl.
* Transport winds.....Northeast 5 to 10 mph.
* Ventilation Index...Poor (25-60) increasing to fair (272-426) in
  the afternoon.

.TONIGHT...
* Sky/weather.........Mostly cloudy. Hazy. A chance of showers and
  a slight chance of thunderstorms in the evening. A slight chance
  of showers after midnight.
* Min temperature.....46-56.
* Max humidity........78-93 percent...except 70-80 percent ridges.
* Humidity recovery...Excellent...except Good ridges.
* 20-foot winds.......
*     Valleys/lwr slopes...Drainage winds less than 5 mph.
*     Ridges/upr slopes....light winds less than 5 mph.
* CWR.................10 percent.
* Chc of lightning....20 percent (slight chance).
* Mixing height.......Near surface.
* Transport winds.....East around 5 mph shifting to the northwest
  after midnight.
* Ventilation Index...Poor (35-103) decreasing to poor (25-39)
  after midnight.
```

Fire weather zones the forecast covers and general description of the area

Temperature, humidity and wind forecast — key considerations for burning

Chance of wetting rain — the threshold for the amount of precipitation needed to qualify as wetting varies by region. Look for a high chance of wetting rain in the days following a burn to extinguish residual patches of fire.

Mixing height, transport winds and ventilation index will help you plan for mitigating smoke impacts.

Figure 1.10. Example fire weather forecast obtained from the National Weather Service.

National Weather Service spot forecast

On the day of the burn, it is ideal to obtain a spot weather forecast from the National Weather Service. These forecasts are specific to the local area of your burn unit and give you a higher level of accuracy that other forecasts cannot provide. When requesting a spot forecast, input your on-site weather measurements in the days before the burn to help weather forecasters more accurately predict conditions. While spot weather forecasts are generally more accurate than normal weather forecasts, they are not perfect and should not be solely relied upon. These forecasts are currently open to state and federal fire agencies only, but your state forestry agency may help you obtain one for your burn.

Remote Automated Weather Stations

You can also retrieve forecasts from one of the nearly 2,200 Remote Automated Weather Stations across the U.S. RAWS, https://raws.dri.edu/, report on a variety of weather parameters every hour, if they are working properly. When positioned near your planned burn, they are helpful for weather observation. You can also get weather measurements going back several decades, depending on when a particular RAWS was installed.

Apps and websites

You may choose from a variety of other websites and weather apps. Every smartphone comes with a weather app, and there are numerous others you can download. The Windy app is particularly useful for monitoring winds. The app uses several different wind models. Try out the different models and compare them to on-site weather observations to determine which one works best for your local area. Sample a variety of weather sources to determine which is the most accurate for your area.

Weather observations

ON-SITE MEASUREMENTS

Many weather variables can be measured on-site and recorded before burns and every hour or so during burns. As conditions can fluctuate, continuous weather monitoring during and after the burn is essential.

Air temperature, relative humidity, wind speed and wind direction are always measured on-site. Kestrels, belt weather kits or other devices can measure relative humidity, wind speed and direction, and temperature. More advanced Kestrels can also calculate fine dead fuel moisture, probability of ignition, dew point and many other elements.

Prior to the burn, the individual measuring weather should meet with the burn boss or burn manager to determine which weather metrics to take and report on, the time intervals at which to measure them, and where to take the measurements.

Where to measure weather

Take measurements in the shade in or near the burn unit, over representative fuels and upwind of the fire to ensure that readings are not affected by indrafts or by air warmed by fire or smoke. Do not take measurements on a road, in or near a vehicle, in the black, in the sun, near a water source or in an area with different fuels and vegetation than the burn unit. Always record your weather observations.

Timeline	What to review
Several days prior to burning	Long-term general weather
One or two days prior to burning	Weather forecasts and on-site weather observations
Day of the burn	Spot forecast and monitor on-site weather conditions before and during the burn and during mop-up to be aware of any deviations from expected conditions.
End of the burn	Record and document all weather observations taken during the burn. You may need to continue monitoring weather in the days after the burn, particularly if dry or windy conditions are expected.

Table 1.5. Fire weather timeline. Record weather observations (wind speed, direction, temperature and relative humidity from the period prior to the burn through the end of the burn).

When to measure weather

Measure on-site weather at the burn unit in the days leading up to the burn (Table 1.5). This will give you daily weather trends, help you decide when to start fires on burn days and assess how accurate the forecast is for your burn unit.

Measure weather as soon as you arrive at the burn unit on burn day and continue to take measurements at set intervals throughout the burn. The most common time interval for weather measurements is every hour.

If you observe rapid weather changes, shift to half-hour intervals so that burners can be prepared for incoming changes in fire behavior. The trend in weather throughout the day is as important as the specific measurements, because your fire behavior will follow those trends.

When communicating weather observations to other units on the burn, relay the change in each weather measurement since the last observation. For example, if your first temperature reading was 60°F and your next reading was 65°F, mention that the temperature increased by 5°F.

Measurements to report

Typically, you will want to note location, time, temperature, relative humidity, wind speed and gusts, and wind direction after taking each weather measurement. Fine dead fuel moisture and the probability of ignition are often calculated from weather measurements and reported simultaneously, as they help predict fire behavior (see "Fuels" for more information). Advanced Kestrels will do these calculations for you, but you will need to use the tables in your Incident Response Pocket Guide to calculate them if you are using a basic Kestrel or belt weather kit. Periodically check and calibrate Kestrel weather sensors or other devices used for weather measurements (Figure 1.11).

National Wildfire Coordinating Group's Belt Weather Kit Tutorial: https://www.youtube.com/watch?v=IIpngk3Ow8A

Kestrel Digital Weather Meter Tutorial: https://www.youtube.com/watch?v=MduAlzd1vEE

Kestrel Weather Meter



Basic Kestrels like the Kestrel 3500FW measure temperature, relative humidity and wind, while more advanced models like the Kestrel 5500FW provide additional measurements and also calculate fine dead fuel moisture and probability of ignition.

Steps for measuring weather with a Kestrel

1. Let the unit become acclimated to surroundings (two to five minutes)
2. Position yourself in shade over representative fuels and away from anything that may influence your measurements. Hold the Kestrel about eye level facing into the wind and at arm's length, so your body does not interfere with the measurement.
3. Record the average wind speed as well as the speed of wind gusts.
4. For temperature, relative humidity and other measurements, wait until your Kestrel starts to give you consistent readings and is done adjusting to the surroundings. Once you have a fairly stable reading, record numbers for the other measurements.

A word of caution: Be certain to calibrate your Kestrel regularly and ensure that the date, time and other settings are accurate for more advanced models that calculate fine dead fuel moisture and probability of ignition. An inaccurate meter can provide false readings, which can result in a hazardous field situation.

Figure 1.11. Steps for taking weather measurements with a Kestrel. Image of Kestrel Weather Meter courtesy of Leslie Boby.

How to report weather

The person collecting weather on the burn should have a radio or other type of communication device that allows them to report weather measurements to the burn boss, burn manager, firing boss and holding boss. It helps if everyone on the burn receives weather reports.

Request that all units stand by for weather, report the time the weather was recorded, location where the weather was measured and all measurements the burn boss or burn manager requested. Repeat the forecast a second time. Then the burn boss or burn manager, firing boss and holding boss will confirm receipt of the weather report.

Following the burn, communicate your on-site weather observations to the National Weather Service if you received a spot forecast so they can use that information to improve their weather forecasts.

Fire indices and tools

A variety of indices estimate different potential fire behavior or weather-related factors. You don't have to understand all of the indices and tools, but it can help to compare the readings with fire activity on your burn to gauge their usefulness for your local area.

Wildland Toolkit mobile application

The Wildland Toolkit app is produced by Peakview Software and works on Android and iPhone. With this app, you can calculate relative humidity, dew point, fine dead fuel moisture, probability of ignition and vapor pressure deficit based on standard on-site weather observations. The app also includes the Incident Response Pocket Guide and other helpful materials.

U.S. Drought Monitor

Drought is a measure of the relative dryness of an area. The U.S. Drought Monitor depicts the location and intensity of drought across the country. Use caution when burning in drought conditions, as heavy fuels are more likely to ignite and contribute to higher fire intensity, affecting vegetation and soils. Deep duff, in which the lower layers generally remain moist, can also be dry and readily burn under drought conditions, potentially damaging tree roots that grow into the duff, particularly in older forests.

How to report the weather

- All resources on the Highway 93 RX, please stand by for your 1200 weather.
- ***Pause***
- The weather was taken near the test fire location. Temp of 65 up 5, RH of 34 down 4, winds are 2 to 4 gusting to 8 from the SE.
- Fine dead fuel moisture of 5 down 1 and probability of ignition of 60 up 10. BREAK
- ***Pause***
- ***Repeat all weather information***
- All resources, how do you copy?

Weather report script

- All resources on the _____ please stand by for your _____ weather.
- ***Pause***
- Weather was taken near _____. Temp of _____ up/down _____, RH of _____ down/up _____, winds are _____ to gusting to _____ from the _____.
- Fine dead fuel moisture of _____up/down _____ and probability of ignition of _____ up/down _____BREAK
- ***Pause***
- ***Repeat all weather information***
- All resources _____ _____ _____
- How do you copy?

The Fire Danger Forecast

This tool from the Wildland Fire Assessment System accounts for current and antecedent weather, fuel types, and live and dead fuel moisture to map fire danger from low to extreme across the country. At higher levels of fire danger, your burn will likely be more challenging to control and may require you to have additional holding resources or delay the burn until a future date. Your state forestry agency may also post a fire danger forecast or rating specific to your locality.

Ventilation Index

This metric is included in the National Weather Service fire weather forecast and indicates the potential for air to disperse pollutants. This index is calculated by multiplying the transport wind speed by the mixing height. The higher the index, the better the smoke dispersal will be when burning. The categories for this index are general, and individuals are encouraged to develop criteria suitable for their local area.



Figure 1.12. Burning under appropriate weather conditions allows you to keep the fire under control, meet burn objectives and reduce smoke impacts. Credit: Christina Friehauf

Resources

National Weather Service Fire Weather Forecast Directory

- https://forecast.weather.gov/product_sites.php?site=NWS&product=FWF

National Weather Service Fire Weather Dashboard

- https://www.weather.gov/dlh/fwd

National Weather Service Spot Forecast Monitor

- https://spot.weather.gov/

Remote Automated Weather Station (RAWS) Archive

- https://raws.dri.edu/

US Drought Monitor

- https://droughtmonitor.unl.edu/

Wildland Fire Assessment System

- https://www.wfas.net

CHAPTER NOTES



FUEL

Section authors: Micah Schmidt and Heather Heward

Image credit: James Johnson

IN THIS SECTION

- ☐ Introduction to fuel
- ☐ Fuel components
- ☐ Fuel type
- ☐ Fuel characteristics
- ☐ Fuels monitoring
- ☐ Fuels management

Introduction to fuel

Fuel is one of the three components of the fire combustion triangle and the fire behavior triangle (Figure 2.1) and is the most easily changed. In natural environments, fuel is biomass, typically vegetation (both living and dead), that is combustible. Fuels can be trees, shrubs, grasses, downed woody debris, forbs, needle and leaf litter, and anything else that can burn.

Fuels strongly influence the prescribed burn plan parameters, predicted fire behavior, firing techniques used and holding resources needed. While you may find nonvegetative fuels, such as old tires, trash piles and abandoned structures, in a planned burn unit, remove them if possible. Nonvegetative fuels can create negative health impacts, fire control problems and legal issues if ignited.

This chapter includes detailed descriptions of fuel characteristics, methods for gathering fuel information and fuels management considerations.

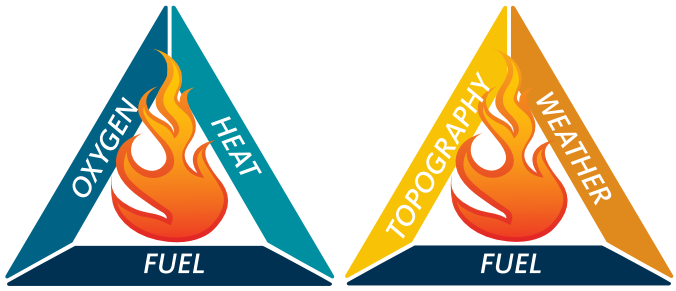


Figure 2.1. The fire combustion triangle (left) and fire behavior (right). The fire triangle shows what it takes for a fire to burn, and the fire behavior triangle shows the factors that affect fire behavior. Fuel is the only one of these factors that can be manipulated, and weather is the most variable. Credit: © Oregon State University

Fuel components

Fuels can be broken down into four major layers: ground, surface, ladder, and canopy fuels (Figure 2.2).

Ground fuels

All combustible materials below the surface litter, including duff, tree or shrub roots, peat, and sawdust, that normally support smoldering combustion without flame.

Surface fuels

All combustible materials lying on or near the surface of the ground, consisting of leaf and needle litter, dead branch material, downed logs, bark, tree cones, and low-stature living plants.

Ladder fuels

All combustible materials that provide vertical continuity between the surface and canopy, thereby allowing fire to carry from surface fuels into the crowns of trees or shrubs, potentially leading to crown fire. Ladder fuels can be small trees, shrubs, tall grasses or other materials that can carry fire from the surface into the overstory vegetation.

Aerial or canopy fuels

All live and dead vegetation in the forest canopy or above surface fuels, including tree branches, twigs and cones, snags, moss and high brush.

Fuel type

Fuel type refers to the primary type of fuel that will carry the fire. Different fuel types are associated with different fire behavior, influencing how quickly fire spreads, how hot it burns, and how resistant it is to burning under given weather conditions. Fuel types are commonly broken up into six broad categories, which include grass, grass-shrub, shrub, timber-litter, timber understory and slash/blowdown (Table 2.1).

A timber litter fuel type does not mean that timber litter is the only fuel present, but that the litter will be the primary carrier of the fire. An oak savanna may have woody fuels present, but it would likely be classified as a grass fuel type as long as grass would be the primary carrier of fire.

Within these categories, more detailed fuel models describe region-specific fuel characteristics, such as those found in the Pacific Northwest. Figure 2.3 shows examples of the six broad fuel types in the Pacific Northwest.

Selecting the primary fire carrier is the first step in selecting a fire behavior fuel model — a common tool in fire behavior modeling, which is discussed in detail in "Fire behavior."

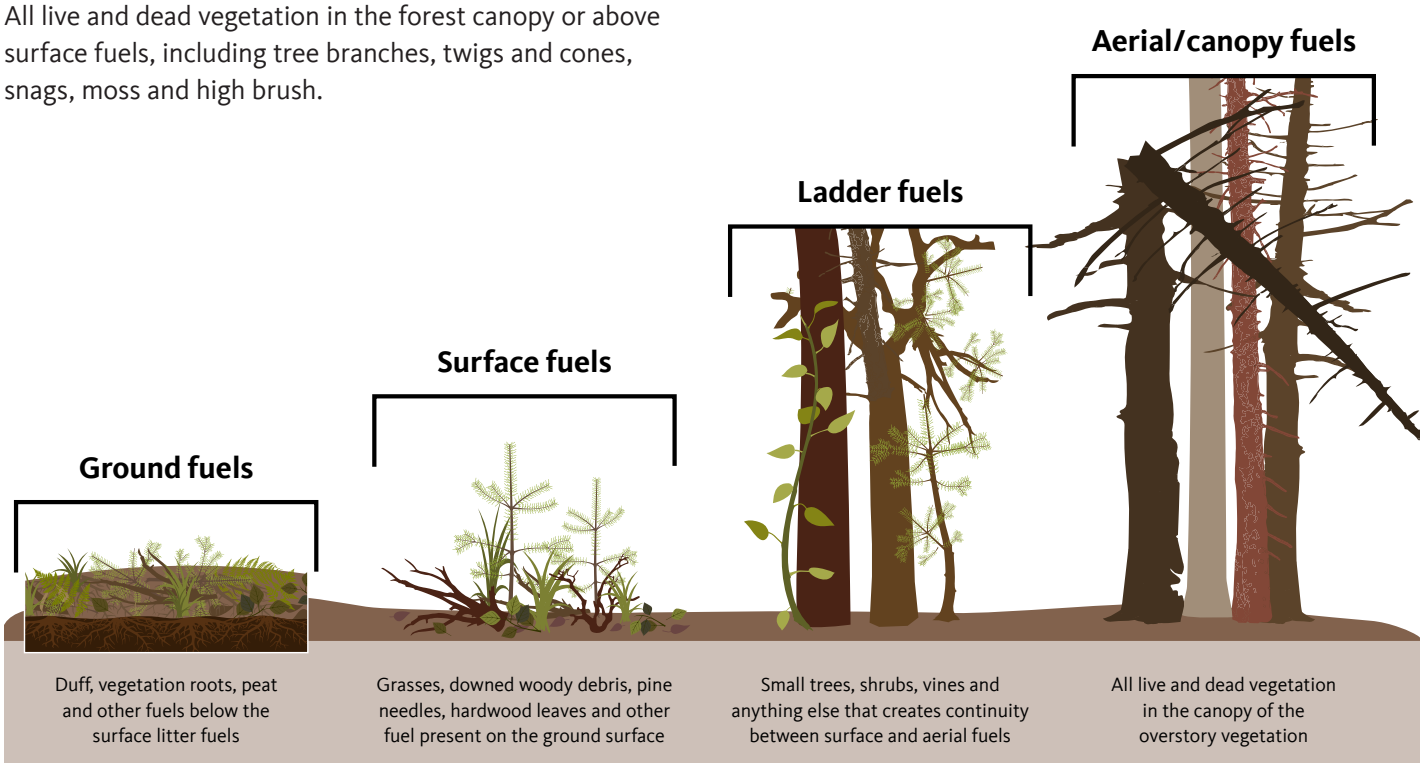


Figure 2.2. Fuel components are categorized according to ground, surface, ladder and aerial (canopy) fuels. Credit: © Oregon State University, adapted from Sam Smith, University of Georgia Extension

Fuel type	Primary carrier of fire
Grass	Solely grass or a combination of grass and herbaceous plants
Grass/shrub	Mix of grass and shrubs
Shrub	Live and dead shrub twigs and foliage in combination with dead and down shrub litter cover at least half of the site. Grass is sparse to nonexistent.
Timber litter	Dead and down woody fuel (litter)
Timber understory	Combination of herbaceous vegetation, shrubs and timber litter
Slash/ blowdown	Limbs and materials remaining from timber harvest or management activities or blown down by storms

Table 2.1. The six broad fuel types and descriptions of the primary fire carriers within each fuel type.

Fuel characteristics

Eight primary fuel characteristics influence how fuels gain and lose moisture and how they burn:

1. Quantity (fuel loading)
2. Size and shape
3. Depth
4. Compactness
5. Arrangement
6. Continuity
7. Chemical content
8. Moisture content

These fuel characteristics interact with one another, as well as with climate, local weather patterns and topography, to influence fire behavior. While each of these fuel characteristics can be measured scientifically and precisely, an experienced burner can estimate them by walking the burn site and recording observations. General fuel characteristics will inform your burn plan prescription.

Recommended video: Introduction to Fuels https://www.youtube.com/watch?v=EA3nXYAqF5s

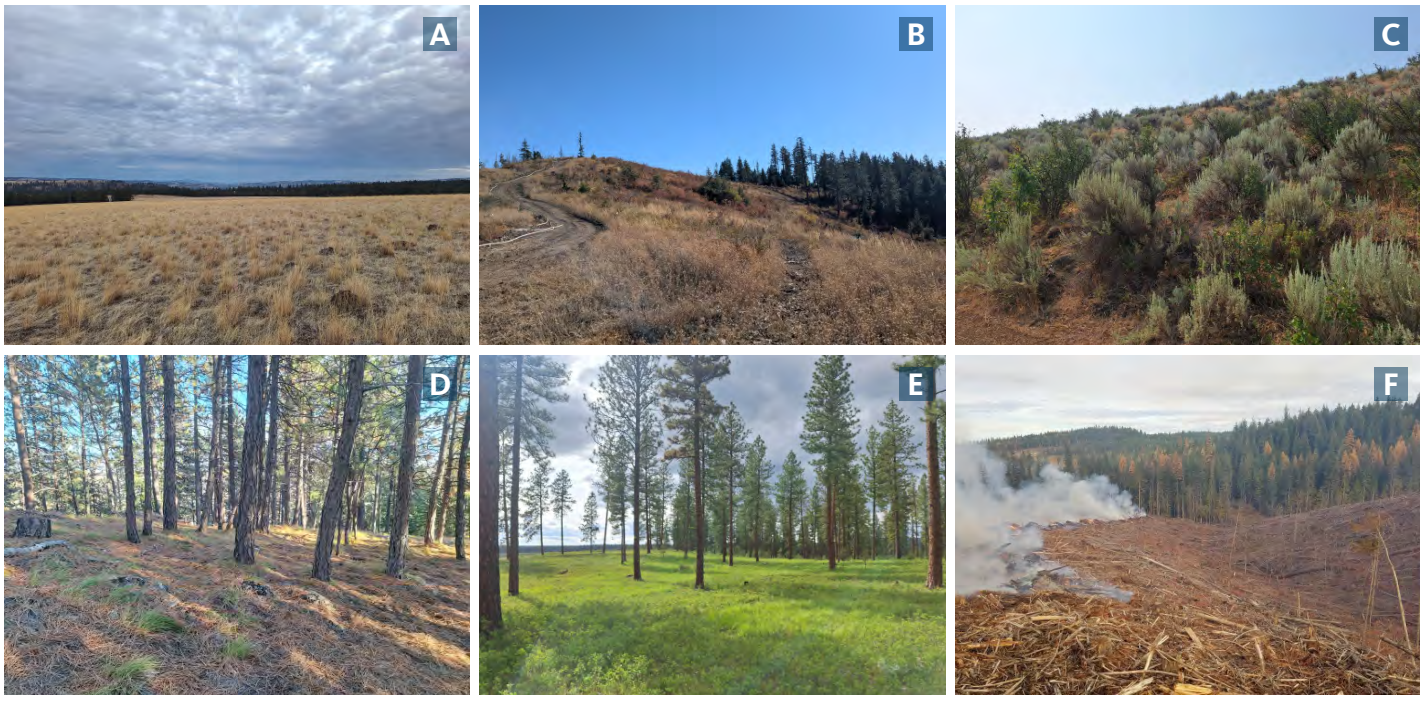


Figure 2.3 A–F. Broad fuel types commonly used in the Pacific Northwest (top left to right): (A) grass, (B) Grass/shrub, (C) shrub, and bottom left to right (D) timber litter, (E) timber understory and (F) slash/blowdown. Credit: Micah Schmidt, © Oregon State University (A, C, D and E) and Heather Heward (B and F)



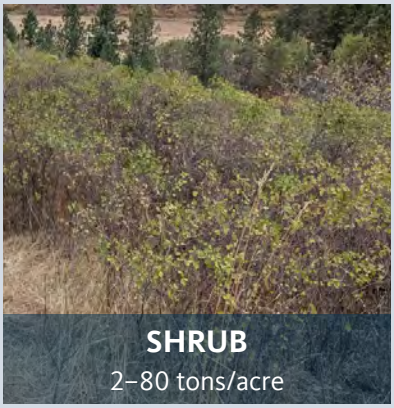






Figure 2.4. Fuel loading ranges for grass, shrub, timber litter and slash. Credit: Heather Heward

QUANTITY

Fuel loading can be described in general terms (low, moderate, high) or measured and described in tons/acre or kg/m2. Total fuel loading includes everything on the site, while available fuel loading is what would likely burn if a fire occurred. Available fuel loading affects fire behavior, smoke production and fire effects. Figure 2.4 shows the general fuel loading ranges for grass, shrub, timber litter and slash fuel types. Later in this chapter, we will discuss how to look up or measure fuel loading.

SIZE AND SHAPE

The surface-area-to-volume ratio influences how fuels gain and lose moisture. The smaller the fuel, the higher its surface area-to-volume ratio, and the faster it will dry out or heat up when exposed to sunlight or fire (Figure 2.5). Fine fuels will gain and lose moisture faster and be consumed by fire more quickly because more of their surface is exposed to the environment. Grass typically has a high surface-area-to-volume ratio, while large logs have a low surface-area-to-volume ratio.

COMPACTNESS

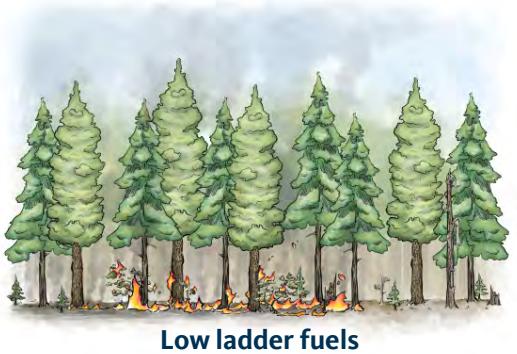
When fuels are tightly packed, combustion is slowed by a lack of oxygen. Compact fuels often retain more moisture because of reduced wind exposure, resulting in slower drying. When fuel pieces are too widely spaced, heat has difficulty transferring from one piece of fuel to the next. Logs that are stacked on top of each other in a pile or on the ground are less likely to ignite. Fallen leaves and pine needles, compressed by snow, might not burn fully because of a lack of oxygen. Heavy equipment can compress slash or create layers of mulched fuel, leading to slow smoldering from oxygen restriction. This type of fire increases heat transfer to the soil, damaging soil and roots and raising the risk of tree mortality following the burn.





Figure 2.5. The larger surface-area-to-volume ratio on the left will lead to faster changes in fuel moisture and faster consumption than the fuels shown on the right. Credit: Heather Heward

LADDER FUELS



Low ladder fuels



High ladder fuels

CANOPY BULK DENSITY



Sparse canopy



Dense canopy

CANOPY BASE HEIGHT



Tall base height



Short base height

CANOPY CLOSURE



Open canopy



Closed canopy

Figure 2.6. Surface and canopy characteristics affect how fire will move from surface to trees and from tree to tree.
Credit: Ciara Bourdeaux

VERTICAL ARRANGEMENT

Ladder fuel, which is continuous fuel connecting the ground to the canopy, facilitates fire's upward spread into the canopy (Figure 2.6). Removing ladder fuels and increasing the height of lower branches through pruning breaks up this vertical continuity and reduces the likelihood that fire will move into the canopies of overstory trees. Trees with dense canopy foliage are more likely to carry fire up the tree. Before using prescribed fire, you may need to reduce ladder fuels in your burn unit, depending on your objectives and burn conditions.

HORIZONTAL CONTINUITY

Horizontal fuel continuity refers to the degree or extent of continuous or uninterrupted distribution of fuel across an area. It essentially represents how evenly the fuels are distributed and affects the fire's ability to sustain combustion and spread. In prescribed fire, horizontal continuity is most important for the surface fuels that will carry the fire. Sparse grass may not carry fire well across a burn unit without help from the wind, while a continuous layer of needle litter will allow fire to easily carry across the unit. Horizontal fuel continuity influences how much of the unit will burn, which can impact your ability to accomplish burn objectives.

CHEMICAL CONTENT

Some plants contain chemicals like terpenes, oils, resins and waxes that allow them to burn even when relatively wet (Figure 2.7). Plants like cattails and other wetland grasses have been known to carry fire across standing water due to their chemical content. Ponderosa pine needles are more volatile than other common Pacific Northwest pine species. Sagebrush, juniper, manzanita and snowbrush are other common Northwest species that are quite flammable because of their chemical contents. Resinous plants are more susceptible to fire.

To learn more about species in your area that contain volatile chemicals, ask a local expert or look up information in the Fire Effects Information System.

MOISTURE CONTENT

Fuel moisture is an extremely important characteristic that affects how easily fuels ignite, how intense the fire will be and how fast the fire will spread. Moisture content differs between live and dead fuels. Dead fuels are influenced by their immediate environment, while live fuels are influenced by the moisture content in the soil and their stage of growth and development.

Introduction to Dead Fuel Moisture: https://www.youtube.com/watch?v=FgjNrgGh5H0

Introduction to Live Fuel Moisture: https://www.youtube.com/watch?v=a8hD5wwcevI

Fuel moisture: The amount of moisture in a fuel class relative to its weight. This value is usually expressed as a percentage.





Figure 2.7. Some plants, such as sagebrush (left) and juniper (right) contain volatile chemicals that can make them burn intensely.
Credit: Micah Schmidt, © Oregon State University

Live fuels

Living plants often have a big impact on fire behavior. If relatively dry, they become additional fuel. If their moisture content is high, they absorb heat, making fire less intense. They may eventually dry out and become receptive fuel.

Plants' flammability changes as they go through their life stages. In the Pacific Northwest, plants generally have high moisture content in the spring when they are actively growing. They become drier as new growth matures in late spring or summer. As they go dormant in late summer or fall, their moisture content is often low. Leaves and other plant parts that have fully died will dry out and become dead fuel.

We can observe these changes in the color of the plants' leaves — bright green, then dark green, then yellowing, then brown (Table 2.2).

Live fuels draw moisture from the ground and are less affected by short-term weather changes. During rainy years, plants stay greener and retain higher moisture contents longer into the summer or fall and may be more resistant to burning. In dry years, plants may be ready to burn quite early in the fire season.

Plants will typically be quite dry over the winter, when they are likely to be dead or dormant. This means you could find receptive live fuels during winter or in early spring before green-up occurs.

Many woody plant species will be quite flammable in the early spring just as they are beginning to break bud. At this stage of development, moisture in the plant shifts to those new growth locations, leaving older leaves or needles and stems at low moisture content for a few days. This is called the "spring dip," as it's when the trees or shrubs take a "dip" in moisture content.

Experienced burners factor in all these elements when choosing the timing of their burns. Early spring burns can be timed to burn off dead vegetation from previous years, before green-up, or delayed a bit to allow the new green plants to reduce fire intensity. You might choose to avoid a spring burn if the trees or shrubs in your burn unit are experiencing spring drop and you don't want them to burn. You might be able to pull off a great midwinter burn during a dry spell, even if temperatures are relatively cold.

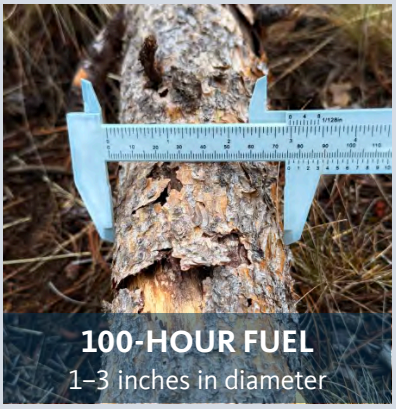
All of this requires good timing and careful monitoring of weather and plant conditions.

Live fuel moisture content (%)	Herbaceous plants	Woody plants
>150 to 300	Maturing foliage still developing. Fresh foliage fully expanded, vigorously growing. Early in growing cycle.	Maturing foliage still developing. Fresh foliage fully expanded, vigorously growing. Early in growing cycle.
>120 to 150	Mature foliage, new growth complete and comparable to older perennial foliage. Shrubs and grasses resist spread.	Mature foliage, new growth complete and comparable to older perennial foliage. Shrubs and grasses resist spread.
>100 to 120	Mature foliage, new growth complete and comparable to older perennial foliage. Flammable shrubs should burn. Grasses resist spread.	Mature foliage, new growth complete and comparable to older perennial foliage. Flammable shrubs should burn. Grasses resist spread.
>80 to 100	Green color pales. Grasses become less resistant to spread. Avoid 90% to 100% as inputs.	Anticipate flammable shrubs burning aggressively.
>50 to 80	Significant yellowing and curing. Live fuels contributing to spread.	Leaves are yellowing and curing. Expect shrubs to contribute to fire intensity.
>30 to 50	Mostly to completely cured; treat as dead fuels.	Dormant, leafless deciduous shrubs, increased dead fuel loads.

Table 2.2. Live fuel moisture content in relation to plant development stages. Credit: National Wildfire Coordinating Group







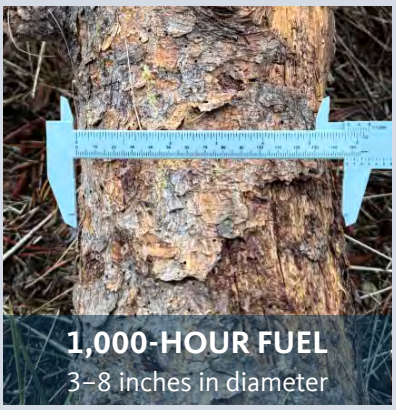


Figure 2.8. Fuel time-lag classes for 1-, 10-, 100- and 1,000-hour fuels and their respective diameters. Credit: David Clabo

Dead fuels

Dead fuel moisture content is assessed using time-lag fuel classifications. Time-lag classes are measured by the diameter of the fuel (Figure 2.8), but the time lag actually refers to how quickly fuel of that size responds to changes in relative humidity and temperature.

In one time-lag period (for instance, 1 hour for a 1-hour time-lag fuel), the fuel will adjust its moisture content by about 2/3 of the amount it could eventually change if the surrounding atmosphere stayed at a constant relative humidity and temperature.

Size or time-lag classes are measured by diameter and include 1-hour, 10-hour, 100-hour, 1,000-hour and 10,000-hour dead woody fuels. 1-hour fuels have the highest surface-area-to-volume-ratio and change moisture the fastest. 1-hour fuels can dry substantially on a warm, dry day and then recover moisture overnight if the following night is cool and humid. A 10,000-hour fuel on that same day would experience almost no change in moisture content.

This means that in your burn units, different-sized fuels could have very different moisture contents and potential to burn.

Experienced burners can easily identify the time-lag class of dead woody fuels by glancing at them. If you're new to fuel identification, use a go-no-go gauge or caliper to quickly check fuel diameter and gauge what time-lag class it falls into (Figure 2.9).

Under most prescribed fire conditions, dead fuels will be the main fuels carrying fire, and the 1-hour fuels (also known as fine dead fuels) will be the primary drivers of the fire's rate of spread. Larger dead fuels will influence how long the fire burns in any one area. Most prescribed fires in the West are conducted within a 5%–12% fine dead fuel (1-hour) moisture range.

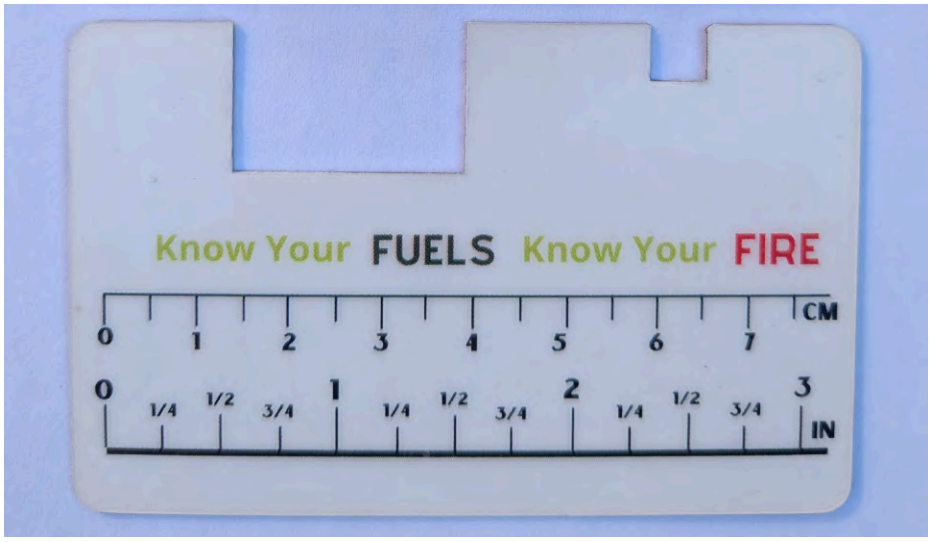


Figure 2.9. Go-no-go gauge made of hard plastic with ¼-inch and 1-inch notches. Credit: Heather Heward

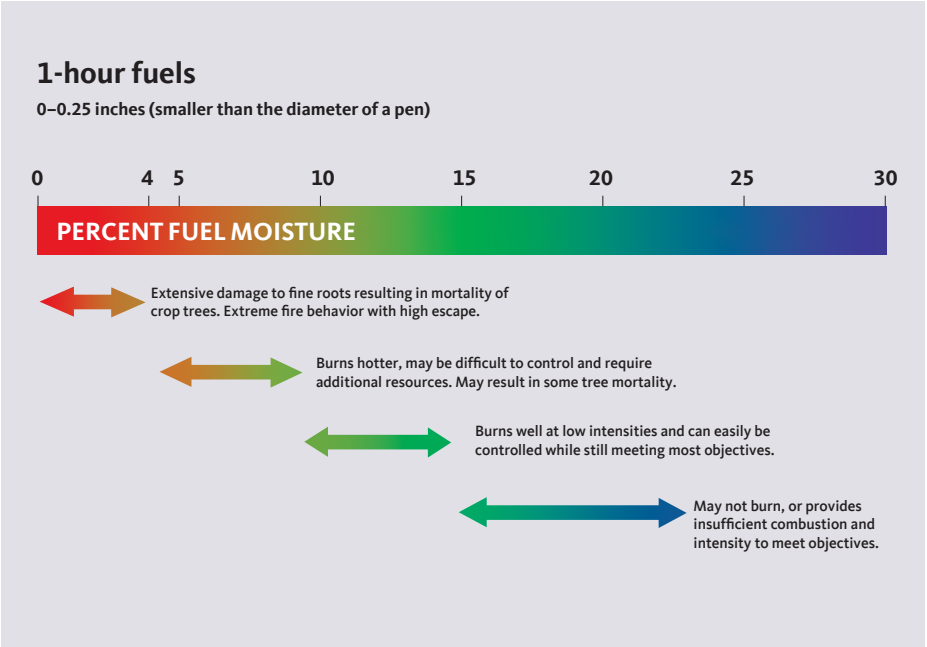


Figure 2.10. Percent of fuel moisture of 1-hour fuels and its effects on fire behavior. Credit: Melanie Quinton

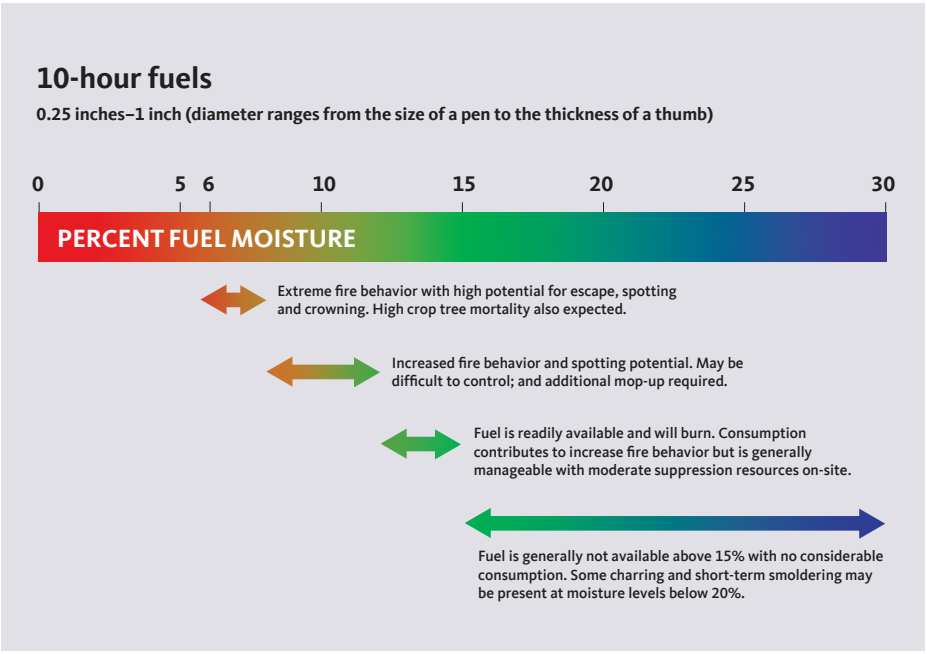


Figure 2.11. Percentage of fuel moisture of 10-hour fuels and their effects on fire behavior. Credit: Melanie Quinton

1-hour fuels (less than 0.25 inches in diameter) include leaves, needles and twigs smaller than about the width of a No. 2 pencil (Figure 2.9). One-hour fuels are the reason that a fire may not burn during the morning hours when the air is cool and moist but may burn readily a few hours later once temperatures increase and relative humidity drops (Figure 2.10). These fuels are the most important to assess on the day of the burn.

10-hour fuels are slightly larger (0.25-1" diameter) and fall between the diameter of a pencil and a thumb width (Figure 2.11). These fuels may be partially or fully consumed by the fire depending on conditions. They are less susceptible to the environmental changes that take place in a single burning period but can change significantly over a 10-hour time span.

100-hour fuels (1 inch to 3 inches in diameter) are about the size of a thumb width to the size of a person's wrist or forearm. It takes about four days of consistent weather to change 100-hour fuel moisture to the point where they reach their equilibrium with the moisture of the surrounding environment.

1,000-hour fuels (3 to 8 inches in diameter) are about the size of a person's arm to the size of a person's thigh. These fuels take several weeks or months to respond to changes in their environment. It is important to be aware of the approximate fuel moisture of these heavy fuels, as they can contribute to intense fire behavior, excessive smoke production and greater impacts to trees and soil if dry.

The relationship between fuel moisture across different size classes depends on the combination of moisture and drying a site receives. For instance, in early fall, the 1,000-hour fuels have likely been drying out all summer. There may have been several moderate rainfall events that have wetted the outer parts of 1,000-hour fuels but not really changed their internal moisture.

100-hour fuels were likely wetted internally from moderate rainfall, and they now have higher fuel moisture than the 1000-hour fuels. If the last few days have been dry, the 1-hour fuels will have dried out.

This leaves you with dry 1,000-hour fuels, wet 100-hours and dry 1-hours. When you burn, you may get full consumption in fine fuels, but little consumption in your 100-hour fuels. Monitor moisture content across various dead fuel sizes to achieve your prescribed burn objectives.

Large dead fuels like stumps and rotten logs don't fit easily into time-lag classes and can significantly affect your burn. Freshly cut stumps rarely burn, although pitch on a pine or fir stump may burn for a while. Rotten stumps and logs, catch fire easily and burn for long periods. Rotten logs may be hidden under other surface fuels and carry fire where you don't anticipate it.

Old stumps that catch fire can release embers that start spot fires outside your burn unit. Fire may burn slowly through their root systems and emerge outside your control line days, weeks or even months after the burn day. Careful mop-up and patrols are needed to manage them.

Old, rotten wood material can be widely distributed in some burn units and will support long-term smoldering combustion that produces lots of smoke, complicates mop-up and causes significant soil and root impact if not mopped up. Watch out for rotten logs and stumps outside your burn unit, too — they are magnets for embers and are often where spot fires start (Figure 2.12).

The duff layer is another important type of dead fuel to be aware of. Duff is the upper layer of organic matter in the soil profile (part of the ground fuels). Forest stands that are frequently burned are less likely to have a duff layer. For example, ponderosa pine stands that are frequently burned will not develop much of a duff layer.

If you are planning a prescribed fire in a stand that has not been burned in a long time, it is especially important to be cognizant of the duff layer. This soil horizon becomes deeper and accumulates near the base of large, old trees in long unburned forests (Figure 2.13).

The large accumulations of duff around trees are often referred to as "duff mounds." Trees tend to develop fine feeder roots in the duff mounds and burning them can result in detrimental impacts to the trees, sometimes causing mortality of old trees. Burning in deep duff can also result in smoldering fire behavior that leads to higher smoke emissions and extensive mop-up.



Figure 2.12. Stumps and rotten logs can serve as receptive fuelbeds that release the embers that start spot fires. Fire can also spread through the root systems of stumps. Credit: Heather Heward

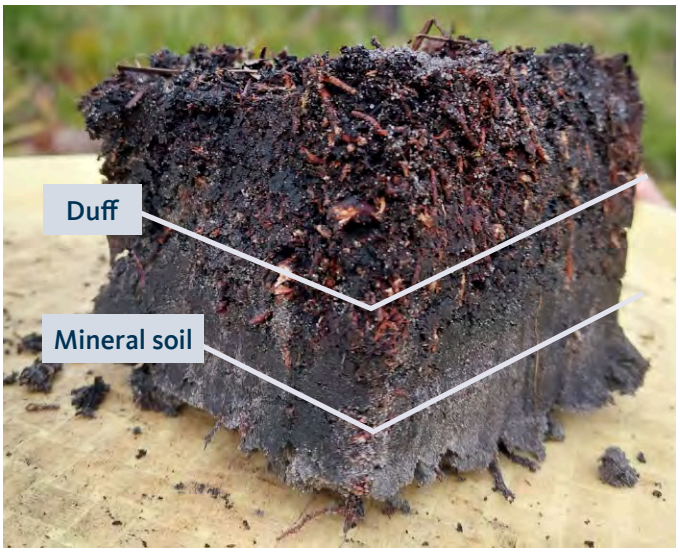


Figure 2.13. Cubic soil sample, showing roots growing into the partly decomposed material (duff) on the forest floor. Credit: Mac Callaham

Fuels monitoring

Monitoring fuels can range from simply taking a picture to spending extensive time gathering field data and compiling it into a report. The two primary pieces of information to gather are fuel moisture and fuel loading.

FUEL MOISTURE

Dry and weigh fuels

The percent moisture content of fuels is equal to the wet weight of the fuel minus the dry weight, then divided by the dry weight. The most accurate method for assessing fuel moisture is to collect fuel samples, weigh them to establish the wet weight, dry them in an oven to remove the moisture, and then weigh them again to establish the dry weight. You can then use that information to calculate your fuel moisture.

See the video: How to Sample Fuel Moisture, https://www.youtube.com/watch?v=X15fbzGjj3M.

Be sure to separate fuels into their respective time-lag classes to get accurate measurements. A variety of field moisture analysis instruments are also available for drying and weighing fuels in the field for quick and efficient moisture measurements. You can use this method to measure the fuel moisture of dead fuels (including woody fuels, duff and litter) and live fuels, but live fuel moisture can be estimated more easily using Table 2.2.

Feel the fuels

Simply listening to the crunch of the fuel under your feet or in your hand can give you a sense of how dry it is. It is best to accompany this feeling with an actual fine dead fuel moisture measurement to calibrate. Once you have measured and felt your fuels, you can get a sense of whether fuel moisture is rising or falling based on changes in their sound and feel, which is important for understanding how your burn conditions are changing over time. Figure 2.14 shows a rough estimate of fuel moisture based on how far you can bend a pine needle before it breaks.

Feeling the fuels is also helpful for evaluating duff moisture. While duff moisture is not often directly measured to prepare for prescribed burns, it will influence how much smoke is produced by your burn and how much mop-up is needed, as well as the burn's impact on soils and tree roots.

To assess duff moisture conditions via the "touch test," (Table 2.3), feel the duff layer at several locations in the burn unit with different environmental conditions, such as in the shade, in full sunlight and under deep and light litter layers. Sticky, wet duff is unlikely to burn and be consumed, which may be favorable or not depending on your burn objectives. You can also assess duff moisture with a portable duff moisture meter or by drying and weighing duff samples to measure moisture. These methods are usually not necessary.

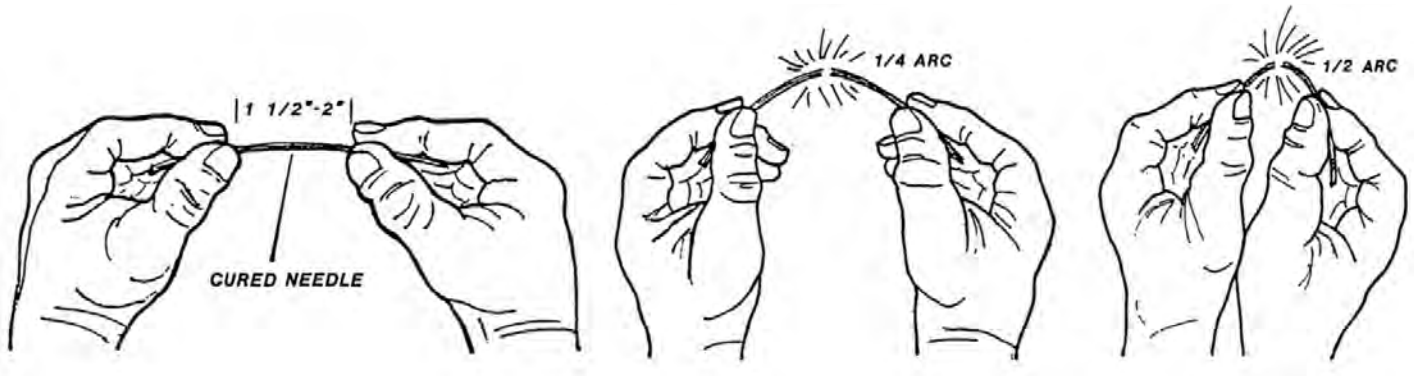


Figure 2.14. Field method for estimating dead ponderosa pine moisture.

Cured needle: If the needle does not break, the fuel moisture is high, and the burning conditions are marginal. **¼ arc:** Moisture content 4%–7%. Burning conditions are very favorable. **½ arc:** Moisture contents 8%–11%. Burning conditions are favorable.

Source: *NWCG Guide to Fire Behavior Assessment*, PMS 437-1, https://fs-prod-nwcg.s3.us-gov-west-1.amazonaws.com/s3fs-public/publication/pms437-1.pdf.

Fine dead fuel moisture calculations

Fine dead fuels (or 1-hour fuels) are anything below ¼ inch in diameter, including grass, needles, sticks, leaves and herbaceous material. These smaller fuels respond quickly to changes in temperature and relative humidity and are also affected by shading and topography. They can be estimated using weather and topographic conditions. The easiest way to get fine dead fuel moisture is to use a Kestrel 5500FW which calculates it for you, phone apps like Wildland Toolkit, or you can also use the lookup tables found here and in the *Incident Response Pocket Guide* (Tables 2.4-2.6).

ASSESSING DUFF MOISTURE: THE TOUCH TEST

1. Rake back litter to expose upper duff.
2. Touch test
   - Touch the duff.
   - Does the material stick to your skin?
   - Does it feel wet?
3. Dig a little deeper and repeat Step 2, as moisture levels can differ throughout the duff. Some deeper layers may be drier than upper layers, and vice versa.
4. Repeat Step 3 until you reach the mineral soil.
5. Repeat Steps 1–4 at multiple trees and locations that represent the different conditions within the site.
6. If your samples of duff moisture across the burn site meet your desired conditions, then you are ready to burn.

Table 2.3. How to perform a touch test to check fuel moisture.

Day Time 0800 – 1959

1	Relative humidity (%)																				
Dry bulb temp (°F)	0 – 4	5 – 9	10 – 14	15 – 19	20 – 24	25 – 29	30 – 34	35 – 39	40 – 44	45 – 49	50 – 54	55 – 59	60 – 64	65 – 69	70 – 74	75 – 79	80 – 84	85 – 89	90 – 94	95 – 99	100
10 – 29	1	2	2	3	4	5	5	6	7	8	8	8	9	9	10	11	12	12	13	13	14
30 – 49	1	2	2	3	4	5	5	6	7	7	7	8	9	9	10	10	11	12	13	13	13
50 – 69	1	2	2	3	4	5	5	6	6	7	7	8	8	9	9	10	11	12	12	12	13
70 – 89	1	1	2	2	3	4	5	5	6	7	7	8	8	8	9	10	10	11	12	12	13
90 – 109	1	1	2	2	3	4	5	5	6	7	7	8	8	8	9	10	10	11	12	12	13
109 +	1	1	2	2	3	4	4	5	6	7	7	8	8	8	9	10	10	11	12	12	12

Table 2.4. Reference fuel moisture

2E	EXPOSED	Feb Mar Apr Aug Sept Oct																			
		Exposed – Less than 50% shading of surface fuels																			
Aspect	Slope	0800 to			1000 to			1200 to			1400 to			1600 to			1800 to				
		B	L	A	B	L	A	B	L	A	B	L	A	B	L	A	B	L	A		
N	0 – 30%	3	4	5	1	2	3	1	1	2	1	1	2	1	2	3	3	4	5		
	31%+	3	4	5	3	3	4	2	3	4	2	3	4	3	3	4	3	4	5		
E	0 – 30%	3	4	5	1	2	3	1	1	1	1	1	2	1	2	3	3	4	5		
	31%+	3	3	4	1	1	1	1	1	1	1	2	3	3	4	5	4	5	6		
S	0 – 30%	3	4	5	1	2	2	1	1	1	1	1	1	1	2	3	3	4	5		
	31%+	3	4	5	1	2	2	0	1	1	0	1	1	1	2	2	3	4	5		
W	0 – 30%	3	4	5	1	2	3	1	1	1	1	1	1	1	2	3	3	4	5		
	31%+	4	5	6	3	4	5	1	2	3	1	1	1	1	1	1	3	3	4		
2S	SHADED																				
		Shaded – Greater than or equal to 50% shading of surface fuels																			
N	All	4	5	6	4	5	5	3	4	5	3	4	5	4	5	5	4	5	6		
E	All	4	5	6	3	4	5	3	4	5	3	4	5	4	5	6	4	5	6		
S	All	4	5	6	3	4	5	3	4	5	3	4	5	3	4	5	4	5	6		
W	All	4	5	6	4	5	6	3	4	5	3	4	5	3	4	5	4	5	6		

2E	EXPOSED	Nov Dec Jan																			
		Exposed – Less than 50% shading of surface fuels																			
Aspect	Slope	0800 to			1000 to			1200 to			1400 to			1600 to			1800 to				
		B	L	A	B	L	A	B	L	A	B	L	A	B	L	A	B	L	A		
N	0 – 30%	4	5	6	3	4	5	2	3	4	2	3	4	3	4	5	4	5	6		
	31%+	4	5	6	4	5	6	4	5	6	4	5	6	4	5	6	4	5	6		
E	0 – 30%	4	5	6	3	4	4	2	3	3	2	3	3	3	4	5	4	5	6		
	31%+	4	5	6	2	3	4	2	2	3	3	4	4	4	5	6	4	5	6		
S	0 – 30%	4	5	6	3	4	5	2	3	3	2	2	3	3	4	4	4	5	6		
	31%+	4	5	6	2	3	3	1	1	2	1	1	2	2	3	3	4	5	6		
W	0 – 30%	4	5	6	3	4	5	2	3	3	2	3	3	3	4	4	4	5	6		
	31%+	4	5	6	4	5	6	3	4	4	2	2	3	2	3	4	4	5	6		
2S	SHADED																				
		Shaded – Greater than or equal to 50% shading of surface fuels																			
N	All	4	5	6	4	5	6	4	5	6	4	5	6	4	5	6	4	5	6		
E	All	4	5	6	4	5	6	4	5	6	4	5	6	4	5	6	4	5	6		
S	All	4	5	6	4	5	6	4	5	6	4	5	6	4	5	6	4	5	6		
W	All	4	5	6	4	5	6	4	5	6	4	5	6	4	5	6	4	5	6		

2E	EXPOSED	May June July																			
		Exposed – Less than 50% shading of surface fuels																			
Aspect	Slope	0800 to			1000 to			1200 to			1400 to			1600 to			1800 to				
		B	L	A	B	L	A	B	L	A	B	L	A	B	L	A	B	L	A		
N	0 – 30%	2	3	4	1	1	1	0	0	1	0	0	1	1	1	1	2	3	4		
	31%+	3	4	4	1	2	2	1	1	2	1	1	2	1	2	2	3	4	4		
E	0 – 30%	2	2	3	1	1	1	0	0	1	0	0	1	1	1	2	3	4	4		
	31%+	1	2	2	0	0	1	0	0	1	1	1	2	2	3	4	4	5	6		
S	0 – 30%	2	3	3	1	1	1	0	0	1	0	0	1	1	1	1	2	3	3		
	31%+	2	3	3	1	1	2	0	1	1	0	1	1	1	1	2	2	3	3		
W	0 – 30%	2	3	4	1	1	2	0	0	1	0	0	1	0	1	1	2	3	3		
	31%+	4	5	6	2	3	4	1	1	2	0	0	1	0	0	1	1	2	2		
2S	SHADED																				
		Shaded – Greater than or equal to 50% shading of surface fuels																			
N	All	4	5	5	3	4	5	3	3	4	3	3	4	3	4	5	4	5	5		
E	All	4	4	5	3	4	5	3	3	4	3	4	4	3	4	5	4	5	6		
S	All	4	4	5	3	4	5	3	3	4	3	3	4	3	4	5	4	5	6		
W	All	4	5	6	3	4	5	3	3	4	3	3	4	3	4	5	4	4	5		

Tables 2.5. Dead fuel moisture content corrections. Credit: *NWCG Guide for Wildland Fire Modules*

HOW TO USE THE TABLES

1. Obtain on-site measurements of air temperature and relative humidity. Collect the measurements in a shaded area, over fuels that are representative of those in your burn unit.
2. In Table 2.4, look up your reference fuel moisture based on your combination of air temperature and relative humidity.
3. Choose the correct Table 2.5 that matches the month.
4. Determine whether your burn unit will be mostly shaded or mostly unshaded. Shading can come from the trees or tall shrubs in the unit, or from clouds. Burn units with trees will probably have some areas that are shaded and others that are unshaded. You can calculate fine dead fuel moisture for both shaded and unshaded, or you can calculate whichever best represents your burn unit. Unshaded values will represent the most intense fire behavior.
5. Find the combination of aspect (the direction the slope faces), slope (rise over run as a percentage, not the same as degrees of angle) that corresponds to your fuel's location, the time of day and whether you are level, above or below your fuels. For prescribed fire, you should always be close enough to choose level (L), which allows you to be up to 1,000 feet higher or lower in elevation than the fuels. The number corresponding to these factors will be your fuel moisture correction.
6. Add your reference fuel moisture and correction factor. This gives you your estimated fine dead fuel moisture content. Note that while you must always collect the air temperature and relative humidity in the shade, the tables adjust to estimate unshaded fuel moisture if you need that value. Fine dead fuel moisture content is a key number for prescribed fire practitioners, as it is an excellent indicator of fire behavior.
7. Using your shaded air temperature and fine dead fuel moisture content, use Table 2.6 to look up the probability of ignition. Use the unshaded fine dead fuel moisture for the unshaded probability of ignition and the shaded fine dead fuel moisture for the shaded probability of ignition. Probability of ignition, or PIG, is expressed as a percentage and indicates the likelihood that an ember will start and carry a fire if it lands on receptive fuels. Along with helping ensure that you can meet your burn objectives, PIG is useful for determining how likely it is that spot fires will happen during your burn. For example, a PIG of 30 indicates that three out of 10 embers landing in receptive fuels would ignite a fire, while a 70% PIG means seven out of 10 would. That makes a big difference for the individuals on your holding team in understanding the likelihood of spot fires. TABLE C shows fine dead fuel moisture look-up tables from the *NWCG Guide for Wildland Fire Modules*, PMS 431, https://fs-prod-nwcg.s3.us-gov-west-1.amazonaws.com/s3fs-public/publication/pms431.pdf

Use a protimeter for coarse woody material

Roughly, 10-hour fuels are 1%–3% wetter, and 100-hour fuels are 2%–4% wetter than fine dead fuels. For instance, if one-hour fuel moisture is 7%, anticipate 10-hour fuel moisture to be 8%–10% and 100-hour fuel moisture to be 9%–11%. Remember that this doesn't always hold true, as the moisture content in these fuels can vary across different time-lag classes. It is important to monitor the moisture content of all your fuels, as it determines whether they are available to burn and whether you will achieve your burn objectives.

Using a protimeter is an easy way to more directly estimate dead fuel moisture in 10-hour and larger fuels. Protimeters (sometimes referred to as moisture meters) are battery-powered and contain two sharp pins that are inserted into pieces of wood. They use electrical resistance to measure the moisture content (Figure 2.15).



Figure 2.15. A protimeter uses two metal pins to measure the electrical resistance of the wood between the pins. On larger-diameter pieces, cut a fresh edge to measure the moisture inside the wood. Take measurements on a variety of wood particles to capture the variability. Credit: Heather Heward

PROBABILITY OF IGNITION TABLE

	Shading (%)	Dry Bulb Temperature (°F)	Fine Dead Fuel Moisture (%)															
			2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
3E	Unshaded < 50%	110+	100		80	70	60	60	50	40	40	30	30	20	20	20	20	10
EXPOSED		100 - 109	100	90	80	70	60	60	50	40	40	30	30	20	20	20	10	10
		90 - 99	100	90	80	70	60	50	40	40	30	30	30	20	20	20	10	10
		80 - 89	100	90	80	70	60	50	40	40	30	30	20	20	20	10	10	10
		70 - 79	100	80	70	60	60	50	40	40	30	30	20	20	20	10	10	10
		60 - 69	90	80	70	60	50	50	40	30	30	20	20	20	20	10	10	10
		50 - 59	90	80	70	60	50	40	40	30	30	20	20	20	10	10	10	10
		40 - 49	90	80	70	60	50	40	40	30	30	20	20	20	10	10	10	10
		30 - 39	80	70	60	50	50	40	30	30	20	20	20	10	10	10	10	10
3S	Shaded > 50%	110+	100	90	80	70	60	50	50	40	40	30	30	20	20	20	10	10
SHADED		100 - 109	100	90	80	70	60	50	50	40	30	30	30	20	20	20	10	10
		90 - 99	100	90	80	70	60	50	40	40	30	30	20	20	20	10	10	10
		80 - 89	100	80	70	60	60	50	40	40	30	30	20	20	20	10	10	10
		70 - 79	90	80	70	60	50	50	40	30	30	30	20	20	20	10	10	10
		60 - 69	90	80	70	60	50	40	40	30	30	20	20	20	10	10	10	10
		50 - 59	90	80	70	60	50	40	40	30	30	20	20	20	10	10	10	10
		40 - 49	90	80	60	50	50	40	30	30	30	20	20	20	10	10	10	10
		30 - 39	80	80	60	50	50	40	30	30	20	20	20	10	10	10	10	10

Table 2.6. Probability of ignition. Credit: *NWCG Guide for Wildland Fire Modules*

1-hour fuels are challenging to measure with a protimeter. You can place them on top of a larger stick for support or just use the fine dead fuel moisture calculations above. 10-hour fuels can be measured on the side. Cut a fresh edge on 100+ hour fuels and take measurements on the inside, as moisture varies as you go deeper into the wood. It is important to avoid placing the pins in cracks, as this can provide an incorrect reading.

Take a variety of measurements in each size class. Choose sticks low to the ground and elevated, with bark and without bark, and of the different species present. Record five to 10 observations for each size class — more if you find a large variation in values. Provide the range and average of fuel moistures in your reporting. Do not include the moisture from sticks that were recently alive, as they will retain moisture for many months.

FUEL LOADING

Fuel loading is used in monitoring, fire behavior modeling and smoke modeling. Reducing the fuel loading in different size classes is a common prescribed fire objective. For example, reduce 1-hour fuel by 50%. Measure or estimate your fuel loading before and after burning to determine if your objectives were met.

You can look up fuel loading or measure it. Looking up fuel loading is much faster, but it may not represent actual conditions on the ground. Ideally, take the time to learn to measure fuel loading, so you have context for what various fuel loadings look like. Then, if you are short on time and need to look up fuel loadings, you can determine if the estimates are reasonable.

Fuel load estimate photo guides

Northern Rocky Mountain vegetation types
- https://research.fs.usda.gov/treesearch/26755

Associated visual training tool for photoload sampling
- https://research.fs.usda.gov/treesearch/36328

Eastern Oregon sagebrush-steppe, juniper and ponderosa pine, and spotted owl nesting habitat in the Pacific Northwest
- https://research.fs.usda.gov/treesearch/43073

Digital photo series for selected sites across the U.S.
- https://depts.washington.edu/nwfire/dps/

Common vegetation types in the Pacific Northwest
- https://research.fs.usda.gov/treesearch/7568

Douglas-fir-hemlock forests in the WIllamette National Forest
- https://research.fs.usda.gov/treesearch/26289

Coastal Douglas-fir-hemlock forests
- https://research.fs.usda.gov/treesearch/24486

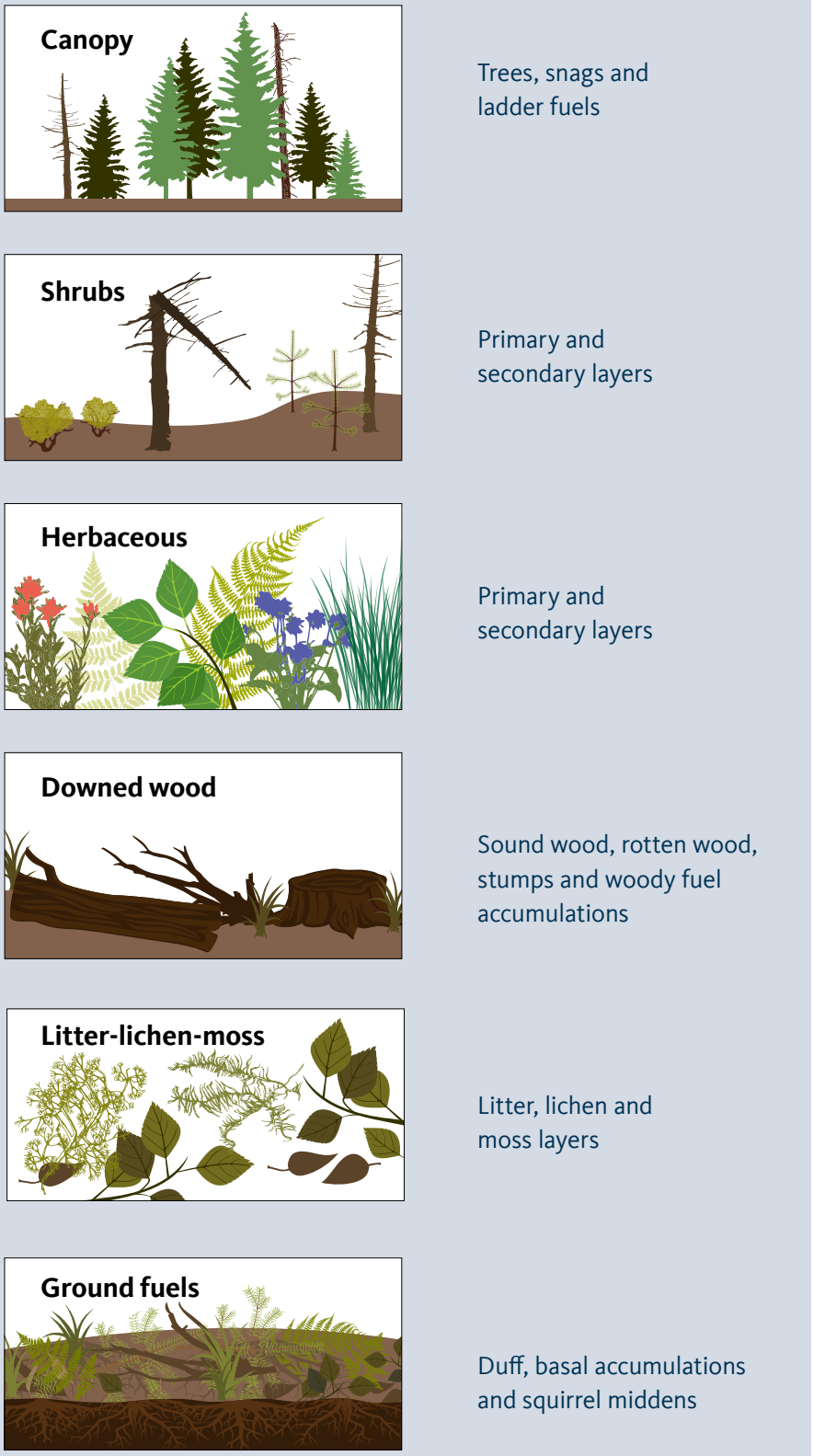


Figure 2.16. Fuel strata represented in the Fuel Characteristic Classification System. Credit: © Oregon State University, adapted from PNW-GTR-887, https://www.fs.usda.gov/pnw/pubs/pnw_gtr887.pdf

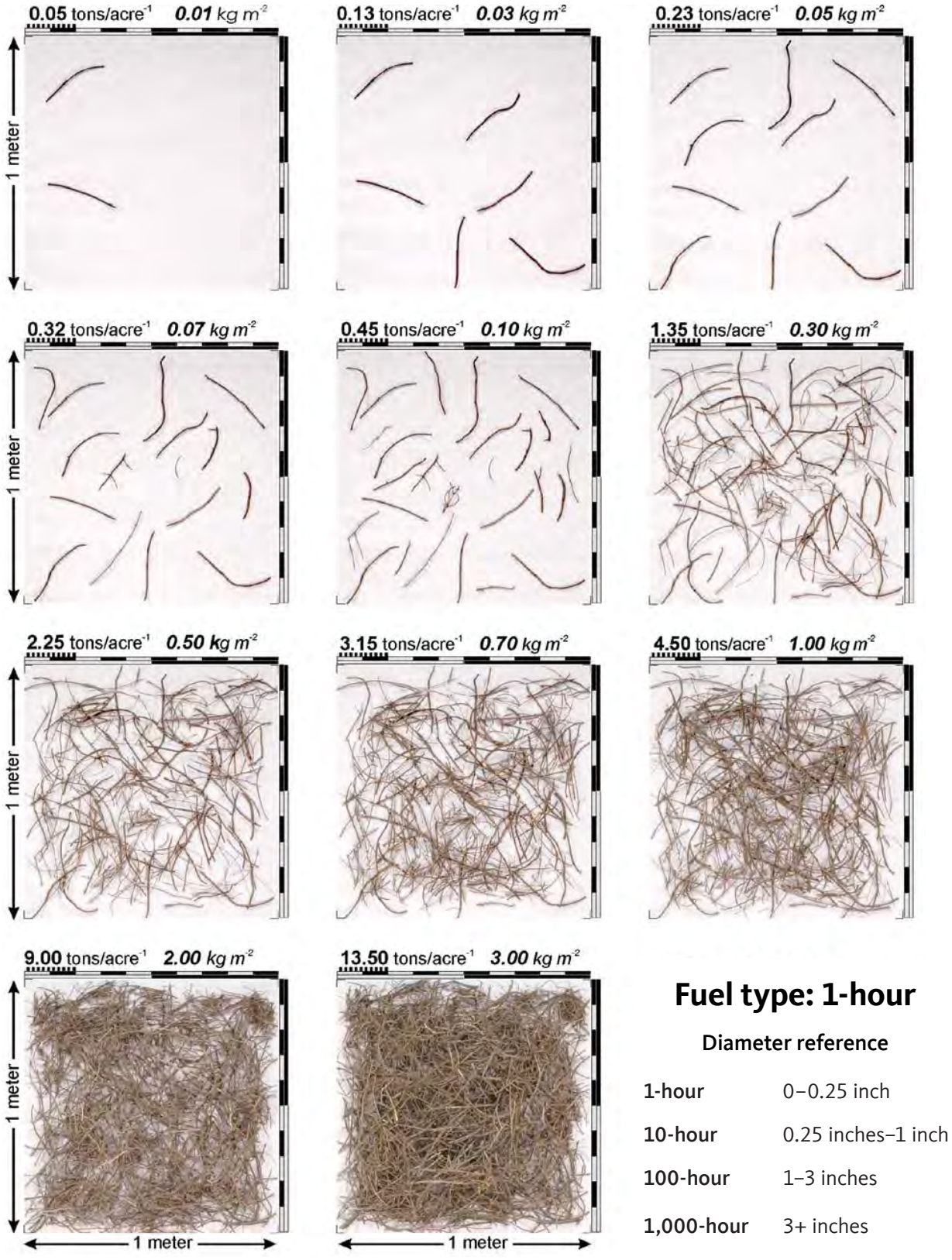


Figure 2.17. Reference fuelbed for 1-hour fuels from the *Photoload Sampling Technique* guide. The sticks in the framed area have a known weight. If your fuelbed has similar amounts of fuel, it will have a similar amount of loading. See the *Photoload Sampling Technique* for more fuel types. Credit: *The Photoload Sampling Technique: Estimating Surface Fuel Loadings From Downward-Looking Photographs of Synthetic Fuelbeds*, RMRS-GTR-190, https://www.fs.usda.gov/rm/pubs/rmrs_gtr190.pdf

Looking up fuel loading

An efficient method for looking up fuel loading is to use photo guides. The U.S. Forest Service, state forestry agencies, university researchers and others produce a variety of publications that picture fuel load estimates for different regions of the U.S. (see "Fuel load estimate photo guides"). Scan the photos and find the one that best resembles your burn unit.

Estimating fuel loads visually requires practice, so work with an individual who has experience burning in your local fuel types to hone your skills.

Fire behavior fuel models are collections of information about fuels that serve as inputs for fire behavior modeling. They are a shortcut that saves the fire behavior modeler from having to collect extensive data on fuels. The descriptions of these fuel models include fuel load, but it's best to measure fuel load and use it to help you select and fine-tune a fuel model. Fire behavior fuel models are commonly used in fire behavior modeling and are discussed in detail in "Fire behavior."

The Fuel Characteristics Classification System is a series of over 500 fuelbeds (collections of fuels occurring together) that describe all the fuel layers included. (Figure 2.16). These fuelbeds can be a useful reference for a rough estimate of the fuel loading for the area you are burning, but they should be carefully reviewed and adjusted based on what you have observed or measured in your burn unit. FCCS fuelbeds can be used in the Fuels and Fire Tool to model potential fire behavior and smoke emissions (https://depts.washington.edu/fft/webtool/).



Figure 2.18. Transect tape laid across a hill. Fuels would be counted each time the transect line crosses a stick. Credit: Micah Schmidt, © Oregon State University

Recommended video: Fuels and Fire Tool Overview, https://youtu.be/0FseagVYku8

Measuring fuel loading

In the **photoload method**, you compare small, square plots in your burn unit to a series of pictures with known fuel loads (Figure 2.17). The photoload reference guides shown above were created for Rocky Mountain fuels. The woody fuels guides work well in any conifer fuels. The guides for plants work well in Idaho, Eastern Oregon and Eastern Washington, and can be used elsewhere if applied thoughtfully.

The Fuels Data App provides a way to record the information, and you can request a report from the app when you are done collecting.

Recommended video: Introduction to the Photoload Sampling Technique, https://www.youtube.com/watch?v=6PxBtxGHpwU

Fuel loading can also be measured with the **planar intercept method**, commonly referred to as Brown's Transects. This sampling technique involves counting dead fuels that cross established transect lines. A more useful method for landowners is the SIMPLE transect, which is a modified Brown's transect developed by the Oregon Department of Forestry. The SIMPLE transect is used for measuring fuel loading to assess potential smoke emissions associated with prescribed fire (Figure 2.18 and Table 2.7). SIMPLE transects measure live and dead fuels. Measurements can be entered into an online calculator to estimate fuel loading and then be used for smoke modeling.

The photoload method has been shown to represent better estimates of fuel loading in natural fuels, while the transect method is better suited to activity or slash fuels.

Over time, fuel characteristics can change due to vegetation growth, fuels-management interventions or disturbance events such as storms, which can cause a blowdown of shrubs or trees and increase fuel loading. For these reasons, it is important to assess fuel characteristics

SIMPLE TRANSECT TALLY SHEET																				
Date:						Unit Name:														Name:
Area/Forest:						Registration #:														Photo Series:
Unit/District:						Aspect:														Fuel Model:
Location:						Elevation:														Other:
			6'	6'	10'	35'														Special notes:
TRANSECT	SLOPE	TREE SPECIES	0"–.25" (1 HR.)	.25"–1" (10 HR.)	1"–3" (100 HR.)	DIAMETER & SPECIES OF SOUND LOGS (3+")		DIAMETER & SPECIES OF ROTTEN LOGS (3+")		SOUND STUMP (SPECIES, DIAMETER, HEIGHT)	ROTTEN STUMP (SPECIES, DIAMETER, HEIGHT)	SHRUB HEIGHT & SPECIES	LIVE SHRUB % GROUND COVER	DEAD SHRUB % GROUND COVER	GRASS/FORBES HEIGHT & SPECIES	LIVE HERBS/GRASS % GROUND COVER	DEAD HERBS/GRASS % GROUND COVER	LITTER DEPTH	DUFF DEPTH	
1						1	2	1	2	1	1	1	1	1	1	1	1	1	1	Special locations/descriptions:
						3	4	3	4	2	2	2	2	2	2	2	2	2	2	

Table 2.7. SIMPLE transect form example. Credit: Oregon Department of Forestry (Fuel load estimating tools), https://www.oregon.gov/odf/fire/pages/burn.aspx

when creating a burn plan and then to reassess current conditions before burning. Check with your state forestry agency to ensure you meet the fuel documentation guidelines for your state.

Fuels management

Prescribed fire is an effective fuel management tool, but it may not be the first fuels-management activity you should undertake in any particular burn unit. Fuels management is used to influence potential fire behavior and fire effects, but other management practices may be needed to prepare the unit to receive fire productively. Applying prescribed fire without any prior fuels-management actions could have unintended consequences.

Forests may have much higher stand densities and greater duff and litter loadings than historically existed when fire burned more frequently, which can lead to more intense fire behavior and more difficult burning conditions. The presence of invasive species in the burn unit should also be a concern, as fire can sometimes cause invasive plants to spread or more fully occupy the site. When planning a prescribed burn, consider fuels management holistically. You may need to take a variety of steps before burning to give your burn the best chance of meeting your objectives.

Recommended video: Introduction to Fuels Management, https://www.youtube.com/watch?v=AvhC4z4w3G0

Pre burn fuels management options and considerations

- **Thinning or logging:** Reduces the tree density and canopy continuity. Material can be piled and burned or lopped and scattered if the cut material is sparse enough.
- **Pile burning:** Removes dead and downed material and reduces fire intensity in a subsequent underburn or broadcast burn. Piles can be built with machines or by hand.
- **Lop and scatter:** Spreading out thinned material across a landscape can allow for a recycling of nutrients into the soil over time. This method increases fire risk and potential fire intensity in the short term, depending on the amount of fuel present and site productivity. It is not recommended for dry forests where fuels take a long time to decompose.
- **Mastication, mulching or chipping:** The grinding of woody material can remove shrubs and small trees that might otherwise serve as ladder fuel. This can be an effective vegetation management technique, but it can raise concerns for fire management, as it doesn't actually remove fuel and instead redistributes it into a more horizontal, compact layer on the ground. This is often a replacement for prescribed burning rather than preparation for it. If burned, the biomass from these processes can smolder for long periods of time, causing smoke and control issues and heat damage to soil and roots.

- **Tree well burning:** Burning under tree canopies can reduce needle buildup during seasons when ground fuels are moist but the litter beneath trees dries out sufficiently, like in spring after snowmelt. This is most often used to reduce fuels around old ponderosa pine trees to prepare for an underburn, so that the old trees will be less likely to be killed by the fire.
- **Fuel moving:** During logging or thinning, it is common for dead and down material to accumulate at the base of trees. Pulling material away from the base of trees, and ideally beyond the reach of their branches, can increase the likelihood they will survive a fire. Other fuel accumulations and piles may need to be spread out or burned separately, as they can become concentrated areas of higher-intensity fire and create control issues.
- **Herbicide:** Can be applied after burning to decrease the abundance of invasive species. This may be most important on control lines, equipment tracks or areas of higher-severity burns where more disturbance occurred. This is also commonly used following rangeland burns, particularly where invasive annual grasses are an issue.
- **Native planting:** If the site is prepared with fire or herbicide, native seed can be planted to speed its recovery and help keep invasive species from becoming established.

Getting to know the fuels in your intended burn unit and their responses to fire is an essential part of becoming a successful prescribed fire practitioner. You can get some of this information from books and websites, but much of it comes from training with experienced fire practitioners. Take advantage of local experts' knowledge and build your own by starting with low-complexity burns, documenting your observations, and building up to larger and more complex burns over time.

References

Anderson, H.E. 1982. *Aids to Determining Fuel Models for Estimating Fire Behavior*. United States Department of Agriculture Forest Service, Intermountain Forest and Range Experiment Station. General Technical Report INT-122.

Anderson, H.E. 1978. *Graphic aids for field calculation of dead, down forest fuels*. USDA Forest Service, General Technical Report INT-45. Intermountain Forest Range and Experiment Station, Ogden, UT.

Brown, J.K. 1974. *Handbook for inventorying downed woody material*. USDA Forest Service, General Technical Report INT-16. Intermountain Forest and Range Experiment Station, Ogden, UT.

Holley, V.J., and R.E. Keane. 2010. *A visual training tool for the photoload sampling technique*. USDA Forest Service. General Technical Report RMRS-GTR-242. Rocky Mountain Research Station, Fort Collins, CO.

Keane, R.E., and L.J. Dickinson. 2007. *The photoload sampling technique: estimating surface fuel loadings from downward-looking photographs of synthetic fuelbeds*. USDA Forest Service, General Technical Report RMS-GTR-190. Rocky Mountain Research Station, Fort Collins, CO.

Maxwell, W.G., and F.R. Ward. 1980. *Photo series for quantifying natural forest residues in common vegetation types of the Pacific Northwest*. USDA Forest Service. General Technical Report PNW-GTR-105. Pacific Northwest Forest and Range Experiment Station, Portland, OR.

National Wildfire Coordinating Group. 2024. *Fire Behavior Field Reference Guide*, PMS 437.

Scott, J.H., and R.E. Burgan. 2005. *Standard fire behavior fuel models: a comprehensive set for use with Rothermel's surface fire spread model*. USDA Forest Service, General Technical Report RMRS-GTR-153. Rocky Mountain Research Station, Fort Collins, CO.

Wright, C.S., R.E. Vihnanek, J.D. Restaino and J.E. Dvorak. 2012. Photo series for quantifying natural fuels. *Volume XI: Eastern Oregon sagebrush-steppe and spotted owl nesting habitat in the Pacific Northwest*. USDA Forest Service. General Technical Report PNW-GTR-878. Pacific Northwest Research Station, Portland, OR.

CHAPTER NOTES



FIRE BEHAVIOR

Section authors: Heather Heward and John Punches

Image credit: Heather Heward

IN THIS SECTION

- ☐ Introduction to fire behavior
- ☐ The fire behavior triangle
- ☐ Fire influences fire behavior
- ☐ Describing fire behavior
- ☐ Parts of a fire
- ☐ Fire behavior modeling
- ☐ Meeting objectives with ignitions

Introduction to fire behavior

Understanding the factors influencing fire behavior is key to using prescribed fire safely and effectively. When you burn, you are, in essence, reversing the process of photosynthesis. Plants store the sun's energy while capturing carbon dioxide and releasing oxygen. Fire releases energy and carbon dioxide while using oxygen. Fire does this rapidly — breaking down organic material and returning the components to the soil and air. It's nature's way of clearing the slate and setting the stage for new growth.

Fire can only exist if three things are present: fuel, heat and oxygen (Figure 3.1, left). A more detailed way to state this is that fire (or combustion) can only occur if receptive fuel in the presence of adequate oxygen is heated to its point of ignition.

Once ignited, fire behavior is dictated by the interaction of three factors (Figure 3.1, right):

1. Fuel (what is burning or available for burning)
2. Weather (atmospheric conditions)
3. Topography (physical features of the land)

Together, these factors determine the fire's potential, which in turn drives its behavior. That behavior then produces fire effects, which are the ecological and physical impact on the environment such as vegetation response, water quality and air quality. This relationship loops back on itself: Fire effects influence which fuels will be available next time, which changes the fire's potential (Figure 3.2). As a prescribed fire practitioner, your choice of when, where and how to light a fire affects the entire cycle.

Fire behavior is dynamic; it is vital to be an active and humble observer of fire behavior under a variety of conditions. Every day brings slightly different conditions, so you should never expect to see the same fire behavior from one day to the next. After a fire, re-evaluate the fire's behavior and strategize for future desired outcomes.

This chapter walks you through what influences fire behavior, how to describe it and how to influence it to meet your land-management objectives. It assumes you have already read the Fuel and Weather chapters.

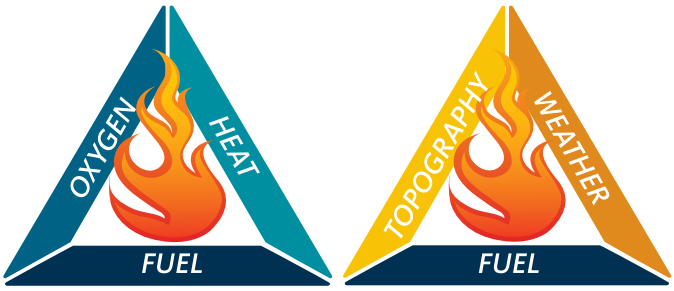


Figure 3.1. The fire combustion triangle (left) and fire behavior triangle (right). The fire combustion triangle shows what it takes for a fire to burn, and the fire behavior triangle shows the factors that affect fire behavior. Fuel is the only one of these factors that can be manipulated, and weather is the most variable. Credit: © Oregon State University

The fire behavior triangle

Fuels, topography, weather and the fire itself influence fire behavior. By understanding how each of these factors work you can better anticipate what the fire will do and implement a burn that produces the effects you want.

FUELS

Fuels are the propelling force behind fire behavior and are the part of the fire behavior triangle that can be manipulated. Fuel characteristics are covered in more depth in "Fuels," but in short, the type, amount, arrangement and moisture of fuels all influence fire potential.

- A lot of dry fuel = high fire potential
- A little fuel or wet fuel = low fire potential



Figure 3.2. The continuum shows how fire potential, fire behavior and fire effects relate and influence each other. Credit: Ciara Bordeaux

Not all fuels are available to burn; they might be too wet, too compacted or too large to ignite. The amount of available fuel — the fuel that will actually burn — influences fire behavior. Before burning, assess what fuels are available to burn and whether they will increase or decrease fire behavior. This can involve simply breaking sticks and bending pine needles to estimate fuel moisture; taking more exact measurements using a protimeter; or collecting, weighing and drying fuel samples (Figure 3.3).

When planning your burn, think of your fuels in two categories — live and dead. Each will have different impacts on fire behavior.

Dead fuels

The moisture content of fine dead fuels (often called 1-hour fuels) like grass, pine needles, leaves and small sticks will change quickly, often in hours or minutes,



Figure 3.3. Estimate fuel moisture with a protimeter. Credit: Heather Heward

depending on the moisture in the air and sun exposure (Figure 3.4). Awareness of weather changes allows a burn boss some time to prepare for these changes in fuel moisture. This is particularly important if temperatures rise and humidity drops. When dry, these fuels ignite easily and spread fire quickly, but they also burn out quickly.

Larger fuels (10- to 1,000-hour fuels) such as branches and logs will gain and lose moisture over days, weeks or months, and they can burn for hours or days. 10-hour fuels are also important for fire spread rates when 1-hour fuels remain dry. They contribute to fire spread. Because they burn longer, 10-hour fuels expose 100- and 1,000-hour fuels to heat and increase the chances of ignition in larger fuels as well.

Dead fuel moisture, which usually ranges from 2% to 30%, is directly influenced by relative humidity and is closely linked to fire behavior.

Live fuels

Living plants can have big impacts on fire behavior, depending upon their moisture content. When the moisture content of live plants is low, they will ignite relatively easily and add to fire intensity and rate of spread. When they have high moisture content, they absorb heat, reducing overall fire intensity and the rate of spread.

Recall from the Fuels chapter that live fuel moisture varies by plant species and their stage of development in a pattern that is generally tied to seasonal changes. Recall, too, that some plant species are inherently more flammable due to their chemical compositions, regardless of their moisture content.

Live fuels draw moisture from the soil and are generally not affected by short-term weather changes. Drought and extended months of hot temperatures, however, can accelerate drying and make plants burn-ready earlier in the season. Above-average summer temperatures over an extended period can increase the rate at which live fuels lose moisture. Plants can also have lower moisture content when you might not anticipate it, such as when they are first breaking bud in the spring. At this time, woody plants shift moisture to their new growth, leaving the older parts of the plant dry and flammable. Remember that this "spring dip" in moisture content can have a big impact on fire behavior.

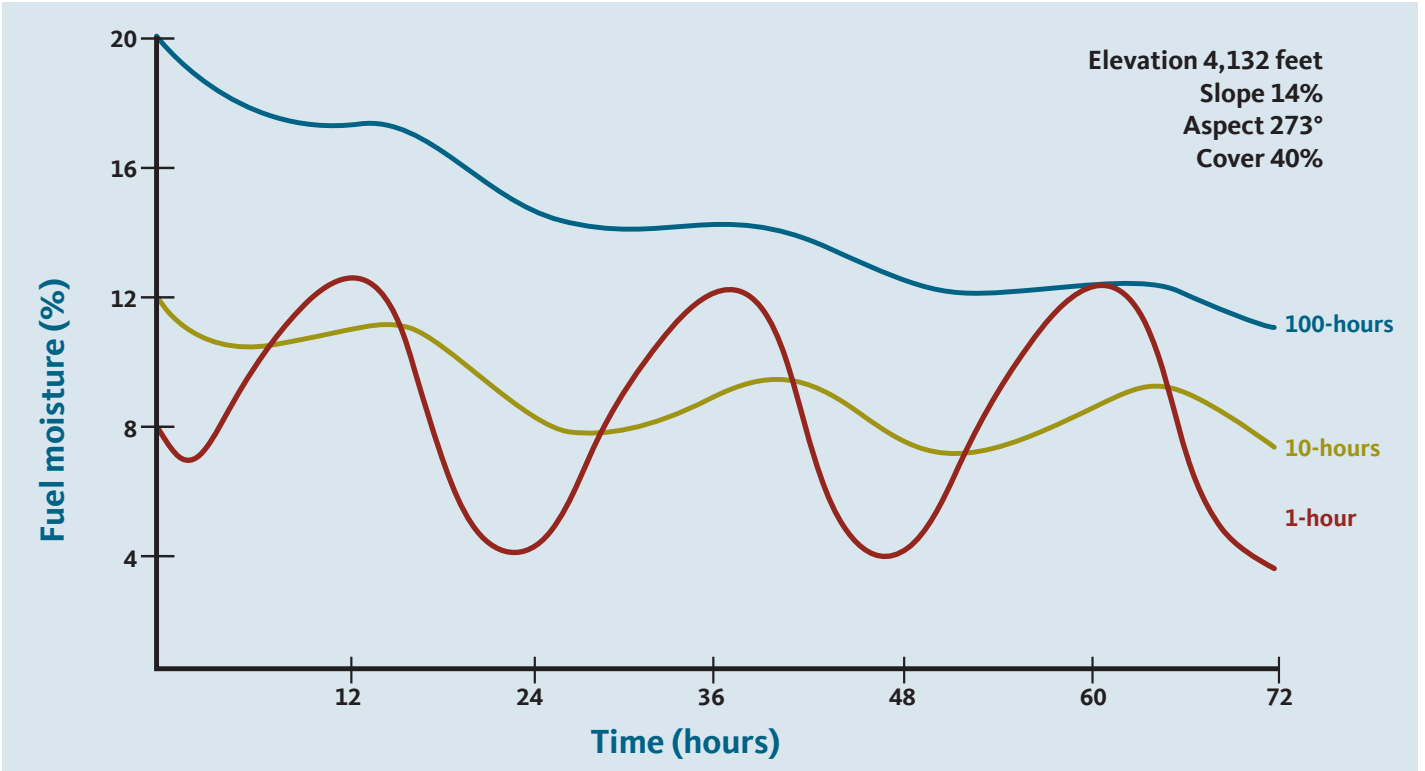


Figure 3.4. Relative rates at which different size classes of dead fuels respond to changes in relative humidity. On any particular day, the moisture content of 1-hour fuels will fluctuate significantly, while the moisture content of larger fuels changes only a little.

Managing live fuels can help you manage your burn's behavior. You can choose to burn when live fuels have more (or less) moisture, or you can directly modify fuels in key locations (such as near control lines) by cutting ladder fuels, mowing grass or shrubs, etc. These will directly affect fire intensity, rate of spread, and the potential to escape your control lines, so pay close attention to live fuels as you plan and implement your burn.

WEATHER

Weather is the most dynamic of the three fire-behavior triangle categories. Humidity, temperature and wind significantly affect fire behavior and are important weather variables for a burn prescription.

As noted in the Fuel and Weather chapters, **relative humidity**, or RH, has a direct influence on the moisture content of fine fuels. A high relative humidity may hinder combustion, while low relative humidity can lead to fire behavior more intense than you'd like.

Temperature amplifies the effect of relative humidity; high temperatures result in lower relative humidity values and heat water in fuels, making them dry faster. Crown scorch is highest on high-temperature days, so if you're burning under trees you want to keep healthy, you may want to set a lower maximum temperature in your prescription.

Wind has perhaps the biggest implications for fire behavior. Increasing wind speed typically results in increased fire intensity and a faster-moving fire, while low wind speed may make it challenging to predict which direction the fire will move. Controlled burns are risky during times of unpredictable winds, which can result from weather systems such as cold or warm fronts.

Your burn personnel need predictable conditions to safely conduct ignitions and to ensure the fire stays within its control lines.

Thunderstorms can pose big challenges for burners. They can occur with little warning and have obvious dangers from lightning strikes. They also create outflow winds that can impact your burn unit even if the storm is miles away. Monitor weather forecasts for the potential for thunderstorms.

Recommended video: Thunderstorms and Wildland Fire Decision-making, https://youtu.be/-Z74OnWmdAA?si=V_goo75znnmA7Lzu

Periods of strong atmospheric convection can significantly impact fire behavior and your burn. A convective atmosphere, technically called an **unstable atmosphere** (see Weather chapter) allows heated air to rise rapidly. To identify these days, consult your weather forecast's mixing height; above 10,000 feet suggests significant instability. You can also identify them through direct, clear signs like outstanding visibility.

Fire burning in an unstable atmosphere will have more intense fire behavior because its heated air rises, pulling fresh air in at the surface and providing the fire with oxygen. These are called **inflow winds**. These days will also be more likely to produce localized thunderstorms because sunlight heats ground surfaces, creating pockets of heated air that can rise rapidly and produce cumulonimbus clouds. This kind of weather system produces inflow winds where air is rising and outflow winds where that air falls back to the surface again.

Recent weather in your burn area also significantly affects potential fire behavior. Several days of rain, followed by a few days of dry conditions, may make exposed fine fuels dry enough to burn but leave shaded fuels wet and resistant to fire. In this scenario, soil and duff may also be moist, slowing the rate at which dead fuels can dry out. A long period of drought will change the moisture in both dead fuels and live fuels, increasing the potential for more intense fire behavior.

For the best success on your burn day, monitor local weather patterns and how they align with weather forecasts. Weather in the days leading up to your burn will inform you of fuel conditions and potential fire behavior. Prior to and on your burn day, keep a record of weather and fire behavior observations. Adjust your firing and holding efforts as needed to achieve the burn results you want. Watch the weather forecast and actual weather following the burn and adjust your mop-up and patrol plans accordingly. Becoming a weather and fire behavior observer will make you a better prescribed fire practitioner, so cultivate these skills.

Weather — particularly wind — has strong interactions with topography. We'll consider that in the next section.

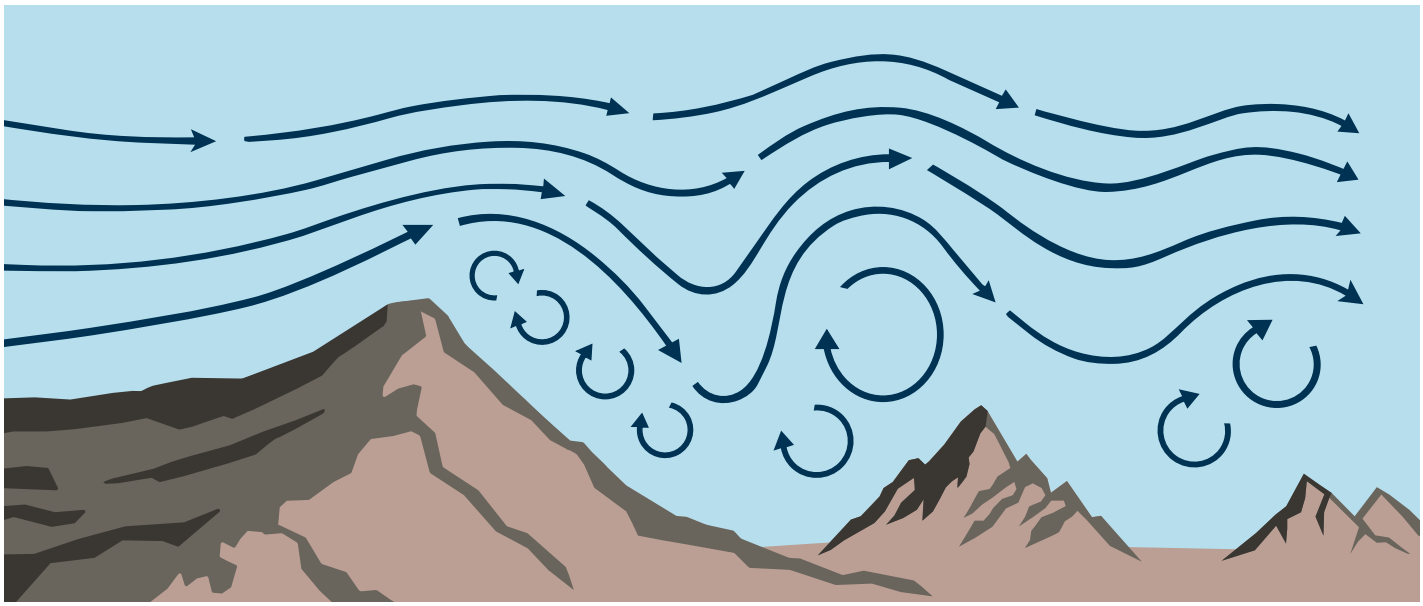


Figure 3.5. Wind moving across uneven ground. Credit: National Wildfire Coordinating Group

TOPOGRAPHY

Topography refers to the shape of the land and includes aspect, slope and elevation. You need to give it special consideration when planning or implementing a burn

When wind moves across uneven ground, it doesn't always blow the way we expect (Figure 3.5). Even on a small burn unit, subtle features like ditches, swales, hummocks and road embankments can bend, speed up or redirect wind in ways that affect fire behavior. For example, think about a 4-acre unit bordered by a gravel road. The road ditch may seem minor, but wind can flow along that low spot much like water in a channel. As the wind is squeezed into the ditch or shallow swale, it can pick up speed, causing flames to lean, increase the rate of spread or throw embers farther than expected.

Small rises in the ground, such as hummocks, terrace edges or cut banks, can act like miniature ridges and points. Wind moving around these features may split, curl or suddenly change direction. Fire backing slowly one minute can shift to a flanking or head fire the next, especially when the wind aligns with the shape of the ground.

Road corridors deserve special attention. Where a road dips, curves or intersects a drainage, winds can funnel through these openings and become gusty, even when general winds are light. These spots often become problem areas for holding, where embers can be lifted and dropped just outside the line.

In short, you don't need steep mountains or large landscapes for topography to matter. On small-acre burns, ditches, shallow draws, road cuts and uneven fields can all influence wind and fire behavior. Identifying these features during prep and observing how smoke and test-fire behavior respond to them can help you anticipate where fire may intensify or spread unexpectedly.

The aspect (or the compass direction that a slope faces) of an area affects fire behavior in multiple ways (Figure 3.6, left). In the Northern Hemisphere, south-facing slopes are drier, while north-facing areas are often cooler and wetter. This means fuels on south aspects will generally be drier than on north aspects, but fuel loads will vary.

The wetter, north aspects support more tall vegetation that grows quickly, while south aspects support slower-growing, shorter, more drought-adapted plants. As a result, fires on south aspects can burn rapidly through dry fine fuels such as grass and brush.

It may be more difficult to get fire to burn on a moist north-facing slope. But if weather conditions allow that slope to dry out, it will often have more available fuel, so fire can actually be more intense on north slopes.

Canyons, saddles and draws

Narrow surface features such as canyons, saddles and draws channel wind, increasing its speed. Upslope winds often funnel through these draws to create what is called a chimney effect.

The chimney effect occurs when unstable air conditions at the top of a draw create a strong convection current through the draw. When the chimney effect is combined with additional upslope winds, the resulting fire can move extremely fast.

Even in the absence of wind, these land features can influence the rate and direction of fire spread by directing it up through the area. For example, when inversions set up in a narrow canyon and then break down during the day, fire behavior can shift rapidly. Canyons have additional effects on fire behavior. The ridgelines have what's called the eddying effect. This occurs when topographic heating causes breezes on the lee side of the ridge. When the breeze winds from two sides, the fire side and the nonfire side of a ridge meet, and there is potential for the column to curl back over the fire, spreading hot embers downhill.

East-facing slopes get morning sun, so they are wetter than west- or south-facing slopes but drier than north slopes. West slopes get the afternoon sun, so they may experience the highest temperatures, particularly during peak seasonal drying. But in the Pacific Northwest, they also get moisture from storm systems moving inland from the Pacific Ocean, so they can have substantial fuel loads in some areas.

The angle of the slope amplifies the sun's impact on fuels. Steeper slopes that tilt the Earth's surface toward the sun increase the amount of solar radiation the area receives, raising soil surface temperature, reducing fuel moisture, and affecting the plant species growing there. This is yet another factor explaining why fire behavior is more intense on steeper slopes. Steep slopes increase fire's spread across the terrain, which means that fires moving up steep slopes are often more intense and move more quickly than fires burning on flatter ground (Figure 3.6, right). Fire on a slope preheats and dries uphill fuels, making them more receptive to fire. Heated air rises and is more easily replaced from the downhill side of the fire, where the slope does not block air. This leads to uphill airflow that bends the flames toward the uphill side, bringing them into direct contact with fuels and preheating them. Steep slopes can contribute to fire spread downslope as well. While fire typically moves slower downhill, rolling debris presents a serious danger on steep inclines. This material can ignite fuels below, starting other fires.

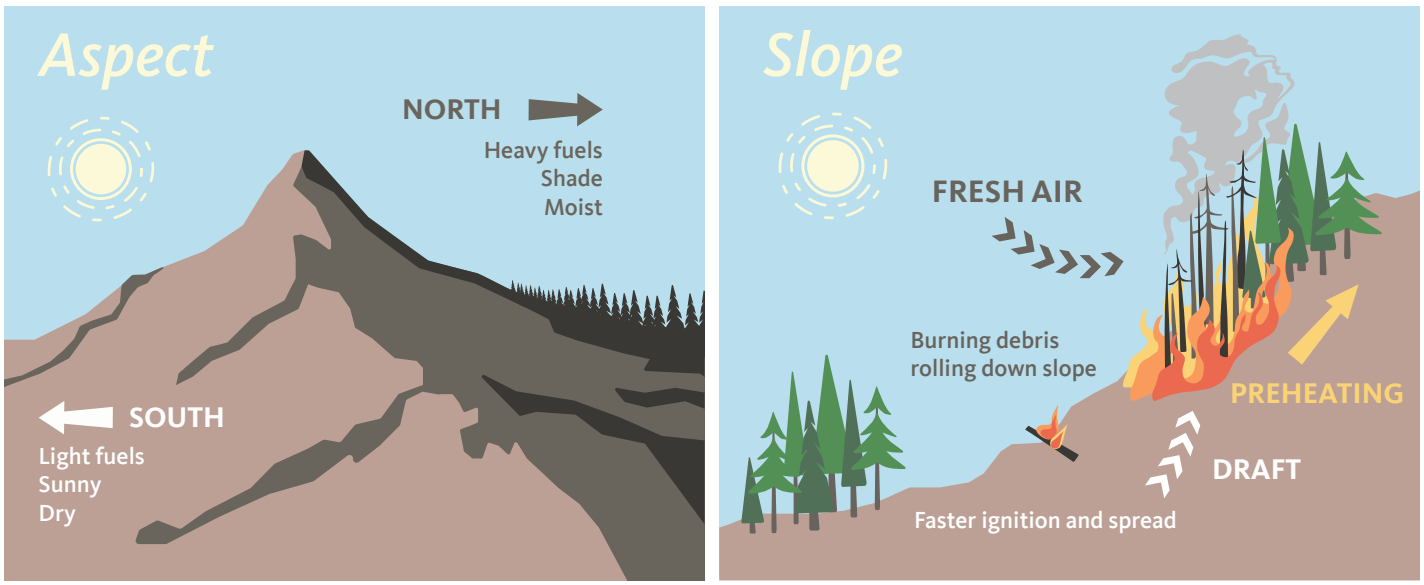


Figure 3.6. South-facing slopes are drier (left), and fire moves faster uphill (right). Credit: © Oregon State University

Variations in heating across different aspects can cause daily patterns in wind shifts, called diurnal winds (Figure 3.7). In valleys, along river drainages and near bodies of water, winds tend to move upslope in the morning as the upper slopes heat up and down in the evening as the lower slopes cool off. This is quite common in mountainous areas with high-elevation snow lingering into the summer months. These can combine with up-valley winds that begin later in the morning or down-valley winds later in the evening.

Diurnal patterns are quite predictable, and prescribed burns often take advantage of this. Good burn planners know when winds are likely to move upslope, timing ignitions to occur while wind conditions are predictable. They also plan for what will happen, particularly with smoke, when the wind shifts downhill in the evening. Monitor these daily patterns of wind in your area as you explore your burn unit to prepare yourself for both planning and implementation.

You can't change topography, but you can plan around it:

- Avoid putting control lines where the slope might funnel wind or fire.
- Anticipate how topography will influence fire behavior and adjust your ignition techniques accordingly.
- Position additional holding resources where terrain features are likely to increase fire intensity or make containment more difficult.

For example, a bend in a road used as a control line, especially where it intersects a drainage, can become a problem area. Monitor it closely during the burn. Midslope control lines are not recommended and present increased fire containment issues. Strategically placed control lines can minimize escape potential.



Figure 3.7. Surface heating causes patterns in wind that can shift between night and day. Credit: © Oregon State University, adapted from Don Baker

Fire influences fire behavior

Fire influences its own behavior. As fire burns, it heats the air above it, causing it to rise. That rising air draws in cooler air from the sides — creating wind, just like with unstable weather.

You might start your burn on a calm morning, only to find winds picking up once the fire gets going. Before adding more fire, pause and think about how this self-created wind could change your fire behavior.

Recommended video: Atmospheric Stability and Wildland Fire, https://www.youtube.com/watch?v=1GXB26R6_Rg

Fire burning in one piece of fuel is also a source of heat that can ignite the next piece. The first piece has only a limited ability to support combustion, so its flame is relatively short. As more fuel is engaged and ignited, the gases being consumed combine their energy, and flame lengths increase.

This means that fire is lowest in energy when first ignited and increases in energy as the fire grows. You can use this fact to fine-tune your ignition pattern in your burn unit. We'll cover this in more detail later in this chapter.

Describing fire behavior

Fire behavior is typically described in two ways:

1. The size of the flames (flame length, flame height and flame depth).
2. How fast the fire moves (rate of spread).

The energy released by the fire is referred to as fire intensity. Intensity influences the impact of fire on the soil, animals, fungi, the built environment and vegetation — known as fire or burn severity. Fire severity leads to the short- and long-term impacts of the fire, known as fire effects. To influence fire effects, the burner can alter fire intensity and severity.

FLAME LENGTH

Flame length is the distance a flame stretches, measured from the midpoint of the flame on the ground to the flame tip (Figure 3.8). Flame length is an important indicator of fire intensity and depends on fuel height, wind speed and slope.

As a guideline, expect flames to be two to four times taller than your fuels under moderate slope and wind. That means 2-foot-tall grasses can produce flame lengths of 4 to 8 feet.

This has important implications for safety and planning. For example, control lines (the cleared or treated edge of your burn unit) should be at least 1.5 times wider than the fuel height. So, for 2-foot-tall grass, your control line should be at least 3 feet wide.

You can reduce the fuel height and associated flame length along the control line by mowing or removing larger fuels ahead of time (Figure 3.9). This provides a more comfortable working environment for the people holding the line. (It's difficult to work near flames longer than 4 feet.)

It's better to modify fuels to a lower profile along the firelines for several reasons. It reduces the likelihood of fire spreading outside the unit, it can reduce time spent on mopping up directly against the line, and it minimizes smoke and heat exposure to holding forces.

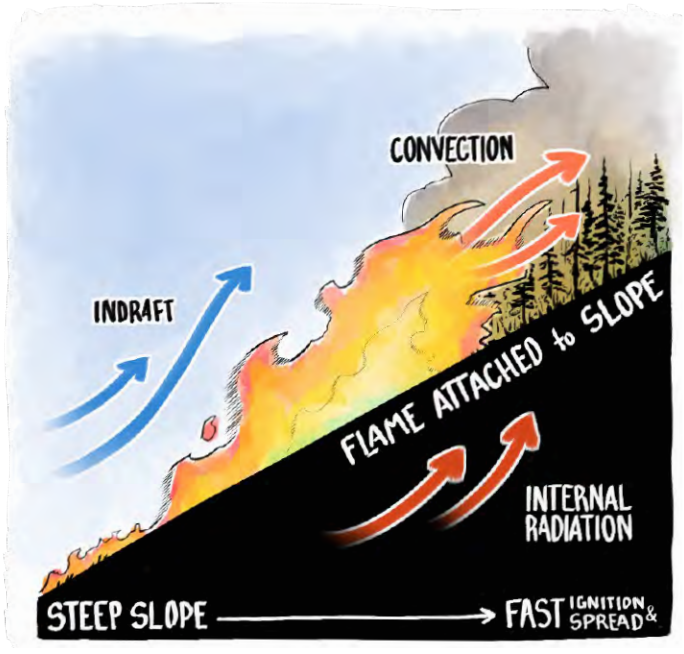


Figure 3.8. Flame structure elements. Credit: Ciara Bordeaux

FLAME HEIGHT

Flame height is the average height of flames as measured vertically, up and down. It may be less than the flame length if the flames are angled horizontally, backward or forward.

You can measure and use flame height in different ways. Flame height is sometimes defined as the height the flame reaches above the soil surface and sometimes as the height above the fuel bed. If you are including flame height in your prescription, specify which definition you're using.

Measuring or modeling flame height is that it gives you a sense of how high the flames will reach into overhead fuels, such as tree crowns. This information is useful for achieving goals related to increasing canopy base height and predicting potential torching.

FLAME DEPTH

Flame depth, or flame zone depth, is the distance from the base of the flames to the trailing edge of the flaming front of the fire. In other words, it refers to how wide the active flame front is across the ground.

Light, fine fuels like grass and pine needles tend to burn in a narrow flame front and go out quickly. Heavier fuel materials — like brush or logging slash — can burn in a much wider flame zone, allowing more heat transfer into the soil and up into the canopy (Figure 3.10).

Flame zone depth is a relatively easy-to-observe indicator of how long fire will burn in any one location — something referred to as residence time. The longer a fire remains in one location, the more time it has to accumulate heat in the soil or canopy, with significant implications for soil conditions and for torching trees or shrubs.

RATE OF SPREAD

The rate of spread, or ROS, is the speed at which fire moves across the landscape. In the United States, the rate of spread is most commonly measured and reported in chains per hour (c/h). A chain is 66 feet and is a common forestry unit of measurement, as it converts easily to acres. Ten square chains equal one acre. There are 80 chains in one mile.

The rate of spread is affected by firing techniques, fire intensity, fuel conditions, wind, topography and vegetation. For example, a fire burning up a slope will spread faster than a fire burning in the same fuel conditions across a flat area. Similarly, wind blowing upslope can increase the rate of spread, while wind blowing downslope can decrease the rate of spread.

One way to measure the rate of spread is to mark out, or visually estimate, a known distance in front of the fire and time how long it takes for the flame front to reach it (Table 3.1). This is often easiest when measuring a smaller



Figure 3.9. Reduce the flame lengths next to the control line by reducing the height of the fuel next to the line. Credit: Heather Heward



Figure 3.10. The upper image shows a wide flame depth in a slash fuelbed. The bottom image shows a narrow flame depth in a pine needle fuelbed. Credit: Heather Heward

distance, such as a foot. There are 60 seconds in a minute and 66 feet in a chain. Therefore, if a fire travels 1 foot per minute, it is moving approximately 1 chain per hour.

Another option is to watch the fire for a set amount of time and estimate how far it traveled.

Both flame length and rate of spread are general estimates — they'll vary across your burn unit depending on fuel type, height, etc. Recording environmental conditions at the time helps you to understand changes in rates of spread and the environment.

Learning to estimate the rate of spread takes practice. Try observing how fast fire moves in different fuels, under different wind speeds, and at different times of day. Eventually, you'll be able to look at a fire and quickly estimate how long it will take to reach another part of your unit.

Recommended video: Effects of Slope and Wind on Fire Behavior, https://www.youtube.com/watch?v=DAh6pOuCUsc

A chain (66 feet) is a unit of measurement commonly used in wildland fire and forestry. There are 80 chains in a mile.

Measuring rate of spread — A fire moving 1 foot per minute is roughly 1 chain an hour. You can use this estimate to scale up or down. If a fire moves 4 feet in 15 seconds, that is roughly 12 chains an hour. If a fire moves half a foot in a minute, that is half a chain per hour.

Distance	Time	Rate of spread
Distance*(seconds/60) = ROS chains/hour		
1 foot	10 seconds	6
	15 seconds	4
	30 seconds	2
	1 minute	1
	2 minutes	0.5
5 feet	10 seconds	30
	15 seconds	20
	30 seconds	10
	1 minute	5
	2 minutes	2.5
10 feet	10 seconds	60
	15 seconds	40
	30 seconds	20
	1 minute	10
	2 minutes	5
30 feet	10 seconds	180
	15 seconds	120
	30 seconds	60
	1 minute	30
	2 minutes	15

Distance	Time	Rate of spread
(Seconds/60)*distance = ROS chains/hour		
15 seconds	1 foot	4
	5 feet	20
	10 feet	40
	20 feet	80
	30 feet	120
30 seconds	1 foot	2
	5 feet	10
	10 feet	20
	20 feet	40
	30 feet	60
1 minute	1 foot	1
	5 feet	5
	10 feet	10
	20 feet	20
	30 feet	30
2 minutes	1 foot	0.5
	5 feet	2.5
	10 feet	5
	20 feet	10
	30 feet	15

Table 3.1. Rate of spread look-up tables based on measures of distance or time.

The parts of a fire

Fire doesn't behave the same in all directions (Figure 3.11 and Table 3.2).

Recommended video: Introduction to Fire Behavior, https://www.youtube.com/watch?v=SB4pk91yq24).

HEADING FIRE

The head of the fire is the most noticeable; it moves the fastest and produces the longest flames. Heading fires typically burn with the wind and uphill, making it the most intense part of the burn.

BACKING FIRE

A backing fire, on the other hand, burns into the wind or down the slope and slowly creeps along. It's lower in flame length and rate of spread, making it a good tool when you want more control or need longer residence time.

FLANKING FIRE

Flanking fire moves sideways, perpendicular to the wind or across the slope. Flanking fires are less predictable — if the wind direction changes even slightly, they can quickly turn into heading fire.

On any particular burn you will likely have a combination of heading, backing and flanking fire behavior. If fire gets out of your intended burn area, it's the heading fire behavior you'll need to be able to contain with holding resources. Prescribed burning uses all these techniques in some combination, depending on the burn objectives.

Dangers of interior ignition

Strip-head fires, point-source fires and flanking fires all require burners to enter the burn unit while lighting, often called interior ignition. To safely ignite within the burn unit, ensure there is a way to communicate and coordinate with the burners, to avoid a burner becoming surrounded by fire (sometimes called entrapment).



Figure 3.11. Flame structure elements. Credit: Ciara Bordeaux

Fire type	Direction of fire	Intensity	Temperature	Rate of spread	Ease of containment or control
Backing fire	Against the wind, or downslope	Low	Generally, the coolest fire type	Slow	Easiest
Flanking fire	Fire spreads at right angles (90°) to the wind	Moderate	Cooler than heading fires, but can become hotter	Medium	Moderate–difficult
Heading fire	With the wind	High	Hottest	Fast	Difficult

Table 3.2. Types of fire spread and characteristics. Credit: University of Georgia Extension

SPOTTING

Control lines prevent fire from moving freely outside of the intended area, but embers can fly over, creep across and under, or roll over the line and cause spot fires.

When preparing your burn, keep an eye out for areas where spot fires are more likely, based on what is burning, the receptiveness of the fuel outside, soil organic matter and topographic features that may funnel air and embers over the line or cause them to roll down the hill. Consider spotting when placing lines to avoid areas where firebrand sources are near firebrand receptors.

Tables 3.3 and 3.4 offer advice on what to look for and how to mitigate common spot fire situations. Holding resources must monitor the outside of the burn and not the prescribed burn itself. Not included in the table are the many sources and receptors of fire brands from human-made material. Consider any human-made material to be a potential source and receptor for firebrands.

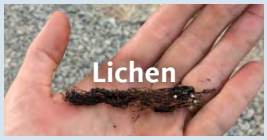
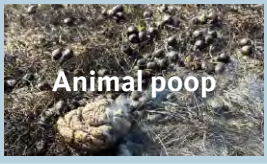
Common firebrand sources	Description	Mitigation
 Canopy fuels	When trees and shrubs torch, the small branches, leaves, bark or flower remnants can lift up in the air, hold heat for several minutes and float on wind currents. They are large enough to start spot fires in a variety of fuelbeds and are small enough to fit behind the collar of your shirt or between your glove and sleeve.	To reduce the likelihood of fire moving up into canopy fuels, remove ladder fuels, including brush, and limb flammable branches. Burn when flame lengths will not reach the heights of the lowest branches. Consider live fuel moisture content when selecting a time of year to burn.
 Snags	Snags (dead trees) can be hazards for the people working on the burn. They can be the source of large and small firebrands. Large portions of the burning material can fall across firelines, and small embers can float across. Some trees (alive and dead) have hollow centers or boles that can funnel fire through them, so look up when searching for sources of fire brands.	If possible, and to the extent allowed by your management goals, remove all snags near any control line. Should removal be impossible or unadvisable, encircle them with a fire-resistant line and keep water accessible during ignition. Mark snags as hazard trees so they will be easy to see and make their locations known in the briefing.
 Lichen	Lichen ignites easily and can detach from trees, floating for long distances in the air. Lichen is light but compact and can carry heat long enough to land on receptive fuelbeds.	Wet down trees near the line that carry lichen, or burn on a day when higher humidities will decrease lichen's receptivity to fire. Remove lichen-covered limbs that cross control lines in advance.
 Pinecones	Pinecones and bark can catch fire on the tree and fall to the ground. Once ignited on the ground, pinecones and bark can carry flame even while rolling. They can drop fire as they roll, establishing fire along the way.	If you have line on a downhill side of the burn, dig a ditch (cup trench) into the line that will catch rolling material such as pinecones. Ensure the trench is deep enough to capture the rolling material, and that the downhill side of the trench is clean soil that will stop fire.
 Logs and root wads	When burning logs are perpendicular to the slope, there is potential for them to break off and roll downhill, spreading fire. Root wads are also prone to loosening after they have started to burn.	Identify the potential for large rolling material. If possible, secure logs in place by rotating them to roll up and down rather than across the slope. Early mop-up after the burn may prevent logs from spreading spots later. In extreme cases, place a barrier at the bottom of the hill to prevent the material from passing.
 Animal poop	Large mats of dried, condensed patties often litter fields where large animals have grazed. When burned, they can turn into disks of heat that become light enough to be lifted by moderate winds and carried over the control line.	When possible, throw patties away from control lines and let them burn out. Be prepared with water in areas where patties are present and you expect moderate, especially swirling winds. Patrol until these more-dense fuel sources are cold.

Table 3.3. Common spot fire sources and mitigations. Credit: Heather Heward and Nathan Hallam (animal poop).

Common receptive fuel types	Description	Mitigation
 Rotten wood	Rotten logs and stumps will catch firebrands and provide a place for the fire to slowly grow. Sometimes they can smolder unnoticed for long periods before fire becomes more active.	Before ignition, identify stumps and logs outside the line and wet them down. Plan to patrol regularly after the burn, paying special attention to these more receptive fuel sources.
 Fine fuels	Fine fuels such as grass and litter take little time to ignite. Even firebrands that can hold heat only for short periods can cause spot fires. Look out for cow patties in grazed areas — they can be a receptive fuel for spot fires.	Wet areas immediately outside of the burn area directly before ignition to decrease their receptiveness. Consider burning under conditions that will not allow rapid spread of fire in finer fuels, such as when live fuel moistures are high. Have a good backup (contingency) plan for how and where you can catch fire if you can't catch it in the fine fuels.
 Moss and lichen	Firebrands can easily ignite moss and lichen. This picture shows a fire starting on the top and sides of the tree and then falling to the ground.	Recognize the high potential for spotting in these fuel types and plan for extra patrols that include careful evaluation of the ground and trees. Be ready with pressurized water to spray any spot fires in the trees. Consider burning on days when these fuels are less receptive.
 Snags	Snags outside your burn unit can be receptive to embers, particularly snags with rot pockets, peeling bark or branches holding dead needles. Snags are also safety hazards for your personnel.	Remove snags in advance, if feasible. Task holding resources with watching snags outside your unit and responding quickly should they ignite. Ensure you have enough water pressure to reach fire high in the snag.

Table 3.4. Common receptive fuel types and mitigations. Credit: Heather Heward

Fire behavior modeling

Fire behavior modeling provides a helpful framework for exploring how changes in fuels, weather and topography influence fire behavior, but it should not be taken as 100% accurate. Take the outputs you get from modeling programs and apply your own knowledge. Fire modeling can be as simple as a lookup table or a feature on an app, or more complicated programs used by fire professionals for landscape-level prescribed fire planning. This section introduces some prominent fire modeling programs. Learn more by taking additional training through the Wildland Fire Learning Portal.

Fire behavior fuel models form the basis for most fire modeling programs. Fire modeling applications provide fire planners with the most accurate outcome projections. It is important to know the assumptions and limitations of the models. These will help you better interpret results.

Fire behavior fuel models are compilations of fuel bed characteristics that allow fire behavior to be modeled without entering a long list of data into the fire behavior modeling tool. The United States has 53 standard fuel models representing most fuel beds and their fire behavior conditions (Table 3.5). Note that fire behavior fuel models do not represent all fuel conditions; they are intended to describe fire behavior.

Read detailed descriptions in *Standard Fire Behavior Fuel Models: A Comprehensive Set for Use with Rothermel's Surface Fire Spread Model*, https://www.fs.usda.gov/rm/pubs_series/rmrs/gtr/rmrs_gtr153.pdf

Recommended video: Introduction to Fire Behavior Fuel Models, https://www.youtube.com/watch?v=XCa10jUWAKI.

Fire behavior fuel model reference table (A)

* =dynamic fuel model

FM code	FM #	Fuel model name	Bed depth (ft)	1-hr	10-hr	100-hr	Live herb	Live woody	Flame length	ROS	Moist extinc
DRY CLIMATE FUEL MODELS											
PRIMARY FIRE CARRIER: **GRASS (GR)**											
FM1	1	Short Grass	1	0.74	0	0			L	VH	12
FM2	2	Timber (Grass Understory)	1.1	2	1	0.5			M	H	15
*GR1	101	Short, sparse dry climate grass	0.4	0.1	0	0	0.3	0	L	M	15
*GR2	102	Low load dry climate grass	1	0.1	0	0	1	0	M	H	15
*GR4	104	Moderate load dry climate grass	2	0.25	0	0	1.9	0	H	VH	15
*GR7	107	High load dry climate grass	3	1	0	0	5.4	0	VH	VH	15
PRIMARY FIRE CARRIER: **GRASS-SHRUB (GS)**											
*GS1	121	Low-load dry climate grass shrub	0.9	0.2	0	0	0.5	0.65	L	M	15
*GS2	122	Moderate-load dry climate grass shrub	1.5	0.5	0.5	0	0.6	1	M	H	15
PRIMARY FIRE CARRIER: **SHRUB (SH)**											
FM4	4	Chaparral	6	5.01	4.01	2			VH	VH	20
FM5	5	Brush	2	1	0.5	0			L	M	20
FM6	6	Dormant brush, hardwood slash	2.5	1.5	2.5	2			M	H	25
*SH1	141	Low load dry climate shrub	1	0.25	0.25	0	0.15	1.3	VL	VL	15
SH2	142	Mod load dry climate shrub	1	1.35	2.4	0.75	0	3.85	L	L	15
SH5	145	High load dry climate shrub	6	3.6	2.1	0	0	2.9	VH	VH	15
SH7	147	Very high load dry climate shrub	6	3.5	5.3	2.2	0	3.4	VH	VH	15
PRIMARY FIRE CARRIER: **TIMBER UNDERSTORY (TU)**											
*TU1	161	Light load dry climate timber-grass-shrub	0.6	0.2	0.9	1.5	0.2	0.9	L	L	20
TU4	164	Dwarf conifer with understory	0.5	4.5	0	0	0	2	M	M	12
TU5	165	Very high load dry climate timber-shrub	1	4	4	3	0	3	M	M	25
HUMID CLIMATE FUEL MODELS											
PRIMARY FIRE CARRIER: **GRASS (GR)**											
FM3	3	Tall grass	2.5	3.01	0	0			H	M	25
*GR3	103	Low load very course humid climate grass	2	0.1	0.4	0	1.5	0	M	H	30
*GR5	105	Low load humid climate grass	1.5	0.4	0	0	2.5	0	H	VH	40
*GR6	106	Moderate load humid climate grass	1.5	0.1	0	0	3.4	0	VH	VH	40
*GR8	108	High load very course humid climate grass	4	0.5	1	0	7.3	0	VH	VH	30
*GR9	109	Very high load humid climate grass	5	1	1	0	9	0	EX	EX	40
PRIMARY FIRE CARRIER: **GRASS-SHRUB (GS)**											
*GS3	123	Moderate load humid climate grass	1.8	0.3	0.25	0	1.45	1.25	M	H	40
*GS4	124	High load humid climate grass	2.1	1.9	0.3	0.1	3.4	7.1	VH	H	40
PRIMARY FIRE CARRIER: **SHRUB (SH)**											
FM7	7	Southern rough	2.5	1.13	1.87	1.5			M	M	40

Table 3.5 A–B. Fire behavior fuel model reference table adapted from GTR 153 by Heather Heward

Fire behavior fuel model reference table (B)

* =dynamic fuel model

FM code	FM #	Fuel model name	Bed depth (ft)	1-hr	10-hr	100-hr	Live herb	Live woody	Flame length	ROS	Moist extinc
SH3	143	Mod. Load humid climate shrub	2.5	0.45	3	0	0	6.2	L	L	40
SH4	144	Low load humid climate timber-shrub	3	0.85	1.15	0.2	0	2.55	M	H	30
SH6	146	Low load humid climate shrub	2	2.9	1.45	0	0	1.4	H	H	30
SH8	148	High load humid climate shrub	3	2.05	3.4	0.85	0	4.35	H	H	40
*SH9	149	Very high load humid climate shrub	4.4	4.5	2.45	0	1.55	7	VH	H	40
PRIMARY FIRE CARRIER: **TIMBER UNDERSTORY (TU)**											
TU2	162	Moderate load humid climate timber-shrub	1	0.95	1.8	1.25	0	0.2	L	M	30
*TU3	163	Moderate load humid climate timber-grass-shrub	1.3	1.1	0.15	0.25	0.65	1.1	M	H	30
DEAD FUELS ONLY FUEL MODELS											
PRIMARY FIRE CARRIER: **TIMBER LITTER (TL)**											
FM8	8	Timber litter with normal dead	0.2	1.5	1	2.5			VL	VL	30
FM9	9	Hardwood litter/Open pine with grass	0.2	2.92	41	0.15			L	M	25
FM10	10	Timber litter with heavy dead	1	3.01	2	5.01			M	M	25
TL1	181	Low load compact conifer litter	0.2	1	2.2	3.6	0	0	VL	VL	30
TL2	182	Low load broadleaf litter	0.2	1.4	2.3	2.2	0	0	VL	VL	25
TL3	183	Mod. Load conifer litter	0.3	0.5	2.2	2.8	0	0	L	VL	20
TL4	184	Small downed logs	0.4	0.5	1.5	4.2	0	0	L	L	25
TL5	185	High load conifer litter	0.6	1.15	2.5	4.4	0	0	L	L	25
TL6	186	Moderate load broadleaf litter	0.3	2.4	1.2	1.2	0	0	L	M	25
TL7	187	Large downed logs	0.4	0.3	1.4	8.1	0	0	L	L	25
TL8	188	Long-needle litter	0.3	5.8	1.4	1.1	0	0	L	M	35
TL9	189	Very high load broadleaf litter	0.6	6.65	3.3	4.15	0	0	M	M	35
PRIMARY FIRE CARRIER: **SLASH-BLOWDOWN (SB)**											
FM11	11	Light logging slash	1	1.5	4.51	5.51			L	M	15
FM12	12	Medium logging slash	2.3	4.01	14.03	16.53			M	M	20
FM13	13	Heavy logging slash	3	7.01	23.04	28.05			H	M	25
SB1	201	Low load activity fuel	1	1.5	3	11	0	0	L	M	25
SB2	202	Moderate load activity or low load blowdown	1	4.5	4.25	4	0	0	M	M	25
SB3	203	High load activity fuel or moderate load blowdown	1.2	5.5	2.75	3	0	0	H	H	25
SB4	204	High load blowdown	2.7	5.25	3.5	5.25	0	0	VH	VH	25
INSUFFICIENT WILDLAND FUEL MODELS											
NONBURNABLE (NB)											
NB1	91	Urban/Developed	Nonburnable fuel models will not show fire spread when modeling. When you have identified a nonburnable fuel model in your area it is very important to consider if it is still nonburnable under current conditions. For example agricultural fields are burnable at certain times of the year and urban areas could be burnable under certain conditions.								
NB2	92	Snow/Ice									
NB3	93	Agricultural									
NB8	98	Open water									
NB9	99	Bare ground									

Table 3.5 A–B. Fire behavior fuel model reference table adapted from GTR 153 by Heather Heward

Thirteen of the fuel models have been around since the 1980s and are referred to as the "original" fuel models, Anderson's fuel models, or just "the 13." Forty additional fuel models, introduced in 2005, are known as the "new" fuel models, the Scott and Burgan fuel models, or the "40." The newer 40 models tend to be most useful for prescribed fire; however, the 13 still have useful applications. All 53 are listed in Table 3.5A–B.

Note that some fuel models are considered "dry climate" and others "humid climate." This can be a bit misleading. The Western U.S. has a generally dry climate, but some of our fuels burn like fuels found in humid climates. The difference is that dry climate fuels are considered to be resistant to combustion at dead fuel moisture contents ranging from 12% to 15%. These fuel models need dry fuels to burn.

In contrast, humid climate fuels will burn with moisture contents as high as 40%. These are known as the fuels' moistures of extinction, or the moisture contents above which combustion is unlikely to occur.

Experienced prescribed fire planners use modeling to develop their prescriptions and refine their holding and contingency plans. As a new or casual prescribed fire practitioner, you may not need to do modeling — you can get advice from professionals.

Modeling has become easier and provides excellent information to guide your burn planning and implementation processes, so we'll offer a brief introduction to a few common resources or programs, with the following caveat: Modeling rarely, if ever, exactly predicts fire behavior, but it can be a useful guide.

Guidebook to Fire Behavior Assessment

https://www.nwcg.gov/publications/pms437-1

This National Wildfire Coordinating Group publication has many helpful resources for assessing the wildland fire environment. The information is geared toward wildfire but can be useful for prescribed fire as well. In a section on fire behavior lookup tables, you can choose a fuel model and receive fire behavior estimates based on winds and fuel moisture. This is a good starting point for new prescribed fire practitioners.

Behave7 Fire Modeling System

https://www.frames.gov/behave/home

Behave7 is a software program you can download and use offline. After selecting a fire behavior fuel model or models that represent your fuel conditions, you can enter a variety of weather and fuel moisture conditions to compare possible fire behavior (Figure 3.12). The program is easy to use and includes surface fire modeling, spotting potential, torching and crowning potential, and estimates of crown scorch height. You can also use it to anticipate behavior of escaped fire, so you can develop reasonable holding and contingency plans.

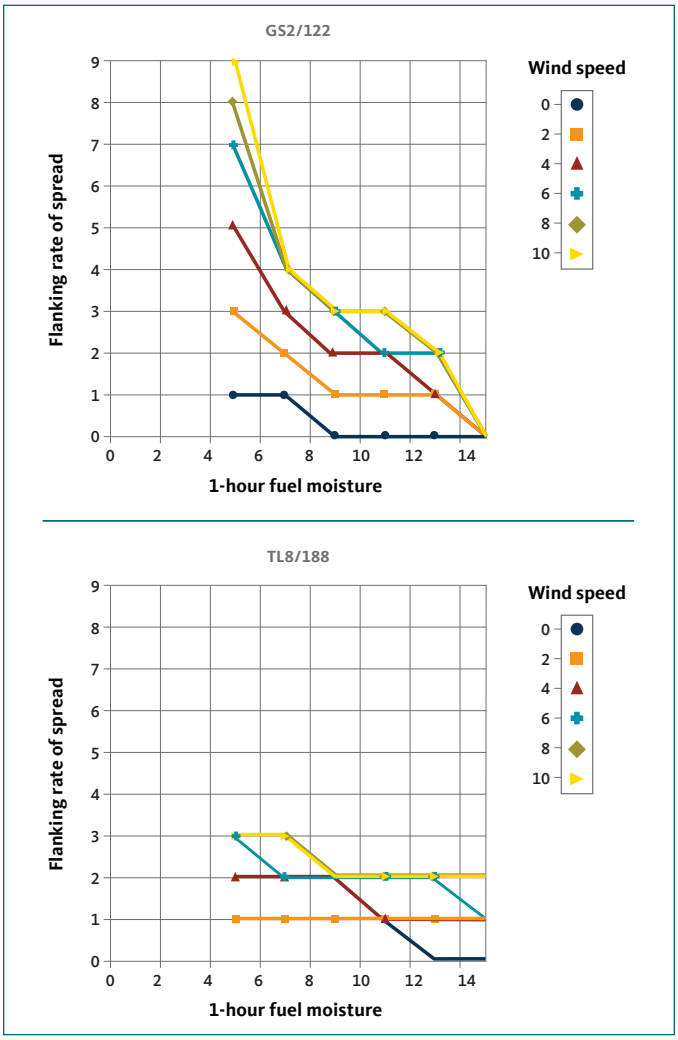


Figure 3.12. Behave7 output showing flame length for two fuel models (a grass model and a timber litter model, both common in the Pacific Northwest). The lines indicate fire behavior with different wind speeds and fuel moistures. Outputs like this can help refine prescription parameters. Credit: Behave7

Interagency Fuels Treatment Decision Support System

https://iftdss.firenet.gov

The Interagency Fuel Treatment Decision Support System, or IFTDSS, is a web-based application designed to make fuel treatment planning and analysis more efficient and effective. LANDFIRE data with a 30-by-30-meter (about 100-by-100-foot) resolution was used to model landscape fire behavior (Figure 3.13). At this resolution, the model may miss fine details, but it provides excellent guidance for large burns.

IFTDSS is a spatial representation of the same fire behavior models used in Behave7 and is helpful for visually mapping fuels and fire behavior, locating critical holding points and comparing the impact of fuel treatments on fire behavior across a landscape. This program requires a free login and has a robust help feature.

Find training on the program on the Wildland Fire Learning Portal: https://www.wildlandfirelearningportal.net

Fuel Characteristic Classification System

This system provides detailed fuelbed descriptions and basic fire behavior and smoke modeling outputs (Figure 3.14). In the program, you can select or create up to five fuelbeds, making it useful for comparisons across the fuelbeds present on your burn, or comparing modified fuelbeds to see how fuel management might affect fire behavior, https://depts.washington.edu/fft/webtool/. Note that the fuelbeds in this system differ from the 53 fuel models described earlier.

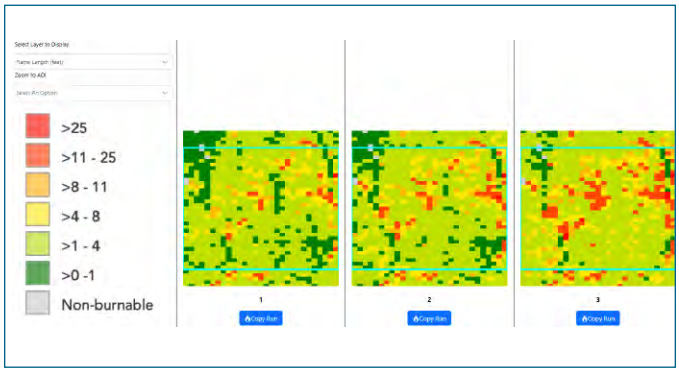


Figure 3.13. IFTDSS flame length output under low-, desired- and high-prescription conditions. The maps show where different fire intensities, expressed as flame length, are likely to occur across a landscape.

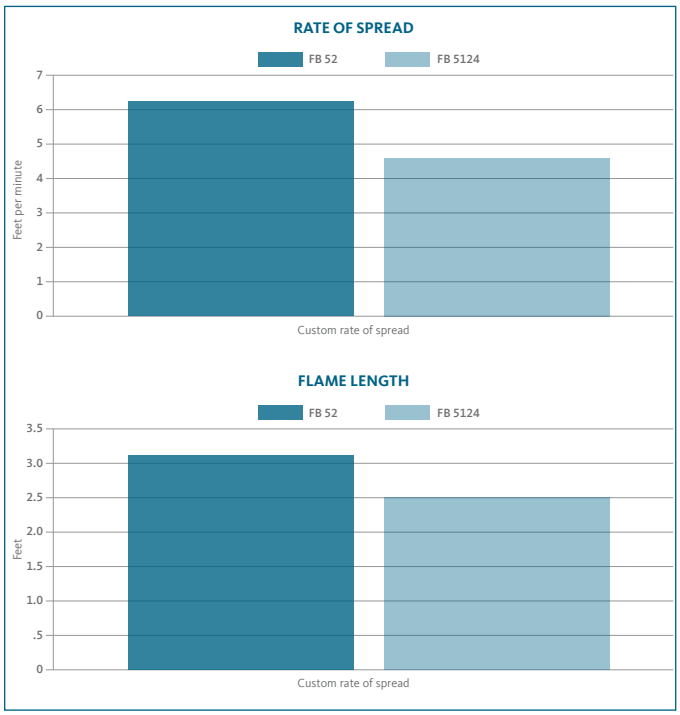


Figure 3.14. Fuel Characteristic Classification System

Meeting objectives with ignitions

Your burn objectives — whether you're reducing brush, promoting grasses or preparing a seedbed — should guide every fire you light. The way you apply fire, using different ignition patterns and techniques, will influence both fire behavior and the fire's effects.

IGNITION PATTERNS

Ignition pattern is the specific layout of ignition on the ground. There are many ways to apply fire based on your fuels, weather, topography and resources. Some patterns use slow-burning backing fire to increase residence time and increase how much fuel is consumed; others use faster-moving head fire to flash through dry material. The method you choose should be based on what is most likely to keep the fire contained and meet your burn objectives under your current conditions.

Most ignition patterns require the establishment of **blackline** — the widening of the control line on the uphill or downwind side of the burn. Blackline establishment is often time-consuming, where fire is applied directly on the

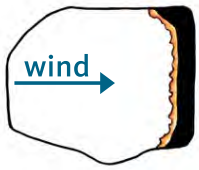
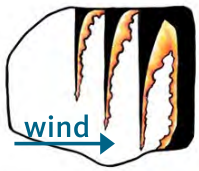
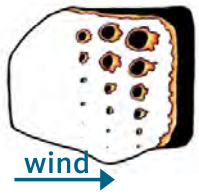
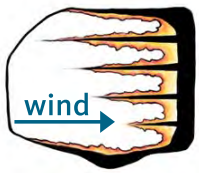
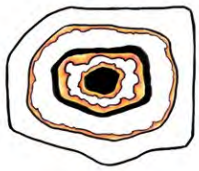
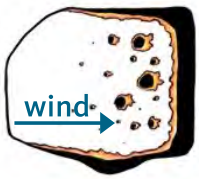
Pattern	Graphic	Description	Example goal	Residence time	Fire intensity	Fuel use	Physical effort	Time
Backing fire		Lighting the downwind side and letting the fire move into the wind. Used in black lining.	Reduce the thatch in the dominant grass.	High	Low	Low	Low	High
Strip-head fire		Continuous strips of ignition perpendicular to the wind at set spacing and stagger with the intent for the strips to come together.	Limit mortality in the overstory trees while increasing mortality in the understory trees.	Low/ Mod	Mod/ High	High	High	Mod
Dot fire		Dots of ignition at set intervals with the intent for the dots to come together.	Reduce the intensity of a strip head fire during drier fuel conditions.	Mod	Low/ Mod	Low/ Mod	Mod/ High	Mod
Flanking fire		Continuous strips of ignition moving into the wind at set spacing, forming chevrons on topography.	Limit mortality in the overstory trees while increasing mortality in the understory trees AND decreasing the time to completion.	Mod	Mod	Mod	Mod	Low/ Mod
Center fire		Ignition starts from the center, often on elevated topography. Concentric circles of ignition around the center.	Increase smoke lift and limit animal mortality.	Low/ Mod	Mod/ High	Mod	Mod	Mod
Ring fire		Ignition around all sides of the perimeter with fire burning inward.	Increase smoke lift and vegetation mortality.	Mod	High	Low	Low	Low
Jack-potting		Dots of ignition in receptive fuel without the intent for the dots to come together.	Consume available fuel and fuel use on non-available areas.	Low	Mod	Low	Mod	Mod

Table 3.6. Common ignition patterns for prescribed fire, with example objectives and ratings of pattern characteristics.

unit edge and slowly widened, generally with backing fire. The width of the blackline depends on the ignition pattern and fire behavior expected for the rest of the unit.

It is important to initiate the blackline directly on the edge of the unit where it meets the control line. Applying fire a few feet off the control line allows fire to spread toward the control line and potentially escape. Blacklining takes patience and time.

Table 3.6 shows the most common ignition patterns and compares their residence time, fire intensity, fuel use, effort and time. It is important to monitor the impacts of your ignition patterns and adjust accordingly. You can change ignition patterns midburn to adjust the outcome.

It is also important to monitor whether your ignition pattern is meeting the intended objectives of the burn and adjust accordingly. Changes in how fire is applied affect how it behaves, its effects, and the overall outcomes of the burn.

Some patterns use **convergence** — letting two flame fronts meet — to boost fire intensity. As two flame fronts draw close, they pull oxygen in from the sides and ramp up in intensity. When they meet, you can get a sudden spike in flame length — sometimes two to three times taller than before. This can help kill off brush or remove stubborn thatch, but be prepared for a burst of extreme fire behavior.

IGNITION TECHNIQUES

Ignition techniques refer to both the pattern selected and the way it is applied on the ground. For example, if you choose the strip-head fire as your pattern, you will also choose the number of lighters, their spacing (the distance between strips), stagger (the offset between lighters), and speed (Figure 3.15). The techniques you choose depend on whether you want to build more or less heat.

Observe fire behavior and adjust your technique to meet objectives — Table 3.7 provides options for building more or less heat. Remember, if fire behavior is not meeting objectives, you can pause or stop the burn and reevaluate.

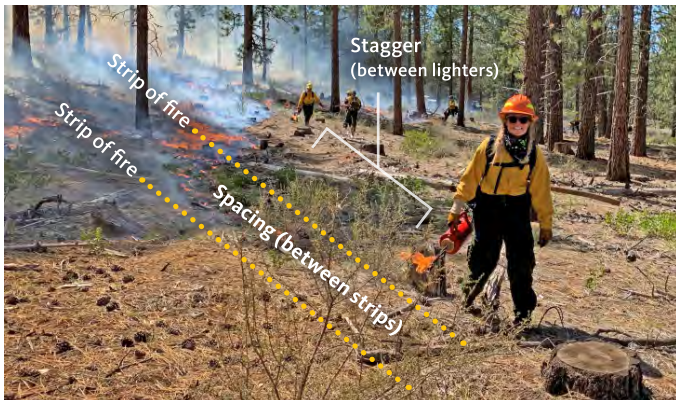


Figure 3.15. Strip-head-firing example showing spacing (distance between strips of fire) and stagger (offset between lighters). Credit: John Punches, © Oregon State University

Tool	Description	Build MORE heat	Build LESS heat
Pattern	•Heading •Center •Flanking •Ring •Backing •Jackpot •Dot	•Strip-head •Ring •Center	•Backing •Flanking •Dot •Jackpot
Number	Number of lighters	More lighters	Fewer lighters
Spacing	Space between strips of ignition	•Wet? Less spacing •Dry? More spacing	•Wet? More spacing •Dry? Less spacing
Stagger	Offset (angle or time) between lighters	Reduce stagger	Increase stagger
Speed	How fast the lighters move	Faster lighters	Slower lighters
Stop/pause	If you are not meeting objectives after adjusting ignition, consider stopping or pausing ignition.		

Table 3.7. Techniques for adjusting the amount of heat during firing.

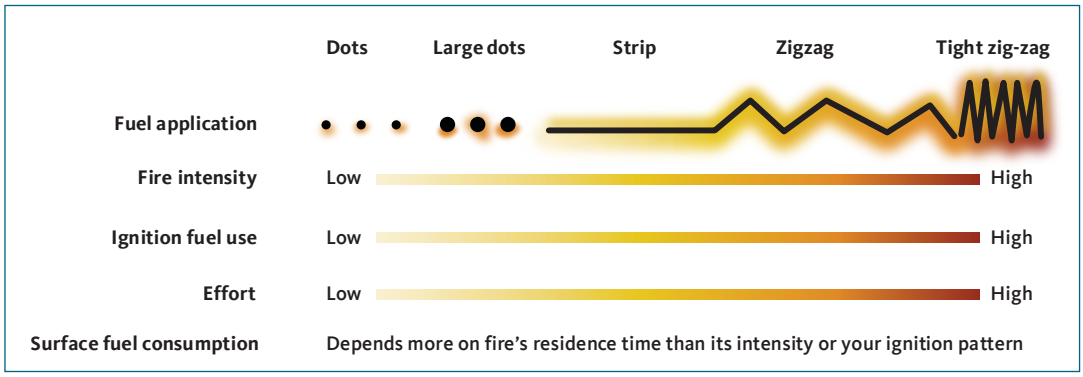


Figure 3.16. Implications of how ignition fuel is applied for fire intensity, amount of ignition fuel uses, effort and surface fuel consumption. Credit: © Oregon State University, adapted from University of Georgia Extension

The way an individual applies ignition fuel within a given pattern and technique can influence the fire intensity, fuel load consumption (that is, dead and live vegetative fuels), ignition fuel use (torch fuel, for example) and effort (Figure 3.16). If you are trying to build more heat and you have plenty of ignition fuel, you can zig-zag lines of fire on the ground. If you want less heat or ignition fuel is limited, you can use dot or jackpot ignition patterns.

IGNITION TOOLS

There are a variety of ignition tools with a spectrum of functions. It helps to have a variety of ignition tools at your disposal; leverage their individual strengths according to the day's conditions (Table 3.8). For example, a drip torch might work well under low-to-moderate fuel moisture conditions, but a propane torch will perform better under high fuel moisture conditions (Table 3.9). When using drip torches, consider fuel moisture when calculating your ratio of diesel to gas to get the best results for your burn (Table 3.10).

Condition	Suggested tool
• Small to medium fire area • Values at risk near the line • Complex unit share	• Drip torch • Fusee
• Steep terrain interior • Flashy fuels interior • Desire to reduce fire behavior interior	• Flare launcher • Fusee
• Perimeter ignition for a large fire area near the road	Terra torch
Interior ignition for a large fire area	• PSD — helicopter or UAV • Helitorch
Piles	• Drip torch • Propane torch • Terra torch

Table 3.8. Example ignition tools for common prescribed fire conditions.

Container size (gallons)	Cool-weather mix (3:1)		Warm-weather mix (4:1)	
	Diesel (gallons)	Gas (gallons)	Diesel (gallons)	Gas (gallons)
1.25	0.9375	0.3125	1	0.25
2.5	1.875	0.625	2	0.5
5	3.75	1.25	4	1
10	7.5	2.5	8	2
20	15	5	16	4

Table 3.10. Drip torch fuel-mixing guide.

Ignition device	Description
Matches 	•Simple, cheap and readily available •Relatively free of fumes and residual chemicals •Can be used to light clusters of needles or grass, which can then be dragged by hand or tool •Often used to ignite other devices, such as drip torches •Not recommended for exclusive use on large acreages because the ignition process will likely be time-consuming, and it may be difficult to achieve a continuous strip of ignition
Drip torch 	•1.25-gallon canister containing a mixture of diesel fuel and gasoline. Gas promotes ignition; diesel sticks to surface fuels and extends the duration of heat. •Widely used for prescribed burns •Diesel-to-gas ratio can be adjusted (3:1 ratio for cool days, 4:1 ratio for warm days) •Proper training is required to use; it can be hazardous •Works well on all types of surface fuels •Often leaves residual chemicals, particularly in wet surface fuels •You will have to refill torches if igniting more than a few acres. Have additional torch mix on hand. •Specialized tool — not likely to be available at your local hardware store •Requires eye and hand protection (PPE)
Fusee 	•Lightweight and portable •Works best on continuous surface fuels •Can be re-lit if extinguished •Can be attached to a stick for easier use •Can be broken into smaller parts and thrown for interior ignitions •Burns very hot — requires eye and hand protection (PPE) •Emits toxic fumes — not a first choice for prescribed fire ignitions, but may have specific applications in remote areas, for example
Propane torch 	•Commonly used for pile and ditch burning •Applies long-duration heat to ignite wet or large fuels — good for blacklining in advance •Leaves minimal or no residual chemicals — good for riparian ignitions •Works well on a variety of surface fuels •Needs to be connected to a propane cylinder. Consider adapting a backpack frame to carry the cylinder. •Requires a specific filling station. Keep extra cylinders on hand if using for large-scale ignitions.

Table 3.9. Ignition tool descriptions, including advantages and disadvantages. Credit: Heather Heward and USFS (fusee)

BEFORE YOU BEGIN

Before you light the full unit, always start with a test fire (Figure 3.17). Choose a spot that is representative of the fuels and topography of your burn area and can be easily controlled. A test fire gives you a preview of the flame lengths and rate of spread to expect (Figure 3.18). It also shows you what your smoke is likely to do. Remember, conditions generally get warmer, drier and windier as the day goes on, so don't assume fire behavior at 9 a.m. will match behavior at 2 p.m.

Test fire

- Representative location
- Easy to control
- Large enough to see fire behavior

Discuss the results of the test fire with your burn crew. If it's not producing the fire behavior, fire effects and smoke dispersal you want — or if it's too intense to control — it's OK to put it out and wait for a better day or better time of day.

By learning how fire behaves and how to influence that behavior, you can shape your burns to meet your objectives safely and effectively. The more you practice, observe and plan, the more confident you'll become in understanding fire and working with it rather than against it.



Figure 3.17. Test fire in representative fuels at an easy-to-control location. Credit: Heather Heward



Figure 3.18. Test fire operation will continue until the area is large enough to reveal the behavior of both fire and smoke. Credit: Christina Friehauf

CHAPTER NOTES

CHAPTER NOTES



SMOKE MANAGEMENT

Section author: Micah Schmidt

Image credit: Holly Campbell

IN THIS SECTION

- ☐ Introduction to smoke management
- ☐ Smoke components and stages of combustion
- ☐ Factors affecting smoke production and dispersal
- ☐ Smoke impacts
- ☐ Basic smoke management practices
- ☐ Estimating potential smoke impacts
- ☐ Smoke screening and modeling tools
- ☐ Smoke mitigation strategies by stage of burning

Introduction to smoke management

Smoke is a known air pollutant that can impact human and animal health, reduce road visibility and be a nuisance. Where there is any fire — wildfire or prescribed — there will be smoke.

Unlike wildfires, prescribed fires are planned and conducted in conditions selected to achieve specific results and to minimize potential negative impacts from smoke. Steps needed to manage smoke depend on burn characteristics such as size, complexity and proximity to communities and other smoke-sensitive areas. For many small burns, smoke management may be a simple matter of visiting the burn unit, identifying any sites that could be affected by smoke, and ensuring the wind pushes the smoke away from sensitive areas during the burn. For example, if a school is located a couple of miles south of your burn, you would not want to burn when a north wind (blowing south) is present. In its simplest form, managing smoke is about common-sense precautions. While this chapter includes recommendations focused specifically on managing smoke, many of these actions are likely already incorporated into your prescribed burn plan.

Managing smoke during prescribed fires involves considering potential smoke impacts and ways to avoid them during planning, implementation, and after the burn is complete. Smoke management begins with

understanding how factors such as weather conditions, topography, fuels and vegetation treatments influence smoke behavior. This chapter highlights the factors that affect smoke production, dispersion and direction, as well as recommended basic smoke-management practices, smoke screening tools and strategies to reduce smoke impacts.

Goals of smoke management:

1. Minimize the amount of smoke produced.
2. Move smoke away from sensitive areas or populations.
3. Reduce the concentration of smoke through dispersal.
4. Respond to smoke issues as they occur.

Prescribed burners have a responsibility to protect their communities' health and safety and to manage the smoke from their burn. Smoke management is possible if the burn is carefully planned and executed. Ongoing training, planning, preparation and practice by prescribed burners can help support the continued use of this valuable land management tool.

Check with your local air-quality regulatory agencies for any region-specific smoke-management guidelines that might apply to your situation.

Smoke components and stages of combustion

Smoke forms when a fuel is burned (combusted) and consists of tiny particles, water vapor, and trace gases that are suspended in the air; some components are visible to the naked eye. As a smoke plume travels away from the site, it may become harder to see but will still carry tiny particles of soot (particulate matter) and gases (such as ozone precursors). Smoke plumes from large fires or multiple burns in the same geographic region can travel for hundreds of miles before completely dispersing (Figure 4.1).

There are different types of smoke emissions and amounts of smoke that are released at each stage of combustion (Figure 4.2). Smoke emissions include water vapor, particulate matter (PM), hot air, trace gases, carbon monoxide (CO), and carbon dioxide (CO^2).

Below are the four stages of combustion:

1. **Pre-ignition stage:** Fuel particles absorb heat, start to release water vapor, and the pyrolysis process, where heat breaks down solids and liquids into flammable gases, begins. Little smoke is released during this stage, as fuels are just beginning to combust.
2. **Flaming stage:** Active flames can be seen as combustible gases and vapors that were created during pre-ignition begin to mix with oxygen. More smoke is released during this stage as fuels are actively combusting.
3. **Smoldering stage:** Flames start to disappear as the fire temperature drops because there are fewer combustible gases and vapors produced. This stage of combustion releases more smoke than any other stage.
4. **Glowing stage:** Materials at the surface glow from access to oxygen. Most combustible materials and volatile gases have already been combusted. This stage will continue until all available fuel has been burned or all heat is extinguished. Little smoke is released during this stage.

Smoke emissions at some stages of combustion can be more harmful to human health than at other stages. However, the types of fuel also influence how the fire will burn and the emissions produced. An efficient flaming stage driven by dry fuels and good burning weather can

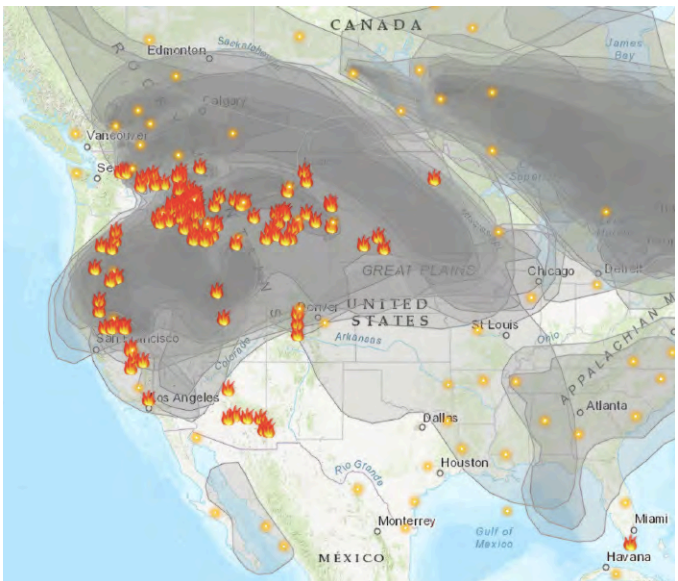


Figure 4.1. Modeled smoke plumes from summer wildland fires across the U.S. as seen on the AirNow website on July 27, 2021. Credit: AirNow

result in more complete combustion and less smoke production. The greatest amounts of smoke and potential associated impacts to human health are generally produced during the smoldering stage, which can often persist for hours or days after the flames are extinguished, particularly when wet fuels are burned, resulting in a shorter flaming stage with less efficient combustion.

Factors affecting smoke production and dispersal

Many different factors affect how much smoke is produced, how well it is dispersed, and where it travels (Figure 4.3). These factors can be categorized as burn site conditions (fuel characteristics, location and topography), weather and atmospheric conditions, and burn timing and technique (how and when you burn). Some burn site conditions are relatively constant, as location and topography do not change. Fuel characteristics (type, size and load) generally change slowly unless fuel reduction practices are implemented. Weather and atmospheric conditions are always shifting. Since fuel moisture is driven by weather, it constantly changes and significantly impacts smoke production. There are many options for when (timing) and how (technique) you burn that can affect smoke production and dispersal.

BURN SITE CONDITIONS

Fuel characteristics, geographic location and topography are known variables that do not change at the burn site (except for changes in fuel load and moisture content). These factors strongly impact smoke production and dispersal. The location of a burn and the topography at the burn site remain the same from planning through implementation and will inform how a plan develops and which considerations are taken into account for smoke management.



Figure 4.2. 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: © Oregon State University, adapted from University of Georgia Extension

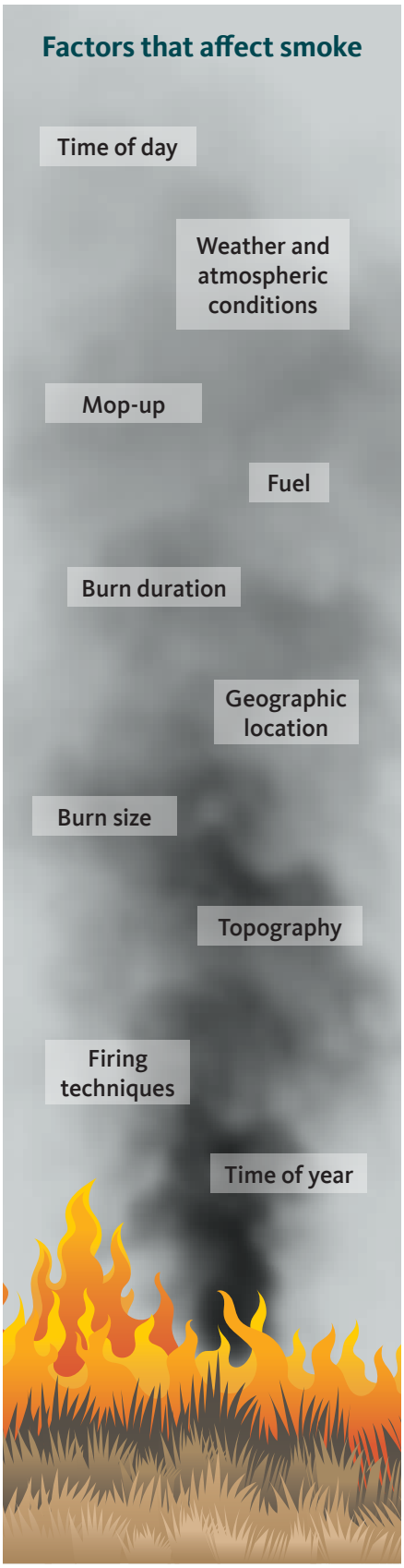


Figure 4.3. Factors that affect smoke. Credit: © Oregon State University, adapted from University of Georgia Extension

Fuel characteristics

The type and size of fuel, the amount of fuel available to burn (called "fuel load") and its moisture content determine the amount of fuel that can be consumed in a fire and are directly related to the amount of smoke that can be produced. Fuel load will vary depending on the time since the last burn, past fuel management practices and the type of fuels.

Smoke production is also influenced by fuel size. For example, fine fuels like grass will burn quickly and produce a considerable amount of smoke during the active combustion phase but will not smolder. Conversely, a stand of pine trees with a thick surface fuel layer and a thick duff layer may produce more smoke through smoldering combustion if the duff layer begins to burn.

Dry fuels generally burn more efficiently and often will produce less smoke, while wetter fuels, if they do burn, are likely to create considerable smoke.

Geographic location

Geographical areas across the region contain differing vegetation and weather patterns. These factors will play a role in the creation and dispersal of smoke. Legal and social considerations, such as air-quality regulations and nearby population density, may also vary by burn location.

Burns near urban or suburban areas may require greater consideration to reduce smoke impacts on communities than burns in rural areas with lower populations. This will vary, depending on a variety of other factors. Burns near highways and other main travel corridors will also need greater consideration.

Topography

Topography influences where smoke moves. In flat areas, wind and atmospheric stability drive smoke dispersal and direction. In hilly or mountainous areas, however, smoke disperses differently. 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 roadways, particularly when there is an inversion.

Winds are also affected by slopes and time of day, which will factor into smoke dispersal. Winds in a given area often follow a fairly consistent pattern at different times of year, so consulting with someone familiar with your burn unit can help you predict wind patterns and draft your burn plan.

WEATHER AND ATMOSPHERIC CONDITIONS

Good smoke dispersion, or the scattering and dilution of smoke, is essential in a prescribed burn. Since smoke is in a gaseous state, it can move vertically and horizontally. When smoke enters the atmosphere, its concentration in any one place at a given time depends on the weather factors and atmospheric conditions that transport and disperse it.

Depending on the stage of combustion, weather and atmospheric conditions may have a greater or lesser effect on smoke. See "Weather" for more details on weather considerations. Several important weather factors that influence smoke behavior are detailed below (and depicted in Figures 4.4 and 4.5).

Atmospheric stability and mixing height

The stability of the atmosphere (a measure of how a parcel of air moves when pushed upwards) and the mixing height (the height where air and smoke mix due to turbulence and convection) are highly correlated. Atmospheric conditions are more likely to be stable in the morning, evening and through the night. When the atmosphere is more stable, the mixing height is typically lower, which keeps smoke close to the ground surface and slows dispersion.

When the atmosphere is more unstable (which is more common in the afternoon), the mixing height is typically higher. High mixing heights allow smoke to rise farther into the atmosphere, where it can be more effectively diluted and dispersed by transport winds (the winds within the mixing layer that carry smoke away from the fire). 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.

Wind

The direction and strength of the wind affect the movement and dispersion of smoke. Smoke is easier to manage and more predictable when wind speed and direction are consistent. Fire weather forecasts from the National Weather Service provide expected wind conditions throughout the day.

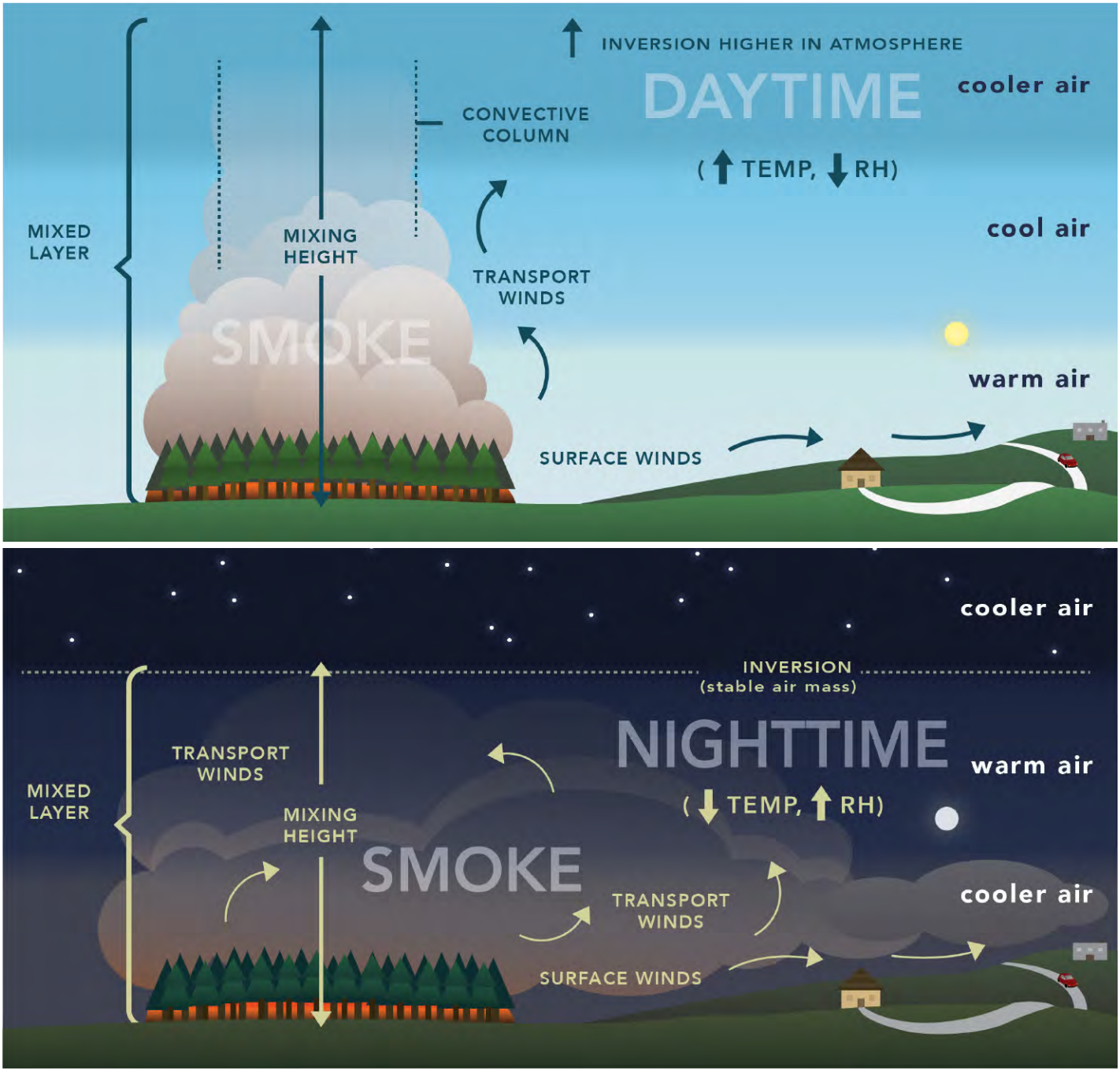
Atmospheric stability indicates how rapidly air is vertically mixed.

Mixing height is the height at which smoke will be diluted and dispersed.

Inversions are a stable air mass or atmospheric layer that increase in air temperature as it moves higher, and are difficult for smoke to penetrate.

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.



Figures 4.4 and 4.5. Atmospheric and weather conditions and how they may influence smoke behavior during the day and night. Credit: Laura Costa, Southern Regional Extension Forestry

Temperature inversions

Inversions are an atmospheric layer where temperature increases with height, as opposed to typical atmospheric layers, which cool as they rise. Inversions are a stable air mass that can be difficult for smoke to penetrate. During a temperature inversion, cooler air is closer to the ground and warmer air is above. The warmer air above can trap smoke near the ground surface when an inversion is present. This means that the smoke will linger and not disperse. Typically, temperature inversions occur in the evening and continue through the night and early parts of the following morning.

Relative humidity

Relative humidity strongly influences moisture content in fuels. While fine fuels will dry out quickly when there is a low relative humidity, larger fuels are only affected by changes over longer periods of time (see "Fuels" chapter for more information on time lags).

High relative humidity can make fuels too moist to burn efficiently, increasing smoldering and smoke production, or preventing ignition altogether. Drier fuels generally produce less smoke. Burns are often planned for times when the relative humidity is low enough to dry out fine fuels such as pine needles and grass, but fuel moistures are high enough to prevent larger fuels and duff layers from burning too intensely.

BURN TIMING AND FIRING TECHNIQUES

When conducting a prescribed fire, many management decisions affect smoke production, such as the size of the burn and the acceptable range of weather conditions. Other decisions, such as the burn start time and duration, are made on the day of the burn. The pattern of ignition (firing technique), duration of the burn and steps taken when the fire is complete all contribute to smoke production.

Size

If all else is equal, larger burn units produce more smoke than smaller units.

Time of year

The time of year can affect how much smoke is produced during a prescribed burn because plants go through different stages of growth that change how easily they burn. High live fuel moisture in the early growing season can reduce ignition and limit combustion, typically leading to less smoke, though outcomes depend on fuel composition and burn objectives. As the season progresses and plants begin to go dormant, their moisture levels drop, making them easier to burn and more likely to produce more smoke.

If you can time it correctly, burning when precipitation is coming in the days following the burn can help extinguish smoldering fuels and greatly reduce smoke. Weather

Fire type	Effect on smoke
Backing	Consumes more fuel in the flaming stage and produces less smoke over the course of the burn; however, backing fires move slowly and may limit how much acreage can be burned based on the burn plan.
Heading and point- source	Often burns with a faster rate of spread than backing fires. A fire that moves very quickly, will have shorter residence time and result in less fuel overall burning, which could lower smoke production. However, if it burns very intensely, it could burn more fuel overall, which could increase smoke production.
Center and circular (ring)	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 windrows	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).

Table 4.1. Types of fire and effects on smoke

systems that bring precipitation often also bring wind, so pay close attention to the weather forecast.

Time of day

The time of day can affect how much smoke is produced by your prescribed fire and how it disperses. Day and night have different weather patterns.

In the morning, the temperature is lower, and the relative humidity is higher, which may make it harder to start a burn. Temperature typically peaks during the afternoon, and relative humidity drops to its lowest levels during that same period.

As the sun goes down, transport winds and mixing heights tend to decrease, too. Daytime burns are typically conducted starting in late morning and completed by early evening. Nighttime burns vary more in timing.

Firing technique

Firing techniques can affect smoke production (Table 4.1). Firing techniques that create more backing fire result in slower-moving fire that consumes more fuels in the flaming stage and reduces smoke.

Head fires burn more quickly through fuels and may result in incomplete combustion and increased smoke production, particularly when fire intensity is low.

You may also hear experienced burners talk about building more heat to lift smoke. Firing techniques that increase fire intensity (the amount of energy or heat emitted) can create more convective lift, sending smoke higher into the atmosphere for dispersal. For an explanation of different firing techniques, see "Fire behavior."

Mop-up

After a burn, logs, stumps, brush piles, duff or snags (standing dead trees) that were ignited may smolder, producing residual smoke. Mop-up is the process of walking the burned area (the black) and extinguishing flames or smoldering fuels after the burn. Smoldering can continue for multiple days if not addressed.

Mop-up can particularly help avoid the effects of nighttime smoke (Figure 4.6). As night sets in, mixing heights decrease, and smoke may settle close to the ground and cause impacts. Good mop-up also reduces the chance of an escaped burn in the days or weeks following burn day.

Smoke impacts

AIR QUALITY

Air quality changes constantly based on local weather conditions, regional weather systems and emissions from vehicles, factories, wood stoves and other human sources. The quality of the air (or concentration of pollutants) on any given day is monitored by local, state or federal agencies.

The U.S. Environmental Protection Agency has established acceptable concentration limits of six major pollutants due to their negative health effects and risks to the environment. These pollutants include particulate matter, or PM, ozone, nitrogen dioxide, sulfur dioxide, carbon monoxide and lead.

Smoke emissions from fires contain PM, carbon monoxide and other trace gases, though the greatest concern is PM. These particulates consist of microscopic amounts of solid matter such as ash or dust resulting from the incomplete burning of organic matter.



Figure 4.6. Mopping up heavy fuels can help avoid nighttime air quality impacts, as smoke tends to settle lower in the atmosphere during the night. Credit: Micah Schmidt, © Oregon State University

You will often see air quality warnings related to PM2.5 or PM10. These numbers refer to the maximum diameter of the particle in microns. Because of their small size, particles can become trapped in the nose or throat, be inhaled deep into the lungs and, in some cases, enter the bloodstream. Both PM2.5 and PM10 pose risks to human and animal health, but PM2.5 is especially harmful, since its microscopic particles can penetrate further into the lungs than PM10 and cause inflammation and tissue damage while increasing the likelihood of respiratory and cardiovascular diseases.

Tightened air quality standards in 1997, 2006 and 2013, along with the implementation of a national monitoring program, have led to a significant reduction in PM concentration in the air from various human sources. With the overall reduction in PM from other sources, prescribed fires, and wildfires in particular, now make up a larger proportion of PM emissions in many regions. For these reasons, smoke management during prescribed fires is especially important to reduce impacts to the public.

HEALTH

Smoke can impact the health and safety of people and animals. Smoke has the greatest impact on vulnerable populations, including:

- Infants, children, older adults, pregnant women (and their unborn children)
- People of low socioeconomic status
- Individuals with impaired health
- People living downwind of the burn
- Outdoor workers

For this reason, it is important to limit the amount of smoke produced and prevent smoke from reaching areas where more vulnerable populations can be found (smoke-sensitive areas). These Smoke Sensitive Areas, or SSAs, include schools, daycares, nursing homes, hospitals and agricultural operations with animals present.

It is important to coordinate with agencies overseeing prescribed burns to make sure you are aware of what other burns may be occurring in your area at the time you plan to burn. Smoke production from several burns can cause unnecessary impacts.

It is also important to protect individuals implementing a burn from smoke as much as possible. While burners should expect to inhale some smoke during a burn, they should avoid it as much as possible. Wearing a properly fitted N95 mask or other filtration device is the best option for reducing smoke inhalation, but simply moving out of the smoke when it is not necessary to stand in it is another great option.

Ongoing research continues to find more evidence that smoke is heavily affecting the long-term health of firefighters and fire practitioners who inhale it regularly. This results in an increased risk of lung cancer and other respiratory issues. Burners must reduce the amount of smoke they inhale as much as possible to protect their health.

SAFETY

The presence of smoke can result in a variety of safety issues. Smoke that moves through or collects in roadways, airports or railways is a major public safety issue. Smoke can move into these areas quickly, which does not provide much time for motorists, pilots and others to respond or to be notified of danger. Reduced visibility on roadways from smoke can cause fatalities and injuries, and it carries a risk of liability and potential legal problems. Airports may postpone or even cancel flights if smoke is a safety concern.

Fog can create hazardous conditions on the road by itself; however, smoke and fog can combine to form superfog, an extremely dangerous, dense mixture. “White-out” conditions can occur due to superfog during the day or night, further limiting visibility.

For these reasons, it is important to coordinate with agencies responsible for roadways and other travel corridors when smoke from your burn could pose a risk.

Basic smoke management practices

One of the first steps to properly managing smoke is learning and understanding Basic Smoke Management Practices (Table 4.2). Using BSMPs helps burners achieve four goals:

1. Reducing the amount of smoke produced
2. Transporting smoke away from sensitive populations and other target areas
3. Dispersing smoke to reduce its concentration
4. Reducing impacts to communities by providing notifications and outreach to affected areas

Most federal, state and local agencies that use prescribed fire must follow BSMPs or Smoke Management Plans, but private landowners are not required to do so in all states. Research the requirements for your area: You may be required to get a burn permit, register your burn for smoke management, report on your burn accomplishments or submit other documentation.

Many BSMPs should already be included in your prescribed burn plan, as they are best practices not just for smoke management, but for prescribed fire overall. For example, they include practices such as identifying smoke-sensitive areas, conducting a test fire immediately before a burn and informing neighbors you will be burning.

In addition to following these BSMPs, some states require that landowners use state-specific Smoke Management Plans, or SMPs. Your state forestry agency or air quality agency can provide more information on BSMPs and SMPs relevant to your state.

Basic Smoke Management Practice	When should the BSMP be applied?
1. Identify, map and avoid impacting smoke sensitive areas	Before and during
2. Use appropriate smoke impact screening tools	Before
3. Use a test fire to verify expected smoke dispersion	During
4. Only burn when smoke dispersion conditions are favorable and avoid burning at night if smoke is a major concern	During
5. Monitor changing weather conditions and respond to unintended smoke impacts	Before, during and after
6. Understand and follow local, state, federal and tribal prescribed fire laws and regulations	Before, during and after
7. Notify appropriate parties (neighbors, public agencies, authorities) of intent to burn	Before
8. When feasible, use ignition patterns and methods that minimize smoke production	During
9. Minimize impacts from smoldering smoke by completing adequate mop-up	During and after
10. In high smoke risk areas, explore alternative methods to burning or conduct additional outreach to communities that may be affected	Before
11. Enhance smoke management skills through training and experience	Before, during and after
12. Try to identify other burning activity and sources of pollution in your area	Before and during

Table 4.2. Basic Smoke Management Practices and when they should be applied during the prescribed burn process. Adapted from University of Georgia Extension

Be aware of any additional rules governing prescribed burns near urban and suburban areas. Some states may have burn bans in counties surrounding major metropolitan areas, or on days when air quality is poor. Before burning, check the air quality index forecast for your area and any state or local air quality restrictions to ensure that there are no Air Quality Alerts. Alerts are issued when ozone levels are high due to other emission sources in the area.

If you are unsure of what smoke mitigation measures you should take to manage smoke, contact your state forestry agency or other experienced burners in your local area for assistance.

Estimating potential smoke impacts

Smoke management starts when planning a burn, when you evaluate potential smoke impacts.

For less complex burns, the first two BSMP steps, focused on estimating smoke impact, might involve a simple screening process and only a few steps.

For a more complex burn, consider using additional tools that account for greater complexity. Smoke screening, which involves mapping the potential direction of smoke based on several weather variables, is an important process, especially for complex burns. If smoke screening shows that a proposed fire would impact a Smoke Sensitive Area, choose a different wind direction or alter the burn plan in other ways to protect sensitive populations. Protecting sensitive areas is crucial, yet smoke management plans must account for all populations.

Smoke screening and modeling tools

Different tools can be used to model potential smoke impacts from prescribed burns (Table 4.3). The two most common tools in the Pacific Northwest are the Simple Smoke Screening Tool and BlueSky Playground.

SIMPLE SMOKE SCREENING TOOL

If the burn is not near SSAs and is unlikely to impact nearby communities, prescribed burners can either draw a representative map or use a web-based tool to complete their smoke screening. Instructions follow for each method (Figures 4.7 and 4.8).

Smoke modeling tool	Description	Inputs
Simple smoke screening tool (online)	• Identifies smoke sensitive areas • Simple screening tool to help identify Smoke Sensitive Areas that may be impacted	• Fuel type (four categories) • Burn size • Ignition method • Direction of the wind (assumed constant)
Simple smoke screening (instructions for drawing by hand)	• Identifies smoke sensitive areas • Draw lines on a map to identify possible SSA impacts (instructions are below)	
BlueSky Playground (3.5)	A modeling framework that integrates other tools and predicts cumulative smoke impacts. Includes tools for estimating: • Fuel loading • Fuel consumption • Emissions calculations • Trajectories • Dispersion	• Location (latitude/longitude or select point on map) • Burn size (acres) • Time zone (PST, CDT, etc.) • Fuels (1,200 choices include fuel type plus management information) • Fuel moisture (very wet to very dry) • Consumption (you can select defaults) • Number of days

Table 4.3. Tools for estimating potential daytime smoke impacts

The Simple Smoke Screening Tool allows burners to make quick smoke predictions, essentially creating a digital representation of the hand-drawn version. This tool uses limited data, so its primary use is to identify smoke-sensitive areas that may be affected by your burn so that you can conduct further planning and smoke screening as needed.

BLUESKY PLAYGROUND

Burns that are more likely to cause smoke impacts to communities may require more advanced smoke modeling. A smoke model is particularly beneficial if known impacts are possible within 10 to 15 miles downwind of the burn. Advanced smoke models combine fire information with meteorological information to predict where smoke from fires may drift.

BlueSky Playground is an advanced modeling framework that integrates different tools to predict cumulative smoke impacts as well as forecasting ground-level smoke concentration. This tool is better suited for more complex burns. The framework progresses through a series of tools and will assist you in estimating fuel loading, consumption, emissions estimates, smoke trajectories, and dispersion, and more. For details and examples for using BlueSky modeling software, see https://info.airfire.org/playground.

Smoke mitigation strategies by stage of burning

Planning the burn

- Consider management practices to reduce fuel loading before burning (mechanical and manual treatments, mowing, grazing, etc.).
- Use a smoke screening tool to plan for appropriate wind conditions.
- Prepare multiple burn units to match each to suitable weather conditions.
- Develop a plan to communicate potential smoke impacts to nearby communities. Work with local agencies or experienced burners if you require guidance.

ONLINE SIMPLE SMOKE SCREENING TOOL

1. Go to the online site: https://weather.fdacs.gov/Simple-Smoke/index.html
2. Obtain input variables from the weather forecast and burn plan. (**NOTE: Make sure to input weather data specific to the time of the day of the burn**). These include:
   a. Latitude and longitude
   b. Burn acreage
   c. Fuels
   d. Ignition method
   e. Transport wind direction and speed
3. Click on "**Update Map**"
4. Select **Map** or **Satellite view**
5. Examine the map to identify smoke sensitive targets, especially within critical smoke-sensitive areas (**identified in the red zone on the map**). This is the most probable smoke impact area. **If there are smoke-sensitive targets within this critical zone, burning is not recommended under the current prescription, additional screening must be used (using a different wind direction and speed), and a different burn day must be selected.**
6. Record all observations for planning and documentation purposes. This could include a screenshot, or saving the data for display in Google Earth by saving the KML output.
7. Add any necessary information from the output into your burn plan.



Figure 4.7. Output generated from the Simple Smoke Screening Tool using a satellite map. The red zone identifies critical Smoke Sensitive Areas. This is the most probable smoke impact area. The yellow zone shows an area of less severe impact. Credit: University of Georgia Extension

Before the burn

- Do not burn until weather and fuel conditions are acceptable.
- Do not burn during pollution alerts or stagnant conditions.
- Contact all parties that could potentially be affected by your fire's smoke before and on the day of the burn, including local authorities and neighbors.
- Post signs on roads near the burn alerting drivers of the smoke, if needed.
- Coordinate with local agencies and other burners to see what burns are planned for a given time.
- Temporarily close roads if necessary (in coordination with the local transportation department).
- Establish a contingency plan to terminate the burn if smoke becomes a problem.

During or after the burn

- Try to burn after inversions have lifted and be done well before sunset, as dispersion conditions are generally best at this time.
- Complete burns in a safe and timely manner.
- Limit the hours smoke is generated throughout the day; this may mean burning the unit in small sections or using firing techniques known to burn hot and fast.
- Consider firing techniques that reduce smoke while also accomplishing burn objectives.
- Keep sufficient burn crew members on hand to monitor smoke beyond the immediate burn unit. These people can alert SSAs of potential impacts.
- Document smoke behavior through images and descriptions.
- Monitor smoke on roads and contact the appropriate agency if smoke encroaches on roadways or causes other hazardous conditions. These authorities may be able to help with tasks such as posting additional signage and directing traffic.
- Shut down the burn if smoke is intruding on SSA.
- Begin mop-up along roads as soon as possible to reduce impacts on visibility.
- Mop up heavy fuels across the burn unit to reduce smoldering. Focus on areas where residual smoke is more likely, such as stumps or snags.

DRAWING A MAP BY HAND

1. Locate and draw burn unit on a map.
2. Determine the distance(s) at which smoke could affect the surrounding area based on the size of your burn and the fuel load, then draw that distance as a circle on the map using a compass or protractor. Multiple rings could be drawn based on the predicted amount of smoke produced. Typically, rings could be ½ mile, 1 mile, 5 miles, 10 miles, etc.
3. Label the area on the map and determine if anything in the critical area is smoke sensitive.
4. Draw an additional circle for the smoke sensitive distance to ensure there is nothing that would be smoke sensitive.
5. Select a wind direction that would avoid anything in the critical smoke sensitive area.
6. Use smoke management considerations if something is in the smoke sensitive area or use a different wind direction.
7. Smoke plume lines should pass on the outside edges of the burn unit.

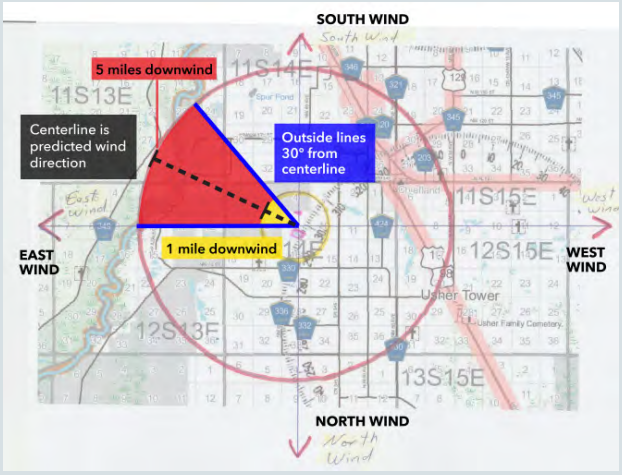


Figure 4.8. A hand-drawn smoke map showing the critical Smoke Sensitive Area (a 1-mile radius, yellow circle) and the smoke-sensitive area (5-mile radius, red circle). This burn's primary fuel source was grass, so the critical area is smaller than if it were burning larger fuels. Assigning a smoke plume of 30 degrees from the predicted centerline is a reasonable assumption, but the angle may be larger if sporadic weather conditions are expected. Though there are no smoke-sensitive features within the critical area, there are a town and multiple roads to the northeast. A southwest wind would be undesirable in this case, but not impossible if favorable dispersion conditions and other mitigation measures are in place. Credit: University of Georgia Extension

CHAPTER NOTES



Image credit: Christina Friehauf

Action chapters

A HOW-TO GUIDE

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MASTER TIMELINE

STARTING

PLANNING

6 MONTHS–1 YEAR BEFORE

Getting started

See page 90

- [ ] Start the process of research
- [ ] Walk the proposed burn area (preburn evaluation)
- [ ] Determine property objectives

Develop a burn plan

See page 98

- [ ] Determine the burn unit
- [ ] Define goals and objectives
- [ ] Gather information on site conditions
- [ ] Develop the prescription
- [ ] Determine the timing

BEFORE THE BURN

Preburn preparation

See page 106

- [ ] Prepare the burn unit
- [ ] Make your PACE plan for resources
- [ ] Create maps

Weeks before the burn

See page 120

- [ ] Review the burn plan and visit the burn unit
- [ ] Check control lines
- [ ] Monitor weather
- [ ] Review the smoke management plan
- [ ] Look for safety hazards
- [ ] Assemble and check equipment
- [ ] Contact people who can assist
- [ ] Confirm PPE requirements
- [ ] Notify neighbors
- [ ] Complete agency notifications and obtain permits

CONDUCTING

EVALUATING

DAY OF THE BURN

AFTER BURN

Days before the burn

See page 122

- ☐ Review burn plan again
- ☐ Make copies of the plan
- ☐ Check onsite conditions
- ☐ Monitor weather
- ☐ Notify emergency services and neighbors that the burn is imminent
- ☐ Review smoke management plans
- ☐ Prepare your fire equipment and supplies

Morning of the burn

See page 123

- ☐ Obtain fire weather forecast to print
- ☐ Burn permit/smoke registration

Immediately before the burn

- ☐ Monitor and log weather onsite and several times during the day
- ☐ Brief the crew
- ☐ Review "Go/no-go checklist"
- ☐ Notify dispatch
- ☐ Complete a test burn
- ☐ Start burning

During the burn

- ☐ Adjust firing techniques as needed
- ☐ Keep the fire contained
- ☐ Monitor crew safety

End of the burn

- ☐ Perform mop-up activities
- ☐ Conduct after action review

Immediately after the burn

See page 138

- ☐ Patrol until fire is declared out
- ☐ Assess your burn success

Within a week after the burn

See page 141

- ☐ Conduct initial evaluation
- ☐ Assess first-order fire effects

Months after the burn

See page 144

- ☐ Conduct secondary evaluation
- ☐ Assess second-order fire effects



GETTING STARTED

Section authors: Micah Schmidt and Chris Adlam

Image credit: Chris Adlam, © Oregon State University

IN THIS SECTION

- Getting started on your burn plan
- Frequency and timing of burns
- Resources for burning

Getting started on your burn plan

Careful planning is essential for conducting a prescribed burn safely and effectively. Most prescribed burns need a burn plan that clearly outlines why, when and how a burn will be completed. The development of a burn plan revolves around the goals and objectives you are trying to achieve with your burn.

1. UNDERSTANDING GOALS AND OBJECTIVES

Carefully developed goals and objectives are crucial for guiding the planning, implementation and monitoring of any type of land management. They provide a roadmap for managing forests, grasslands and other vegetation in a way that aligns with a landowner's desires. Goals and objectives are central to prescribed fire, and it is important to distinguish between the two.

Goals are broad, long-term statements about the desired condition or outcomes for an area. Some examples of land management goals include maintaining a healthy forest, reducing hazardous fuels, improving wildlife habitat or restoring an ecosystem to its historical condition. While those goals make sense, they are not specific and cannot be easily measured. This is where objectives come in.

Objectives are the specific conditions that must be met for the goals to be achieved. When developing objectives, think about the **SMART** framework. Objectives should be:

- **S**pecific
- **M**easurable
- **A**chievable
- **R**elevant
- **T**ime-bound

GO FARTHER USING SMART OBJECTIVES

S Specific	M Measurable	A Achievable	R Relevant	T Time-bound
State what you will do with action words	Determine a way to evaluate your objective	Make sure you can accomplish the objective. Clearly identify steps that need to happen to guarantee a successful project.	Make sure the objectives align with the overarching goals and help make progress toward them.	Set a date for when your objective needs to be completed

PUTTING SMART INTO PRACTICE

Getting specific objectives

GENERAL	SPECIFIC
A. Improve forest health	**A.** Reduce density of fire-intolerant trees by 30%–50%
B. Reduce invasive species	**B.** Consume 70%–100% of invasive species
C. Reduce hazardous fuels	**C.** Reduce woody fuel loading by 60%–80%
D. Improve wildlife habitat	**D.** Burn in a mosaic pattern and retain all snags

Following the SMART Process

SPECIFIC	I will conduct a prescribed burn on a recently thinned forest to reduce the potential for severe fire in the future.
MEASURABLE	• Woody debris left over from the thinning will be reduced by at least 75%. • The fire will consume 60%–80% of fine fuels. • Seedings and saplings of fire-intolerant species will be reduced by at least 50%.
ACHIEVABLE	I will work with my state forestry agency and local Prescribed Burn Association to learn more about best practices and what resources are available to me. If needed, I will also pursue help from qualified individual to write the burn plan and lead the burn.
RELEVANT	These objectives are relevant because they align with reducing the risk of severe wildfire and improving forest health.
TIME-BOUND	Woody debris and fine fuel reduction will be measured immediately post-burn. Fire-intolerant seedling and sapling mortality will be measured one month following the burn.

If your goal is to maintain a fire-resilient mixed conifer forest, one SMART objective could be to reduce the density of fire-intolerant tree species by 50%–80% within five years. Be as specific as possible but practice developing a few objectives for each goal without trying to be perfect. The more you practice, the easier it will become. **Remember:** Objectives should answer the question "what do I want to accomplish when I apply fire to this unit?"

2. DETERMINE IF PRESCRIBED FIRE FITS WITH YOUR LAND MANAGEMENT GOALS

Before you plan a prescribed burn, determine whether prescribed fire will help you meet your overall land management goals. If you don't already have one, this is a good time to work with a professional to develop a land management plan, which outlines the goals and objectives for the management of a property.

Prescribed fire can help achieve a variety of management objectives, but it may not always be the best tool, depending on site conditions, overarching management goals or other factors. When determining whether to use prescribed fire, think about how you expect the characteristics of an area to change following a burn. For instance, what will be eliminated or consumed, or what will be left following the burn?

Remember that using fire can often result in unexpected outcomes, which could be positive or negative, depending on your land management goals and burn objectives. Careful planning and implementation can help reduce uncertainty, but be aware that fire is more of a broad-brush tool than thinning or other treatments where you directly decide which vegetation is impacted. Thinking through all of this can take some time, but it is important for determining if, when and where to use prescribed fire on your land.

3. DETERMINE YOUR PRESCRIBED FIRE GOALS AND OBJECTIVES

If you have determined that prescribed fire will help you meet your land management goals, it is time to set goals and objectives for your burn. The goals and objectives should be outlined in the burn plan and designed to ensure that you make progress toward your overall land management goals. Table 5.1 shows examples of the process of translating land management goals into prescribed fire objectives.

If the SMART objectives framework doesn't resonate with you, try NEAT objectives

Another way to think about good objectives is that they should be NEAT:

- Name and size (pick a category or specific species and the size)
- Effect (reduce, retain, or increase)
- Amount (the amount of the effect you want, usually given as a range)
- Timing (immediate or some years after the burn)

A NEAT objective for improving wildfire resilience may be to reduce (E) understory tree density (N) by 50%–75% (A) one year after the burn (T).

Examples of prescribed fire goals:

- Reduce the risk of severe fire
- Improve habitat, thereby increasing populations of threatened and endangered plant species
- Improve forage for grazing
- Promote fire-adapted tree species

Examples of SMART prescribed fire objectives:

- Reduce downed woody fuel loading by 30%–50% immediately following the burn
- Reduce cover of invasive plant species by 75%–100% immediately following the burn
- Reduce understory tree density by 40%–70% within one year of the burn
- Reduce duff and litter cover to bare soil across 50% of the unit immediately following the burn to prepare the seedbed for germination

LAND MANAGEMENT GOAL *Why are you burning?*	PRESCRIBED FIRE GOALS *What do you hope to see?*	PRESCRIBED FIRE OBJECTIVES *What can you measure?*
Restore native grasses, shrubs, and forbs	Increase populations of native understory plants	• Reduce cover of invasive species by 75% immediately following the burn. • Reduce duff and litter depth by 60%–90% in burned areas immediately following the burn. • Burn fuels down to bare mineral soil on at least 40% of the burn unit immediately following the burn.
Improve forest health and wildfire resilience	Promote growth of vigorous, fire-adapted trees	• Reduce density of understory trees <6" diameter at breast height by 50%–80% within one year following the burn. • Reduce 1-, 10-, and 100-hour fuels by 50%–80% immediately following the burn.

Table 5.1. Example goals and objectives of a prescribed fire and how they relate to one another.

Frequency and timing of burns

WHEN SHOULD I BURN?

Base the timing of your prescribed burn on when you can meet at least some of your objectives and maintain control of the fire.

Be aware that even marginal days can help you meet some of your objectives. Waiting for the perfect burn day often results in burns not being completed.

If you aren't targeting a specific plant response, it is better to burn when conditions allow, rather than skip a burn because it is during a different season than you had hoped for. This may not apply if you have important or sensitive species that you are hoping to maintain or promote. If that is the case, plan your burn in consultation with local experts.

Pro tip: Look up species information in the Fire Effects Information System to learn how your target plants respond to fire at different times of the year, https://research.fs.usda.gov/feis.

HOW OFTEN SHOULD I BURN?

Prescribed fire is a process and not a singular event. Ideally, burning should be conducted regularly, but the frequency depends on the specific ecosystem and management objectives.

Attempting to emulate historical fire return intervals is a common practice when burning to meet ecological objectives, as plants and animals are adapted to the historical fire regime. Fire history studies can provide ranges of fire frequency and severity for ecosystem types in specific regions. If you cannot find this information, reach out to local experts to help you find it.

Try various timeframes and seasons to see which best meet your management goals.

TIME SINCE LAST BURN OR LAST MANAGEMENT ACTIVITY

The amount of time since a burn or management activity occurred factors into how you conduct your burn and helps you prioritize how to burn and which unit to burn first.

If you plan to conduct a prescribed burn on land that has not been burned or otherwise managed in a long time, be aware of the amount of fuel present, because this will affect the intensity of the burn. You may need to complete management actions before the burn, such as thinning smaller trees and understory shrubs.

The initial burn on a site is generally the most challenging. If you are looking to burn a large area, break it into smaller units for the initial burns. Maintenance burns after that initial burn are generally less complex, less expensive and may be able to be implemented over a larger area.

Resources for burning

ASSISTANCE

State and federal agencies, university Cooperative Extension partners and nongovernmental organizations often provide outreach and educational support for prescribed fire in the form of webinars, workshops and trainings. The expertise, services and assistance that these entities provide vary by area.

The USDA Natural Resources Conservation Service may be able to provide financial and technical assistance with burning.

State forestry agencies may be able to assist with developing burn plans, providing financial assistance, burn permitting and providing equipment.

Some local agencies, conservation districts and nongovernmental entities have prescribed fire programs. Your neighbors or other nearby landowners may also be able to assist, as can prescribed burn associations (see "Prescribed burn associations").

Considerations for hiring consulting foresters and/or prescribed burn contractors

- If possible, compare multiple service providers. Depending on the number of vendors in your area, this may be difficult.
- If you live in a state that provides a Burn Manager Certification, request a copy of their certificate.
- Request a list of three to four references and contact them to get a feel for the quality of work the contractor provides.
- Request a copy of their insurance policy. Make sure their policy is current and covers the activities they will be completing for you.
- Request a copy of the completed burn plan to ensure that it includes basic information such as: objectives, resources needed, burn parameters, maps, etc. You can typically find more information on what to expect in a burn plan on your state forestry agency website.

These agencies may offer the following assistance:

- Development of a burn plan
- Construction of firebreaks or control lines
- Loan or rental of personal protection equipment
- Loan or rental of standard prescribed burn equipment, such as rakes, shovels and drip torches
- Personnel while a burn is being conducted
- Cost-share or grant programs

Consulting foresters and prescribed burn contractors can also be a valuable source of expertise, particularly for landowners new to prescribed burning. They can develop a burn plan or assist with the burn itself, if they have the appropriate experience. Your state forestry agency, Cooperative Extension or other local entity may keep a list of qualified contractors.

TRAINING

In-person training

State certification programs

Oregon and Washington currently have programs to certify individuals to lead burns on private lands. Oregon's Certified Burn Manager Program and Washington's Certified Burner Program require individuals to participate in classroom instruction, pass a final exam and implement burns under a certified individual, although the programs differ in their specific requirements. For individuals who have prior burn leadership experience or NWCG Burn Boss qualifications, there are more direct paths to certification. These programs are designed for individuals who already have some prescribed fire experience. Your state forestry agency can direct you to these programs.

Prescribed Fire Training Exchanges

Prescribed Fire Training Exchanges, or TREX programs, are immersive one- to two-week trainings. Individuals learn about a variety of prescribed fire topics while burning on any day with conducive weather conditions. TREX opportunities are open to any individual who has taken basic firefighter training (FFT2) and completed the work capacity test. Admission is competitive, but the trainings offer the opportunity to participate in multiple burns in a short timeframe.

Prescribed burn association events

Joining a prescribed burn association for a prescribed burn is a great way to gain experience (Figure 5.1). PBA burns are typically open to the members of the public, including those who are new to prescribed fire. PBAs also host a variety of other educational events, such as pile burning workshops, skills trainings, fire apparatus building classes and burn unit preparation days.

Prescribed burn associations

A prescribed burn association is a group of landowners and other interested citizens who form a partnership to conduct prescribed burns. Association members pool their knowledge, capacity and equipment to help other people in their association conduct prescribed burns. More than 130 PBAs are now found across the United States.

Online training

Free or low-cost online training is also available. Oregon State University Extension and partners are developing a self-paced online course for prescribed burning. Check course listings at https://workspace.oregonstate.edu/catalog-page#all-courses.

eFire is another virtual, interactive experience, https://efire.cnr.ncsu.edu/efire/. It was developed by North Carolina State University and is focused on the southern United States but has material that applies to prescribed fire across the country.

While eFire or other online trainings are not a substitute for actual burning experience, they can provide you with information to feel more confident in your understanding of prescribed fires. By strengthening your foundational knowledge, you will be better prepared to take the next steps, such as attending a prescribed fire workshop or joining a prescribed burn association.



Figure 5.1. The best and most practical way to learn about prescribed burning is to participate in live burns. Gain experience by joining a local prescribed burn association or participating in live fire trainings. Credit: Micah Schmidt, © Oregon State University

Supporting resources for burners

About the organization	How can they help?
The **Cooperative Extension System** provides unbiased, research-based information to individuals and communities to address challenges and find solutions. They are supported by your state land-grant university.	• Certified Burn Manager courses • Access to prescribed fire research and publications • Educational resources, training and webinars
State forestry agencies are responsible for protecting and expanding forests through proper management, protection and public education.	• Educational resources • Certified Burn Manager courses • Expertise in writing land management plans • Fire equipment (varies by state) • Burning regulations and permit information
Prescribed burn associations are composed of landowners and other community members who form a partnership to conduct prescribed burns. They can be found throughout the country.	• Association members pool their knowledge, capacity and equipment to help other members conduct prescribed burns • Great resource for first-time burners • Participate in live fire
The **Natural Resources Conservation Service** provides technical expertise, conservation planning and financial assistance for farmers, ranchers and forest landowners wanting to make conservation improvements to their property.	• Educational material and publications • Financial assistance may be available through a variety of programs.
Federal and state fish and wildlife agencies provide technical assistance, specialized planning, collaborative partnerships and direct implementation.	• Technical expertise • Planning • Assistance with implementation
Nonprofit organizations sometimes have prescribed fire programs and may offer technical expertise, financial assistance and other resources.	• Educational resources and training • Technical expertise • Financial assistance
Conservation districts are local, flexible entities that can sometimes offer technical expertise, educational materials and financial assistance for burning.	• Educational resources • Technical expertise • Financial assistance • Assistance with implementation
Volunteer fire departments consist of volunteers who perform fire suppression and other related emergency services for a local jurisdiction.	• Wildfire suppression experience • Some local departments assist with prescribed burning.

Other resources for burners

About the organization	How can they help?
Prescribed fire councils offer information-sharing and networking opportunities for all parties interested in prescribed burns. They are organized at local and state levels.	• Forum for local and regional collaboration • Regular meetings for information-sharing, policy updates, and networking
The **Joint Fire Science Program** funds scientific research on wildland fires and distributes results to help policymakers, fire managers, and practitioners make sound decisions. It is a national collaboration of 15 regional fire science exchanges. Explore your local exchange to learn more about regional resources such as the Northwest Fire Science Consortium.	• Regional newsletters, fact sheets and research briefs • Webinars • Workshops and field tours • Models, tools and maps
Prescribed Fire Training Exchanges provide an experiential learning opportunity for professional fire practitioners.	• Hands-on training completed through one- to two-week events • Networking with other fire practitioners
The **National Wildfire Coordinating Group** provides national leadership to support wildland fire operations at local, state and federal levels.	• Educational material and research briefs • Training material (primarily for wildland fire suppression)
The **Fire Learning Network** is made up of fire practitioners across the United States who are dedicated to building a world where beneficial fire can do its work on the landscape and harmful fire is less common and more effectively managed.	• Networking with other fire practitioners

CHAPTER NOTES



PLANNING THE BURN

Section authors: Heather Heward and John Punches

Image credit: Micah Schmidt, © Oregon State University

IN THIS SECTION

- Introduction to burn planning
- Location and notification
- Goals and objectives
- Burn area description
- Prescription
- Timing
- Preparing the burn unit
- Resources
- Human safety
- Communication
- Creating maps
- Managing liability
- Components of a burn plan
- Planning the burn checklist

Introduction to burn planning

Fire can be a powerful management tool, but it takes thoughtful planning to use it safely and effectively. The planning process starts with the location. This is followed by developing objectives, defining the prescription and identifying the resources you have to accomplish the burn (Figure 6.1).

This is not a linear process; each element affects another. While developing your plan, maintain the flexibility to revise any part of it.

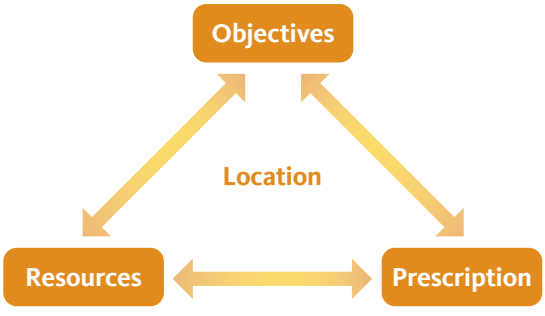


Figure 6.1. Planning a burn starts with its location. Objectives, the burn's prescription and resources needed to implement the burn all relate to the burn's location and its characteristics, and to each other. Credit: Heather Heward

To get a burn permit, you'll typically need a burn plan (see "Typical components of a broadcast burn plan" on page 116). While burn plans may initially be viewed as an inconvenience or a box to check, they serve at least five important purposes. A burn plan will:

1. **Guide** your thoughts and actions when planning your burn.
2. **Communicate** your plan to others.
3. Provide a **reference** and support when implementing a burn.
4. Serve as a **record** for future prescribed fire planning.
5. **Show evidence** that you were careful in your planning and implementation and possibly reduce liability if there are unintended outcomes from your burn.

Some burn plans may be short, simple documents; others are complex. The length or complexity of your burn plan will depend on your location, objectives, burn factors, state regulations and personal preferences. The following sections outline the information typically included in burn plans; refer to your state's specific requirements and organizational guidelines as you prepare your plan.

Location and notification

Location can significantly influence the success of a burn operation. Vegetation, existing or potential control lines, and values at risk are all location factors. If you are reading this guidebook, you probably have some places in mind that could benefit from fire; it is just a matter of deciding the size of the area and the type of control lines. Those factors are influenced by the prescribed fire objectives, prescription and resources — it really is all connected.

Since you need to begin somewhere, start the planning process by identifying an area with the highest likelihood of becoming your burn area. Adjust the location as you move through the planning process.

Burn plans include basic information about the area to be burned. This includes location, size and ownership. The plan should also include contact information for adjacent landowners and any relevant authorities or groups that should be notified.

Do I need a different plan for each place I want to burn? No, you can create a plan that works for a variety of areas. There is some information that is specific to a certain burn unit like coordinates, name, maps and control lines, but you could have a plan that covers multiple units. Talk to your local fire contacts for their recommendation on how to handle multiple units in one plan.

Goals and objectives

Goals and objectives (as discussed in "Getting Started") are important to identify early on, as they will inform what information you collect from the field and how you plan. Take your time with this process; your goals and objectives are the foundation of everything you do. Consider what you want to promote (plants such as native grasses) or reduce (trees of a certain size, for example). Think about changes you want to see in both the short and long term.

Remember to make your objectives **SMART** — specific, measurable, achievable, relevant and time-bound, so there is a clear operating picture of what you are accomplishing, and you can measure your success after the burn (see "Evaluating the burn").

Burn area description

Descriptions of the burned area must consider the conditions inside and outside the planned unit. Design your burn area using existing features or barriers such as roads or open bare areas free of vegetation. This will reduce unit prep work, help with holding efforts and allow for easier access for suppression and mop-up.

Consider the properties of the area inside the unit to ensure objectives are met, and outside the unit to ensure the fire will remain under control if it moves out of the intended area.

Burn area descriptions should include the following details.

FUELS

Fuels are anything that might be consumed; this includes living vegetation and dead fuels. The characteristics of fuel drive the potential fire behavior (see "Fuels").

Fuel type

This can be a general description, such as grass, shrubs, timber or slash, or can be more specific with fire behavior fuel models (Figure 6.2, left). Consider the fuel types that will be the primary fire carrier. Fire in grass fuel types will spread fast but burn out quickly. Shrub areas may also burn quickly, but they burn for a longer period. Fires under timber may exhibit low-intensity fire behavior when burning in shaded or compacted surface fuels but may still spread into surrounding trees (Figure 6.2, right).

Fuel continuity

Is the fuel continuous or patchy? Continuity affects the ability of fire to spread from one area to another and has horizontal and vertical components. Patchy fuel within the burn unit may make it challenging for the fire to spread and meet objectives. Continuous fuel outside the unit may make an escaped fire hard to control. Ladder fuels provide pathways for fire to spread from surface fuels to tree or shrub canopies. Fires in the timber understory with moderate to heavy slash may burn slowly but with extreme intensity.

Fuel loading

At a basic level, fuel loading can be described as low, moderate or high. The more material on the ground, the higher the loading. Measures of fuel loading are in tons per acre and can be collected using a variety of methods.

Canopy characteristics

Cover, height, diameter and species are common pieces of information to consider when planning the burn (Figure 6.3). Canopy cover affects the amount of shading the area receives and the potential for fire to spread from tree to tree. Height, diameter and species affect the ability of the trees to survive fire and the potential for ember production.

TOPOGRAPHY

The shape of the land influences the way the air moves (Figure 6.4). On flat ground, wind is the primary driver of fire spread. Steep slopes will increase the fire's rate of spread as flames lean closer to the fuels, preheating them. Valleys, draws, and saddles funnel the air, causing it to move faster. Ridges and canyons can make the wind swirl and change direction.

Because air movement affects the movement of the fire, understanding these patterns is essential.

Aspect also affects the type and condition of the vegetation. South-facing slopes get more direct sunlight and typically have more grass, fewer trees and drier fuel. East-facing slopes heat up early in the day, while west-facing slopes heat up later in the day. North-facing slopes tend to have more trees and denser fuels but higher fuel moisture.

When planning a burn, consider how topography will influence fire behavior throughout the day.



Figure 6.2. Fuel characteristics have a huge impact on fire behavior, so it's important to document them in your burn plan. The grassy fuels in the photo at left will burn quickly with high rates of spread, but the fire will also go out quickly. The more compacted understory fuels in the photo at right will burn more slowly, with lower rates of spread, but will take much longer to burn out. Credit: Heather Heward



Figure 6.3. Forest stands are made of multiple vertical layers of vegetation, which can be fuels for fire. To safely meet burn prescriptions, it's important to grasp how fuel layers interact. Credit: Jessica Shaklee

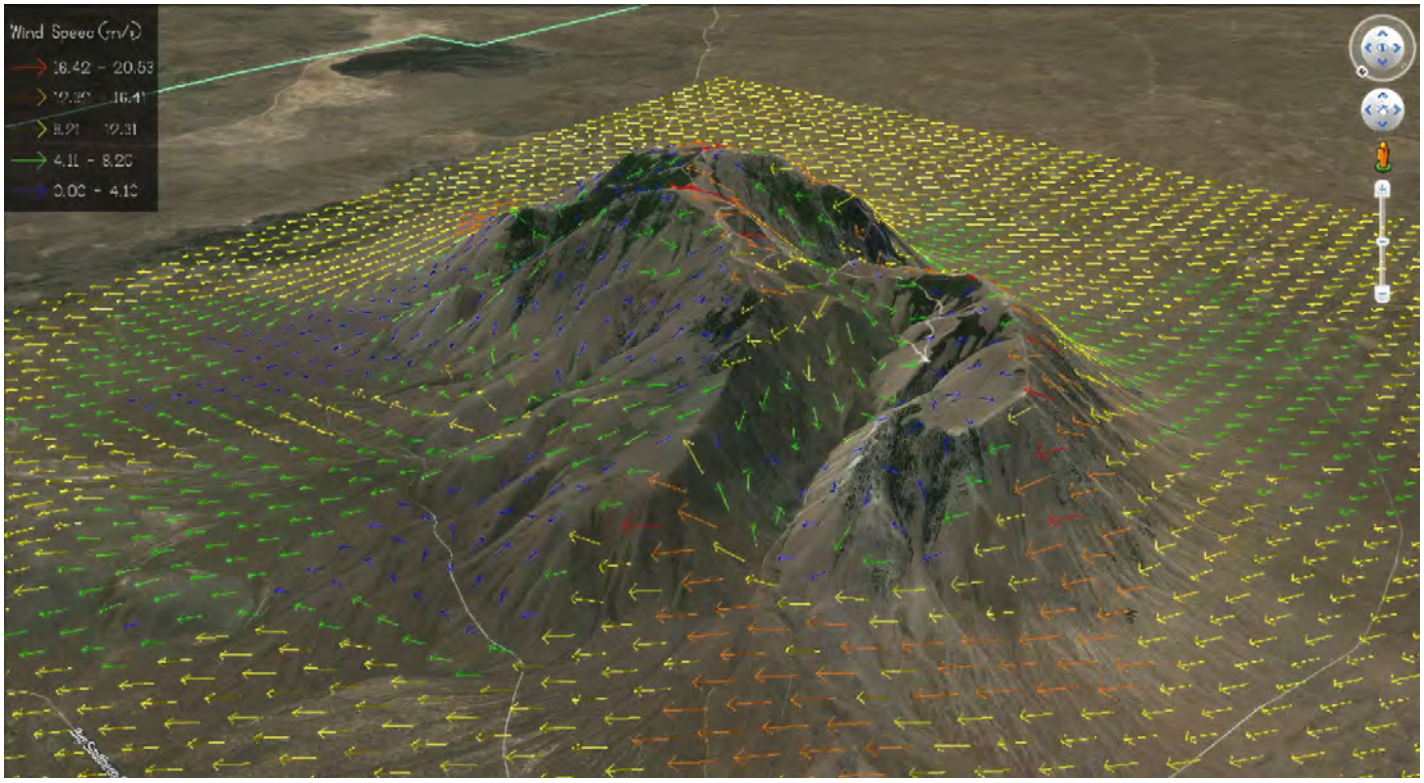


Figure 6.4. Topography influences wind patterns within and around your burn unit. It also influences fuel type and moisture content on different slopes. It has a direct influence on fire behavior. Credit: National Wildfire Coordinating Group, https://www.nwcg.gov/publications/pms437/weather/estimating-winds-for-fire-behavior

ACCESS TO WATER

Know the location of the nearest water sources. Ideally, map the location. Water sources include both human-made sources, such as hydrants and stock tanks, and natural sources, such as ponds and rivers.

Always confirm the water source is viable at the time of year you plan to burn. For example, a creek may be wet in the spring when you are planning the burn, but dry in the fall when you conduct the burn. Depending on the size and complexity of the burn, you may need a portable pumpkin tank, fold-a-tank or tender on location if water sources are limited or the turnaround time for refill is long (Figure 6.5).



Figure 6.5. A "pumpkin" is a flexible receptacle for water. Credit: Heather Heward

VALUES

It is likely your burn unit will include, or be near, things you don't want the fire to impact. These may include trees, fences, power lines, gas lines and other structures (Figure 6.6).

Consider the level of risk to these values and place them on the map to make them known. Identify a plan for mitigating the risk to these values, such as pulling material away from the base of trees, wetting down fences or contacting the power company to help prepare the power lines. Power lines have been known to arc when exposed to heavy smoke. Use caution when burning in or around power lines.



Figure 6.6. A pile located under a power line. This pile was also unknowingly built on a gas line, necessitating its relocation. Credit: Heather Heward

HAZARDS

There are many hazards to working outside aside from fire. Some common examples are insects, snags, barbed wire, trash and power lines. Label the hazards inside and outside the unit on a map, in case fire moves out of the intended area. Reduce hazards by removing or avoiding snags (Figure 6.7) and identifying and removing any human-made items such as wire or trash.

SMOKE SENSITIVE AREAS

Smoke Sensitive Areas include but are not limited to airports, highways, recreation areas, schools, nursing homes, hospitals, urbanized areas and large farming operations. If any of these areas are adjacent to or downwind from the burn site, draw up specific smoke-management strategies. See "Smoke management."



Figure 6.7. The snags pictured here may be valued wildlife habitat you would like to protect from fire, or hazards you would like to remove, depending on their location and your objectives. Credit: Heather Heward

Prescription

A prescription is the set of conditions needed to meet objectives and maintain control of the fire. Just as a doctor prescribes a treatment with specific doses and conditions, a prescribed fire practitioner applies fire under defined conditions to achieve desired results.

Common variables in a prescription are temperature, relative humidity, fuel moisture and winds. Other variables that are less common but may be meaningful in your area include days since rain and fire danger rating indices.

The variables you use might be based on your required burn plan template. A good prescription variable is highly correlated with fire behavior (when it changes, fire behavior changes in predictable ways), and it is easy to measure or look up.

Prescription values are given in ranges (for example, temperature between 45°F and 80°F). The range you choose in your prescription is your "contract." Signing the burn plan signifies your agreement to operate solely within the specified conditions. A prescription that is too broad does not give necessary guidance to meet objectives, and a prescription that is too narrow could unnecessarily limit your opportunities to burn.

Burn bosses working for fire agencies spend a great deal of time using fire behavior modeling tools to build their prescription values. Even with all the effort, much of the decision about which values to use is based on their experience or the experiences of others who have observed fire under a variety of conditions. It is, therefore, critical to observe fires regularly to build an understanding of how conditions affect fire behavior. Talk with people who have more experience and whose insights inform your prescription development.

TEMPERATURE, RELATIVE HUMIDITY AND FUEL MOISTURE

Temperature and relative humidity are easy to look up in a forecast and to measure at the burn site. They are primarily useful because they influence dead fuel moisture, which is not typically reported in forecasts or readily available when taking the weather on site. As temperature increases, relative humidity decreases (see "Weather").

Lower relative humidity means the air can draw more moisture from fuels, leading to lower fuel moisture and more active fire behavior. The larger the dead fuel, the longer it takes for its moisture content to change. You may then have different prescription parameters for different sizes of dead fuel (often referred to as 1-, 10-, and 100-hour fuel).

During the times of year when we commonly implement broadcast burns, temperatures ranging from 45°F to 80°F, and relative humidity from 30% to 60% can yield acceptable fuel moistures.

In the Pacific Northwest, dead woody fuels will generally carry fire when their fuel moisture content is 12% or less; they will be flammable and difficult to manage at 5% or below. Monitor these before, during and after the burn.

WIND SPEED AND DIRECTION

Wind influences the direction and rate of fire spread and smoke dispersion. It also helps to disperse heat from fire, reducing scorch. In prescribed fire, we monitor wind at several levels, each of which has implications for the impacts of our burn.

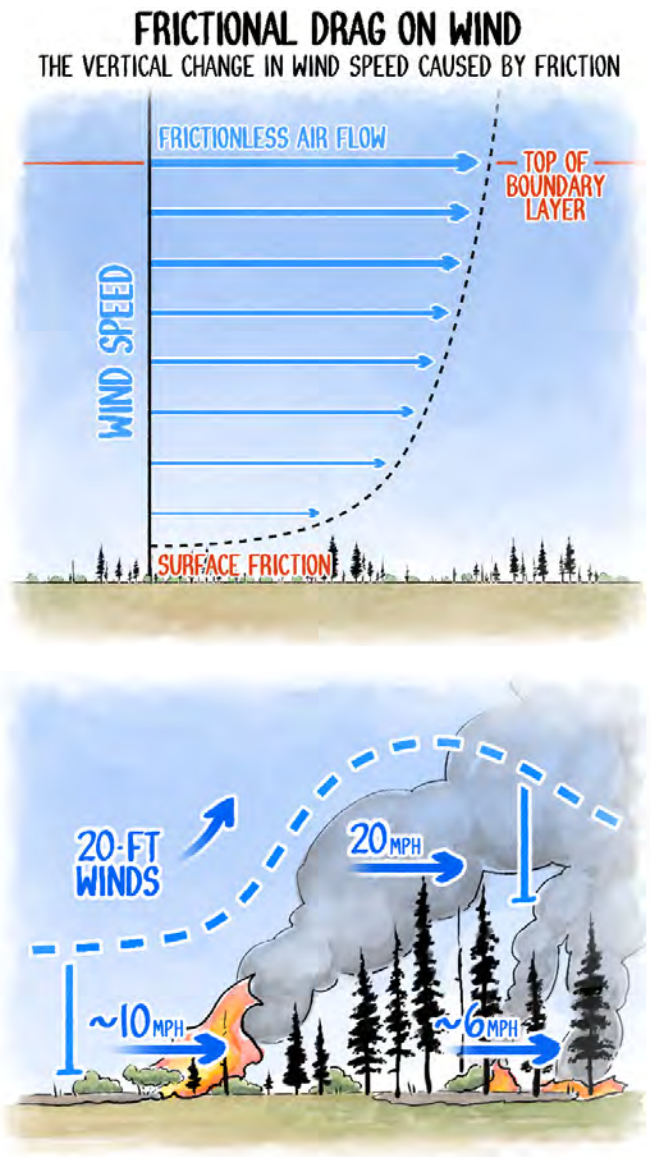


Figure 6.8. Wind speed is slower near the ground due to friction with the surface and vegetation. The "surface" winds reported in weather forecasts are measured 20 feet or more above the ground and its vegetation. This means the wind speed you get from the forecast will be higher than the "eye-level" winds you experience if standing on the ground. Credit: Ciara Bordeaux

Eye-level winds are what a person will observe at their location on the fire. Eye-level winds are excellent indicators of fire behavior in surface fuels. Surface fuels are the most frequently targeted in prescribed fire and the primary driver of overall fire behavior. Eye-level winds are assumed to be the same as "midflame" wind speeds referenced in fire behavior modeling software.

The winds reported in a weather forecast are not eye-level winds; they are reported from 20 to 30 feet above the vegetation and are less impacted by the surface characteristics. Eye-level wind speeds typically range from 50% to 80% of the forecasted values, but can accelerate with gusts, (Figure 6.8, Table 6.1). This means your prescription should account for the eye-level winds you will observe on the site and the forecasted winds you will check when looking for potential burn days.

In grassy fuels, avoid eye-level wind speeds above 5 mph (equivalent to forecasted winds of 10 to 15 mph). A bit more wind can be acceptable in short, compacted fuels such as pine litter, but always consider what's outside your burn unit. If surrounding areas have the potential for higher rates of spread, ensure you have ample holding and contingency resources available. Alternatively, choose to burn under wetter conditions (lower temperatures and higher relative humidities) to improve your ability to catch any spot fires or slop-overs that may occur.

If smoke is a significant concern for your burn unit, consider including transport winds and mixing height as variables in your prescription.

Higher transport winds will allow smoke to disperse but will also likely lead to higher surface winds. Higher mixing heights will lead to greater smoke dispersion but also to a greater potential for the fire to grow larger. Transport winds and mixing height need to be sufficient to move smoke away from your burn unit, and acceptable wind directions are dictated by where you don't want fire and smoke to go. Winds are communicated in the direction they are coming FROM (Figure 6.9). See "Weather."

The prescription can have any number of variables, but remember — if it is in your prescription, you should monitor it and record the values on the day of your burn. Pick only the variables that are meaningful to the outcome of your burn.

While you may find it acceptable to burn when fuel moisture is low (for example, 6%) and wind is moderate (5 mph, for example), you may not find it acceptable to burn when it is dry and windy. If you are burning under dry conditions, you may have a lower acceptable wind, and when it is wetter, you may have a higher acceptable wind.

Figure 6.10 shows two different examples of prescription tables in burn plans. Some plans specify allowable high

Vegetation and topography	20 feet to eye level	Eye level to 20 feet
Grass and shrubs taller than 3 feet on open level ground or ridges	20-foot winds * 0.5	Eye-level winds * 2
Grass and shrubs 1 to 3 feet on open level ground or ridges	20-foot winds * 0.4	Eye-level winds * 2.5
Short grass or timber litter less than 1 foot with low tree density (less than 20%) on open level ground or ridges, or any type of fuel midslope	20-foot winds * 0.3	Eye-level winds * 3.3
Open canopy with a flat or gentle slope at the base of a mountain, with steep slopes above	20-foot winds * 0.2	Eye-level winds * 5
Closed canopy with a flat or gentle slope at the base of a mountain with steep slopes above	20-foot winds * 0.1	Eye-level winds * 10

Table 6.1. Wind adjustment factors allow you to estimate eye-level winds from forecasted 20-foot winds, and vice versa. *Example: In an area with grass 1 to 3 feet tall, where topography is not blocking the wind, and a 20-foot wind of 15 mph is forecast, the expected eye-level wind would be 15 multiplied by 0.4, or 6 mph.* Adapted by Heather Heward and John Punches from *The Fire Behavior Fuel Reference Guide*

and low values, while others show ranges for acceptable and desired conditions. Do not exceed the ranges you set for acceptable or high and low values, which would deviate from your plan.

A good prescription should be wide enough to cover the range of conditions you would consider burning under, but not so wide that it does not provide guidance. The hottest or driest end of the prescription and the highest winds should be considered together. Are you still meeting objectives at the hottest end of the prescription? Will there be holding issues in the fuels outside the unit? Base holding resources on this portion of the prescription. When picking a range, ask yourself, "If it were one point higher on the day of the burn, would fire behavior be too low or too high to meet the objectives?"

Certain critical variables in burn day selection may not appear in your prescription table. The live fuel moisture content of shrubs and trees affects the likelihood of fire spreading into the canopy, which is harder to control than a surface fire and usually undesirable in prescribed fire. Live fuel moisture content in grassy and herbaceous fuels can impact fire intensity, including rate of spread and flame length.

If you make assumptions about live fuel moisture content when determining allowable wind, temperature or other items in your prescription, note these assumptions in your plan; they often appear as a comment below the prescription. In the week before your intended burn, check live fuel moisture content in key fuels. Either collect samples for weighing and drying (see "Fuels"), or estimate moisture content by observing the fuels' stages of development (based on the time of year and the presence of drought). Live fuel moisture is highest in the plant's green-up period and lowest in dormancy — this includes the early spring when plants have not started to pick up moisture.

Duff and soil moisture can affect the amount of consumption. Assess this by feeling the duff and soil and stirring up the dust in an area. If your objective is to keep some duff on the site to reduce erosion or invasion of undesired plant species, you may want to burn when there is some moisture present in duff and soil.

All of these are general considerations. Consult experts to fine-tune your prescription values based on your fuels, topography, objectives, etc. Experts typically use fire behavior modeling software provided in the Appendix, such as Behave or the Interagency Fuels Treatment Decision Support System (IFTDSS – pronounced "iff-tee-diss"), to support the development of prescribed fire prescriptions and justify their values. Find training videos online and on the Wildland Fire Learning Portal if you want to know more about using advanced tools to develop your prescriptions.

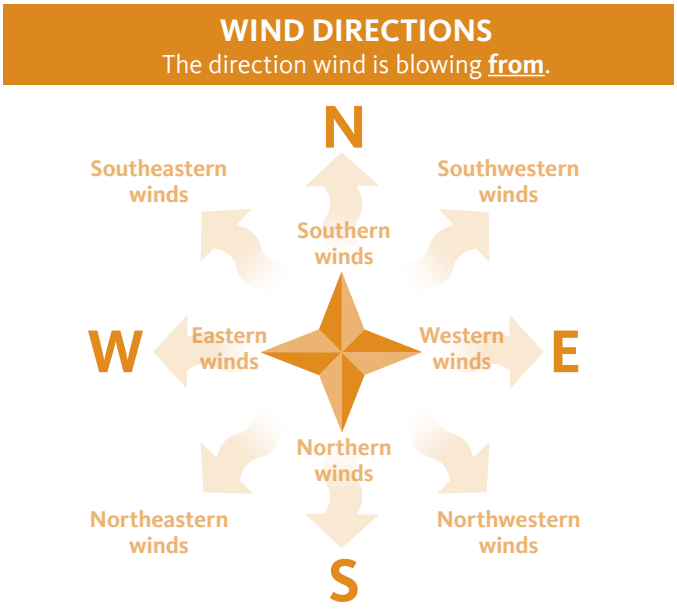


Figure 6.9. Wind direction is always expressed as the direction from which the wind is coming. Credit: Jessica Shaklee.

ENVIRONMENTAL PARAMETERS AND FIRE BEHAVIOR					
ENVIRONMENTAL PRESCRIPTION			ACCEPTABLE FIRE BEHAVIOR		
	Low	High		Low	High
Temperature (°F)	40	85	Flame Length (ft)	0.5	4*
Relative Humidity (%)	25	90	Rate of Spread (ch/hr)	0.2	20
20-ft. Wind Speed (Forecasted)	0	20			
20-ft. Wind Direction (Forecasted)	S, SE, SW, W				
Eye-Level Wind Speed (Observed)	0	6			
Eye-Level Wind Direction (Observed)	Any				
Transport Wind Direction	S, SE, SW, E, NE				
Fine Dead (1-Hr) Fuel Moisture	4	12			

Prescription Comments: Pine Corner subunit includes TL8 and GR1 fuel components, with sparse patches of weedy materials and dispersed, non-contiguous grass. (Additional text is cropped in the supplied JPG.)

PRESCRIPTION							
Weather							
	Temp.	RH	Fuel moisture	Winds (surface)	Wind (forecasted)	Wind direction	Min. Ventilation
Acceptable	45 - 84	15-70	6-13	0-6	5-15	SE, S, SW, W	>30
Desired	50-70	20-30	7-9	1-3	2-7	W	>60

Figure 6.10. Prescription tables from state burn plans.

Timing

Consider the time of year and time of day when you are most likely to meet objectives. The time of year can significantly affect the plant's response after the fire. For example, trees entering dormancy in fall may be more likely to survive a burn. An invasive grass species may thrive after a fire at one time of year but be reduced by fire at another. Learn more about specific plant responses to fire from the Fire Effects Information System discussed in the Appendix.

The season when a burn takes place can have an impact on other ecological systems. Birds such as turkeys build nests in brush during spring and lay their eggs in piles. Deer are fawning, and elk are calving in late spring. Water sources may be limited during fall burning.

You may also adjust the time of day to meet objectives. During the day, east-facing aspects that warm up early can be the starting location, and west-facing slopes that warm up later can be the end.

You could also conduct burns at night in wetter and cooler conditions if your permit allows, but a word of caution: Night burns can lead to greater smoke impacts as smoke settles down into lower elevations. Additionally, operating around hazards at night make them more dangerous. Do not attempt night burning if you are not familiar with an area.

Preparing the burn unit

CONTROL LINES

Identify the location and types of control lines. Existing roads provide the best control. Roads provide access and established edge. Main highways or highly traveled roads are not ideal. If there are switchbacks, put in a control line to cut off the switchbacks and avoid long bows in the line. If your unit has horseshoes, elbows or doglegs (Figure 6.11), consider modifying its shape by adding or removing sections to smooth the edges and reduce holding issues later.

Using natural features, such as locating lines on ridges and areas free of vegetation, helps during burn implementation.

Control lines can take many forms. These are often determined by what is already in place and the resources you have to install them (Figures 6.12 and 6.13). The control line should be at least 1.5 times wider than the height of the vegetation carrying the fire (see "Fire Behavior").

If you can only put in a narrow control line, reduce the height of the vegetation by cutting trees, weed whacking or mowing the areas adjacent to the control line. Pull any slash that you generated far enough away from the line inside the unit, so that it doesn't reduce the effectiveness of the control line. Always check your control lines before starting your burn to make sure they are secure.

CRITICAL HOLDING POINTS

These are areas where you are more likely to have control issues or areas where the consequence of fire outside the control line would be more damaging. Examples of critical holding points include narrow control lines, thicker vegetation or fuels, or midslope lines with the burn unit on the downslope side. Identify these areas before the burn and put extra protections in place by widening the control line, reducing vegetation height adjacent to the control line, or wetting the areas outside the unit just before ignitions.



Figure 6.11. These tricky unit shapes can lead to control issues. Credit: Micah Schmidt, © Oregon State University

Human-made control lines



Road

When using a road as a control line, consider the vehicle and foot traffic and how smoke will impact visibility. Some roads have consumable material over them and need to be prepared before the burn.



Dozer, disc or plow

Ensure the scrape is down to mineral soil and that the berm of dirt and material is pulled to the outside of the unit. Berms in the unit cause holding issues with long-term smoldering.



Handline

Handline should be scraped to mineral soil and be wide enough to prevent fire spreading across. Reducing fuel height next to the line with mowing or weed-whacking can increase the effectiveness of the line.



Mow with wet line

Mowing reduces fuel height and continuity. After mowing, apply water directly ahead of ignition to prevent fire from spreading into the remaining stubble. Continue wetting the mowed area as ignition progresses to maintain an effective control line.



Rake or leaf-blown line

A rake or leaf-blown line is created by removing leaf litter, needles, fine fuels and other combustible material down to bare mineral soil. The line should be inspected and improved before ignition, as fuels may blow back onto the line.



Sprinkler

Set up a reliable pump and water source and turn them on long enough for the water to soak into the fuels. This may be done the day before and again the morning of the burn.

Figure 6.12. Human-made control lines. Credit: Christina Friehauf (A and C) and Heather Heward (B, D, E and F)

Natural features used as control lines



Standing water

Standing water such as ponds, canals and marshes are natural control features. Water may be present during the planning phase but may change at the time of implementation or after the burn. Always confirm the presence of adequate water.



Rock

Make sure there is not burnable material between the rock. If there is, remove it or to wet it down to prevent fire from creeping through the rocks. Scree piles often have accumulations of duff and litter, rodent middens, etc., and carry smoldering fire.



Shade

Depending on the aspect and vegetation, there may be sufficient shade in parts of the unit to provide an area where conditions are too wet to spread fire. This is an advanced technique and should not be used without approval from your local fire authority.



Snow

Because broadcast burning and continuous snow cover rarely occur at the same time, snow is not a common control feature for broadcast burning. However, it is a common control line for pile burning. Ensure the snow is continuous to avoid creeping between snow patches.



Black

Fire can be carefully applied to any control line to widen it. This blacklining operation should be done with care to keep fire behavior on the main control line low. Build sufficient black line to hold the expected fire behavior from the rest of ignition.



Agricultural fields

Agricultural fields with no crop can serve as control lines. The cover of the ag fields changes regularly, so it is important to check the field's cover type before burning. A field that has crop residue will likely not work for the control line.

Figure 6.13. Natural features used as control lines. Credits: Micah Schmidt (A and B) and Carrie Berger (E), © Oregon State University, and Heather Heward (C, D and F).

WITHIN UNIT PREPARATIONS

If protecting trees is a priority and there are large accumulations of material around the base, consider pulling material away from the trees.

Rotten stumps that are near a control line but inside the burn unit may burn for long periods and produce embers. You may wish to dig a line around them to exclude them from the fire or cut them lower to the ground and allow them to burn out. This way, you don't have to worry about them the next time.

Snags can be a safety issue and a holding issue if they produce embers or fall over the control line. When possible, exclude snags by digging around the base. If they are a safety hazard to people, consider taking them out.

On the day of the burn, put water around features you want to protect from the fire. You may need to pile distributed slash to achieve better combustion or pull it away from trees to protect them from heat.

Resources

Resources include people and equipment you plan to have on the burn helping with ignition and holding. They also include the resources you expect to be available to help if the burn moves outside of the intended area.

You may create a plan with a certain number of desired resources, but if you can't reasonably count on all those resources, you'll have to adjust the plan to the actual resources available.

This is where the objectives, prescription and resources need to align. If you do not have the resources to conduct a burn under the conditions that will meet your objectives, adjust the prescription or call off the burn.

Think through this process using the PACE model, in which you come up with a primary, alternate, contingency and emergency plan for your intended burn (Figure 6.14). Consider each part of the PACE model for every burn. We will outline considerations for the resources you will need at various levels of activities.

PRIMARY

In an ideal world, where everything in your burn goes perfectly, the only resources you would need would be the firing team. This assumes the fire behavior is just as you expected and presents no challenges, all your control lines work perfectly, and no one makes a mistake.

Your plan would include the number of people needed to carry out the ignitions and any equipment and supplies they need. In this scenario, your ignition (firing) plan is your primary plan.

It's not realistic to assume everything will go perfectly, so burn plans always include the full range of plan stages, as illustrated in the PACE model (Figure 6.14).

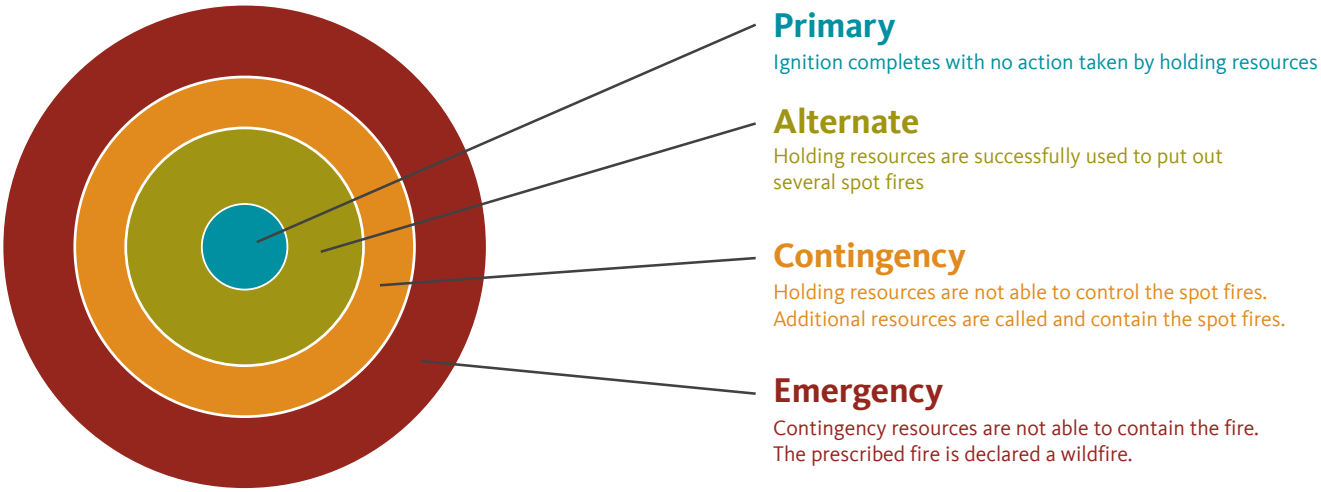


Figure 6.14. Prescribed fire burn plans should address the full range of plan stages within the PACE model. Credit: Heather Heward

The firing plan for a simple burn might include a lighter and a rake to spread burning material (Figure 6.15). More commonly, firing is accomplished by teams using drip torches or propane burners to ignite fuels in specific patterns. Large burn operations may use aerial ignition from drones or helicopters. See "Fire Behavior" for more details on considerations for ignition devices and patterns.

The number and type of primary resources depend on the size of the burn and the speed at which you wish to work. If you have a small or medium unit and all day to let the fire slowly spread, you may not need many ignition resources. Bring more than enough fuel — a drip torch (1.25 gallons) can last anywhere from 15 minutes when pouring into wet piles to several hours if used sparingly in dry fuels.

ALTERNATE

Putting fire on the ground creates opportunities for that fire to cross your control lines. You need to have an alternate, or holding, plan for these circumstances. It is common for some fire to cross a control line, whether that is a small spot in a punky log or a fire that starts to spread.

The holding plan lists resources ranging from people with hand tools and backpack pumps to ATVs, engines, tenders and hose lays that can deliver water (Figure 6.16). These resources are referred to as holding resources; the quantities and types you need depend on what you will need to control a fire if it spreads outside of the intended area, although you may also use them proactively to cool hot areas and prevent fire from crossing a control line.



Figure 6.15. The ignition team implements the primary plan for a prescribed burn. Credit: Heather Heward

Some examples:

- If you have tall grass outside your burn area, prepare resources capable of suppressing fire in tall grass. This would require large amounts of water and quick reaction times.
- If you have heavy downed material outside your burn area, be ready with water, saws and hand tools.
- If you are considering burning under dry conditions, increase holding resources to contain spot fires before they get too large.

CONTINGENCY

If fire crosses your control line and your holding crew can't stop it right away, you'll need a contingency plan. A good contingency plan considers what might happen under the worst conditions (hot, dry, windy) allowed in your burn plan. It is generally developed for the most flammable, highest-rate-of-spread fuel adjacent to the burn unit. Your contingency plan should estimate the firefighting resources needed to catch a fire that escapes from your burn unit and the strategy for doing so.

Contingency plans or actions can be implemented at any time during a prescribed fire and do not constitute a wildfire declaration.

Firefighting resources vary in their ability to control fires. Some can move quickly and set up control lines fast, while others are slower. When planning, think about three things:

1. How much control line could those resources build or hold if needed?
2. How long would it take them to arrive and start working?
3. How long can they continue working before needing to rest or leave?

The safest option for landowners is to have contingency resources on-site during the burn so they can respond immediately. That might be as simple as extra people with water packs and tools, a tractor with a disk or blade staged nearby, or a fire engine from your local fire department. Having extra resources on site isn't always possible. If contingency resources cannot be on site during the burn, they should be nearby and available upon request.

Prescribed fire tools		How they are used
	Radios	Radios are used for communication throughout the burn. There are many options that range in price and utility. Always ensure radios are working properly when preparing a burn.
	Wildland fire pumper unit	This equipment is commonly used on agency prescribed burns to rapidly access areas of concerns. They are generally mounted onto smaller, four-wheel drive vehicles. They are used to extinguish, soak, wet or cool down fuels.
	ATV / utility vehicles	Often, reliable and swift mobility is needed on the fire line. ATVs and utility vehicles are used to patrol the burn unit and to transport equipment and personnel.
	Backpack pumps	These manual pumps are used to extinguish, soak, wet or cool down fuels. They are especially important in that they can go where traditional water pumper units cannot go, making them a vital tool in quickly putting out hotspots. They hold 5 gallons of water.
	Leaf blowers	Leaf blowers are used to blow debris back into burn units along the edge of the firebreak. They are also effective in clearing out leaves and duff from under hard-to-reach areas.
	Chain saws	Saws are used to fell snags, cut logs into manageable size pieces, or clear thick shrubs/brush from under trees. Carry a hand saw or ax for small jobs.
	Drip torches	This is the primary ignition tool, and it is commonly filled with a mixture of diesel and gasoline fuels. The fuel mix ratio may change depending on conditions (see “Fire behavior”).
	Propane torch	The propane torch is ideal for starting piles as you can leave the wand in place for a period of time while the pile starts. A normal propane tank lasts longer than a drip torch but is not as portable.
	Pulaski	This piece of equipment is a combination of an ax and adze in one head, with a rigid handle of wood, plastic or fiberglass. The Pulaski is a versatile tool for constructing firebreaks, as it can be used to both dig soil and chop wood.
	Fire swatters	Fire swatters are an effective tool for smothering small grass or brush fires. They should be dragged across and held on hot spots to smother them.
	Shovel	This common tool can be used to place soil on stumps, logs, or other burning material. It can also be used to mix water into soil to cool down hot spots.
	Rakes / McLeods	Rakes can be used to pull debris to create a fuel break, cut down small shrubs and brush, and drag limbs and logs. This tool is useful to protect fire-sensitive objects like signs, power poles and utility boxes.

Figure 6.16. Credit: Micah Schmidt, © Oregon State University, adapted from University of Georgia Extension

If you realize that you won't be able to catch an escaped fire before it grows too large or leaves your property — even with additional help — then your prescription is too risky. Adjust your plan so that you burn only under cooler, wetter or calmer conditions, which make the fire easier to control.

In many cases, the best plan for catching an escaped fire is to have backup control lines (called contingency lines or secondary lines) that have been identified, mapped and prepared for use. You may also rely on variations in fuels or topography to serve as contingency control features. This could be green, moist, riparian areas, areas with minimal fuel, or shaded areas with fuels that would burn slowly and give contingency personnel time to respond and control the escape.

Deciding on the holding and contingency resources you'll need, or how to plan the use of contingency features, isn't always straightforward. This is where advice from experienced wildland firefighters or prescribed fire practitioners can be invaluable. Their wildfire suppression experience gives them a good sense of how much fire can be contained with different crews, tools and conditions.

EMERGENCY

Even with careful planning, things don't always go as expected. Your emergency plan is the last resort when safety is compromised and the situation escalates beyond your control. Your plan should focus on life safety, including escape routes, safety zones, communication coordination with suppression resources and the specific conditions under which an escaped prescribed fire could become a wildfire.

Setting a specific trigger in your burn plan helps everyone on the burn crew know when to implement the emergency plan. One example: "*The burn will be declared a wildfire if resources cannot stop the fire within 15 minutes or if structures are threatened.*"

If you think you might need outside help, **call early**. It's always better to have suppression resources on the way and turn them back if you get the fire under control than to wait until it's too late. This decision can feel difficult in the moment, but being proactive protects you, your property and your neighbors.

In some cases, the decision to declare an escaped fire a wildfire is dictated by state law. For instance, in Oregon, if your fire crosses onto someone else's property and they were not a co-signer on your burn permit, then that fire is automatically a wildfire — even if you think you can catch it.

Before the burn, talk with local fire suppression agencies so they know about your burn and can respond quickly if called. Also, learn how they will take command once the burn is declared a wildfire, so the transition is smooth.

Escaped fires aren't the only type of emergency to plan for. Other emergencies include smoke drifting across roads or into nearby homes. This may require outside help to manage traffic, notify residents or even put the fire out. Equipment breakdowns in the unit are also a type of emergency because they can create hazards, requiring extra hands to remove machinery or suppress fire around it.

Human safety

Medical emergencies are another critical consideration. Preparation for physical health starts far before the burn. People working on the fire should be physically capable of walking on uneven ground with occasional smoky conditions, carrying equipment and using tools.

> **Know your limits, listen to your body and help others on the burn do the same.**

Common injuries to plan for include burns, stings, cuts, falls, overheating, falling trees and vehicle accidents. Discuss hazards to avoid during the briefing and protect yourself by wearing personal protective equipment. Every burn plan should identify the nearest hospital and possible helicopter landing sites, and include a clear plan for transporting injured people to a hospital. Always keep an adequate medical kit on site and assign someone who knows how to use it (Figure 6.17).

Having a well-thought-out emergency plan does not mean you expect things to go wrong. It means you are prepared to act quickly and effectively if they do.

Communication

People on the burn need to talk to each other so they can work in coordination. The burn plan should specify the communication methods and equipment that will support the burn's implementation.

First-aid kit components



1. Alcohol wipes
2. Pads/gauze (large gauze pad, rolled gauze, medium nonstick pad with adhesive tab, small nonstick pad with adhesive tabs)
3. Bandage tape
4. Nonsterile gloves, latex or nonlatex
5. Self-adhesive wrap, also referred to as vetwrap
6. Bandage scissors
7. Bandages (wound closure bandages, waterproof bandages)
8. Sterile bandages
9. Ace bandages
10. Safety pins
11. Tweezers
12. Poison ivy and oak scrub
13. Epinephrine pen injection
14. Pain relievers such as ibuprofen, liquid or chewable aspirin or naproxen sodium
15. Eye saline
16. Allergy relief
17. Antibiotic ointment
18. Equate anti-itch cream
19. Cold pack
20. Liquid Skin or moleskin

Figure 6.17. First-aid kit components. Credit: Jessica Shaklee

Inexpensive Family Radio Service, or FRS, devices are an option for talking among people on a small- to modest-sized burn. FRS devices are readily available and use publicly available frequencies, but they may not transmit more than a quarter mile, and the channels may be in use by others not on the burn. You may experience radio traffic from other people using these open channels.

You may also find that FRS devices from different manufacturers don't work together as intended. Professional-grade VHF (very high frequency) radios offer greater range, but you need specific permission to use any particular frequency. If local fire or emergency services personnel participate in your burn, you may be able to borrow radios from them and/or obtain permission to use their frequencies. Make sure you understand their radio use procedures — the federal government regulates their use.

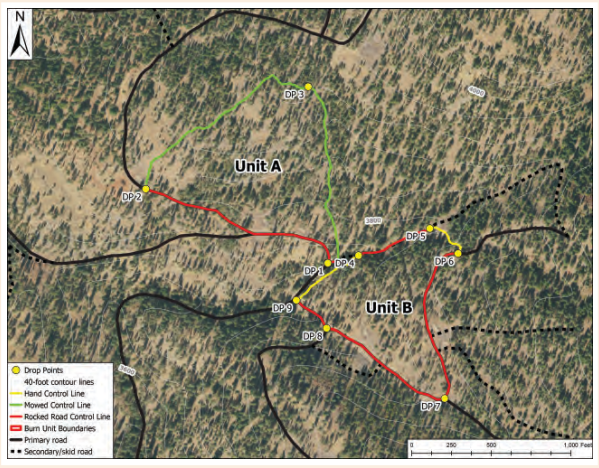
Cell phones are another valuable tool to contact off-site resources. As part of your planning process, determine where you can get a cell signal and if it will support voice calls or only text.

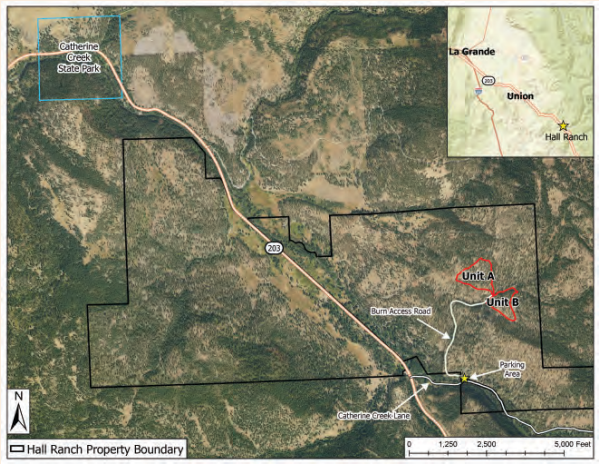
Radios are better for communication on the burn, so everyone there is aware of the activities taking place. The key to your planning process is to figure out the communications function in advance, as it's essential to a safe and effective burn.

Creating maps

Maps provide essential visual context for the plan. At a minimum, include a map of your burn unit with critical details clearly labeled (Figure 6.18). Also, provide a map that shows where your burn unit is relative to easy-to-locate landmarks like a major road or a city. How you make the maps is up to you — they can range from simple, hand-drawn versions to computer-generated georeferenced maps that you can share with people's phones using Google, ArcGIS, On X, Avenza or CalTOPO (Figure 6.19).

Other maps that may be useful in a burn plan could include locations and types of secondary control lines; locations of water sources that don't appear on the unit or vicinity maps; maps breaking out individual units on a multi-unit plan; and Smoke Sensitive Areas.





BURN UNIT MAP

- ☐ Control lines — distinguish different types
- ☐ North arrow and scale bar
- ☐ Imagery to show vegetations
- ☐ Water sources
- ☐ Critical holding points
- ☐ Drop points
- ☐ Topographic lines
- ☐ Values at risk
- ☐ Ownership boundaries

VICINITY MAP

- ☐ Transportation route
- ☐ Nearest city or recognizable feature
- ☐ Water sources
- ☐ Marker for the unit
- ☐ North arrow and scale bar
- ☐ Helispots

Figure 6.18. Examples of unit and vicinity maps.
Credit: Micah Schmidt, © Oregon State University

Hand-drawn burn map and tools to help



CalTOPO

- Create simple, easy-to-read maps
- Mark boundaries, roads, water sources, fences, buildings and other important features

Google maps: Google

- View satellite imagery, create and save maps for offline use
- Drop location points and measure distances between them
- Discover potential smoke-sensitive features with aerial view (homes, businesses and roadways downwind of the proposed burn unit)

Figure 6.19. Comparison of two common mapping programs.
Credit: University of Georgia Extension

Washington, Oregon and Idaho treat legal liability for prescribed fire differently

- In **Washington**, a person conducting a prescribed burn can be held liable if they fail to exercise reasonable care. If the person doing the burn is a Washington Certified Burn Manager, the bar for liability is raised; they would only be held liable if shown to have demonstrated a conscious, reckless disregard for reasonable care.
  - ↳ Washington also has a prescribed fire claims fund that provides funding to address claims for damages from prescribed fires implemented by Certified Burn Managers or cultural fire practitioners on tribal lands or lands protected by the Department of Natural Resources.
- In **Oregon**, a person may be held legally liable if their fire escapes and causes harm, and the landowner or burner can be shown to have failed to take reasonable actions to prevent the escape. In addition, even if the escape was purely accidental and the landowner or burner complied with all applicable laws and rules, the state can hold them responsible for up to $300,000 of the cost of extinguishing the fire. If they don't follow all the laws and rules, the state can hold them responsible for the full cost of fire suppression.
  - ↳ If the burner is an Oregon Certified Burn Manager, the law says that they and anyone working with them on a burn may not be held liable for property damage unless they are found negligent. This doesn't, however, relieve them from potential responsibility to the state for suppression costs. Oregon has a prescribed fire liability program that allows certain burns to qualify for funding if unintended damage occurs.
- In **Idaho**, landowners and other burners are held to the reasonable care standard. If shown to have violated laws or rules, they can be held responsible for fire suppression costs in addition to civil damages. Idaho does not yet have a Certified Burn Manager program or a prescribed fire liability fund.

Managing liability

Liability refers to a person's legal responsibility for their acts or omissions. In simple terms, it means that if you do something harmful, either intentionally or unintentionally, you can be held responsible for it. With respect to prescribed fire, it means that a landowner or burner may be held accountable for damage to other people, their property, or society more broadly if their fire escapes or smoke causes harm.

The specific ways that liability works vary among the states, and there is no guarantee you can't be sued by another person over the impact of your fire or smoke. You can, however, take steps to make it far less likely that their lawsuit will succeed.

- Follow all applicable laws, regulations and rules for the state where you are burning.
- Have and follow a well-written burn plan.
- Ensure you have sufficient holding and contingency resources so you can capture an escaped fire quickly, before it can cross onto someone else's property.
- Do all you can to keep smoke away from sensitive areas.
- Maintain a record of weather conditions and your fire and smoke behavior throughout your burn.
- Keep your neighbors informed of your burn intentions, so they won't be surprised and can take actions to reduce smoke impacts and avoid your fire resource traffic.
- Notify local fire authorities and invite them to the burn.
- Don't burn under risky conditions or when you don't have the resources to ensure you are safe and effective.
- Use a Certified Burn Manager (or become one yourself) recognized by your state to implement your burn.

All these actions provide important evidence that you are conducting your burn with a high level of care. They are also good practices that will help you achieve your prescribed fire objectives.

Typical components of a broadcast burn plan

General information

- Landowner name, address, phone number, email
- Name of burn unit
- Location of burn unit (latitude/longitude, TRS, county)
- Size of burn unit (acres)
- Anticipated burn dates

Signatures

- Burn plan preparer (name, date, signature)
- Burn boss/manager (name, date, signature)
- Landowners (name, date, signature)

Registrations and permits

- Burn notification and permit number
- Smoke registration or permit number

Notifications

- Neighbors (names and contact information)
- Agencies (as applicable)
- Forestry or wildland fire agency and contact information
- City or rural fire department or district and contact information
- 911 dispatch nonemergency contact information
- Air-quality agency contact information

Smoke management

- Smoke Sensitive Areas (type, distance and direction)
- Mitigations
- Reporting requirements

Landowner goals (broad intent)

Burn unit objectives (SMART)

Preburn fuels and vegetation description inside the unit

- Overstory tree species (height and diameter range, height to base of live crown, density)
- Midstory tree species (height and diameter range, height to base of live crown, density)
- Surface vegetation type and species, height, continuity, ladder-fuel potential
- Litter type and depth
- Duff depth
- Fuel loading (tons/acre)

Preburn fuels and vegetation description outside the unit

- Same details as above.
- Break down by location (for example, north of unit, south of unit) if fuels differ

Values at risk

- Type (homes/structures, utilities, fences, agricultural features, habitat, etc.)
- Mitigations

Prescription (minimum, maximum, desired)

- Temperature
- Relative humidity
- Eye-level wind speed and direction
- Surface (20-foot or 10-meter) wind speed and directions
- Transport wind speed and direction
- Mixing height
- Fine dead fuel moisture
- Live fuel moisture

Acceptable fire behavior (minimum, maximum, desired)

- Flame length
- Rate of spread

Weather monitoring

- Desired conditions before burn
- Source of weather forecasts and data
- On-site weather observation and reporting procedure

Holding

- Control line descriptions or standards
- Preburn preparations
- Critical holding points
- Water sources (location, distance, accessibility)

Firing

- Test fire locations
- Anticipated techniques

Mop-up

- Perimeter standard or depth
- Interior actions

Patrol

- Frequency and duration
- Standard for declaring fire out

Contingency

- Action points or triggers
- Resources and response times
- Secondary control lines
- Contingency response plan (where to catch fire)

Wildfire declaration

- Criteria
- Protocol
- Chain of command

Resources by stage of burn (ignition, mop-up, patrol)

- Required personnel (type/qualification and number)
- Required equipment (type and number)

Communication

- Dispatch/agency communication procedure (cell, text, radio with frequency or channel)
- On-site (tactical) communication (radio frequency or channel if applicable)

Medical and safety

- Nearest hospital
- Nearest clinic
- EMS response time
- Medical personnel on scene (number and training level)
- Medical equipment on scene

Fire effects assessment

- Preburn measurement protocol
- Postburn measurement protocol
- Reporting

Maps

- Unit
- Vicinity

Checklist (go/no-go)

CHECKLIST for planning prescribed fire

DEVELOP A BURN PLAN

- [ ] Determine the burn unit
- [ ] Define the goals and objectives
- [ ] Gather information on site conditions
- [ ] Develop the prescription
- [ ] Determine ideal timing
- [ ] Prepare the burn unit
- [ ] Make your PACE plan for resources
- [ ] Create maps

PRE BURN TASKS AND CONSIDERATIONS

- [ ] Determine the size of your crew
- [ ] Determine fire equipment needs
- [ ] Estimate the number of hours needed to complete the burn
- [ ] Identify adjacent landowners to notify
- [ ] Establish control lines
- [ ] Protect values at risk
- [ ] Develop contingency plans
- [ ] Assemble personal protective equipment (PPE)
- [ ] Obtain fire equipment

CHAPTER NOTES



CONDUCTING THE BURN

Section author: John Punches

Image credit: John Punches, © Oregon State University

IN THIS SECTION

- ☐ Introduction to conducting the burn
- ☐ Weeks before the burn
- ☐ Days before the burn
- ☐ Day of the burn
- ☐ On the fireline
- ☐ After the burn
- ☐ Conducting the burn checklists
- ☐ Go/no-go checklist

Introduction to conducting the burn

Burn days ("conducting the burn") represent the culmination of weeks, months or even years of careful preparation, planning and hard work. At this point, a burn plan should have been developed, control lines prepared, preburn unit preparations (including evaluation) completed, fire and safety equipment accounted for, and personnel ready.

This section will outline what to expect in the weeks leading up to, on the day of, and in the days immediately following the burn. We've included many tips to help you succeed.

Weeks before the burn

REVIEW THE BURN PLAN

As you get closer to the day of the burn, review the burn plan so its specifics will be fresh in your mind. Revisit your safety considerations, ignition techniques and holding plans to see if they still make sense. Visit the burn unit and identify any new hazards that need to be mitigated and reevaluate the plan based on current conditions.

Check the following items that may have changed since the burn plan was developed and adjust as needed:

- Have the burn objectives changed?
- Has the amount or type of fuel within the burn unit changed? Can you burn as planned, or do you need to treat the changed fuel or alter your plan?

- Examples could include downed wood from storms, heavier-than-expected grass or herbaceous fuel loads from a wet spring, fuels left behind by firewood cutting or logging activities, or debris that someone dumped.
- Has the risk associated with the burn changed due to nearby new construction, new neighbors who are not as comfortable with fire, a new fence that complicates your access or a change in water sources?

CHECK CONTROL LINES

Verify that control lines (often called firelines or firebreaks) have been established. Check their conditions, being especially aware of any new litter or plant growth that might carry fire across the established perimeter (Figure 7.1). All control lines should be clean and clear of flammable material. This is also a good time to check for any other preparations, like resource exclusions.

MONITOR WEATHER

Monitor weather patterns in the weeks leading up to the proposed burn date. Pay close attention to temperature and moisture trends, noting when it has rained, how long it has been since it rained, and how warm it has been — all of which will affect fuel moisture. Compare recent weather conditions and resulting fuel conditions to your burn prescription and make your best estimate of when you'll be able to conduct your burn.

REVIEW YOUR SMOKE MANAGEMENT PLAN

Prescriptions for burns address smoke management concerns and are generally designed to minimize smoke production or hazards. However, depending on current conditions, you may need to reassess for any new smoke hazards. Review your state's smoke management requirements and ensure you'll be able to comply.

Talk with one of your state's smoke management forecasters — they can help identify other burns occurring in the same timeframe and determine whether your smoke will be acceptable or create problems.

WALK THE BURN UNIT AND LOOK FOR SAFETY HAZARDS

Look for any situations that have the potential to promote escaped fire or human injury. For example, there may be snags or dead trees that could hurt someone, new debris from a storm or an area with more ladder fuels. Address these hazards before burning. You could cut down hazard trees, for example. Add any remaining safety hazards to the burn unit map.

ASSEMBLE AND CHECK EQUIPMENT

Collect the equipment you need or make plans to borrow or acquire it (Figure 7.2). Ensure you have enough hand tools and ignition devices, and that they are in good working order. If you are relying on pumps and hoses or equipment, test them before ignition. Have a backup plan in case something doesn't work or isn't available. Know where you can get replacements.



Figure 7.1. Before burning, check control lines to ensure they are installed or prepared as specified in your burn plan and are ready for the burn. Credit: John Punches, © Oregon State University



Figure 7.2. An equipment operator tests his skidgine — a skidder with a water tank and pump — before a prescribed burn in southeastern Washington. Credit: John Punches, © Oregon State University

CONTACT PEOPLE WHO CAN ASSIST IN THE BURN

Reach out to people who are willing to help and let them know your proposed and alternate dates. Secure their commitment so you can be confident you'll have enough help on the day of the burn. It's best to confirm more help than you think you need, as their availability may change.

CONFIRM PPE REQUIREMENTS

Determine which personal protective equipment is appropriate for your burn. If you will provide this gear to personnel, determine how much is needed, plan to have it on hand and distribute it. If relying on personnel to arrive with their PPE, communicate with them well in advance and ensure they understand expectations. See Figure 7.3 for examples of typical personal protective equipment.

NOTIFY NEIGHBORS THAT YOU ARE PLANNING TO BURN

Reach out to neighbors who could be affected by the burn and let them know of your plans. Do this far enough in advance so you can address concerns if they arise, but not so far in advance that they'll forget about your burn. Offer them a copy of the burn plan — it can help relieve their concerns to see how much thought and effort you've put into the process.

COMPLETE REQUIRED AGENCY NOTIFICATIONS AND OBTAIN PERMITS

Your state, county or fire district may require a notification or permit before you burn. You may also be required to obtain a permit for the release of smoke. Ensure you have all these requirements covered.

Days before the burn

REVIEW THE BURN PLAN AGAIN

Refamiliarize yourself with the burn plan and develop a briefing plan for the people who will assist you during the burn. Provide copies of the burn plan to key people, such as those leading holding and firing. As an alternative, make and share a shortened version of the plan (an incident action plan, or IAP) that features key information. Prepare these documents well in advance so they'll be ready on burn day.

Personal protective equipment for prescribed burners



Figure 7.3. Agency wildland firefighters wear specific personal protective equipment, or PPE. However, for most private landowners, 100% cotton long-sleeved shirts and pants, as well as leather boots, gloves and eye protection, will provide sufficient protection. Images courtesy of Carie Berger, © Oregon State University. Adapted from: Jessica Shaklee

MAKE COPIES OF THE BURN MAP FOR ALL PARTICIPANTS

Ensure everyone will have a copy of the burn map and that all burn units are identified. If you're handing out an IAP, this will be a central part of that document.

Check onsite conditions:

- Check all control lines to ensure they are still clear of any branches, fallen leaves, conifer needles or other material.
- Check duff and organic soil moisture.
- Look for any additional safety hazards.
- Check prep needs as identified in the burn plan, such as resource exclusions.

MONITOR WEATHER

Check weather forecasts from multiple sources in the days leading up to the burn. Access the National Weather Service and other forecasting applications on mobile devices. Watch for any developing weather fronts or storms that may halt your burn.

Forecasts generally predict seven to 10 days in advance but can change overnight. Weather forecasts will be more accurate as the day of the burn approaches. The variables you need to track or report will vary by location and regulations, but should always include the wind direction and speed, relative humidity and ambient air temperature. These ranges vary due to state agency guidance, permit requirements, management objectives and site conditions. Compare these to your prescription to ensure you'll have suitable conditions. Think also about the weather forecast for the days following your burn. Avoid burning if you suspect those conditions could make the fire rekindle and escape.

The NWS can produce a custom spot weather forecast for your intended burn area. These are technically only available to agencies, but your agency partners may be able to request one for you, or it's possible that your regional NWS office will have a more lenient interpretation of who can make the request.

Submit the request online: https://spot.weather.gov

NOTIFY EMERGENCY SERVICES AND NEIGHBORS

If multiple forecasts predict weather that falls within the prescription parameters, notify adjoining property owners of the impending burn. Update your local permitting agency and 911 dispatch, using their nonemergency phone numbers. You should have already informed your neighbors and these agencies some months or weeks ago that you were planning a prescribed burn, so this is just a reminder.

REVIEW SMOKE MANAGEMENT AND GENERAL BEST PRACTICES

Smoke management is a critical consideration for any prescribed burn, and it can often create more challenges than the burn itself. By the day of the burn, a smoke management plan should be in place. This information can play a central role in protecting human health, preventing unnecessary air pollution and mitigating visibility issues. See "Smoke management" for more detailed information on predicting smoke patterns and actions you can take to minimize smoke.

PREPARE YOUR FIRE EQUIPMENT AND SUPPLIES

- Make sure you have the proper equipment and sufficient fuel for ignition.
- Check pumps and vehicles. Make sure that they run and have fuel.
- Check other tools to ensure they are functional.
- Check radios or other communications equipment to make sure they are working and fully charged or have enough batteries.
- Ensure you have water, food, medical supplies and any other things you need to support your helpers.

Day of the burn

OBTAIN WEATHER FORECAST

Check weather conditions on the day of your burn and ensure they are consistent with the ranges listed in your prescription. The National Weather Service's hourly weather forecast is a dependable source. Visit the website, click on a map and get a detailed forecast for the area you plan to burn.

Preparing and using drip torches

The most common method of ignition for prescribed fire is the handheld drip torch. A drip torch holds ignition fuel and it is used to purposefully ignite fires by dripping flaming fuel onto surface fuels.

Step 1. Fill the diptorch about 75% full with fuel

- Extra space is needed to allow room for fuel to expand when temperatures increase. If the torch is filled to the top, it is likely to leak as pressure builds up, wasting fuel and creating a safety concern.

Step 2. Ignite the drip torch

- Pour a ***small*** amount of fuel on some leaf litter or pine needles and make sure the fuel saturates the wick.
- With your gloves on, ignite the fuel on the ground with a lighter.
- Place the wick of the torch in the flames and hold it there for about 5 seconds, while avoiding pouring excess fuel. Or, use use an existing source of fire to light it.

Step 3. Control the flow of fuel released from the drip torch

- Adjusting the air breather valve (No. 6 in the figure) controls the amount of torch fuel released. When it is closed, the drip torch will have a limited or intermittent flow. If fully open the stream of fuel can overshoot the wick and not ignite.
- As you use the torch, adjust the air breather valve to get the fuel flow rate you desire.

Step 4. Extinguish the drip torch

- Smother the drip torch flame by grasping the wick while wearing a thick leather glove. The drip torch should be extinguished whenever the drip torch is not in use.

⚠ **Do NOT blow a drip torch out, as there is a high risk of burning your face.**

COMMON FUEL RATIOS FOR DRIP TORCH MIX

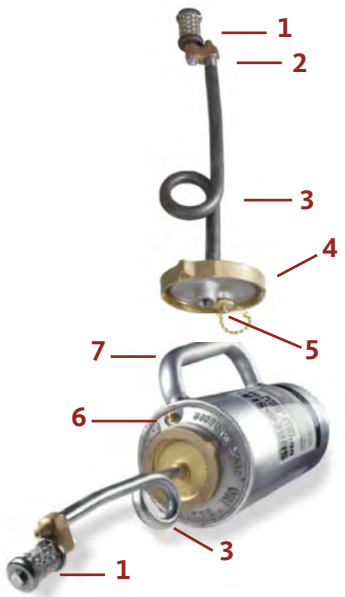
3 parts diesel: 1 part gasoline

If there is too much diesel, the torch will be difficult to light. If there is too much gas, the torch fuel can burn up before igniting the surface fuels. The exact ratio will depend on weather and fuels, but 3:1 is a common mix. Consult your local expert for guidance on your area.

DRIP TORCH CAUTION:

When getting ready to assemble drip torches, loosen the main ring first. The torches often build up pressure inside their container during transport, and loosening either the air breather valve or discharge plug can result in fuel spraying on you. Once tank pressure has been released, it is safe to open the breather or plug.

NEVER swap parts among drip torches unless you are certain they are the same models and makes. There is no standard for these parts. Swapping them can result in leaks or the unit falling apart during use.



1. **Wick** – Maintains a small flame on the end of the drip torch for fuel to pass over and ignite.
2. **Spout** – Fuel exits the canister through this nozzle and pours onto the wick.
3. **Fuel trap loop** – This loop prevents the fire from backing into the main canister. When a torch is assembled, this loop should always be facing the opposite direction of the handle.
4. **Locking ring** – Holds the torch assembly together, whether it is configured upright or inverted for storage.
5. **Discharge plug** – This plug prevents the flow of fuel during transport and storage when screwed into the fuel outlet at the base of the fuel trap. If your torch is assembled and not pouring fuel, double check to ensure this plug has been moved over to its parked position.
6. **Air breather valve** – Allows air to enter the canister while fuel is exiting and controls the flow of fuel.
7. **Handle** – For holding the drip torch. Do not hold the drip torch by any other part.

Credit: John Punches, © Oregon State University. Diagram adapted from *Drip torches, deconstructed*, North Carolina State University

A fire weather forecast is ideal but may not be available at the time of year you burn. The NWS local forecasts, and particularly their hourly forecasts, are great alternatives. If possible, seek an NWS spot weather forecast, which technically needs to be requested by an agency rather than a private individual. If you are working with an agency to implement your burn, its associates may be able to request the SPOT forecast.

Other sources of weather information include state forestry agencies, private weather forecasting sites and on-site observations. Don't trust any single source of weather information — compare multiple sources. If weather conditions and resulting fuel conditions are predicted to be outside of your prescription parameters during your burn, **DON'T BURN**.

CONFIRM YOUR BURN PERMIT AND SMOKE PERMIT ARE VALID

Check with your burn permitting agency to ensure your permit is valid for that day, and that your smoke permit or registration is valid. These permissions will specify the day and its conditions and may require you to burn within a designated time period. If you are unsure if you have the required permissions, **DON'T BURN**.

ENSURE YOUR EQUIPMENT AND PEOPLE ARE ON SITE AND READY

Make sure the people and equipment listed in your burn plan are present and ready to work. Swapping people and equipment is OK, as long as the replacements are equal to or more capable of doing their jobs. If you're missing key resources, **DON'T BURN**.

CHECK FUEL AND DUFF MOISTURE

Fuel moisture levels will determine how the fire burns (Figure 7.4). Fine fuels (one-hour fuels, equal to or less than ¼ inch) and duff will be key to overall fire behavior, so double-check that their moisture levels are within the ranges you identified in your burn plan.

ENSURE YOUR CONTROL LINES ARE STILL CLEAN

Check all control lines on the day of the burn, before starting ignitions, to ensure they are still clean. Leaves, pine needles or other debris can fall on or blow onto your lines, which could allow fire to cross them. A leaf blower is an ideal tool for this last-minute cleanup.

MONITOR AND RECORD WEATHER ONSITE BEFORE AND DURING THE BURN

Check your on-site weather conditions throughout the day. Anticipate that air temperature will rise and the relative humidity will fall over the course of the day. This means you should start your burn when the temperature is on the low end of its prescription range and the relative humidity on its high end.

The winds at your burn unit will probably pick up in the uphill direction as the sun heats surrounding areas and then slow and perhaps reverse direction (downhill) in the evening. Watch for these trends, ensure they remain within your prescription ranges, and keep the people on the burn informed of any significant changes.

A good practice is to report on-site weather (wind direction and speed, air temperature, and relative humidity) on the hour throughout the ignition phase of the burn (Figure 7.5).

Many burn managers also include the calculated values for fine dead fuel moisture content and probability of ignition.

Keep a good record (written or digital) of the weather readings and fuel moisture calculations throughout the burn, at least until ignitions are complete and you are confident in your ability to hold the fire within your unit. Most burn managers continue recording onsite weather



Figure 7.4. Checking fuel moisture before the burn using a handheld moisture meter. Credit: John Punches, © Oregon State University

well into the mop-up phase. Records can be submitted to the National Weather Service in your area to help them with future predictions. An online form is available as part of the spot weather forecast website.

BRIEF YOUR CREW

Once all necessary notifications have been made, the next step is to provide a thorough briefing for all individuals assisting with the prescribed burn (Figure 7.6). Review burn objectives, discuss your safety plan, point out key locations and concerns on the maps, and clarify how you expect everyone to communicate. Make sure everyone understands their jobs. Remind them of the resources they need to protect and confirm that everyone has appropriate personal protective equipment.

Share an overview of the general plans for holding and firing and then provide breakout opportunities for leaders of those roles to go into detail with their teams. Keep your briefing short while covering all essential details. Ensure everyone knows when and where you want to conduct your test fire (as described below). Make sure this briefing occurs BEFORE you begin ignitions, and give yourself enough lead time to ensure your crew is ready to work when your fuel moistures come into prescription.

USE SIGNS SO PASSERSBY WILL KNOW YOURS IS A PRESCRIBED BURN

People passing your burn may see smoke or fire, assume it's a wildfire and report it to 911. To minimize this unnecessary confusion, place signs to let people know your burn is prescribed (Figure 7.7).

REVIEW GO/NO-GO CHECKLIST

Review your go/no-go checklist as a final action before starting ignitions. It can also help to attach this list to your burn plan for reference and documentation. A go/no-go checklist is provided at the end of this chapter.

On the fireline

COMPLETE A TEST FIRE

With the crew briefing complete and the go/no go checklist reviewed and confirmed, it's time to proceed to the test fire (Figure 7.8). A test fire is a small fire (anywhere

Kestrel Weather Meter



This tool measures air temperature, relative humidity, and wind speed. More advanced versions will determine wind direction, fine dead fuel moisture content and probability of ignition.

A word of caution: Weather meters are not perfect and may differ in their readings. When measuring weather on-scene, use the same meter all day to ensure each hour's readings are comparable.

Figure 7.5. Credit: Leslie Boby



Figure 7.6. Briefing personnel before a burn in Western Oregon. Credit: John Punches, © Oregon State University



Figure 7.7. Well-placed signs can inform the public that your burn is prescribed, avoiding unnecessary calls to 911. Credit: National Interagency Fire Center

from a few square yards to one-quarter of an acre) in fuels representative of the greater burn unit, started in an area that will be easy to control.

An uphill, downwind edge or corner of the unit that can be readily accessed by personnel and equipment is an ideal test fire location, as long as the fuels are representative.

If your burn unit contains more than one fuel type, consider conducting multiple test fires.

Test fires allow you to see how fire and smoke will behave on your burn day. This step is vital in determining whether conditions are favorable for achieving your objectives and managing smoke dispersion. Key considerations are wind direction, fuel that is sufficiently dry to carry fire, fire behavior that aligns with your burn objectives, smoke lift and the direction it drifts. Anticipate that conditions and fire behavior will change over the day and think carefully about whether it's OK to proceed.

If the test fire meets your expectations for fire behavior and smoke dispersal, as outlined in the prescription parameters, proceed with the burn as planned. If the test fire does not meet expectations, **DON'T BURN**. Delay the burn until you have better conditions.

This may mean a brief pause while fine fuels dry out on your targeted burn day, or you may need to postpone the burn to another day or even another year. In some cases, your test fire may persuade you that your burn can't be conducted the way you thought it would work, and you'll need to come up with another plan of action.

START BURNING

The way you apply fire to the ground will significantly affect how the fire behaves, and you can use this to accomplish your objectives. Igniting the burn is called "firing," and there are several common techniques and patterns that burn bosses and their firing bosses use. Firing needs to consider and adjust for topography, fuels and weather factors.

A common approach to firing in Pacific Northwest fuels is to start on the downwind and uphill side of the unit and light along that control line (Figure 7.9). This will result in a backing fire that burns slowly and with minimal flame lengths. Once this fire has burned into the unit and created a sufficient "blackline," crews can add strips of

Communicate with your fire agency

Before putting fire on the ground, contact the agency that issued your burn permit and let them know you are about to burn. They may want this information by phone or text, or with their dispatch center.

They may also want updates as your burn progresses, such as when you are proceeding from the test fire to ignitions, when ignitions are complete, status of mop-up, and your overnight and succeeding days' patrol plans. The specifics will vary by agency, so talk to them in advance and have their requirements documented in your burn plan.



Figure 7.8. Crew members initiate a test fire on a burn unit in Central Oregon. It is burning representative fuels in an easy-to-contain location. Credit: John Punches, © Oregon State University

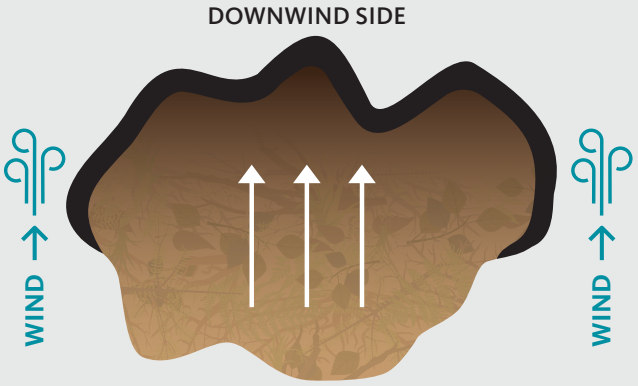


Figure 7.9. The downwind side of a burn is located opposite the prevailing wind. In sloping terrain, this is often also the uphill side. Initiating your burn on the downwind, uphill side allows many options for managing fire behavior. Credit: © Oregon State University, adapted from Jessica Shaklee

fire deeper in the unit. Crews allow those fires to burn as heading fires that then extinguish when they reach the area already burned.

As firing proceeds, crew members ensure the edges in the unit along the control lines are burned and blacklined to keep up with ignitions inside the unit. This is just one of many examples of how to apply firing tactics — see "Fire behavior" for more options.

Exercise care when conducting a burn on sloping or steep terrain. A fire traveling up a steep slope will move more quickly and burn more intensely than a fire on level terrain. Conversely, a fire traveling down a hill may cause the fire's front to move slowly and with less intensity.

Fuel moisture is also affected by slope, with south-facing slopes tending to be drier and north-facing areas often cooler and moister.

The behavior of your fire will vary across the burn unit and as the day's weather conditions change; adjust firing techniques and patterns accordingly. Note that wind blowing upslope will combine wind and slope impacts on fire behavior, while wind blowing downslope will offset the slope impact.

ADJUST YOUR FIRING TECHNIQUES

As you burn, evaluate and change your firing technique, spacing and stagger to obtain the desired fire behavior (Figures 7.10 and 7.11). Backing fire is an excellent technique to strengthen containment on the downwind side of the burn unit and flanking fire along its sides. A variety of firing patterns can be applied within the burn unit to manage flame length and rate of spread.

Continuously monitor fire behavior throughout your burn

Also monitor the amount and direction of the smoke from your burn. Depending upon your observations, you may need to adjust firing techniques or move holding resources to meet burn objectives.

Reminder of firing techniques

Backing fire

- Moves against the wind, or downhill, and much more slowly than heading fires.
- Typically lit along the downwind edge of a burn unit in order to slowly create burned areas or "blackline" close to the control line.

Heading fire

- Moves with the wind and at faster speeds.

Strip heading fire

- Set upwind of a control line and secured by the control line or a blackline.
- Adjusting the spacing between strips controls flame length, with closer strips resulting in shorter flames (in dry fuels).

Flanking fire

- Set by igniting a line or lines of fire directly into the wind or as you walk downslope.
- Can be used along the sides (flanks) of a burn unit or with multiple drip torches and fire crew members for interior ignitions.

Dot fire

- A line or grid of dots can be used to burn at a lower intensity. Each dot results in a combination of heading, backing and flanking fire.
- Adjusting the spacing between dots manages the amount of heat the fire produces at any one place and time.

Ring fire

- Can be used to "ring" an object, such as a leave tree, power pole or structure, to protect it from more intense fire.
- Can be used to put fire around the perimeter of a burn unit, allowing it to burn toward the center. This can be combined with interior dots if needed.

Find fire technique diagrams in "Fire behavior."

HOLDING: KEEPING THE FIRE CONTAINED

As soon as the burn begins, crew members assigned to holding roles should patrol the fire perimeter. Holding personnel patrol control lines and watch for any areas where fire crosses the line or threatens to do so (Figure 7.12). Key places to watch include:

- Downwind control lines
- Trees or snags burning near a control line
- Adjacent fuels that either burn hot inside the unit or would be likely to ignite outside the unit
- Large debris piles close to control lines
- Localized topography that channels winds

Holding crew members need to keep their heads on a swivel and focus on the area outside of the burn unit (the "green"), while also watching fire activity inside the unit for indicators of embers or intense fire (Figure 7.13). Position some holders in the green while others monitor the control line. They "follow" the firing team, working the control lines next to where fuels are being ignited, but also watching any areas that fire could move into. Holders may hear a spot or slop before they see it, especially if they are in the smoke, or the green fuels are tall and hard to see through.

Here are some key things to watch and listen for:

Spot fires

Spot fires occur when embers are blown across control lines and create an ignition outside of the intended burn unit. This can happen when wind gusts, convection columns, snags or other fuels loft embers that cross the line. If these embers land in an unburned receptive fuel, they can ignite small spot fires. You need to anticipate them and catch them quickly while they are still small.

We have used spot fire here in a generic sense — when reporting them, be specific about what you are observing. Is it a small "duffer" smoldering in a rotten log or other duff? Does the spot fire have active flame? Are you observing torching? Are you just seeing embers crossing the line that may result in fires? How big is the spot fire (dinner-plate size, truck size, 1/10th acre, etc.)?

Rolling debris

Fire burning on steep terrain can ignite and release debris that can roll downhill and across control lines, igniting



Figure 7.10. Strip headfiring in pine litter and shrubs. Adjusting the spacing between strips allows for management of flame length. Credit: John Punches, © Oregon State University



Figure 7.11. Dot firing reduces overall fire intensity and manages heat buildup under tree canopies. Credit: John Punches, © Oregon State University



Figure 7.12. Holding resources on a burn in southeastern Washington. Credit: John Punches, © Oregon State University

unburned fuels on the other side. Position control lines to avoid these hazards or dig cup trenches to minimize the risk of a rollout ignition (Figure 7.14).

Slop-overs

Slop-overs are areas where fire crosses a control line and ignites fuel immediately outside the unit. These typically happen when a line isn't wide enough and heat radiates across it, igniting unintended fuels. Wind changes can also push fire across a line, causing slop-overs. Sometimes, fuel within the unit and near the control line burns through and falls across the line (Figure 7.15). In other instances, slop-overs occur when igniters don't put out their drip torch when pausing or leaving the unit.

Proper preburn preparation along the inside of lines is your best defense against slop-overs. Cooling hot spots with water is a key holding tactic.

Sneaky fire

Smoldering fires can follow buried root systems, peat, thick duff layers and other organic soil infills. Scrape control lines to mineral soil levels to prevent fire from sneaking beneath them. Keep them free of leaves, needles and twigs, which can allow fire to cross the line. When using mowed line or wetline as your control line, you'll need to patrol it well. Creeping and smoldering fire often compromises these lines. Also patrol mineral soil lines, as buried root systems can penetrate the mineral soil break, and smoldering roots can pop up in the green.

If fire crosses your control line, your holding resources should detect and respond to the situation. In this case, they are acting as suppression resources, and their job is to contain and extinguish the unintended fire.

If your holding resources have any doubts about their ability to catch the fire, call contingency resources to



Figure 7.13. Crew members along a recently ignited section of control line. They will spread out as the burn progresses. A key part of their job is to monitor the "green" outside the burn unit for spot fires or slop-overs — so these people should really be facing the outside of the unit. Credit: John Punches, © Oregon State University



Figure 7.14. A cup trench control line will catch flaming or smoldering debris rolling out of a burn unit located above it on a slope. Note the mound of bare earth on the downhill side of the line — this is the key to cup trench performance. Credit: John Punches, © Oregon State University



MY FIRE ESCAPED! WHAT SHOULD I DO?

STOP all ignition activities as soon as you are safely able to do so. Evaluate potential fuel, size, rate of spread and location, and decide whether you need additional suppression resources.

Consider your contingency plan. A good contingency plan should anticipate potential issues and state the resources needed to mitigate problems as they arise.

Contact your local forestry agency or fire department sooner rather than later!

assist. If your contingency resources are unable to catch the fire within a reasonable period or at an acceptable size, it's time to declare your burn a wildfire.

Clearly identify the specific conditions that will trigger contingency resources or wildfire declaration in your burn plan. In any case where fire has crossed your control line, stop firing operations within the burn unit as soon as you can safely do so, then wait to see if those resources can proceed or need to be reassigned to holding roles. The idea is to reduce complexity while ensuring your burn is appropriately managed.

MONITOR CREW SAFETY

Keep track of your personnel throughout the burn. Know their locations and the conditions they are facing. Rotate personnel out of the smoke when feasible and ensure they work safely and use their PPE properly. Consider heat exposure and rotate people to cooler work or rest environments as needed. Ensure they drink water and keep up on their food and electrolyte needs.

MOP-UP

When ignitions are completed within an area, and the fire has burned out to an extent that it is no longer a holding concern, mop-up becomes the next task. Mop-up is the slow and precise work of extinguishing smoldering fire and cooling hot spots within the burn unit. It is one of the most important jobs during a prescribed burn, as it can be crucial to preventing fire escapes and minimizing smoke problems.

Mop up begins along control lines and moves inward (Figure 7.16). How deep into the unit you mop up depends on several factors:

- Permit details (what your agency requires)
- How much you want fuels to continue burning
- How long smoke will be tolerated
- Current and anticipated weather
- The potential for an area to rekindle and allow fire to cross a line

Burn plans often designate a mop-up distance (for example, 60 feet interior along downwind control lines and 30 feet along others for timbered units). Mop-up may



Figure 7.15. The bulge along this control line is an area where smoldering combustion was spreading across a section of the mowed line several hours after ignition. What had appeared to be a well-contained fire would have eventually crossed the line had holding resources not extinguished it. Credit: John Punches, © Oregon State University

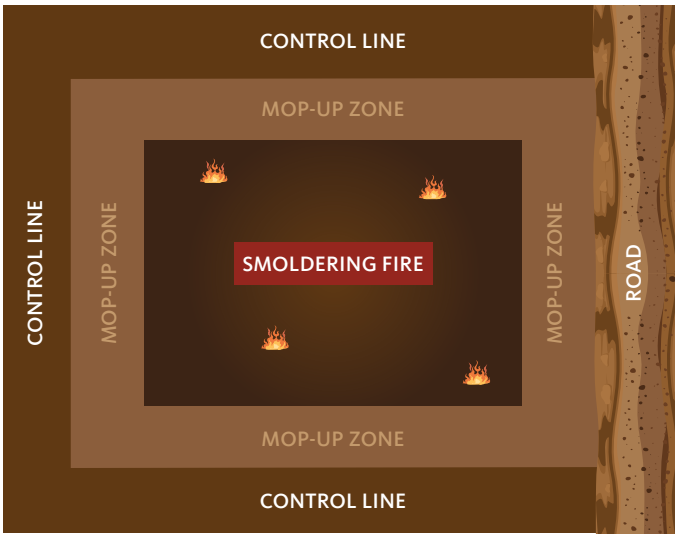


Figure 7.16. Mop-up diagram. Zone depth will vary, depending on fuels outside the unit, topography, adjacent values, control line type and width, and expected postburn weather. Credit: John Punches, © Oregon State University.

Mop-up is extinguishing or removing burning material near control lines. In general, create a 25- to 30-foot mop-up zone parallel to fire breaks. Customize that depth to your burn, its fuels, risk factors and anticipated weather. In some cases, no mop-up is needed. In others, complete mop-up is the right course of action. Your burn permit may specify mop-up requirements.

also extend farther inside the unit to put out burning and smoldering stumps and large downed wood that are sources of smoke.

There is a balancing act between letting your fire burn long enough to accomplish fuel-reduction objectives and completing mop-up before nighttime air temperatures drop, and smoke lingers or drifts downslope.

Use weather forecasts and observed weather trends to fine-tune mop-up activities. If you expect nighttime temperatures to be cool, humidity high and wind speeds low, you may be able to turn over logs and stir smoldering fuels to expose them so they'll absorb moisture. This lets the weather do some of your work for you. If winds are anticipated to be higher than desired, focus on the downwind side of the burn unit and add mop-up depth.

Mop-up can be conducted with water (wet mopping) or without (dry mopping). Wet mopping is generally considered the easier option.

In wet mopping, you expose burning (usually smoldering) fuels a little at a time and apply water to cool and extinguish them (Figure 7.17). Start at a logical point and work systematically to ensure you don't miss burning fuel. When working the edge between burned and unburned fuels, expose the unburned fuels far enough to ensure you haven't missed smoldering combustion hidden below the surface. Smoldering fire can be sneaky.

Wet mopping requires a careful combination of hand-tool work and water application. If done properly, it requires minimal water. Avoid the temptation to spray lots of water on a burned or burning area — this often cools the surface but leaves fire smoldering in lower layers, only to reappear once the surface dries. Firefighters refer to this as "cold capping."

Water for mop-up can come from hose lays, backpack bladder bags with hand pumps, tanks mounted on UTVs or ATVs, or tanks in trucks or on farm equipment.

Dry mopping uses soil moisture to extinguish fire. Clear an area of organic material, down to bare mineral soil — preferably moist mineral soil. Then mix burning or smoldering organics into the mineral soil in about a half-and-half mixture. When done properly, the soil cools the organics enough to stop them from burning while also limiting the fire's access to oxygen.



Figure 7.17. Crew members perform wet mopping to extinguish smoldering combustion. Note the combination of water and hand-tool work. Credit: John Punches, © Oregon State University

Wet mop-up techniques
Apply a fine water spray from the firebreak inward
Use a straight stream to penetrate or reach a target
Spray, stir and spray again as necessary
Use foam or another wetting agent
Break apart and spread fuel concentrations to lower fire intensity
Dry mop-up techniques
Boneyarding: Place small, unburned limbs and logs in the black (previously burned area)
Chunking and piling: Allow materials to completely burn themselves out
Spreading: Spread out heavy concentrations of materials to lower fire intensity
Banking: Cover fuels temporarily to prevent them from igniting
Turning: Move materials that could roll so they are perpendicular to the slope, and then place trench below them

Credit: Wet and dry mop-up techniques, adapted from National Wildfire Coordinating Group

QUICK TIP: Feel for heat in burned materials by using the back of your hand. After removing your glove, place the back side of your uncovered hand approximately 1 inch away from the item. If you don't feel any heat, touch the item with the back of your hand to confirm that it is fully extinguished.

A downside of dry mopping is that the mixing action also disturbs plant roots and soil organisms, so don't do more digging and mixing than necessary. Note that dry mopping can be difficult to accomplish if the soil is dry or fuel loads are heavy.

Mop-up is smoky, dusty, work and puts people in the burned area. Ensure your mop-up crew members watch for hazards such as burned snags and stump holes. Rotate them out of the smoke periodically and begin mop-up early enough to be sufficiently complete before nighttime inversions hold smoke at the ground.

Mop-up crew members should wear PPE to protect them from hot soil and burning materials, including glasses or goggles to protect their eyes from ash and steam and gloves for handling hot materials and avoiding steam burns. They should also consider wearing a mask or kerchief (dry, not wet) to cover their mouths and noses and help keep out smoke, ash and dust. An N95 mask is the best protection from smoke particles. Be cautious with masks — they are generally made of materials that melt when exposed to fire.

Ultimately, final mop-up ensures that the fire has been extinguished or that remaining hot or smoldering spots are cooled and managed to fall within acceptable risk levels. Remember to never leave a burn until all control lines are secure. You can test for heat in mopped-up areas using the back of your ungloved hand.

HOLD A POSTFIRE WRAP-UP DISCUSSION

As you wrap up the burn, bring the crew together and briefly review how the burn went. Did everything go as expected? Were there any unwelcome surprises? Did you achieve burn objectives for the day? What could be done differently next time? What needs to be done before crews leave the burn? This discussion will help you evaluate the burn, identify further tasks and improve on future burns.

After the burn

PATROL

Regularly check the fire until no smoke is visible or heat is detected. While the burn crew may leave a fire after mop-up is complete, the burn boss is responsible for ensuring the fire is contained — even after normal work hours. Your burn permitting agency may have additional requirements for how long you need to patrol a burn and when it can be declared out; follow their rules.

If strong winds or weather fronts are predicted postburn, continue patrolling the burn site. These conditions can jeopardize the integrity of control efforts and lead to an escape. A good practice is for patrol resources to take on-site weather measurements when they visit the burn unit and compare them with the forecast. It may also help to visit the burn unit at night to identify remaining hot spots.

Once the fire is officially declared out, congratulate yourself and your crew on a job well done!

ASSESS YOUR BURN SUCCESS

Evaluate your burned area the day of the burn or soon after. Evaluations can be as simple as listing the date of the burn, recording some notes and compiling a few photographs. Evaluations can be more detailed, and it's important to note that certain objectives can only be assessed in the weeks to months after a burn. See "Evaluating the burn" for more information on how to formally evaluate your burn.

CHECKLIST for conducting prescribed fire — preparation

WEEKS BEFORE THE BURN CHECKLIST

- [ ] Review the burn plan and visit the burn unit.
  - Have objectives changed?
  - Has fuel load changed?
  - Has risk changed?
- [ ] Check control lines and other prep needs (establish if needed).
- [ ] Monitor weather:
  - Identify trends in temperature and moisture.
  - Anticipate fuel conditions and compare to burn prescription.
- [ ] Review the smoke management plan.
  - Check smoke management forecasts.
  - Discuss with smoke management forecasters.
- [ ] Walk the burn unit and look for safety hazards.
  - Scout for snags, hanging limbs, storm debris.
  - Mitigate hazards.
- [ ] Assemble and check equipment:
  - Ensure you have the right kind and the correct amount.
  - Verify that it works.
  - Identify replacement source.
- [ ] Contact people who can assist with the burn.
  - Get commitment.
  - Be ready with backups.
- [ ] Confirm PPE requirements.
  - Find out who has their own.
  - Determine what others need.
- [ ] Notify neighbors.
  - Convey anticipated burn dates and plans.
  - Offer a copy of the burn plan.
- [ ] Do your paperwork.
  - Complete agency notifications.
  - Obtain burn permits or waivers.
  - File smoke emission registration or permits.

DAYS BEFORE THE BURN CHECKLIST

- [ ] Review burn plan again.
  - Refamiliarize yourself.
  - Develop your briefing outline.
  - Craft an Incident Action Plan if desired.
- [ ] Make copies of the plan or IAP.
- [ ] Check onsite conditions.
  - Are the control lines clean?
  - Inspect duff and soil moisture.
  - Identify any new safety hazards.
- [ ] Monitor weather.
  - Look for trends in temperature, humidity, wind speed and direction, mixing height, etc.
  - Use multiple sources.
  - Watch for potential burn days and weather following those days.
- [ ] Notify emergency services and neighbors that the burn is imminent.
- [ ] Review smoke management plans and practices.
- [ ] Prepare your fire equipment and supplies:
  - Make sure you have the proper equipment.
  - Purchase fuel for ignitions.
  - Check pumps and vehicles — make sure they work and have fuel.
  - Check radios and other communication equipment.
  - Ensure you have water, food, medical supplies, etc.

CHECKLIST for conducting prescribed fire — day of

DAY OF THE BURN CHECKLIST

- [ ] Obtain weather forecast.
  - Compare forecast with prescription parameters.
  - Consider burn day and the days following.
- [ ] Confirm your burn permit and smoke registration/ permit are valid.
- [ ] Ensure required equipment and people are on site.
- [ ] Check fuel and duff moisture.
- [ ] Ensure control lines are still clean.
- [ ] Monitor and record on-site weather before and during the burn:
  - Check hourly on-site weather reports.
  - Include fine dead fuel moisture and probability of ignition.
  - Report trends (what's up, what's down).
- [ ] Brief your crew on important details:
  - Burn size, boundaries, fuels, map overview
  - Hazards and safety issues, including escape routes and safety zones
  - Objectives
  - Anticipated fire and smoke behavior
  - Crew organization and assignments
  - Ignition and holding plans
  - Communication plan
  - Contact with the public
  - Locations of main roads, vehicles, etc.
  - Location of backup equipment, supplies, water
  - Suppression plan and contingency resources
  - Medical emergency procedures
- [ ] Answer crew questions.
- [ ] Set up signs to inform passersby.
- [ ] Review the go/no-go checklist.
- [ ] Notify the fire agency or dispatch that you are beginning the burn.
- [ ] Complete a test fire:
  - Use representative fuels in an easy-to-control location.
  - Decide whether to proceed.
- [ ] Start burning.
- [ ] Adjust your firing techniques as needed to achieve objectives.
- [ ] Keep the fire contained.
  - Shift resources as burn progresses.
  - Respond to changing weather conditions.
- [ ] Monitor crew safety.
  - Rotate for breaks from smoke.
  - Ensure active situational awareness.
- [ ] Conduct mop-up
- [ ] Adjust mop-up requirements to current and anticipated weather.
- [ ] Hold a postfire wrap-up discussion (after action review).

AFTER THE BURN

- [ ] Patrol until the fire is declared out.
- [ ] Assess your burn success.

EVALUATING THE SUCCESS OF YOUR BURN

- [ ] Conduct an initial evaluation after the burn is completed (within days).
- [ ] Conduct a secondary evaluation during or after the first growing season (from weeks to three to six months later), depending on your burn objectives.

GO/NO-GO CHECKLIST

PREBURN (BEFORE CREW BRIEFING)

- [ ] Burn unit is as described in the plan, and a copy of the plan is on site.
- [ ] Required control lines are complete and appropriate for current and predicted conditions.
- [ ] Permits obtained and documented in the burn plan.
- [ ] Burn boss assigned.
- [ ] Required number of personnel are present.
- [ ] Short- and long-range weather and smoke management forecasts obtained and within prescription.
- [ ] Notifications complete.
- [ ] Required equipment for holding, weather monitoring, ignition and suppression on-site and functioning.
- [ ] Personnel have reviewed equipment for readiness.
- [ ] Planned ignition, holding and containment methods are appropriate for current and predicted conditions.
- [ ] Planned contingencies, mop-up and patrol are appropriate for current and predicted conditions.
- [ ] Off-site contingency resources are operational and available.

CREW BRIEFING

- [ ] Review burn unit size, boundaries and fuels inside and outside the unit. Provide maps for reference.
  - Hazards and safety issues.
  - Prescribed burn objectives.
  - Anticipated fire and smoke behavior.
  - Organization of crew and assignments.
  - Methods of ignition, holding, mop-up, and communications.
  - Contact with the public, traffic concerns.
  - Location of main roads, vehicles, keys and nearest phone.
  - Location of backup equipment, supplies and water.
  - Suppression plan and use of contingency resources for escaped prescribed fire.
  - Medical emergency procedures.
- [ ] Answer crew questions.

TEST FIRE

- [ ] On-site weather and fuel conditions are within prescription and consistent with the forecast.
- [ ] Test burn conducted and fire and smoke behavior are within prescribed parameters.

POSTBURN

- [ ] Mop-up completed to standards as described in the burn plan.
- [ ] Night patrol assigned, if needed.
- [ ] Personnel and equipment assigned for days following burn, if needed.
- [ ] Complete notifications or reports of completed burn, if required.
- [ ] Debrief or after action review.

CHAPTER NOTES



EVALUATING THE BURN

Section authors: Carrie Berger, Chris Adlam and Micah Schmidt

Image credit: Micah Schmidt, © Oregon State University

IN THIS SECTION

- How burn evaluation improves future burns
- Understanding burn goals and objectives
- Preburn evaluation
- Observations during the burn
- Postburn evaluation
- Using evaluation to improve the next burn
- Diving deeper into evaluation

How burn evaluation improves future burns

Prescribed fire is a tool we use to care for forests, grasslands, and other landscapes. But burning is only part of the work. To know if a burn did what we wanted, we need to evaluate it. Evaluation means looking at what happened before, during, and after the fire to learn from it and make future burns even better.

Before a burn, check the site. Note which plants and fuels are present, what the weather is like, and consider the goals you want to meet. These goals might include reducing fuels, helping certain plants grow, improving wildlife habitat, or keeping larger trees healthy. These "before burn" observations give us a starting point, so we know what to compare to later.

During the burn, watch how the fire behaves. Look at things like flame length, how fast the fire moves, what firing patterns the crew uses, and how the wind and weather affect the flames. These notes help us understand why the fire left the results we see afterward. Even simple observations during the burn can make a big difference in understanding the outcomes.

After the burn, check and revisit the area. Some changes show up right away, such as scorched needles, burned shrubs, or how much fuel was consumed. Other changes take weeks or months, like new sprouts coming back, delayed tree death, changes in grasses and wildflowers, what and how animals are using the area, or how fuels start to build up again. By looking at these short and long-term changes, we can tell whether the burn met its goals and what we might do differently next time.

By the end of the chapter, you will understand some methods for evaluating prescribed burns. Postburn evaluations help you connect planning, fire behavior, and the results on the ground, so you can make better decisions and improve future burns.

Understanding burn goals and objectives

The "Getting started" chapter explains how to write burn goals and objectives for a burn plan using the SMART framework: Specific, Measurable, Achievable, Relevant and Time-bound. Objectives are not just planning tools; they also form the foundation of your evaluation process. Clear objectives make it possible to judge whether the burn worked as intended and what adjustments you might need to make in the future.

Most prescribed burn objectives fall into a few core categories:

- Fuel reduction and hazard mitigation
- Ecological restoration and management
- Range management
- Wildlife habitat improvement
- Site preparation
- Disease and pest control

Each objective should point to something you can observe and measure during evaluation. For example, if your overall goal is to improve forage for grazing, a matching SMART objective might be: "Reduce understory tree density by 40%–70% within one year following the burn." (Figure 8.1)

This objective tells you exactly what to look for when evaluating the burn:

- **Before the burn:** Measure or photograph understory density, so you have a baseline.
- **During the burn:** Observe whether fire behavior is likely to achieve the desired level of tree reduction (for example, flame length, scorch height, and ignition patterns).
- **After the burn:** Document how many small trees were consumed or scorched, and you return during the next growing season to check whether density has decreased by the target amount.



Figure 8.1. An example of a prescribed burn that reduced shrub cover and juniper seedlings to improve forage for grazing. Credit: Micah Schmidt, © Oregon State University

By clearly linking burn objectives to evaluation, you transform the burn from a one-time event into a learning process. SMART objectives tell you what to measure, when to measure it, and how to decide if the burn effectively supported your broader land management goals.

Preburn evaluation

Preburn evaluation should take place when you are just "Getting Started" (see chapter). Walk around the area you plan to burn and collect information that will help you interpret the burn later. Information to collect includes:

- **Site conditions:** slope, aspect, soil
- **Fuels:** characteristics of live and dead vegetation in the burn area (see "Fuels")
- **Sensitive resources:** trees to preserve, snags, high-value plant species

As stated earlier, determine your goals and objectives for the burn. For example, if your goal is to reduce the risk of severe fire, then your burn objective may state, "reduce downed woody fuel loading by 30%–50% immediately following the burn."

Your preburn evaluation should include estimates of existing fuel loads. Be aware that some agencies require reporting of total fuel loading (tons per acre) for the site, so check with your local state agency for specific requirements.

Consider also if the burn area is ready to accept fire. If it's not, refer to your management plan to guide future preparations (thinning, etc.) for burning.

During your preburn evaluation, take pictures at different locations throughout the area to compare these "photo points" with your postburn evaluation (refer to the quick field reference).

Any notes, pictures or observations you take when you are getting started will be helpful for future prescribed burns.

Taking photo points

Ideally, photos taken before and after a burn align. One way to do this is to pick locations that can easily be found again after the burn, such as a place that has meaning to you. This could be a stump of a particular tree, a deer stand, or the intersection of two roads or trails. Consider marking the location with a wooden or metal post or another type of marker. At each photo location, keep notes and record:

- Date
- Direction the photo was taken
- Height photo was taken (eye level or other)
- Orientation of the photo (landscape or portrait)
- Other camera settings, such as the aspect ratio

Ideally, take photos on overcast days when the lighting is more consistent.

Observations during the burn

Observing key factors during the burn not only helps you adjust operations as you go (see "Fire Behavior") but also allows you to relate fire behavior to fire effects. Observation helps explain the results you see afterwards. Key factors to observe during the burn include (refer to the "Quick field reference"):

- **Flame lengths and rate of spread:** How long the flames are and how fast the fire moves across the unit.
  - ↳ These observations indicate fire intensity and potential ecological impacts.
  - ↳ Longer flame lengths and faster rates of spread generally reflect higher fire intensity, which may or may not align with desired burn objectives.
- **Firing techniques:** Including spacing between lighters, ignition speed, ignition pattern and the amount of fuel applied.
  - ↳ Firing techniques strongly influence fuel consumption, scorch height, soil heating, patchiness and other fire effects.
  - ↳ A backing fire, for example, burns slowly against the wind and typically produces low scorch heights, but often results in high fuel consumption. In some cases, its slow movement can result in more heat in the soil than desired.
- **Weather throughout the burn:** Measurements of wind, temperature, relative humidity and fuel moisture at different times during the burn.
  - ↳ Changes in weather during the burn help explain variation in fire behavior across the unit, such as why some areas burned hotter, cooler or more patchily than others.

By connecting what happened during the burn to what you see afterwords, you get a clearer picture of why the burn produced certain results and what you can change the next time.

Postburn evaluation

Prescribed burns are evaluated so you can see how well the burn met its objectives and so you can learn what to improve for the next burn. But evaluation doesn't just help with the burn itself; it also helps you make better decisions about your overall land management.

For example, imagine one of your long-term goals is to convert part of your property into a meadow. After the burn, you might want to plant native seeds right away. But a good secondary evaluation done months later may show new invasive plants coming in. If that happens, you might decide to treat those invasives before seeding. In this way, burn evaluation gives you the information you need to time your actions wisely and protect the results you're aiming for.

Evaluations can be simple or more detailed, depending on your comfort level, time, capacity and objectives. For some people, a few notes and photographs are enough. Others prefer a more detailed assessment that includes comments on each burn objective and ideas for improving

future burns. There is no single evaluation form or process used by all landowners, agencies or fire practitioners.

At a minimum, your postburn evaluation should include taking photos from the same points where you took preburn photos, matching the directions and techniques you used the first time. Add observations about whether your burn met its objectives, as well as outcomes of interest.

A more detailed assessment will examine two categories of fire effects: First-order and second-order. First-order effects are direct results of the fire and are observable immediately or relatively soon (within a week) after the burn (Figure 8.2). Second-order effects happen in response to first-order effects, and they can take some time to appear (often the following spring, with some effects taking a year or more). While there are countless fire effects that you can evaluate, here are some common first- and second-order effects to monitor following prescribed burns. Many of these apply only to burns in forested areas, although we have included effects observed after burns in grass, shrub or other nonforest ecosystems.



Figure 8.2. An ash trail left where a log once lay can help you visually estimate consumption. Credit: Micah Schmidt, © Oregon State University

Whenever possible, take your postburn evaluation photographs and notes from the same locations you used before the burn. This makes it much easier to compare conditions and document changes. It also helps you meet postburn reporting needs, such as estimating how much fuel was consumed and confirming that smoke management rules were followed.

FIRST-ORDER EFFECTS

As soon as possible following the burn, walk the burn unit in an organized manner and observe the following:

- **The portion of the burn unit that actually burned.** This is a measurement of the area blackened by fire and usually expressed as a percentage (for example, 70% of the unit received fire).

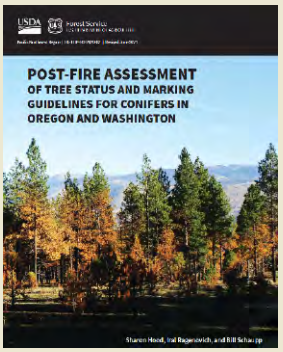
Then, within the areas that burned, look for:

- **Seedling and shrub consumption or scorch (Figure 8.3). Example:** 50% of the seedlings were scorched and are expected to die. 20% of shrubs were burned back to their root collars, and another 40% experienced scorch (see “Quick field reference”).
- **Crown scorch in trees:** brown needles or leaves heated by the fire but not consumed. (Sometimes these are hard to see until three to five days following the burn.) This can be expressed as the height above ground to which heat scorched leaves (typical scorch height was 20 feet, for example), or as a percentage of crown length (30% to 50% of crown length, for example). See Figures 8.4–8.6.



Figure 8.3. Both consumption and scorch can be observed in small trees and shrubs, indicating that the objective of reducing understory fuels was accomplished. Credit: Chris Adlam, © Oregon State University

- **Crown char:** Foliage actually burned or torched (black needles and ashes). This indicates these trees were partially or completely torched. It's typical to report this as a percentage of the total trees (for example, 15% of trees under 30 feet experienced torching).
- **Bark char:** Blackening or darkening of a tree's bark caused by heat or flames. It's useful to describe the height to which tree stems were charred (for example, trees typically experienced char to a height of 6 to 10 feet), char depth (for example, bark char rarely exceeded ¼ inch) and where char is present around the trees (for example, on all sides, on the side that faced the wind, etc.).
- **Consumption of downed wood:** Estimate the portion of downed wood, in each size category, that burned to ash (for example, 90% of one-hour fuels, 60%–70% of 10-hour fuels, 30%–50% of 100-hr fuels consumed). Large wood may merit more description, such as "logs over 10 feet were primarily charred, rather than consumed" or "solid large logs charred, but rotten logs were fully consumed."
- **Consumption of litter and duff:** Expressed as percentages (for example, 90% of litter and 30% of duff were consumed, on average, within the unit's burned areas). It may be more useful to describe the depth to which they were burned (for example, in most areas, approximately 2 inches of duff was consumed). In grassy areas without trees, assess the percentage of thatch consumed.



Postfire assessment resource:

Post-fire Assessment of Tree Status and Marking Guidelines for Conifers in Oregon and Washington, https://www.fs.usda.gov/rm/pubs_journals/2021/rmrs_2021_hood_s003.pdf, U.S. Forest Service

- **Soil exposure:** Small patches are common after a fire and are good seedbeds for native plants; large patches can increase risk, such as erosion, invasive plant establishment or tree root stress. If you observe this, it's probably best to describe where you see it so you can follow up and watch for erosion or invasive species.
- **Soil color:** The color of the soil following a burn can indicate soil burn severity and its impacts on the roots of sprouting plants, such as bunchgrasses, which are generally intended to be top-killed during prescribed burns. Brown soils indicate a low-severity burn, which is most common with prescribed fires. Black or grey soils indicate a more severe burn that will likely cause some plant mortality. Areas with black or grey soils should be monitored for invasive plants and may need to be seeded with desirable plants to accelerate recovery. Be sure that you are looking at the soil and not at blackened fuels on the soil surface.



Figure 8.4. Examples of crown scorch percentages. Credit: © Oregon State University, adapted from University of Georgia.



Figure 8.5. Scorched needles or leaves in the overstory become visible a few days after a burn. This stand will fully recover. Credit: Chris Adlam, © Oregon State University



Figure 8.6. Ponderosa pines have thick insulating scales that protect their dormant buds. The presence of heavily scorched needles does not indicate the branch is dead; surviving buds can regrow foliage during the next growing season. If the buds were active during the burn, they would be much more likely to be killed by scorch. Credit: Chris Adlam, © Oregon State University

Interpreting bark char

Bark char is the blackened or darkened area on a tree's trunk after a fire. It's one of the easiest clues for understanding how hot the fire burned near the ground. Use these steps to quickly and safely assess bark char during your postburn walkthrough.

1. Look at the height of the char

- Estimate how high the blackened bark reaches on the trunk.
- Taller char usually means taller flame lengths and higher fire intensity.

2. Check the depth of the char

- Light, surface-level char (thin, black layer that brushes off easily) often means the tree is not damaged underneath.
- Deep, cracked or "alligator"-patterned char may indicate heat reached the living cambium.

3. Examine the base of the tree

- Pay special attention to trees where duff or woody debris was piled at the base.
- Heavy smoldering can overheat the root collar and fine roots, increasing the chance of delayed mortality.

4. Look for other warning signs

- Sap or resin leaking from the trunk
- Bark pulling away from the tree
- Fresh insect activity (boring dust or small holes)

5. Flag trees for follow-up

- Mark any trees with deep char or signs of heat stress.
- Recheck these trees in a few weeks or months to watch for delayed symptoms.

Bark char alone doesn't mean a tree is dead. Many tree species, especially thick-barked ones, tolerate bark char well. The key is noticing where char suggests deeper injury and where it's simply a record of surface heating. This legacy ponderosa pine was killed by a fire that consumed the mound of litter at the base of the trunk, leaving a distinct charred ring indicating the litter level.

Image credit: Chris Adlam, © Oregon State University



SECOND-ORDER EFFECTS

Evaluating your burn for second-order effects requires patience, persistence and some organization. Some second-order effects may be evident in the growing season following the burn; others may take years. Think about what effects are important to you and then organize your return trip(s).

This follow-up evaluation is important because it documents how well the area responded to the burn in relation to your land management objectives over a longer period.

Information from this evaluation can improve the planning process for future burns. If repeat burns are conducted in the same stand, ongoing evaluation can help track your progress toward long-term stand management objectives.

The timing of a secondary evaluation depends on site conditions and objectives. Needle and leaf scorch is best observed one to four weeks after a burn. Delayed tree mortality can take a year or more to be noticeable. At a minimum, take pictures of the site six months to a year postburn and record the date and any other notes for a secondary evaluation.

Secondary evaluations are particularly important for grasslands and other nonforest ecosystems, where the primary objectives often include improving forage, diversifying species composition or managing invasive weeds. You may not see the effects of the burn on these objectives until the next growing season.

Here are some questions to think about (refer to the "Quick field reference"):

- **Is there any tree mortality?** Tree mortality may be evident as early as one year postburn, but it can take up to three years (Figure 8.7). Clues that a tree may be dying or dead include abundant red needles, bark cracking or separation, excessive resin or sap flow on the trunk, wood-borer or bark beetle activity, and dying tops or branches.
- **How many snags survived?** Also, observe if other trees were torched out and will become the next generation of snags.
- **Is there resprouting and vegetation recovery?** Look for shrub and hardwood basal sprouts, conifer bud survival and new needle flush (Figure 8.8).



Figure 8.7. High rates of ponderosa pine seedling mortality, which was desirable for this burn, became evident a few months following the burn. Credit: Micah Schmidt, © Oregon State University



Figure 8.8. Most broadleaf shrubs and trees resprout from the base, like this serviceberry one year after a burn. Credit: Chris Adlam, © Oregon State University



Figure 8.9. Basin wildrye and other grasses resprouting one month after a spring burn in a native grassland. Credit: Micah Schmidt, © Oregon State University

- **What is the grass and forb response?** Look for plants that may not have been visible in the burn area before the burn, as fire stimulates seeds held in the soil to germinate and allows more growing space for plants that were suppressed by competing vegetation (Figures 8.9 and 8.10). Assess whether the grass height and crown cover have improved compared to previous years.
- **Are there invasive species present?** Look for areas that had invasives before the burn. Have they been reduced or are they expanding? Check areas where the fire burned more intensely for any new patches of invasive.
- **Is the soil stable, or are there signs of runoff and erosion?** Look for persistent bare patches after heavy rain events (Figure 8.11).
- **Is fuel starting to accumulate?** Shrubs and tree sprouts can rebuild within a couple of years in some burned areas. Plan follow-up burns as they begin to compete with desirable trees (Figure 8.12 A–C).

Finally, a key question to ask yourself during either evaluation — initial or secondary — ***was whether the objectives of the burn were met, and why or why not?***

By getting into the habit of evaluating after every burn, you will continue to learn and improve your burns.



Figure 8.10. A variety of grasses, sedges, forbs and shrubs come up in spring following a fall burn that reduced decadent shrub cover. Credit: Micah Schmidt, © Oregon State University



Figure 8.11. High soil burn severity (in this picture caused by a wildfire) is damaging because it consumes all organic surface matter, severely reduces water infiltration and destroys soil structure and nutrients. Credit: Carrie Berger, © Oregon State University



Figure 8.12 A–C. A forested area in the Willamette Valley shown during prescribed burning (A) the following spring (B) and four years later (C). Note resprouting madrones and fine fuels returning after this interval, indicating it may be a good time for another burn to keep the habitat open. Credit: Chris Adlam, © Oregon State University

Using evaluations to improve the next burn

Congratulations! You have conducted a preburn evaluation, completed your burn and observed both first-order and second-order effects. Now what? ***Turn your notes into action!***

1. **Summarize what worked:** ignition pattern, weather window, holding tactics.
2. **Flag what didn't work:** unexpected scorch, smoldering around legacy trees, invasive species on bare soil.
3. **Adjust the plan:**
   - ↳ **Prescription tweaks:** Adjust weather variables such as relative humidity and wind limits, as well as seasonality and crew size.
   - ↳ **Prep changes:** Thin ladder fuels in advance, remove jackpots of fuel.
   - ↳ **Follow-up timing:** Treat invasives before seeding; schedule repeat burns as fuels reaccumulate.
4. **Share the learning:** Communicate findings to the burn boss, landowner and partners, so the next burn benefits from this one.

Evaluating the burn means learning from the burn and using that knowledge to plan safer, more effective and goal-aligned fires in the future.

Diving deeper into evaluation

If you want to go beyond the basics, there are more advanced methods for monitoring and measuring fire effects.

See the *Fire Effects Monitoring Handbook* from the National Park Service: https://www.nps.gov/orgs/1965/upload/fire-effects-monitoring-handbook.pdf

Regardless of the approach you choose, make sure your evaluation meets a few simple criteria: Is the information useful? Does the landowner need or want it? Is it repeatable in the future?

SparkED Resources: "So you want to be a Fire Effects Monitor (FEMO)?" https://www.youtube.com/watch?v=TM-o89MvpLc

QUICK FIELD REFERENCE

Before the burn

- Photo points set (meaningful place such as a deer stand)
- Fuels measured and described (tons/acre)
- Understory density recorded
- Sensitive resources identified (snags)
- Objectives reviewed (from the burn plan)

During the burn (hourly measurements and observations of fire behavior)

- Flame length (for example, 1–2 feet)
- Rate of spread (feet per minute or chains per hour)
- Firing pattern (strips, dots, heading, backing, flanking)
- Ignition spacing (for example, 10–15 feet)
- Weather changes (wind speed and direction, temperature, RH). Consider calculating fine dead fuel moisture and probability of ignition.

Initial evaluation (up to seven days after the burn)

- Photo points repeated
- Burn coverage estimated
- Scorch and char documented
- Fuel consumption noted
- Soil exposure assessed
- Objectives met? Why or why not?

Secondary evaluation (six to 12 months after the burn)

- Photo points repeated
- Tree mortality and new growth
- Resprouting shrubs
- Grass and forb response
- Presence of invasives
- Fuel regrowth
- Erosion issues
- Objectives met? Why or why not?

CHAPTER NOTES



PILE BURNING

Section authors: Heather Heward and Aaron Groth

Image credit: Ally Steinmetz

IN THIS SECTION

- ☐ Introduction to pile burning
- ☐ When and how to create piles
- ☐ When and how to burn piles
- ☐ What to do when a pile escapes
- ☐ How to avoid pile escapes
- ☐ Alternatives to traditional piles

Introduction to pile burning

Pile burning is a type of prescribed fire used as a land management strategy for several purposes. It may serve as a postharvest or thinning cleanup method, site preparation for replanting, wildfire risk reduction, a prebroadcast burn preparation step to reduce overall fire intensity or simply as a way to maintain an area by removing accumulated fuels.

Pile burning can be conducted under wetter conditions than other forms of prescribed fire, like broadcast burning, and with fewer personnel and equipment. However, managing pile burning requires careful consideration and preparation, similar to what you do before a prescribed broadcast burn.

Planning should include:

1. Firelines or firebreaks
2. Sufficient personnel to monitor the fire
3. Firefighting tools and equipment
4. Adherence to notification requirements

Without careful planning, implementation and monitoring, pile burns can escape, causing wildfire, or create unintended consequences. This chapter covers when and how to create piles, when and how to ignite piles, and what to do when a pile escapes and how to avoid it.

When and how to create piles

TIMING

You can build piles any time of year, but it is best practice to let piles dry for a summer season to reduce smoke and increase the pile's consumption rate. This may be undesirable in some situations, however, because piles can attract beetles and other wildlife. Consult forestry specialists about the best time of year to cut and pile, depending on your species and any insects present in the area.

Cover the tops of the piles with polyethylene plastic (4 millimeters thick is ideal) or waxed paper. The size of the cover will depend on the pile size, with larger, more industrial-sized piles requiring approximately 10 x 10-foot pieces. Covering the pile can dramatically improve ignition success if it has been left to dry over the summer in preparation for a winter burn.

Burning polyethylene plastic is illegal in some states, so remove any plastic coverings before ignition. Consider also placing paper inside the pile to shield the fine fuels at the bottom. Keeping a portion of the pile dry is critical for successful burning in wet conditions.

LOCATION, LOCATION, LOCATION

Flame lengths during pile burning can reach up to three times the pile's height, and heat can radiate as far as three times its width (Figure 9.1). Place piles well away from trees, structures, utilities like powerlines or other features that could be damaged by this heat. Also, consider the prevailing wind and place piles appropriately to avoid damage. Keep piles clear of waterways to avoid contaminating water resources.

CONSTRUCTION METHOD

A well-constructed pile (either hand or machine, Figure 9.2) has several key characteristics:

- Hardwoods such as vine maple placed on the top of the pile.
- Fine fuels at the base that facilitate ignition.
- A mixture of fuel sizes throughout to ensure efficient heat transfer.
- A balance between loose and compact structure: Too much airspace prevents upward heat transfer, while too tight a structure limits oxygen flow.
- A tall, narrow form is preferred over sprawling piles. Taller piles protect the lower material from moisture and encourage upward heat movement. Piles will shrink by almost half as they dry out, so you can build them taller initially.
- No large logs or stumps in piles. These can smolder for extended periods and are harder to extinguish, sometimes reigniting months later.



Figure 9.1 A–B. Expect flames roughly three times the pile's height. Avoid placing the pile beneath branches or power lines that could be affected by flames or smoke. Credit: Heather Heward

When and how to burn piles

PERMITTING AND NOTIFICATION

Check with your state and local fire authorities to find out what permits and notifications are required throughout the year before lighting burn piles. Make a list of neighbors who would appreciate being notified of your planned burn day so they can take protective steps to avoid smoke, such as closing windows or staying elsewhere until the burn is complete.

FUEL MOISTURE

Piles should be burned when the surrounding conditions are too wet to easily spread fire. Keep in mind that piles, especially large ones, can become hot and dry the fuels around them, which can cause fire to spread even when you think conditions are too wet. Always monitor your piles for fire spread and create a control line around them. Consider lighting piles when there is snow on the ground. As long as there is a dry spot to light, they will ignite. (Figure 9.3).

WIND

Because piled fuels typically retain higher moisture content, it may be acceptable to conduct pile burning under wind conditions that would be unsuitable for broadcast burns. Winds between 5 and 10 mph can help the pile burn by providing oxygen and pushing smoke up and out of the area. Again, take care to monitor the piles and watch where embers land to ensure there is no chance for spot fires. Make sure the wind is blowing in a direction that will move the smoke away from areas where smoke is a concern.

SMOKE

Smoke is an important consideration when deciding when to light piles and how many piles to light. Here are some conditions to avoid when burning piles:

- **Air quality advisory:** This tells you that additional smoke will further degrade air quality and could negatively affect the health of people living in the area.

Pile construction methods



HAND PILES

Hand piles are easy and inexpensive to make. They are generally smaller since they are limited by how far your arms can reach. They tend to consist of smaller material, leading them to dry and burn out faster. They can be time-consuming and labor-intensive when working over large areas.



MACHINE PILES

Machine piles vary in size from an average of 15x15 feet to huge landing piles that can be 60 feet across. These types of piles are more likely to contain dirt, especially when bladed machines such as bulldozers are used to push material into the pile vs. loaders that lift the material onto the pile. They contain larger material, and it may be more challenging to organize the pile to contain fine fuel at the bottom. Machine piles may burn for weeks or months and should be monitored until the pile is confirmed to be completely cold to avoid holdovers — piles that reignite the following summer and turn into wildfires.

Figure 9.2 A–B. Credit: Heather Heward

- **Inversion:** When you see low-lying clouds or other smoke settling in the valleys, you may have an inversion, which can cause the smoke from your pile to settle rather than rise and disperse. State and local authorities may require smoke permitting and notification.
- **Nighttime:** Inversions are common at night, and the cooler conditions make smoke less likely to rise and disperse.
- **Very low wind:** Wind helps push smoke away, and a lack of wind allows it to settle. It can also slow the combustion process since there is less oxygen available. When piles are dry, they will burn more efficiently and produce less smoke. To reduce smoke, allow piles to dry and cover them before the rain starts. A leaf blower can help improve combustion efficiency in the pile without causing high winds elsewhere (Figure 9.4).

Monitor the ventilation rate by checking the National Weather Service Fire Weather Dashboard or other service. Pick a day when the smoke will move up and away from the burn area. Ventilation rate is an indication of stability. Figure 9.5 combines mixing height and transport winds. Ideally, burn on days and at times of day when the ventilation rate is highest. If the piles are large and will burn for several days, consider the ventilation rate over several days.

FUTURE WEATHER

Piles can burn for days and hold heat for weeks or even months. Check the forecast to see if conditions are trending drier or windier. This is especially important as you approach the drier summer months. You can delay the burns or ensure the piles are completely out before drier, windier weather arrives.

TEST PILE

If you have many piles to light, start with one as a test pile. Pick a pile representative of the other plies and observe how difficult it is to light and how quickly it starts to burn down. If conditions are favorable, move on to other piles. If they are not, extinguish or monitor the test pile until it is out.



Figure 9.3. Pile surrounded by snow to limit fire spread. Credit: Christina Friehauf



Figure 9.4. A leaf blower can help increase combustion efficiency. Credit: Carrie Berger, © Oregon State University

Fire weather dashboard

	Smoke dispersal	Ventilation rate knot-feet (x1000)
	Excellent	150 or greater
	Very good	100 to 149.99
	Good	60 to 99.99
	Fair	40 to 59.99
	Poor	less than 40

Ventilation rate = transport wind (kts) x mixing height (ft)

Figure 9.5. Credit: © Oregon State University, adapted from NOAA National Weather Service



Figure 9.6 A–B. Propane torches are effective for hard-to-light piles because they produce a flame that can preheat the fuel. Drip torches are most effective when there are dry fuel pockets in the pile to ignite (A). A Terra Torch with a gelling agent can light many piles quickly (B). Credit: Heather Heward

IGNITION DEVICES

Drip torches and propane torches are the most common tools used for igniting piles (Figure 9.6). Propane torches are especially effective at starting wetter piles because they generate more heat and can burn longer. If burning many piles, consider investing in a terra torch such as a FireGel, which uses a gelling agent in the gasoline to extend fuel burn time.

IGNITION

Choose the best spot to light the pile and stick with it until it ignites. If you move your ignition device around the pile and burn up all the fine fuel, you may make it impossible to light.

The best place to light is under the paper or plastic cover you placed earlier. If you didn't place a cover, look for an area protected by the upper part of the pile — ideally, a flat face of the pile where heat from your ignition can start to preheat the fuel above it.

If you want the pile to burn faster and aren't concerned about fire intensity, light it from the upwind or downhill side. However, if you want to temper fire behavior, lighting from the downwind or uphill side will allow the fire to back into the pile and burn with slightly less intensity. If there is no slope and the wind is low, your ignition spot won't matter.

The initial smoke you see will consist of steam leaving the pile. Don't be fooled; the pile hasn't started burning yet, it's just getting ready. You're looking for sustained crackling noises and billowing smoke. When you have achieved this at your first starting spot, start lighting another spot until you're sure the pile will continue to burn.

Recommended video: Combustion Efficiency in Winter Piles, https://www.youtube.com/watch?v=FCHxTqSAXzs

After the pile has burned down, you may want to toss the sticks on the edge into the pile to achieve more complete combustion. This is a labor-intensive and messy process, but it may produce the results you want by removing unwanted biomass. For large machine piles, you may want to have heavy equipment present during burning to re-pile as fire consumes the fuel.

SUPPRESSION EQUIPMENT AND PROPER CLOTHING

At a minimum, stow some buckets of water nearby and a few hand tools, such as rakes, shovels and hoes (Figure 9.7). Tools can help you create control lines before ignition, put out any spots or slop-overs that occur while the pile is burning and help put the pile out when it is done. For larger machine piles, heavy equipment can help place line around piles and add organic material.

While agency personnel might wear full wildland firefighter personal protective gear such as Nomex, it is not necessary. However, it is important that those present

wear 100% natural-fiber clothing (cotton, wool) and avoid synthetic materials. In addition, use eye protection, leather boots and leather gloves. It is also highly recommended to wear a hard hat or helmet if you are working in a forested area.

MONITORING

Piles can burn for days, weeks or months, depending on their size and the material inside. Many wildfires have started from "hold-overs" or piles that were ignited the winter before and then reignited later in spring or summer heat. Heat from these sleeping piles can linger in stumps and root systems, even if it appears that no more heat is rising from the pile. You can use a piece of rebar to probe deep into the pile's ash to feel for residual warmth. If there's concern about fire spreading, put in a control line around the pile and monitor it regularly. You can also bring water to extinguish the pile.

FIRE EFFECTS

Piles, especially large ones with many logs, can have a significant and long-term impact on the soil because the heat they generate alters its structure (Figure 9.8). However, the burned area can be more fertile and face less competition from other plants. After there is no more heat from the pile, long after it has burned down and cooled, you can spread some of the charred material outside the piled area to share the nutrients and place some of the unburned soil or plant material back over the pile to speed up the recovery of the pile scar.



Figure 9.7 A–B. Keep hand tools and water on-site and in place until the piles are cold. Credit: Carrie Berger, © Oregon State University (A) and Heather Heward (B)



Figure 9.8. Large piles with many logs can have a long-term impact on the soil. Credit: John Punches, © Oregon State University (left) and Heather Heward (right)

What to do when a pile escapes

You are responsible for the fire you light. Landowners and operators may assume liability for damage to others' property and for fire suppression expenses, depending on the circumstances. Whenever you use fire, no matter how wet it is outside, you should have a safety plan in place that contains phone numbers for people or groups you can call for help if needed.

If a pile is burning too intensely and begins to slop over or creep, but isn't threatening anything, call in additional help to control the edges. This is why having water nearby is essential.

However, if the fire is spreading and you lack the resources to control it, **call 911**; authorities will help direct resources your way. When firefighting resources arrive, they'll do their best to control the fire, and you may not be able to help directly.

It is essential to carefully prepare and choose a good day to burn.

How to avoid escaped piles

By intentionally planning your pile burn before the day you light it, you are more likely to avoid burning on a day that will lead to negative outcomes. Start small to gain confidence in pile burning. By working with others, you can pool your efforts and resources, leading to a collaborative learning experience. Diligently monitor the pile until you have confirmed that it is out cold.



Figure 9.9. Air curtain incinerators can be a good option to dispose of slash near smoke-sensitive areas. Credit: Micah Schmidt, © Oregon State University

Alternatives to traditional piles

- Some methods of pile construction, ignition and extinguishment promote the development of biochar. This includes stacking larger material on the bottom; lighting the finer fuels at the top and allowing the fire to burn down; and dousing the coals before they completely burn down.
- Air curtain burners offer an alternative to traditional pile burning. These devices may require heavy equipment to load material, but they significantly reduce smoke emissions and minimize soil disturbance. Some models are designed to produce biochar and can even generate usable energy, adding value to the fuel-reduction process.
- Brush piles will decompose over time. Before decomposition, they can provide habitat structure for wildlife, serving as "biodens."
- Scattering the debris disperses the fuels and reduces problems. This is especially true if prescribed broadcast burning in follow-up management.
- Grinding or mulching the brush pile is another alternative; however, it is much more expensive.

CHAPTER NOTES

GLOSSARY - BY CHAPTER

WEATHER

Atmospheric pressure systems: Patterns of high and low pressure that influence wind speed, direction and weather changes affecting fire behavior.

Atmospheric stability: Describes how air behaves when pushed upward; it affects smoke dispersion and fire behavior.

Cold front: Boundary where cold air replaces warm air, often bringing strong winds, low humidity and unstable air.

Dew point: The temperature at which air becomes saturated and moisture condenses, forming dew or frost.

Dry cold front: A cold front without precipitation that brings strong winds, low humidity and unstable conditions.

Fine dead fuel moisture: Moisture content in dead fuels less than ¼ inch in diameter. Fine dead fuel moisture is influenced by relative humidity and temperature and is critical for ignition.

Front: Boundary separating two air masses of different temperatures and humidity.

General winds: Large-scale winds caused by pressure differences and Earth's rotation, affecting broad regions.

Local winds: Small-scale winds influenced by terrain and temperature differences, such as upslope and downslope winds.

Mixing height: Height in the atmosphere where smoke mixes and disperses; higher mixing heights improve smoke dispersion.

Precipitation/drought index: Measure of dryness; drought increases fire intensity and risk.

Relative humidity: Percentage of moisture in the air compared to its maximum capacity at a given temperature.

Transport winds: Winds aloft that carry smoke away from the burn area; used to predict smoke dispersion.

Vapor pressure deficit: The difference between the amount of moisture in the air and the amount the air can hold at full saturation; high VPD means fuels dry out faster.

Ventilation index: Calculated by multiplying transport wind speed by mixing height; indicates smoke dispersal potential.

Warm front: Boundary where warm air replaces cold air, usually bringing clouds and precipitation.

Weather observations: On-site measurements of temperature, RH, wind speed and direction taken before and during burns.

Wind: Movement of air that affects fire spread and smoke transport; expressed by speed and direction.

FUEL

Aerial or canopy fuels: All live and dead vegetation in the forest canopy or above surface fuels, including branches, twigs, cones, snags, moss and high brush.

Canopy bulk density: Canopy bulk density is the mass of available canopy fuel per unit canopy volume.

Chemical content: Presence of volatile chemicals like oils, resins and waxes in plants that influence flammability.

Compactness: Degree to which fuels are packed together, affecting oxygen availability and combustion speed.

Dead fuels: Nonliving fuels whose moisture content changes rapidly with weather conditions.

Duff: Upper layer of organic matter in the soil profile that can smolder and produce smoke for long periods.

Fine dead fuel moisture: Moisture content of dead fuels smaller than 1/4 inch, critical for predicting fire behavior.

Fire behavior triangle: Describes the three key factors that determine how a wildfire spreads and behaves — fuels, weather and topography.

Fire combustion triangle: Refers to three essential elements in a prescribed fire — fuel, oxygen and heat.

Fuel loading: Amount of fuel present, expressed in tons per acre or visually estimated using photo guides.

Fuel type: Primary type of fuel carrying the fire, such as grass, shrub, timber litter, timber understory or slash.

Ground fuels: Combustible materials below the surface litter, including duff, roots, peat and sawdust.

Horizontal continuity: Extent of uninterrupted fuel distribution across an area, influencing fire spread.

Ladder fuels: Combustible materials providing vertical continuity between surface and canopy fuels.

Live fuels: Living plants whose moisture content varies by season and affects fire intensity.

Moisture content: The amount of water in fuels, influencing ignition and combustion; varies between live and dead fuels.

Quantity (fuel loading): Total or available fuel amount that influences fire behavior and smoke production.

Size and shape: Physical dimensions of fuels affecting drying rate and combustion speed.

Surface fuels: Combustible materials lying on or near the ground surface, including litter, branches and low vegetation.

Time-lag class: Refers to how readily a fuel will gain or lose moisture, relative to its size in a given environment. For example, a one-hour fuel will react more quickly to changes in the environment than a 10-hour fuel.

Vertical arrangement: Continuity of fuels from ground to canopy, affecting crown fire potential.



FIRE BEHAVIOR

Backing fire: A fire that burns into the wind or down the slope, moving slowly with shorter flame lengths.

Behave7: A fire behavior modeling system used to predict fire behavior under various conditions.

Blackline: A preburned strip along a control line that prevents new ignitions from crossing.

Crown fire: A fire that burns through the canopy of trees, often driven by ladder fuels and wind.

Flame depth: The width of the flaming front of a fire, indicating how long the fire will burn in one spot.

Flame height: The vertical height of flames, used to assess potential crown scorch and canopy involvement.

Flame length: The distance from the midpoint of the flame at the ground to the flame tip; indicates fire intensity.

Flanking fire: A fire that burns perpendicular to the wind or slope, moving sideways across the landscape.

Head fire: The fastest-moving and most intense part of a fire, burning with the wind or upslope.

Ignition pattern: The layout of ignitions on the ground, such as strip-head, dot or backing fire patterns.

Ignition technique: The method of applying fire within a chosen pattern, including spacing, stagger and speed.

Ignition tools: Devices used to ignite fuels, such as drip torches or propane burners.

Interagency Fuels Treatment Decision Support System: A web-based application for modeling fire behavior and planning fuel treatments.

Mixing height: The height in the atmosphere where smoke and air mix, affecting smoke dispersion and fire behavior.

Rate of spread: The speed at which fire moves across the landscape, commonly measured in chains per hour.

Spotting: The process where embers are lofted by wind and ignite new fires outside the intended burn area.

Strip head fire: An ignition pattern using parallel strips of fire to increase intensity and speed of burning.

Test fire: A small ignition used to evaluate fire behavior and smoke dispersion before full-scale burning.

Topography: The shape of the land, including slope and aspect, which influences fire spread and intensity.



SMOKE MANAGEMENT

Air quality: Measurement of pollutants in the air, including particulate matter (PM), ozone and other gases; smoke from prescribed fires can affect air quality.

Atmospheric stability: Describes how air behaves when pushed upward; it affects smoke dispersion and fire behavior.

Basic Smoke Management Practices: Recommended actions to reduce smoke production, transport smoke away from sensitive areas and disperse smoke.

BlueSky Playground: Advanced smoke modeling tool that predicts cumulative smoke impacts and dispersion for prescribed burns.

Combustion stages: Four stages of burning — preignition, flaming, smoldering and glowing. Smoke production varies by stage.

Firing technique: Ignition pattern used during a burn; influences fire intensity and smoke production.

Fuel characteristics: Type, size, amount and moisture content of fuels; determines smoke amount and duration.

Mixing height: Height in the atmosphere where smoke mixes and disperses; higher mixing heights improve smoke dispersion.

Mop-up: Postburn process of extinguishing smoldering fuels to reduce residual smoke and prevent escapes.

Particulate matter (PM): Tiny solid particles in smoke that pose health risks; PM2.5 and PM10 are common pollutants.

Relative humidity: Amount of moisture in the air; affects fuel moisture and smoke production.

Simple Smoke Screening Tool: A basic tool for predicting smoke movement and identifying sensitive areas.

Smoke: The tiny particles and trace gases suspended in the air when a fuel is burned.

Smoke Sensitive Areas: Locations vulnerable to smoke impacts, such as schools, hospitals and highways.

Superfog: Dense mixture of smoke and fog that severely reduces visibility and creates hazardous conditions.

Temperature inversion: An atmospheric condition where warm air traps cooler air and smoke near the ground, reducing dispersion.

Ventilation index: Indicator of smoke dispersal potential, calculated by multiplying transport wind speed by mixing height.

Wind: Movement of air that affects smoke transport and dispersion; consistent winds improve predictability.

GETTING STARTED

Cultural burning: Traditional Indigenous practice of using fire to sustain food systems, materials, medicines and land health.

Fire regime: Patterns of fire frequency, severity and size over time in a given ecosystem.

Goals: Broad, long-term statements about desired conditions of an area.

Objectives: Specific, measurable conditions needed to achieve goals; often developed using the SMART framework.

Prescribed burn association: Community-based group that collaborates to make prescribed burning safer and more accessible.

Prescribed fire: Controlled use of fire applied under specified conditions to achieve land management objectives.

SMART objectives: Objectives that are specific, measurable, achievable, relevant and time-bound.

Wildfire: An unplanned fire that can cause unwanted effects.

PLANNING THE BURN

Burn plan: A formal document outlining objectives, prescription, resources and procedures for a prescribed fire.

Canopy characteristics: Cover, height, diameter, and species influencing fire behavior and tree survival.

Certified Burn Manager: A credentialed individual recognized by state programs to lead burns.

Communication plan: Methods and equipment for on-site and off-site coordination during the burn.

Contingency plan: Strategy and resources for controlling fire if it escapes primary control lines.

Control lines: Barriers such as roads, trails, or mineral-soil strips used to contain fire spread.

Critical holding points: Areas prone to escape or requiring extra protection during the burn.

Emergency plan: Protocol for life safety and wildfire declaration triggers.

Eye-level winds: Winds observed at ground level, critical for predicting fire behavior.

Fine dead fuel moisture: Moisture content in small fuels (1-hour fuels) affecting ignition and spread.

Fuel continuity: Horizontal and vertical arrangement of fuels affecting fire spread.

Fuel loading: Quantity of fuel, often expressed in tons per acre.

Fuel type: Classification of fuels such as grass, shrubs, timber or slash.

Hazards: Physical dangers such as snags, wires or debris that pose risks during the burn.

Ignition plan: Strategy for applying fire, including devices, patterns and timing.

Ladder fuels: Vegetation that allows fire to climb from surface to canopy.

Liability: Legal responsibility for damages or suppression costs if fire escapes.

Live fuel moisture: Moisture in living vegetation influencing fire intensity and canopy involvement.

Mixing height: Vertical distance available for smoke dispersion.

PACE model: Planning framework — primary, alternate, contingency and emergency plans for burn operations.

Permits: Official approvals required before conducting a prescribed burn.

Prescription: A defined set of conditions (temperature, RH, fuel moisture, wind) under which the burn can be safely conducted.

Resources: Personnel and equipment needed for ignition, holding and contingency actions.

Smoke-sensitive Areas: Locations vulnerable to smoke impacts, such as airports, highways and schools.

Surface winds: Winds measured at 20 feet above ground, typically reported in forecasts.

Topography: Landform features (slope, aspect, valleys, ridges) affecting wind and fire spread.

Transport winds: Winds aloft that influence smoke dispersion.

Values at risk: Assets near or within the burn unit that need protection (structures, habitat, utilities).

Vicinity map: Map showing the burn unit relative to major landmarks for orientation and planning.

CONDUCTING THE BURN

After action review: Short debrief to capture lessons, surprises and improvements for future burns.

Backing fire: Fire that burns against the wind or downslope, spreading slowly with shorter flame lengths.

Blackline: The already burned strip along a control line that prevents new ignitions from crossing.

Burn objectives: Desired outcomes of the prescribed burn, such as fuel reduction or ecological goals.

Burn plan or prescription: Written plan specifying objectives, acceptable conditions, tactics and contingency actions.

Cold capping: Spraying lots of water that cools the surface but leaves lower layers smoldering.

Control lines (firelines/firebreaks): Prepared boundaries intended to stop fire spread.

Cup trench: Control line design with a downhill soil berm to catch rolling debris and embers on slopes.

Dot firing: Spaced point ignitions to reduce overall intensity and manage heat under tree canopies.

Drip torch: Standard hand ignition device used for firing operations.

Dry mop-up: Mixing burning organics into moist mineral soil to remove heat without applying additional water.

Flanking fire: Ignition parallel to the wind direction or along the unit's flanks. Generally results in fire behavior less intense than heading fire but more intense than backing fire.

Go/no-go checklist: Pre-ignition decision aid confirming readiness of people, permits and conditions.

Heading fire: Fire that burns with the wind or upslope, typically with a high rate of spread and longer flames.

Holding: Crew operations that patrol control lines and cool or extinguish any fire that threatens to cross.

Incident Action Plan: Shortened version of the burn plan highlighting critical info for operations.

Kestrel or handheld weather meter: Portable instrument for on-site wind, temperature and RH measurements.

Mop-up: Systematic extinguishing and cooling of smoldering material and hot spots after ignition.

Patrol: Repeated postburn checks for lingering heat or smoke, especially after weather changes.

Permits: Official approvals tied to the day and conditions. If you don't have valid permits, do not burn.

Personal protective equipment: Required clothing and gear to protect personnel from heat and smoke.

Probability of ignition: Calculated indicator used to anticipate fire start or spread under current conditions.

Slop-over: Fire that crosses a control line immediately adjacent to the unit.

Smoke management: Planning and actions to predict dispersion and minimize production impacts.

Sneaky fire: Smoldering combustion that follows roots, peat or duff beneath a line.

Spot fire: Unintended ignition outside the unit perimeter caused by lofted embers.

Strip headfiring: Sequential parallel strips of heading fire inside the unit to manage intensity.

Test fire: Small ignition in representative fuels in an easily controlled area used to validate behavior and smoke dispersion.

Wet mop-up: Applying water while exposing and mixing burning materials to fully extinguish them.

EVALUATING THE BURN

Bark char: Blackening or darkening of tree bark caused by heat or flames; may indicate depth of heat penetration.

Consumption: The proportion of fuels burned to ash or visibly removed.

Crown scorch: Browning of needles or leaves caused by heat but not consumed by flames; often visible three to five days after the burn.

First-order fire effects: Direct effects of fire that are visible immediately following the burn or within the first several days after burning.

Second-order fire effects: Indirect or longer-term effects resulting from first-order changes, including regrowth, invasive species response, soil changes and delayed mortality.

PILE BURNING

Air curtain burner: A device that uses a high-velocity air curtain over a burn box to reduce smoke and particulate emissions while consuming woody debris; some models produce biochar and usable energy.

Biochar: Charred biomass produced by limiting oxygen during combustion; can be created from piles by dousing coals before complete consumption to retain carbon and improve soil.

Control line: A scraped or cleared barrier around a pile that interrupts fire spread into surrounding fuels; installed before ignition and patrolled during burning.

Flame length (in the context of a pile): Expected flame height from a burning pile; can reach up to three times the pile's height, with radiant heat extending roughly three times the pile's width.

Fuel moisture (in the context of a pile): Moisture content of piled material and adjacent fuels; piles are lit when surrounding fuels are too wet to carry fire, while a dry pocket inside the pile is needed for ignition.

Hold-over: Residual heat in piles, stumps or roots that can persist for weeks to months and rekindle later, potentially causing escaped fires if not fully extinguished.

Ignition devices

- **Drip torch:** Handheld device that pours igniting fuel (diesel/gas mix); effective for dry piles, with standard mix ratios adjusted for ambient temperature.
- **Propane torch:** High-heat torch suitable for wetter piles; provides sustained flame and convective heating to establish ignition.
- **Terra Torch/FireGel:** Pressurized gelled-fuel system that projects burning gel to rapidly heat and ignite large or wet piles.

Ignition spot: The protected area (often under the cover) selected to begin lighting; kept in one place until sustained combustion is observed to avoid consuming fine fuels prematurely.

Inversion: A stable atmospheric layer (often at night) that traps smoke near the surface; avoid pile burning under inversions to reduce air-quality impacts.

Monitoring: Regular checks during and after burning to detect residual heat and creep; includes probing ash with rebar to feel for warmth and confirming piles are out cold.

Permitting and notification: Agency approvals and neighbor notifications required before burning; coordinated with state forestry and air-quality authorities.

Pile construction method: Building piles with fine fuels at the base, mixed fuel sizes and a tall, narrow form to promote upward heat transfer and protect lower fuels from moisture.

Pile scar: Area of soil and ash left after pile consumption; can be rehabilitated by redistributing char and covering with unburned soil or plant material.

Slop-over: Fire crossing the control line adjacent to a pile due to radiant heat or rolling material; requires immediate holding actions with tools and water.

Smoke management: Operational steps to minimize smoke impacts — avoid air-quality advisories, inversions, nighttime burns and low winds; use ventilation and drying strategies.

Suppression equipment: Basic tools staged at piles (buckets, rakes, shovels, hoes; optional heavy equipment) to construct line, cool hotspots and extinguish piles.

Test pile: A representative pile ignited first to assess ignition ease, combustion behavior and smoke; it informs whether to proceed with additional piles.

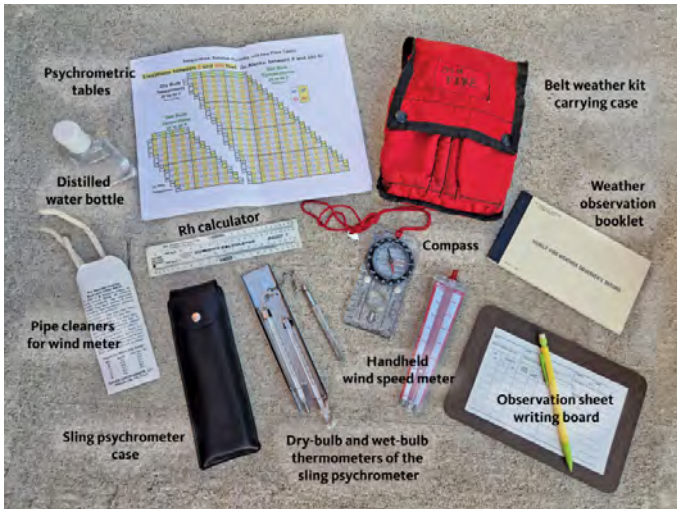
Ventilation rate: Indicator of smoke dispersion combining mixing height and transport winds; select burn periods when ventilation is highest to lift and move smoke away.

Wildland PPE — natural fibers: Personal clothing guidance for pile burns: cotton or wool layers; avoid synthetics; use eye protection, leather boots and gloves, and wildland helmets.

APPENDIX — Resources, tools and apps

WEATHER

Belt weather kit



Source: National Wildfire Coordinating Group

Kestrel Weather Meter

- https://kestrelinstruments.com
- **Basic Kestrels** measure temperature, relative humidity and wind speed. More advanced models include a variety of other measurements and can also calculate fine dead fuel moisture and probability of ignition. Kestrels are available for purchase online, and those used specifically for fire include "FW" (fire weather) in their description. Calibrate your Kestrel regularly using the provided manual and ensure the time, date and other settings are correctly set if your Kestrel calculates fine dead fuel moisture and probability of ignition.
- The **Kestrel drop** or similar weather sensors can gather weather data remotely and help track weather patterns over time.



Basic Kestrels



Kestrel drop

National Weather Service — Fire Weather Forecast

- https://www.weather.gov/fire
- Zone forecasts reporting CWR, RH recovery, mixing height, transport winds and ventilation index.

National Weather Service — Fire Weather Dashboard

- https://www.weather.gov/dlh/fwd
- Interactive dashboard for accessing fire weather information.

National Weather Service – Spot Forecast

- https://spot.weather.gov
- Burn-day, site-specific forecast requested through agencies.

RAWS (Remote Automated Weather Stations)

- https://raws.nifc.gov
- Network of stations providing hourly weather parameters and historical data.

Wildland Toolkit mobile application

- http://peakviewsoftware.com/wildlandtoolkit.html
- This phone application is produced by Peakview Software and can be found wherever you get your phone apps. It calculates relative humidity, dew point, fine dead fuel moisture, probability of ignition and vapor pressure deficit based on standard on-site weather observations. The app also includes the Incident Pocket Response Guide and other helpful materials. The cross-cutting app helps when conducting the burn, monitoring weather and fuels, and predicting potential fire behavior.

Fire Weather Alert System

- https://research.fs.usda.gov/firelab/products/dataandtools/fire-weather-alert-system
- The Fire Weather Alert System monitors nearby weather observations and forecasts that can help identify burn windows and plan upcoming burns. It also provides map-based access to fire-specific weather information.

Fire Danger Forecast from the Wildland Fire Assessment System

- https://www.wfas.net
- The system provides views of fire weather and fire potential over different geographic areas and timeframes (24 hours to 30 days). Fuel moisture and fire danger classes are derived using the National Fire Danger Rating System, drought indices, atmospheric stability and satellite-derived vegetation conditions.

Precipitation/drought index — U.S. Drought Monitor

- https://droughtmonitor.unl.edu
- Drought conditions impact vegetation, soils and water availability, which are important factors to consider when planning a prescribed burn.

Windy app

- https://windy.app
- Popular app offering multiple wind models for local wind monitoring.



FUEL

Photoload sampling technique

- https://www.fs.usda.gov/rm/pubs/rmrs_gtr190.pdf
- A visual method to estimate fuel loading in small plots using reference photographs.

Fuel Characteristics Classification System

- https://depts.washington.edu/fft/webtool
- Library of more than 500 fuelbeds describing fuel strata; supports fire and smoke modeling.

Fuels and Fire Tool

- https://depts.washington.edu/fft/webtool
- Web tool that uses FCCS fuelbeds to model fire behavior and smoke emissions.

Fuels Data app

- https://apps.apple.com/us/app/fuels-data/id6446859468
- Designed for wildland management practitioners tasked with collecting surface fuels measurements in the field

Brown's Transects (planar intercept method)

- https://research.fs.usda.gov/treesearch/28647
- Sampling method to measure downed woody fuels along transect lines.

SIMPLE Transect (Oregon Department of Forestry)

- https://www.oregon.gov/odf/fire/pages/burn.aspx *under the "fuel load estimating tools" dropdown menu.*

Modified Brown's transect for estimating fuel loading; paired with an online calculator.

SIMPLE TRANSECT TALLY SHEET																				
Date:						**Unit Name:**														**Name:**
Area/Forest:						**Registration#:**														**Photo Series:**
Unit/District:						**Aspect:**														**Fuel Model:**
Acres:						**Elevation:**														**Other:**
			6'	6'	10'	37'														**Special notes:**
TRANSECT	**SLOPE**	**TREE SPECIES**	**0"–.25" (1 HR.)**	**.25"–1" (10 HR.)**	**1"–3" (100 HR.)**	**LOGS, SOUND >3"** (Diameter & Species)		**LOGS, ROTTEN >3"** (Diameter & Species)		**SHRUB** (Height & Species)	**SHRUB GROUND COVER%**	**GRASS/FORBES** (Height & Species)	**GRASS/HERBS GROUND COVER**	**LITTER DEPTH**	**DUFF DEPTH**	**STUMP, SOUND** (Species, Diameter, Height)		**STUMP, ROTTEN** (Species, Diameter, Height)		
1						1	2	1	2	1	1	1	1	1	1	1	2	1	2	*(Ave. Log Dia. Sound) (Ave. Log Dia. Rot) (Ave. Stump Dia. @ Hght. Sound) (Ave. Stump Dia. @ Hght. Rot)*

An easy way to estimate fine dead fuel moisture is to use the fine dead fuel moisture tables found in the *Incident Response Pocket Guide* or online. Take on-site readings for temperature and relative humidity using a Kestrel or belt weather kit to complete the required calculations. These tables will provide a close estimate of the fine dead fuel moisture in your burn unit that is directly based on relative humidity and temperature measured on your site and then adjusted based on the month, time of day, amount of shading, and slope. Ensure weather measurements are taken in the shade over representative fuels before using the tables to calculate fine dead fuel moisture. Once you have fine dead fuel moisture, you can also calculate the Probability of Ignition. This is expressed as a percentage and indicates the likelihood that an ember will start a fire if it lands on receptive fuels. Find Probability of Ignition tables in your *Incident Pocket Response Guide*.

Protimeters (sometimes referred to as moisture meters) are battery-powered devices used in the field to estimate dead fuel moisture. Protimeters contain two sharp pins that are inserted into pieces of wood. They use electrical resistance to measure the moisture content.

Protimeters are generally used for 10-hour fuels and larger, as one-hour fuels are challenging to get the pins in. To measure moisture in logs and larger branches, cut out a cross section, so that you can insert the pins into the interior of the wood, as moisture will often vary as you get deeper into the wood.



FIRE BEHAVIOR

Incident Response Pocket Guide

- https://www.nwcg.gov/publications/461
- Reference tables to calculate fine dead fuel moisture and probability of ignition.

Fire Behavior Field Reference Guide

- https://www.nwcg.gov/publications/pms437/fire-behavior-field-reference-guide-pms-437

SMOKE MANAGEMENT

AirNow

- https://www.airnow.gov/
- Check the Air Quality Index forecast before burning. Avoid burning during air quality alerts. Includes an interactive map to see air quality in surrounding areas.

Simple Smoke Screening Tool

- https://weather.fdacs.gov/Simple-Smoke/index.html
- This tool allows burners to make quick smoke predictions, essentially making a digital representation of the hand-drawn version. It is displayed on a state of Florida website; however, the tool can be used anywhere, as it is a digital version of using a map to show the direction of smoke dispersion.

BlueSky Playground

- https://info.airfire.org/playground
- BlueSky is a modeling framework that integrates different tools to predict cumulative smoke impacts and forecast ground concentration of smoke. This tool is better suited for more complex burns than the Simple Smoke Screening Tool. The framework progresses through a series of tools and will help you estimate fuel loading, consumption, emissions estimates, smoke trajectories, dispersion and more.
- BlueSky also includes an advanced smoke-screening option: Burns that are more likely to cause smoke impacts on communities may require more advanced smoke modeling. A smoke model is particularly beneficial if known impacts are possible within 10 to 15 miles downwind of the burn. These models combine fire information with meteorological information to predict where smoke may be transported.

Purple air sensors

- https://www2.purpleair.com/
- These and other similar tools can monitor potential impacts to air quality in areas where you are concerned about smoke impacts.

GETTING STARTED

Fire Effects Information System

- https://research.fs.usda.gov/feis
- The Fire Effects Information System is an online collection of reviews of the scientific literature about fire effects on plants and animals and about fire regimes of plant communities in the United States.

PLANNING THE BURN

CalTopo:

- https://caltopo.com/about/
- An online mapping tool that helps users create simple, easy-to-read maps of their property and burn units. It can be used to mark burn boundaries, roads, water sources, fences, buildings and other important features, making it easier to plan, communicate and safely carry out a prescribed burn.

Guidebook to Fire Behavior Assessment

- https://www.nwcg.gov/publications/pms437-1
- This National Wildfire Coordinating Group publication has many helpful resources for assessing the wildland fire environment. The information is geared toward wildfire but can be useful for prescribed fire as well. There is a section for Fire Behavior Lookup Tables where you can pick a fuel model and get estimated fire behavior based on winds and fuel moisture.

Behave7 Fire Modeling System

- https://www.frames.gov/behave/home
- Behave7 is a program you can download and use offline. You use fire behavior fuel models to represent your fuel conditions and enter a variety of conditions to compare the possible fire behavior. This includes surface fire modeling, spotting potential and distance, and torching and crowning potential.

Interagency Fuels Treatment Decision Support System

- https://iftdss.firenet.gov/iftdss2
- A web-based application for modeling fire behavior and planning fuel treatments.

OnX

- https://www.onxmaps.com
- Mobile mapping app for property boundaries and field navigation.

Avenza Maps

- https://www.avenza.com
- Mobile app for georeferenced maps and field navigation.

Google Maps

- https://maps.google.com
- General mapping tool to create/share unit and vicinity maps.

EVALUATING THE BURN

Post-fire Assessment of Tree Status and Marking Guidelines for Conifers in Oregon and Washington

- https://www.fs.usda.gov/rm/pubs_journals/2021/rmrs_2021_hood_s003.pdf
- A great how-to resource for post-fire assessment of trees.

Tell us what you think!

We hope this guidebook helped you learn more about prescribed fire. Please take a few minutes to complete our survey and share your feedback. Your comments will help us improve this resource and inform future educational efforts.

https://beav.es/PNW_RX_Guidebook_Survey





