Module 2: Principles of Wildland Fire Behavior

Topic 1: Introduction

Principles of wildland fire behavior introduction

Narration Script: Preparation is a key component in effective fire fighting—and it's more than your gear and equipment that need attention—your mental preparation is just as important. Before setting out, you should be fully briefed on the types of terrain you'll encounter, including any obstacles and helpful barriers. You'll need detailed weather reports describing both current conditions and expected forecasts. You'll also want to study the surrounding area to gain a firm understanding of existing fuel types. Once you have the lay of the land, (and air for that matter,) you will have a strong grasp on how each of these factors can affect the fire's behavior. Conditions can change quickly, so stay sharp and stay informed.

Module introduction

As your experience on the *fireline* **grows, you'll realize that it doesn't take much for a** *wildland fire* **to grow out of control, especially if factors influencing the fire go undetected. Like links in a chain, individual factors influencing** *fire behavior* **acquire strength when "working" together. As you'll discover,** *topography***,** *fuel,* **and** *weather* **are the main culprits to watch. Your grasp of environmental factors will help you manage the fire and reduce potential property loss and more important—maintain the safety of you and the** *crew***.**

Sit back and take a good hold on your mouse, and actively dive into this module as it introduces you to factors influencing fire behavior including:

- **Topography**
- **Fuels**
- **Weather**

Narration Script: "Weather makes firefighters work harder: Dry fuel—Eight blazes in Oregon and Washington continue to burn, and lightning may bring more!" This headline was noted in a recent edition of the The Oregonian Newspaper. This typical wildfire headline illustrates the impact that fuel conditions and weather can have on any wildland fire. If you become skilled in identifying and evaluating conditions and recognizing how topography, fuels, and the weather can affect fire behavior, you will be a key player in successful wildland fire management efforts. This module will deepen your understanding of wildland fire behavior and the factors that can affect it.

Topic 2: Topography

Topography introduction

You'd be hard pressed to find a more physically demanding job than wildland firefighter. But as you'll learn very quickly in your career, part of the job description is to be a keen observer. With experience, training, and study, you'll begin to understand the role of the many factors affecting *fire behavior.*

In this topic, we spotlight *topography's* **effect on a fire and specifically discuss the following topographic elements including:**

- *Aspect*
- *Slope*
- **Canyons and terrain**
- *Barriers*

Keep reading to get the lay of the land of this topic.

Narration Script: As your knowledge of wildland fire fighting increases with long hours in the field and even longer ones hitting the books—you'll come to realize that your mind is as much a tool in wildfire management as your muscles. A fire's behavior isn't completely predictable, but there are well-studied factors affecting a fire's behavior you will learn to identify that will give you one heck of an indication of how to approach the situation. In this topic, we turn your attention to topography and how the so-called "lay of the land" can help you understand how a fire behaves.

Topography

Firefighters wear a lot of "hats." One of them is detective. Let's get down and dirty and talk about the clues the terrain provides.

You can lump terms like scenery, landscape, geography, and countryside under the umbrella of topography. No matter the name, the general features of the earth's surface have a tremendous impact on the way a wildland *fire behaves***.**

Local topography affects a fire's:

- *Intensity*
- *Rate* **and the direction of spread**

Narration Script: Topography is essentially the terrain of the land but includes man-made structures. "Topography" or "Terrain" includes the shape of the landscape, its elevation, steepness, the slope, and the direction that slopes face, which is known as the "aspect."

Topography can be friend or foe on the fireline. As you gain experience using topographic maps and compasses, you'll begin to read and interpret the landscape and how it can affect fire behavior. Topography is the third largest factor in wildland fire fighting, with fuels and weather leading the pack—but the good news is that topography is far more predictable than the wind!

Topography's influencing factors

Reading the landscape is another tool we'll touch on shortly—especially to uncover the dangers of *wind* **channeling elements in steep terrain. Before that, let's look into the fundamentals of topography.**

There are two influential topographic features you need to especially concern yourself with because of their influence on wildland fire behavior. They are:

- **Aspect**
- **Slope**

You will investigate each of these features in turn to learn more about their impact on wildland fires.

Aspect

A slope's aspect is the compass direction the slope faces. This includes:

- **North**
- **East**
- **West**
- **South**

The aspect of a slope determines the effect of the sun's heat on the slope's plants and trees, air temperature, and moisture retention of the soil. Solar *radiant* **heating can influence fire behavior by influencing** *fuel moisture* **and ignition points.**

Read the following to get to the point about slope faces.

North Facing Slopes

North facing slopes tend to have more shade. As a result, north facing slopes have heavier fuels, lower temperatures, higher humidity, and higher fuel moistures. A north facing aspect will have less fire activity than a south facing slope.

East Facing Slopes

Eastern and southeastern slope exposures have about equal solar heating as the sun moves across the sky from east to west. With sunrise, east facing slopes will have earlier heating, but also earlier cooling as the sun tracks across the sky.

West Facing Slopes

Similar to eastern and southeastern slopes, southwestern, and western slope exposures have about equal solar heating as the sun moves across the sky from east to west. West facing slopes will have later heating and cooling during the course of the day.

South Facing Slopes

In the Northern Hemisphere, the slopes facing south receive direct sun rays and become hotter than the slopes facing any other direction. The higher temperature on the southern exposures results in lower humidity, rapid loss of fuel and soil moisture, and drier, lighter flashy fuels such as grass. All of these things add together to make southern slopes more susceptible to fires than northern slopes.

Slope

Slope relates to the incline of any land mass—whether it's natural or built by human hands (like a reservoir or the sides of a dam). In the absence of winds, fires usually move faster uphill than downhill, so the steeper the slope, the faster a fire moves.

The increased rate of spread (ROS) is due to several factors:

- **Uphill side of a fire—Flames are closer to the** *fuel* **dehydrating, preheating, and igniting them sooner than they would if they were on level ground.**
- **Wind currents normally move uphill during the day and tend to push heat and flames toward new fuels.**
- **Upslope fires create a draft, increasing the ROS.**

<u>Narration Script: Slope steepness contributes to a fire's rate of spread. Fires usually travel uphill much faster than downhill. The flames of a fire on a slope can preheat, dehydrate, and ignite the fuels located uphill much faster than those downhill simply because of their closer proximity. The steeper the slope, the more preheating of fuels, and therefore, you've got a faster moving fire. On the other hand, a fire at the top of a slope is not able to preheat the downhill fuel and tends to burn slower.</u>

Downslope fire

Wildland fires tend to burn much faster upslope than on level ground because of preheated fuels. These same factors work against a fire when it burns from the top toward the bottom of a slope. So, when you have a fire at the top of a slope, building a *fireline* **just beyond a ridge will help you contain the advancing fire. Although fire doesn't usually move downhill quickly, one serious concern about fires burning down steep slopes is the possibility of burning material rolling downhill, which can ignite fuels below starting another fire.**

Having a fire above you and one below is the reason you'll have pre-planned *safety zones* and *escape routes*. Fighting fires on a steep slope demands your undivided attention.

<u>Narration Script: Usually, fires situated at the top of a slope don't have as much potential for rapid spread as fires moving upslope because there are fewer fuels to preheat. Building a fireline just beyond the ridge is a good way to contain the advancing fire. However, there are significant dangers when working on a slope like burning material such as logs, trees, or bushes rolling downhill. These materials can easily ignite fuels located further down the hill, making your pre-planned safety zones and escape routes an absolute must.</u>

Measuring slope

It's time to flashback to math class. Slope is measured in "rise over run," which is expressed as a percentage. The percentage of slope is based on the ratio of vertical rise to horizontal distance. To calculate a slope's percentage, follow these steps:

1. **Measure the amount of vertical elevation change**
2. **Then, divide that number by the horizontal distance**
3. **Finally, to change the final number into a percent, multiply by 100.**

Get some practice calculating the percentage of slope of nearby slopes or hills—or heck, you can even calculate the rise and run of a staircase. Without a topographic map or special tool like a clinometer to calculate the slope, you'll need the skills to do it yourself.

Narration Script: Let's take you back to math class. To find the percentage of slope, the amount of elevation change is divided by the horizontal distance and the result multiplied by 100. For example, a rise of 25 feet divided by a horizontal distance of 100 feet and then multiplied by 100 represents a 25 percent slope. As another example, a 45-degree slope rises 100 feet for every 100 feet of horizontal distance, so it is a 100 percent slope.

Knowledge Check 1

Multiple choice—check the box of the answer(s) you choose

Are you traveling uphill, or are you on the downhill slide?

Identify THREE correct statements about fire behavior in relation to slope and aspect.

- ☐ **Escape and safety zones are not required for firelines on ridges.**
- ☐ **Downhill fires are usually much faster than uphill fires.**
- ☐ **Upslope fires can increase the rate of fire spread.**
- ☐ **Fires moving downhill increase rapidly.**
- ☐ **Upslope fires can cause burning debris to roll downhill.**
- ☐ **South facing slopes are more susceptible to fires than other aspects.**

The correct answers are upslope fires can increase the rate of fire spread, upslope fires can cause burning debris to roll downhill, and south facing slopes are more susceptible to fires than other aspects.

Chutes and saddles

Topographic elements can be like a roadmap pointing out the path of a fire's direction, and they can also act as warning signs for you and the crew. Some landscape features have played a significant role in past firefighter tragedies. You can count chutes and *saddles* **among them.**

A *chute* is a steep V-shaped drainage, and a *saddle* is a common name for the depression between two adjacent hilltops. Chutes and saddles can:

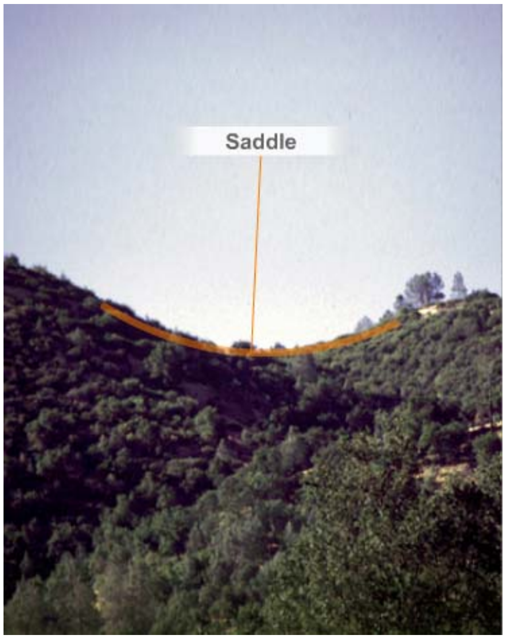
- **Drastically accelerate fires**
- **Alter the flow of winds causing erratic fire behavior**
- **Change the rate and direction of spread by acting as** *chimneys*

Warning

Even seemingly insignificant chutes and saddles, and those concealed by vegetation, have caused firefighter injuries and deaths.

Narration Script: A "chute" is a steep V-shaped drainage area that can easily channel smoke and fire upward at a rapid rate. A "saddle" is a common name for the depression between two neighboring hilltops. Both topographic features can drastically alter a fire's behavior—and NOT in a good way.

Slow-burning fires in wide canyons can blow up as they enter a chute or saddle. Chutes and saddles can also alter the flow of surface winds and produce erratic fire behavior. Even in the absence of wind, these formations can change a fire's rate and direction of spread by acting as chimneys and literally propelling the fire up as if through a stove pipe.



Caption: An example of a saddle.

Wind channeling

Wind channeling is a direct result of natural features like chutes and saddles. Like wind, *convected* **air and superheated fire gasses take the path of least resistance. Chutes and saddles as well as narrow canyons suddenly act like chimneys. You should especially look for deep canyons. They can burn out rapidly because the radiant heat and fire embers generated by a fire on one side tend to ignite the other.**

There are three different types of canyons you should be on the lookout for. They are:

- **Box canyons**
- **Narrow canyons**
- **Wide canyons**

Read the following to learn more about the impact of each type of canyon on wildland fires.

Box Canyons

Fires starting near the base of box canyons and narrow canyons may react similar to a fire in a wood burning stove or fireplace. Air will be drawn in from the canyon bottom creating very strong upslope drafts. These upslope drafts create rapid fire spread up the canyon, also referred to as the chimney effect. This effect can result in extreme fire behavior and can be very dangerous.

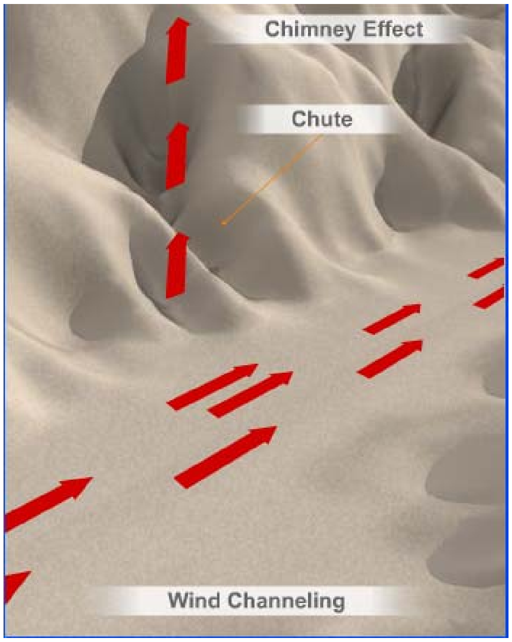
Narrow Canyons

Fire in a steep, narrow canyon can easily spread to fuels on the opposite side by radiation and spotting. You can expect wind eddies and strong upslope air movement at sharp bends in the canyon.

Wide Canyons

The direction, or orientation, of a canyon can alter the prevailing wind direction. Cross-canyon spotting of fires is not common except in high winds. Strong differences in fire behavior will occur on north- and south-facing aspects.

Narration Script: Normal valley winds travel through crevices in a fairly predictable fashion, until the wind encounters a steep crevice or chute, and dramatically increases. This crevice allows heat to rise rapidly, and a chimney effect is created when heated air rises rapidly as it would in a flue pipe. Canyons pose another danger. Narrow canyons can burn rapidly when heat and embers jump from one side of the canyon to the other.



Caption: An example of wind channeling and the chimney effect.

Ridges

Fire burning along lateral ridges may change direction when they reach a point where the ridge drops off into a canyon. This change of direction is caused by the flow of air in the canyon. As the air drops in elevation, the atmospheric pressure increases, which causes the air to compress and heat. The resulting winds can create poor conditions for wildland fire *control***.**

Narration Script: Terrain features can result in different types of winds, having a strong effect on fire behavior. For example, think about “Chinook,” “Santa Ana,” and “North” winds. They are considered gravity winds and contribute to rapid wildland fire spread. These winds result from air being forced over mountain ridges by convection or high barometric pressure. The air then cascades downslope as gravity winds.

Knowledge Check 2

Matching—select the match you choose from the pull down list

Canyons can affect how a fire spreads and behaves.

Match each type of canyon with that canyon's specific effect on fire.

Box canyons	Cross-canyon spotting of fires is not common except in high winds.
Narrow canyons	Cross-canyon spotting of fires is not common except in high winds.
Wide canyons	Cross-canyon spotting of fires is not common except in high winds.

The correct matches are as follows:
Box canyons: The creation of strong upslope drafts results in extreme fire behavior.
Narrow canyons: Fire can easily spread to fuels on the opposite side by radiation and spotting.
Wide canyons: Cross-canyon spotting of fires is not common except in high winds.

Elevation

It is time to elevate your mind. Elevation is another topographic factor influencing environmental conditions and *fuel loads***. Elevation is the height of the terrain above mean sea level (ASL), usually expressed in feet or meters. Because of higher temperatures, fuels at lower elevations dry out earlier in the year than those at higher elevations. Additionally, in extremely high elevations, there may be no fuel at all.**

Elevation can also affect fire behavior in several other ways including:

- **The amount of** *precipitation* **received**
- **Wind exposure and its relationship to the surrounding terrain**

Narration Script: Fires behave differently depending on elevation in large part because of the variability of fuels as elevation increases. If you have ever hiked or driven in mountainous areas, you may have noticed thick brushes and lush forests at the beginning of your trip and scattered trees and perhaps barren rock fields as you rose up the mountainside. So, fires at lower elevations often burn faster due to a larger supply of dry fuels. And conversely, at elevations above tree line, there is often little fuel to burn.

Barriers and fire behavior

A barrier can be a good friend to have on the fireline. A barrier can be defined as any obstruction to the spread of fire, typically an area or strip lacking any flammable fuel. Get familiar with natural and man-made barriers.

Natural barriers include:

- **Rivers**
- **Lakes**

- **Rock outcroppings or slides**
- **Burned areas**
- **Swamps**

Fuels having high moisture contents do not burn as well as others in the same area.

Man-made barriers include:
- **Roads**
- **Highways**
- **Reservoirs**
- **Fireline constructed by fire resources**

When fuels are separated by natural or man-made barriers, radiant heat may not be sufficient to preheat or ignite the surrounding fuels. However, wind may offset the benefits of interrupted *fuel continuity* by accelerating radiant heat transfer.

Narration Script: Barriers can make your job as a firefighter a whole lot easier. Both natural and man-made barriers can help make up their own control lines and act as staging areas, safety zones, or escape routes.

Topic conclusion

You should now understand just how many variables experienced firefighters must take into consideration when predicting and evaluating fire behavior. We covered how different topographical elements affect a fire, specifically:
- **Aspect**
- **Slope**
- **Canyons and terrain**
- **Barriers**

Understanding topography conditions and their effect on a wildfire will let you fight the fire aggressively, stay safe, and assist in predicting the fire's behavior.

Narration Script: This topic took you on a tour of the impact of topography on fire behavior. Now it's up to you to keep an eye on the terrain around your jurisdiction and digest the factors driving fire activity.

Topic 3: Fuels

Fuels Introduction

As a Firefighter Type 2 (FFT2), your responsibilities include wildland fire fighting and monitoring your personal safety. Your understanding of the *combustion* **process and how it functions with the variety of** *fuels* **in a wildland environment will help you with those responsibilities.**

If you've gone through the topics of this module in order, you already know the ins and outs of the combustion process in the wildland and *wildland/urban interface* **environments. This topic takes the process a step further and describes how wildland fuels affect the combustion process and fire behavior. This basic knowledge will keep you safe in the wildland fight.**

Narration Script: Making the grade as a Firefighter Type 2 carries the responsibility for your personal safety and also for being prepared with the knowledge of how wildland fires behave. Your understanding of wildland fire behavior includes knowing how the combustion process is affected by wildland fuels.

Classifying wildland fuels

By now, you know that you cannot have a fire without fuel. Fuel provides energy for fire, and in the wildland, that fuel can be anything from live or dead plant material to structures like cabins or houses. In general, if a material can burn, it is a fuel.

The differences in *fire behavior* **among the different fuel groups are principally related to the amount of fuel present and its distribution. For very detailed information about fire behavior models, see NFES 1574, Aids to Determining Fuel Models for Fire Behavior—available from the** *National Fire Equipment System* **(NFES) at http://www.nwcg.gov/pms/pubs/pubs.htm.**

Firefighters use several different systems for classifying fuels, including:

- **Fuel size—Firefighters sometimes use the fuel size classification system to predict how specific weather conditions will affect the rate of heat transfer and the change of moisture in the fuel based on the environment at the surface of the fuel.**
- **Fuel position—The position of fuels in the wildland environment is another fuel classification system used by firefighters to help predict how wildland fires will behave.**
- **Fuel moisture—Classifying wildland fuels by their moisture content and how various fuels react to changes in environmental moisture is another fuel classification system used by wildland firefighters.**

Narration Script: Knowledge of fuels is a solid foundation that all wildland firefighters need. This knowledge can help you predict fire behavior. Additionally, classifying fuels into groups is one way to keep track of their characteristics.

Fuel types

Adequate identification of available fuels is essential for accurately predicting fire behavior. Each fuel may vary in type within the same area or in different geographical regions of the country. Elevation and soil moisture content cause these differences in fuel types.

Potential fuels include:

- **Grasses**
- **Grasses-shrubs**
- **Shrubs**
- **Timber-understory**
- **Timber litter**
- **Slash and blowdown**

You will examine each potential fuel type in turn.

Narration Script: Knowing how to "read" the fuels in the area of the fires you fight includes recognizing the types of fuel and then putting that information to use in predicting how the fire will behave.

Grasses

Grasses consist of annuals such as rye grass, cheat grass, and wild oats. Examples of perennial grasses include saw grass, love grass, bunch grasses, and various tundra species. Some crops fall into this category.

Grasses:

- **Can be found in all regions of the country**
- **Are the dominant fuel in desert and range areas**
- **Can become prevalent in burned-over timber areas**
- **Burn hottest and fastest of all the fuel types**

Grass-shrub

Grass-shrubs:

- **Can be found in the plains and high deserts**
- **Are a significant contributor to fire spread**
- **Are a mixture of fine grass and** *aerial* **shrub fuels**

Shrubs

Shrubs or brush as a fuel type most often means mature shrubs such as high pocosin, Alaska black spruce, buckeye, chamise, chaparral, coyote bush, manzanita, mesquite, sagebrush, and sugar bush. Some crops fall into this category as well. Certain species of shrubs, such as sage, have very high flammable organic chemical content that can add significantly to fire intensity. Shrubs are found in most geographical regions.

Timber-understory

This category consists of timber and *understory***.**

Timber consists largely of trees, including two sub-groups:

- **Deciduous trees—includes alder, ash, aspen, birch, cottonwood, dogwood, hickory, maple, and some oaks**
- **Evergreens—includes cedar, cypress, eucalyptus, fir hemlock, live oak, and different kinds of pine and spruce**

Timber-*understory* **is found in most areas, and can provide a** *ladder* **to aerial crown fuels.**

Timber litter

Timber litter is most dominant in the mountains—especially in the Northwest, and can provide fuel for ground fires. Litter consists of small matter, such as needles, leaves, twigs, and other natural debris found on the forest floor.

Slash-blowdown

Slash and blowdown is the downed, dead residual material left on the forest floor after natural events or after logging or thinning operations. This category also includes dead falls such as broken limbs and tree trunks that result from freezing, drought, disease, and wind.

Slash is composed of:

- **Logs**
- **Treetops**
- **Limbs**
- **Stumps**

Knowledge Check 3

Matching—select the match you choose from the pull down list.

Although you're not trying to become a botanist, being able to recognize general classifications of wildland fuels goes hand in hand with predicting fire behavior.

Match each fuel type with "in the field" examples.

Slash	Mesquite, chaparral, Alaska black spruce
Timber	Mesquite, chaparral, Alaska black spruce
Shrub	Mesquite, chaparral, Alaska black spruce
Grasses	Mesquite, chaparral, Alaska black spruce

The correct matches are as follows:
Slash: Dead fall, logging residuals
Timber: Oaks, hickory, cypress, cedar
Shrub: Mesquite, chaparral, Alaska black spruce
Grasses: Wild oats, tundra species

Geographical distribution of wildland fuels

The kinds of wildland fuels you encounter often depend on your geographic location. Some fuel species are found only in specific areas of the North American continent and the Hawaiian Islands. Other fuels may be found in more than one area. Generally speaking, the species that predominate in an area are those that are native to that area.

Read the following sections to learn the predominate species in each area.

Narration Script: From coast to coast, man-made structures continue to creep into wildland/urban interfaces. That leaves a lot of room for biodiversity—that is to say, from sea to shining sea, the interface can go from hardwood forests to huge grasslands and even to deserts. Depending on where you find yourself working, your everyday fuel types can differ greatly from region to region.

Eastern fuel species

The most common fuel species combinations in the eastern United States consist of:

- **Oak**
- **Maple**
- **Pine (a variety)**
- **Hickory**
- **Fetterbush**
- **Gallberry**
- **Bay**

Narration Script: Hardwoods and a variety of pines are a large component in the mix of fuels found in the eastern United States.

Northern fuel species

The northern United States and southern Canada boast many predominant fuel species combinations. Typically, you'll find:

- **Tall prairie grasses**
- **Sagebrush**
- **Cedar**
- **Douglas fir**
- **Spruce**
- **Hemlock**
- **Jack pine**
- **Various hardwoods**

This geographical area also includes Alaska, where you will find open tundra and spruce forests with a thick undergrowth of shrubs.

Narration Script: The northern United States and southern Canada, including Alaska, predominantly contain a combination of species including grasses, evergreens, hardwoods, and brush.

Southern fuel species

The southern regions of the United States have fuel type combinations consisting of species such as:

- **Pine trees**
- **Palmetto**
- **Bay**
- **Gallberry**
- **Cedar**
- **Scrub oak**
- **Various hardwoods**

Narration Script: The southern wildland environment is made up of pine forests with palmetto growing beneath the main forest canopy. But like other areas of the country, you'll find other species too. In the case of the southern United States, you'll find bay, gallberry, cedar, scrub oak, and a host of hardwoods.

Southwestern fuel species

Fuel species combinations you'll find native to the southwestern United States consist of:

- **Live oak** *savanna* **with a grassy understory**
- **Mesquite**

- **Sagebrush**
- **Tumbleweed**
- **Pinon**
- **Juniper**
- **Ponderosa pine**

Southeastern fuel species

If you're fighting wildland fires in the southeastern United States, you'll most likely encounter a predominant fuel species combination made up of:

- **Saw grass prairie (such as is found in the Florida Everglades)**
- **Tropical palm trees**
- **Cypress with hanging moss**
- **Pine (various species)**
- **Hardwoods (various species)**

Western fuel species

Western wildlands contain various predominant fuel species combinations. This geographic area supports a wide variety of grasses such as:

- **Cheat grass**
- **Medusa's head**
- **Ryegrass**
- **Fescue**
- **Wild oats**
- **Star thistle**
- **Meadow foxtail**

Here you'll also find a wide variety of trees and woody shrubs that are well adapted to dry summers and moist winters. Depending on the specific area of the West, you'll see:

- **Redwood**
- **Douglas fir**
- **Eucalyptus**
- **Hemlock**
- **Live oak**
- **Ponderosa pine**

Narration Script: In the West, you may be confronted by savannas of prairie grasses interspersed with stands of oak trees.

Hawaiian fuel species

It's hard to imagine fighting a wildland fire in Hawaii, but believe it or not, they do happen there. Now, you just have to figure a way to get mobilized to the Islands!

Wildland firefighters in the Islands encounter a predominant fuel species combination of tropical forest made up of:

- **Beard grass**
- **Broom sedge**
- **Fountain grass**
- **Guinea grass**
- **Molasses grass**
- **Eucalyptus**
- **Pine**

Canadian and northern Pacific Coast fuel species

Areas in western Canada and the northern Pacific Coast of the United States share some of the same fuel species combinations. Depending on the sub-area, you can find wildland fuels consisting of prairie grasses, cypress, fir, hemlock, larch, pine, and spruce.

In northern Canada, you'll find aspen, birch, fir, maple, pine, poplar, and tamarack. The west coast of Canada and the northwest Pacific Coast of the United States share cedar, hemlock, and spruce in the north and chaparral made up of chamise and manzanita, Douglas fir, Ponderosa pine, and oak in the south.

Narration Script: Pacific Coast forests are much more dense than the wildlands of northern Canada that often consist of trees interspersed with open areas of prairie grasses.

Common structures

There's one type of wildland fuel that doesn't fall into a category of vegetation; nevertheless, you can't afford to overlook the growing number of structures in wildland areas. Until recently, undeveloped areas contained few structures. Those that existed were farm and ranch houses and outbuildings. Occasionally, you might have come across an isolated hunting cabin.

Widespread residential and commercial development in the wildland/urban interface has resulted in a dramatic change in the number and character of structures found in the wildlands. In some areas, these structures represent the main source of fuel that burns and spreads fire.

Other examples of man-made fuel sources are:

- **Log decks at saw mills**
- **Authorized and unauthorized dump sites**
- **Aboveground oil and natural gas pipelines**

Narration Script: Although some wildland structures have noncombustible roofs, many of them are constructed of wood, a serious form of fuel for wildland fires, and in some cases, they're the MAIN source of fuel. Other examples of man-made fuels in the wildland interface include saw mills, dump sites, and aboveground oil and natural gas pipelines.

Knowledge Check 4

Multiple choice—check the box of the answer(s) you choose.

All right. The geography lesson is over. You've learned that you'll find different fuels in different geographic locations.

What one fuel might you find no matter where you're fighting fires?

- ☐ **Palmetto**
- ☐ **Hardwoods**
- ☐ **Sage**
- ☐ **Man-made structures**
- ☐ **Tundra**

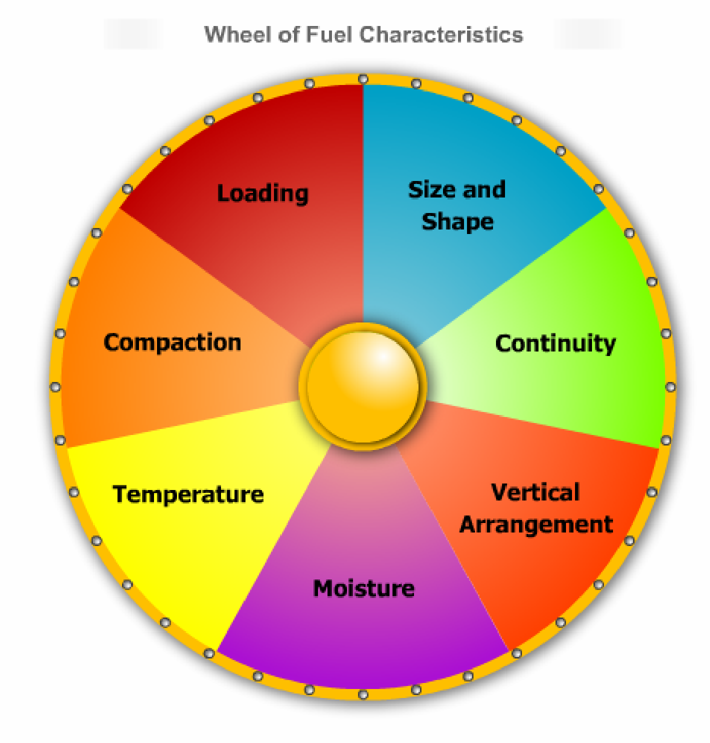
The correct answer is man-made structures.

Fuel characteristics

This may look like a "wheel of fortune," but it's really the Wheel of Fuel Characteristics. Paying attention to what it can tell you will be to your advantage. Knowing the characteristics of wildland fuels and how they affect the chance of ignition is another predictor of a fire's behavior.

No matter what type of fuel or mixture of fuels you're dealing with, fire behavior is dependent on certain fuel characteristics including:

- **Loading**
- **Size and shape**
- **Continuity**
- **Vertical arrangement**
- **Moisture**
- **Temperature**
- **Compaction**



Caption: A wheel figure depicting the major fuel characteristics.

Read the following to increase your fire fighting vocabulary about fuel characteristics.

Loading

Fuel load refers to the amount of both live and dead fuel in a specific area. (Sometimes fuel load is called fuel volume.) Wildland firefighters usually report fuel load in terms of tons per acre (tonnes per hectare or t/ha), with ranges from less than 1 ton per acre to more than 500 tons per acre (2.2 t/ha to 1,100 t/ha). Later in this topic, you'll discover a fire behavior model that combines fuel loading with moisture content and fuel species combinations to help predict fire behavior.

Size and Shape

Fuel size and shape affect the rate of heat transfer and the change in moisture content. In this fuel classification system, firefighters describe wildland fuels as light, medium, and heavy. Identifying the "size" of fuel in an area will help you predict the rate a fire will spread.

Knowing the surface to area volume ratio of a fuel can also help you to predict how quickly a fuel will dry and burn. The ratio relates to the amount of the outer surface of the fuel that is exposed to the air. In general, fine fuels have a higher surface area to volume ratio than heavy fuels.

Continuity

Fuel continuity is a characteristic used to describe the horizontal and vertical spacing of fuels in a given area. Fuel continuity influences the spread of fire. Understanding fuel continuity helps more accurately predict how a fire will behave.

Vertical Arrangement

Fuel arrangement or position greatly influences the behavior of wildland fires. Based on position classification, the wildland fuels are:

- **Subsurface fuels**
- **Surface fuels**
- **Ladder fuels**
- **Aerial fuels**

You'll learn more about fuel position classification in just a bit.

Moisture

In the earth's environment, water is present in the form of precipitation, ground moisture, and atmospheric moisture, which we call humidity. The moisture content in wildland fuels changes constantly as a result of the availability of water in the environment. Fuel moisture is the amount of water in a fuel, expressed as a percentage of the total oven-dry weight of that fuel. You will soon discover more about moisture content in wildland fuels later on in this topic.

Temperature

Heat energy from the sun warms the earth's surface. The earth heats both the surrounding air and the wildland fuels, lowers their moisture content, and brings fuels closer to their ignition temperature.

Compaction

Fuel compaction means the spacing between fuel particles. For example, hay standing in a field before harvesting is less compact than hay that has been cut and baled.

Narration Script: Oh boy, looks like you're going to get rich playing the "Wheel of Fortune." Wait a minute, this isn't the "Wheel of Fortune;" this is the "Wheel of Fuel Characteristics." Sorry. The prizes for this game aren't quite as good as that other one!

But the prizes aren't that bad. By playing this game, you get to know what you're up against when you're on the fireline. And that may be pretty important. The more information you have about the wildland fuels in the area and how they might behave, the safer and more effective you and your crew will be. Get familiar with each of these terms because on the following pages, we are going to look specifically at their effect on fire behavior.

Fuel wheel

Now that you are familiar with each term on the Wheel of Fuel Characteristics, you have the good fortune to examine these concepts closely to find out how fuel characteristics can influence fire behavior. You will investigate each section of the Wheel of Fuel Characteristics in turn.

<u>Narration Script: You already know that misfortune on the fireline can happen as quickly as striking a match. With this fact in mind, you need to be able to identify influential fuel characteristics in order to predict fire behavior.</u>

Fuel load

Fuel load, **or fuel volume, is the amount of live and dead fuel in a given area. Firefighters report fuel load as tons of fuel available per acre (tonnes per hectare or t/ha). Fuel load can range from less than 1 ton to more than 500 tons per acre (2.2 t/ha to 1,100 t/ha). For example, grass can range from 1/4 ton to well over 1 ton per acre (0.56 t/ha to 2.20 t/ha); timber in some areas can average 600 tons per acre (1,320 t/ha).**

With all other factors affecting fire behavior being equal, areas of higher fuel loading will generate more heat than those with lesser fuel load.

<u>Narration Script: The amount of live and dead fuel you find in an area is called fuel load. The loading of the fuels in any given area does not necessarily mean the fire will burn with great intensity. What is more important to know is the quantity of fuels available for combustion. But generally, when you're fighting a wildland fire, you can expect areas with a higher fuel load to generate more heat than areas with a lesser fuel load.</u>

Knowledge Check 5

Multiple choice—check the box of the answer(s) you choose.

By now you must have a load of information on your mind! Select the set of terms that BEST completes the following sentence.

With all other factors affecting fire behavior being equal, areas of ________ fuel loading will generate more heat than those with _______fuel loads.

- ☐ **minimal, maximum**
- ☐ **higher, lesser**
- ☐ **intense, continuous**
- ☐ **aerial, ladder**

The correct answers are higher and lesser.

Fuel size and shape

Fuel size and shape are other characteristics that influence fire behavior. Size affects the rate of heat transfer and the change in *moisture* **content.**

Heat and moisture transfers between the fuels and the environment happen at the surface of the fuel. The larger the fuel surface, the greater the heat and moisture transfer. Depending on weather conditions, this transfer of energy results in either an increase or a decrease in the fuel temperature and moisture content. In turn, the change in temperature influences the combustion process. Wind, *topography***, and fuel conditions can influence the fire's behavior no matter what the size of the fuel.**

Based on size, fuels may be described as:

- **Light**
- **Medium**
- **Heavy**

Read the following in order to weigh in on the fuel size classification issue.

Light Fuels

Light fuels are surface fuels and are also called *fine fuels, flashy fuels,* or *flash fuels.* Light fuels take on and give up moisture faster than heavier fuels. Examples of light fuels are short grasses and light shrubs or brush up to 2 ft. (0.6 m) that burn rapidly and with high intensity. Fuel temperature, winds, and topography greatly influence the rate of spread (ROS) in light fuels. Atmospheric conditions being equal, light fuels produce a relatively high ROS.

Warning—Historically, more firefighters have been killed in light fuels than any other type.

Medium Fuels

Examples of medium fuels include shrubs or brush up to 6 ft. (1.8 m) in height and the grass understory. The tremendous amount of fuel contained in medium fuels can produce moderate- to very high-intensity burning but with a relatively slower ROS than light fuels. In general, medium fuels tend to produce a moderate ROS.

Heavy Fuels

Heavy fuels consist of heavy continuous shrubs or brush more than 6 ft. (1.8 m) in height and timber slash. Combustion characteristics of these fuels include high-intensity burning but generally a low-to-moderate ROS.

Narration Script: One way to think of how fuel size and shape influences fire behavior is to think of the fuel's surface-area-to-volume ratio. It's like building a campfire. You would start with small fuels, such as grass or pine needles that have a large surface area to volume ratio. Then you gradually add larger and larger fuels, such as twigs, sticks, and logs, each with a greater surface area to volume ratio.

This example should show you that fuel size matters when it comes to predicting fire behavior. Be sure you know which fuels produce the highest ROS. And, did you know that more firefighters are killed battling light fuel fires than other types?

Knowledge Check 6

Matching—select the match you choose from the pull down list.

Fighting fires can be like a prize fight with a light-weight speed demon or with a slow and steady heavyweight. Either way, you could find yourself in a ring of fire.

Match each rate of spread (ROS) to the appropriate fuel size.

Slow ROS	Medium fuels
Medium ROS	Medium fuels
Fast ROS	Medium fuels

The correct matches are as follows:
Slow ROS: Heavy fuels
Medium ROS: Medium fuels
Fast ROS: Light fuels

Uniform fuels

Another fuel factor influencing fire behavior is fuel continuity. Fuel continuity refers to the physical spacing between fuels, be it horizontally or vertically. Uniform or *continuous fuels*—are fuels that are close together and spread evenly over an area. Fuel continuity influences the ROS in wildland fires. When fuels are close together, a fire spreads faster because of *radiant* heat transfer. A uniform continuity of fuel guarantees a relatively uniform and predictable ROS.

Patchy fuels

Patchy fuels are fuel concentrations that are separated by bare ground or ground that has little or no flammable materials between the patches. Bare earth, rocky outcroppings, green vegetation, plowed ground, roads, or marshy areas may break the continuity of fuels.

The ROS and direction of fire spread are generally less predictable in patchy fuels. When fuels are patchy, scattered, or separated by natural or man-made *barriers*, radiant heat may not be sufficient to preheat or ignite the surrounding fuels. However, wind may offset the benefits of interrupted fuel continuity by accelerating radiant heat transfer.

Narration Script: You would consider some fuels as "continuous," such as a stand of lodge pole pines or a meadow with thick grass. Other fuels are "patchy," such as a hillside with sparse pinon and juniper trees.

Knowledge Check 7

Multiple choice—check the box of the answer(s) you choose.

Continuous or not continuous, that is the question. Choose the best word or phrase to complete the following sentence.

When fuels are close together, a fire spreads ______ because of radiant heat transfer.

- [ ] **slower**
- [ ] **more evenly**
- [ ] **in a jumping manner**
- [ ] **faster**

The correct answer is faster.

Fuel position

Fuel position is one way of differentiating between types of wildland fuels. This method classifies fuels as:

- *Subsurface* **and ground**
- *Surface*
- *Ladder*
- **Aerial**

Let's examine each position on the pages that follow.

Narration Script: You can also identify wildland fuels by their position. If you use this method of classification, things like roots you will call subsurface fuels; grasses will be surface fuels; surface litter, shrubs, and other moderate-height vegetation will be ladder fuels; and trees will be aerial fuels.

Subsurface and ground fuels

As this classification suggests, subsurface and ground fuels lie underground or on the ground. Examples include:

- **Roots**
- **Deep** *duff*
- **Rotten buried logs**
- **Peat**
- **Partially decomposed organic matter**

Subsurface fuels don't burn rapidly, but once they start on fire, they are often difficult to extinguish completely. Subsurface roots may burn their full length underground only to ignite fuel unexpectedly at the surface at another location. Also, when subsurface fuels such as peat bogs burn, they can create hidden voids you could fall into. There's another hazard for you to look out for.

Narration Script: You may have heard the expression that "still waters run deep," but so do burning subsurface fuels. Once ignited, burning subsurface fuels are often difficult to find and extinguish. And be aware of burning stumps that leave subsurface holes after the stumps have been consumed because you can be injured falling into these holes.

Surface fuels

A surface fuel is one that crunches beneath your feet when you are walking in the forest. Surface fuels are all combustible materials lying on or immediately above the ground and include pine needles, duff, grass, small dead wood, downed logs, stumps, large limbs, and low shrubs.

Often, these fuels are called *flashy* fuels and get their name because they ignite easily and burn quickly and almost completely when environmental conditions are ripe. Flashy fuels are those that are found either on the ground or very close to it, such as twigs, needles, and grass.

Ladder fuels

Ladder fuels provide a path or "ladder" for a surface fire to climb into tree tops. Any of this moderate-height vegetation can be a ladder fuel if in contact with lower surface fuels:

- **Shrubs**
- **Low-hanging branches**
- **Tree moss**
- **Tall grasses**
- **Downed dead limbs or logs**

Narration Script: Fire can spread from surface fuels to ladder fuels or those fuels in contact with a ground fire that might spread the fire into the treetops. Like a fuse, these hanging fuels can catch fire and turn that tree into a nasty firecracker.

Aerial fuels

Aerial fuels—sometimes called crown fuels—are fuels separated from the ground and sometimes from each other. They consist of all green and dead materials located in the upper canopy, such as:

- **Tree tops**
- **Leaves on branches**
- *Snags*
- **Hanging moss**
- **Tall shrubs**

Aerial fuels burn rapidly once they ignite because air circulates easily between these fuels and the ground. The horizontal distance between the fuels affects the ROS in aerial fuels. The further the distance between aerial fuels, the slower they ignite. On the other hand, the closer they are, the faster they ignite. Winds and dry weather also affect ROS in aerial fuels.

Narration Script: Fuels separated from the ground are dubbed "aerial fuels," and they include brush over 6 feet high, tree tops, and leaves on branches. Aerial fuels are sometimes referred to as crown fuels.

Dry and wet fuels

The amount of moisture found in wildland fuels has a huge impact on fire behavior. How well a fuel will ignite and burn is dependent on its moisture content. Because of various sizes and characteristics, different fuels in the same area will have various moisture levels. Similar fuels across a broad area will have different moisture levels based on precipitation received as well as periods of warm, dry weather. *Light fuels* **take on and lose moisture faster than** *heavy fuels***.**

Fuels can be classified as:

- **Dry fuels**
- **Wet fuels**

Read the following for more information.

Dry Fuels

Dry fuels ignite and burn more easily than the same fuels when they are wet. These fuels have low moisture content because of prolonged exposure to sunshine, dry winds, drought, or low relative humidity.

Wet Fuels

Wet fuels have high moisture content because of exposure to precipitation or high relative humidity. This moisture must evaporate before the fuel can burn. As the moisture in a fuel increases, the amount of heat required to ignite and burn the fuel also increases.

Narration Script: Being described as "all wet" isn't usually a compliment, but when it comes to fighting wildland fires, the more moisture in the fuel, the better! In the wildland environment, live fuels contain anywhere from 35 to 250 percent more moisture than they do when they are dead. Weather, soil moisture, humidity, and fuel age all affect the amount of moisture in wildland fuels.

Fuel moisture

The availability of water in the environment constantly varies. For this reason, the moisture content of fuels is constantly changing as well. This is one of the many challenges you face in predicting fire behavior. The percentage of fuel moisture varies according to these factors:

- **Age and species of plant**
- **Weather conditions**

Read the following for more information on each factor.

Age and Species of Plant

The age and species of plants affect the amount of moisture they hold. Old plants are usually drier than young plants. Young, actively growing green vegetation absorbs water, circulating it through all parts of the plant. As a result, live fuels usually have a relatively high moisture content (from 35 percent to over 250 percent of their dehydrated weight).

Dead plants usually have a lower moisture content (1.5 to 30 percent) than live plants. Therefore, vegetation that is dead and dry ignites more readily and burns more intensely than vegetation that is green and moist.

Weather Conditions

Weather conditions affect the amount of moisture content in wildland fuels. For example, a prolonged spell of hot, dry weather reduces the moisture content of vegetation. These conditions can reduce the moisture content of living fuel and make it much more susceptible to ignition.

Initially, heat absorbed by wet fuels drives off moisture through evaporation. As more heat is absorbed, evaporation continues, moisture in the fuels decreases, and the temperature of the fuel can increase to the point of ignition.

Environmental moisture

Whether fuels are dead or live, environmental moisture influences their flammability.

- **Moisture in *live* fuels depends primarily on the moisture in the soil and the phase of the fuels' seasonal growth cycle.**
- **Moisture in *dead* fuels depends on atmospheric temperature,** *humidity*, **and solar radiation. When plants die, most of the water in the plant tissues evaporates.**

Rain, snow, or hail temporarily decreases the flammability of fuels and alters fire behavior. Continual or heavy rains soak fuels and increase moisture content, making both live and dead fuels less susceptible to ignition. However, it is the *duration* of rainfall, rather than the *amount* of rainfall, that has a greater effect on fuel moisture.

Narration Script: Environmental moisture affects the flammability of live AND dead fuels. However, don't get your hopes up about the benefits of occasional rain showers. Short rain showers have little effect on fuel moisture.

Equilibrium moisture content

One system for predicting fire behavior is based on weather cycles and fuel types. It classifies dead fuels according to the time it takes their moisture content to equalize with that of surrounding air—also known as timelag category or equilibrium moisture content.

The timelag system categorizes fuels as:

- **1-hour**
- **10-hour**
- **100-hour**
- **1,000-hour**

Simply put, a 1-hour fuel is one that would take one hour for the moisture in the fuel to equalize with the amount of moisture in the surrounding air. These time-lag categories for fuels also take into account the average diameter of the dead fuels to estimate fuel moisture.

Read the following to get with the times.

1-Hour Fuels

If you are looking at fuel that was less than 1/4 in. (6 mm) in diameter, like pine needles, you can predict that it will take approximately one hour for the moisture in the pine needles to equalize with the moisture in the surrounding air.

10-Hour Fuels

For fuel that is 1/4 to 1 in. (6 to 25 mm) in diameter, such as a small branch, you can estimate that it will take approximately 10 hours for the moisture in the branch to equalize with the moisture in the surrounding air.

100-Hour Fuels

For fuel that is 1 to 3 in. (25 to 76 mm) in diameter, such as a dead tree limb, you can predict it will take approximately 100 hours for the moisture in the dead limb to equalize with the moisture in the surrounding air.

1,000-Hour Fuels

If you are looking at fuel that is 3 to 8 in. in diameter (76 to 203 mm), like a log, you can predict that it will take approximately 1,000 hours for the moisture in the log to equalize with the moisture in the surrounding air. When burning, very dry 1,000-hour fuels can release large amounts of energy and are hard to control. Since 1,000 hours equals 42 days, this category does not normally change between operational periods on a fire. However, a 1,000-hour category can indicate long-term drought or extended wet periods.

Narration Script: Equilibrium moisture content refers to the time it takes for the moisture in fuels to equalize with the moisture in the surrounding air. The diameter of the fuel affects the length of time it takes for the moisture in the fuel to be equal to the moisture in the air. This factor, in turn, affects the length of time it will take for fuels to ignite if they are exposed to heat.

More about moisture

The size and shape of fuels affect the rate at which they absorb and lose moisture. For instance, small wood shavings will ignite more easily than large logs because the shavings have a much higher surface area-to-mass ratio. Therefore, the wood shavings lose moisture more quickly than logs. Likewise, changes in humidity affect grass and pine needles more than logs or slash because of their size and shape. But regardless of size and shape, all fuels are affected by daily and seasonal changes in humidity.

More on Humidity

As temperatures drop at night, even dead fuels absorb moisture from dew. However, daytime solar heating causes moisture to evaporate from fuels. Therefore, fuels lying in full sun may contain as much as 8 percent less moisture than the same fuels lying in shade. For example, cured cheat grass may not burn at all during the early morning hours because it contains so much moisture. But as temperatures rise during the day, the grass loses moisture and will burn explosively if ignited.

Narration Script: All fuels are affected by changes in humidity, no matter what their size and shape may be. In fact, after a prolonged period of warm, dry weather, timber—a 1,000-hour fuel—may actually be drier than kiln-dried lumber.

Moisture and slope faces

Just as fuels in the shade are cooler than fuels in the sun, fuels on north-facing slopes are less affected by solar heating than fuels on level and south-facing slopes. Without the sun's moisture-sapping effect, fuels on north-facing slopes contain more daytime moisture content than fuels on level or south-facing slopes.

<u>Narration Script: The amount of moisture in fuels depends on whether the fuel is on a south-facing slope, a north-facing slope, or level ground. Fuels on north-facing slopes will contain more daytime moisture because they don't get the same amount of solar radiation.</u>

Winds and moisture

Winds also affect fuel moisture. Cool winds reducing surface temperatures sometimes reduce the rate at which fuels lose moisture. However, warm and hot winds typical of wildland fires usually accelerate the loss of moisture by lowering relative humidity and increasing evaporation. Knowing how quickly fuel moisture levels change in response to weather and wind conditions helps you predict a fire's ROS.

Rate of Spread

ROS is the rate of increase in the total perimeter of the fire and the rate of forward progress of the fire front. In general, the drier the fuel is, the more intensely it burns and the faster a fire spreads. ROS is usually expressed in feet or meters per minute at the head, or leading edge of a fire.

Most wildland agencies, measure ROS in *chains per hour*—or approximately 66 ft. (20 m) per hour. That sounds technical, but the conversion is simple—one chain per hour is roughly 1 ft. (0.3 m) per minute.

<u>Narration Script: One way you can report fire behavior is to predict a wildland fire's rate of spread, or ROS. You have to love acronyms, so add them to your arsenal! ROS will help you estimate the overall perimeter of an incident.</u>

Knowledge Check 8

Matching—select the match you choose from the pull down list.

All this talk about moisture making you sweat? Now try some Wildland Jeopardy.

Match each ANSWER below to the MOST appropriate QUESTION.

1-hour fuel	What is a characteristic affecting the moisture content in fuels?
Humidity	What is a characteristic affecting the moisture content in fuels?
North-facing slope	What is a characteristic affecting the moisture content in fuels?
Plant age	What is a characteristic affecting the moisture content in fuels?
ROS	What is a characteristic affecting the moisture content in fuels?

The correct matches are as follows:
1-hour fuel: What is a measurement of equilibrium moisture content?
Humidity: What is a moisture factor that affects wildland fire behavior?
North-facing slope: Where might fuels contain more moisture?
Plant age: What is a characteristic affecting the moisture content in fuels?
ROS: What is rate of spread?

Fuel temperature

You know that heat energy from the sun warms the earth's surface, heating the surrounding air and the wildland fuels. Heat affects these fuels by reducing their moisture and bringing them closer to their ignition temperatures. Fuels exposed to heat from the sun can reach 150° F (66° C). This means that fuels in direct sunlight are more likely to burn than fuels in the shade.

Fuel Ignition Temperatures

Most wildland fuels require temperatures between 400° and 700° F (204° and 371° C) to ignite. Therefore, solar heating will not cause ignition by itself, but it does make ignition easier. Once a fire has started, radiant heat from the fire dehydrates and preheats surrounding fuels, making them more likely to ignite. There are ways of measuring fuel temperature precisely, but this is not normally done in the field.

Narration Script: A day in the park or at your buddy's barbeque is a real good way to learn about the effects of the sun's heat. When you're hot, you hit a patch of shade. In the wildland interface, fuels in the shade are cooler than fuels in the sun, which means they won't ignite as quickly.

Knowledge Check 9

Multiple choice—check the box of the answer(s) you choose.

Will you win the prize for your knowledge about fuel temperature?

Identify THREE true statements about fuel temperature.

- ☐ **Fuels exposed to heat from the sun can ignite when they reach 150° F (66° C).**
- ☐ **The sun's energy warms the earth's surface, heating surrounding air and fuels.**
- ☐ **Fuels in the shade tend to ignite just as easily as fuels in the sun.**
- ☐ **Most fuels must reach between 400° and 700° F (204° and 371° C) in order to ignite.**
- ☐ **Fuels in the sun will ignite more easily than fuels in shaded areas.**

The correct answers are the sun's energy warms the earth's surface, heating surrounding air and fuels; most fuels must reach between 400° and 700° F (204° and 371° C) in order to ignite; and fuels in the sun will ignite more easily than fuels in shaded areas.

Fuel compaction

Fuel compaction means the spacing between fuel particles. While fire spreads readily from piece to piece in highly compact fuels, it generally burns with both a low intensity and a low ROS because the air supply is limited.

For example, wheat standing in a grain field burns more quickly and with a higher intensity than wheat tightly compacted into a bale because air cannot easily circulate around the fuel in the bale. Another example is grass packed to the ground by snow during the previous winter does not burn as quickly or as intensely as grass growing freely.

Reigniting Unburned Material

It's not over till its over—or it's not OUT till the fire is out. After the surface of compacted fuels has burned and if the unburned material beneath is disturbed and exposed to the air, it can reignite and burn.

Knowledge Check 10

Multiple choice—check the box of the answer(s) you choose.

Predicting fire behavior accurately may depend on analyzing the compactness of fuels in the area.

Choose the THREE TRUE statements about fuel compaction.

- ☐ **Disturbing unburned fuel beneath the surface of compact fuels may cause it to reignite.**
- ☐ **Compaction refers to the spacing between fuel particles.**
- ☐ **Fire generally burns at a low intensity and spreads slowly in highly compact fuels.**
- ☐ **Compaction refers to the size of the fuel particles.**
- ☐ **Fire generally burns intensely and spreads quickly in highly compact fuels.**

The correct answers are compaction refers to the spacing between fuel particles, fire generally burns at a low intensity and spreads slowly in highly compact fuels, and disturbing unburned fuel beneath the surface of compact fuels may cause it to reignite.

Topic conclusion

In this topic, you investigated some basic fire behavior concepts, including:

- **General classes of potential wildland fuels**
- **Geographic locations of different fuel types**
- **Specific fuel characteristics that affect fire behavior**
- **Fuel characteristics that produce hazardous situations**

Whether you find yourself in the wildland/urban interface, on a mountainside, or in a dusty wheat field, each piece of information is a valuable tool in helping you fight wildland fires.

<u>Narration Script: The variety of fuels and conditions in the wildland means that fire will behave in certain ways. This topic gave you some new understanding of how fuels and fire will behave in various situations. In fact, if you understand the fuel factors discussed in this topic, you may even be able to say that wildland fires behave in predictable ways.</u>

Topic 4: Weather

Weather introduction

Weather's **influence on wildland** *fire behavior* **makes it worth putting it on your own Doppler radar. Understanding how the local forecast allows you to predict changes in the fire before they happen is a weapon you want to have in your fire fighting arsenal. Profound examples of weather's influence on a fire are all too bountiful.**

Read the following to learn more about a wildland fire that was greatly intensified because of weather.

Warning—South Canyon Fire of 1994

A case in point is the 1994 South Canyon fire near Glenwood Springs, Colorado. Fourteen firefighters were killed in this incident. The investigation showed weather forecasts were not requested or supplied to the fire crews who were overrun by a sudden and unexpected blowup (sudden increase in fire intensity and spread) in one area of the fire. The report concluded that weather "contributed significantly" to the accident and the resulting firefighter fatalities.

<u>Narration Script: Weather consists of short-term variations in the atmosphere and is one of three components of the fire environment. Lightning from thunderstorms can ignite fires, and strong winds can rapidly spread fires. On the other hand, an increase in humidity or precipitation can slow or extinguish fires.</u>

<u>Of the three fire environment components—topography, fuel, and weather—weather is the most variable over time, and at times, difficult to predict. To make safe and effective fire fighting decisions, you must monitor the weather at all times. Monitoring the weather and predicting its effects on fire behavior are the substance of one of the 10 Fire Orders and three of the "18 Watch-Out Situations" you must obey. By paying attention to and understanding weather conditions that impact fire behavior, you can reduce the risk involved in fire suppression.</u>

Definition of weather

Weather is the state of the atmosphere over the surface of the earth. Weather is a result of the interaction of temperature, *wind***,** *relative humidity* **(RH), and** *precipitation***.**

Think for a second about the most changeable factor in fire behavior. It's definitely not a trick question—weather is *the* most changeable factor affecting wildland fire behavior. *Atmospheric stability***, drops in temperature, strong winds, and seasonal and daily weather cycles all lead to potentially erratic fire conditions. The more you learn about the effects of weather on fire behavior, the better you will be able to predict these fire conditions. So get ready to dig deeply into this topic.**

Narration Script: "If you don't like the weather here, wait five minutes and it'll change." How often have you heard that statement about "Anywhere" U.S.A. It's true—local weather conditions may change within a matter of minutes, significantly affecting the rate of fire spread and the intensity of a wildland fire.

Weather elements

There are several important elements to understand about weather and how it affects you as a wildland firefighter. These elements influence every fire *incident* **making them more than "nice to know"—this is "*need* to know" information.**

Weather elements include:

- **Temperature and RH**
- **Precipitation**
- **Atmospheric stability**
- **Wind**

You will check out each weather element in turn. When you are done with these elements, we will move on to describe the critical fire weather conditions you should look out for on any wildland incident and then list the different types of fire weather forecasts and outlooks available to firefighters.

Narration Script: As you already know, weather can be very unpredictable, but what does that really mean? To truly understand how the weather can affect you, you will want to be familiar with four key weather elements—temperature, relative humidity, wind, and precipitation—all of which act together to influence wildland fire behavior.

Temperature introduction

Temperature is a measure of the warmth or coldness of a substance—in this case, air. Air temperature varies with time, location, and height above the earth's surface. Gradual changes in air temperature near the surface of the earth are caused by contact (or *conduction***) with seasonal and** *diurnal* **changes. Seasonal and diurnal temperature changes can be large or small, depending on:**

- **Latitude**
- **Elevation**
- *Topography*
- **Proximity to the moderating influences of nearby oceans or lakes**

Abrupt changes in air temperatures can occur when migrating weather systems transport colder or warmer air into a region.

Narration Script: Here, we hone in on temperature as it relates to weather. Air temperature is variable due to the time of day, the weather, the seasons, proximity to the earth's surface, the elevation, such as high in the mountains or low at sea level, and the type of surface it's near, such as forests, deserts, or large bodies of water.

Temperature and fuels

Solar *radiation* **is the primary culprit for fuel, ground, and air temperature. However, on a smaller scale, large fires can cause heat and above-average temperatures.**

In the wildland fire environment, direct sunlight and hot temperatures can preheat *fuels* **and bring them closer to their ignition point, whereas cooler temperatures have the opposite effect. Higher ground and fuel temperatures make fuels more susceptible to ignition—and fuels in direct sunlight can be as much as 50° F (10° C) hotter than those in the shade. Heated fuels ignite and burn much easier than those at a lower temperature.**

Narration Script: As you probably know, temperature is measured with a thermometer calibrated either to the Fahrenheit scale or the Celsius scale. The sun’s solar radiation affects both wildland fuels and air temperature. The higher the ground and fuel temperatures, the more susceptible they are to ignition. There can be a huge difference between fuel temperatures in the shade as opposed to those in the sun—as much as 50 degrees Fahrenheit.

Relative humidity

Air temperature affects the amount of moisture air can hold. Moisture in the air is known as relative humidity (RH). RH is the percentage of moisture in a volume of air relative to the total amount of moisture that the volume of air can hold at the given temperature and *atmospheric pressure***.**

For example, when the RH is 63 percent, the air has only 63 percent of the moisture it could possibly hold at that temperature and atmospheric pressure. When air holds the maximum amount of moisture, the air is saturated, and its RH is 100 percent.

Relative humidity can add or remove moisture to fuels. More moisture means that you have a better chance at controlling your wildland fire. Less moisture in the air makes it more difficult.

Narration Script: Relative humidity, often referred to as just “RH,” is another factor influencing fire behavior. Relative humidity refers to the percentage of moisture in a volume of air relative to the total amount of moisture that volume of air can hold at the given temperature and atmospheric pressure. Higher RH also makes it *feel* hotter outside in the summer because it reduces the effectiveness of sweating to cool the body by preventing the evaporation of perspiration from the skin. More moisture in the air reduces the ignition point of fuels and therefore helps you as a firefighter.

Relative humidity and fuels

Air can either add moisture to fuels or remove it from them, depending on the RH. If the RH is high, air adds water to fuels by dampening them—thereby making them less likely to burn. But when the RH is low (less than 30 percent), the air absorbs moisture from fuels, dehydrates them, and makes them more susceptible to ignition.

Generally:

- **Low humidity increases fire activity, creates a greater** *fire intensity*, **higher** *rate of spread* **(ROS), and more** *spot fires.*
- **High humidity decreases fire activity.**

Relative humidity is most important to you nearest the ground where it has the greatest influence on *fuel moisture*. Beside the amount of moisture in the air, variations in RH are influenced by a multitude of factors including:

- **Season**
- **Time of day**
- **Slope**
- **Aspect (direction a slope faces)**
- **Elevation**
- **Clouds**
- **Type of vegetation**

<u>Narration Script: Relative humidity below 30 percent quickly removes moisture from fine, 1-hour fuels and as you can imagine, it takes a bit longer in heavier fuels. Generally speaking, low humidity means an increase in fire activity including greater fire intensity, higher rate of spread, and more spot fires. Fires burn freely when RH drops below 30 percent. And if it bottoms out below 10 percent—look out!—you can expect some extreme fire behavior.</u>

RH and temperature

Temperature and RH have an inverse relationship:

- **When the temperature increases, the RH decreases.**
- **When the temperature decreases, the RH increases.**

Because late-night and early-morning air temperatures are generally cooler than those during the day and evening, wildland fuels (especially the light, flashy 1-hour fuels) retain more of their moisture. During these periods, fires are usually less active—giving you more time to get more control of an incident. Be aware, once the temperature starts to heat back up during the day, so will the fire's activity—including *spotting*, **ROS, and horizontal fire activity.**

Narration Script: The majority of large fire outbreaks occur when air temperature is high and RH is low. Usually, this means during the daytime. The nighttime may very well become one of your favorite times because temperatures are usually cooler then and in the early morning. It brings a whole new meaning to the phrase, “The nighttime is the right time,” doesn’t it?

Measuring RH

You should be able to routinely monitor temperature and RH trends. Licking your finger and sticking in the air won’t help measure the RH. You might carry a belt weather kit in the field or invest in newer electronic devices that measure temperature and humidity.

Typically, belt weather kits include a sling psychrometer that measures local temperature and humidity quite accurately. Unfortunately, regardless of the device used, it may not show the precise temperature and humidity except at the exact point of measurement.

Narration Script: Historically, wildland firefighters carry a belt weather kit containing a sling psychrometer that measures temperature and humidity. Newer electronic devices are also on the market allowing you to take measurements of temperature, humidity, and other weather conditions.

Caption: Examples of both a sling psychrometer (left) and a portable electronic weather device (right).

RH patterns

Regardless of factors influencing RH such as season, time of day, *slope*, *aspect*, elevation, clouds, type of vegetation, and geographic location—humidity follows certain basic patterns, and the effects on wildland fuels are the same:

- **Cold air holds less moisture than hot air.**
- **Microclimates can alter fire activity.**

Read the following to stitch the pattern together for each factor.

Cold Air

When the air is cool, there is less transpiration of moisture from the fuels into the atmosphere. Cool air of any kind can help you control wildfires by increasing the level of moisture in the fuels.

Microclimates

Local microclimates may alter the onset or duration of cooler weather. Knowledge of local weather patterns helps you anticipate unusual changes in nighttime temperatures. For example, a wildfire may be located in a desert area that has a local weather pattern where temperatures actually increase during the evening hours because of warm winds or other factors. If you're new to the area, tune into local radio or television weather reports or from an electronic weather monitor.

Narration Script: There's something to be said for a firefighters experiences and knowledge of the local terrain and weather. RH is one of those elements of weather that tends to follow a pattern. If you're new to an area or called in to assist in a fire, consult local firefighters and seek out specific fire weather forecasts.

Knowledge Check 11

Multiple choice—check the box of the answer(s) you choose.

It's all relative when it comes to recalling your knowledge of temperature and RH.

Identify FOUR correct statements about temperature and RH.

- ☐ **Low RH decreases the moisture in fuels.**
- ☐ **RH greater than 30 percent increases fire activity.**
- ☐ **The higher the humidity, the better the chance of a decrease in fire activity.**
- ☐ **Increases in air temperature also increase the temperature of fuels.**
- ☐ **Wet fuels are more likely to ignite than dry fuels.**
- ☐ **The lower the RH, the better chance of increased fire activity.**

The correct answers are low RH decreases the moisture in fuels; increases in air temperature also increase the temperature of fuels; the lower the RH, the better chance of increased fire activity; and the higher the humidity, the better the chance of a decrease in fire activity.

Precipitation

Precipitation is liquid or solid water particles originating in the atmosphere and falling to the earth's surface. *Fuel moisture* **is affected by the amount and duration of the precipitation. Fine fuels react quite rapidly to precipitation because they gain or lose moisture usually within one hour. Heavy fuels are not affected as drastically because they gain or lose moisture more slowly.**

A large amount of precipitation in a short time will not raise the fuel moisture as much as less precipitation over a longer period of time—where the fuels can absorb more moisture before it runs off.

<u>Narration Script: What do mist, rain, snow, sleet, and hail all have in common? They're all a form of precipitation, and they all affect the amount of moisture in wildland fuels. The longer a wildland area receives a steady amount of precipitation, the better—because the fuels will have more time to absorb the moisture.</u>

Knowledge Check 12

Multiple choice—check the box of the answer(s) you choose.

Identify the set of terms that best fills in the blanks in the sentence below.

__________ fuels react quite rapidly to precipitation, while __________ fuels are not affected as drastically.

- ☐ **Heavy, fine**
- ☐ **Light, dense**
- ☐ **Fine, heavy**
- ☐ **Dense, light**

The correct answer is fine and heavy.

Atmospheric stability

Atmospheric motion and the properties of the atmosphere that affect its motion greatly affect wildfires. Most wildland firefighters remember to measure surface winds, temperature, and RH in the fire environment, but they don't always remember to observe atmospheric stability and related vertical air movements. These wildfire influences are less obvious, but no less important.

Atmospheric stability is the degree that vertical motion in the atmosphere is enhanced or suppressed. Stability is directly related to the temperature distribution of the atmosphere. The temperature and stability of the atmosphere is constantly changing with variations over time (day to day or season to season), location, and from one layer of the atmosphere to the next.

Warning

Be aware when the atmosphere becomes unstable, formerly calm fires may suddenly blow up and become very erratic.

Narration Script: The key principle about atmospheric stability for you to know as it affects fire behavior is that unstable air encourages the vertical movement of air and tends to increase fire activity, while stable air discourages the vertical movement of air and tends to reduce fire activity.

Stable atmosphere

First, examine what makes up a stable atmosphere. A stable atmosphere is defined as an atmosphere that resists upward motion. In a stable atmosphere, the extensive heat of the fire generates vertical motion near the surface, but the vertical motion above the surface is weakened, thus limiting indrafts into the fire at low levels and fire intensity.

Narration Script: Atmospheric stability can be determined by measuring the rate of temperature change with differences in elevation. A meteorologist would probably try to make it more complicated, but in layman's terms, air cools as it rises and expands and heats as it descends and compresses.

Atmospheric stability and visual indicators

Visual indicators can reveal important information about local atmospheric conditions. Get to know these indicators of a stable atmosphere:

- **Clouds in layers**
- **Smoke column drifts apart after limited rise**
- **Poor visibility due to smoke or haze**
- **Fog layers**
- **Steady winds**

Steady winds or smoke rising up and spreading out in a horizontal fashion indicate stable air.

Narration Script: Your eyes can help you spot other atmospheric stability indicators. Steady winds indicate stable air. Gusty winds are an indication of unstable air, except where mechanical turbulence (that is usually caused by terrain features) is the obvious cause. Dust devils or whirlwinds are reliable indicators of instability near the surface, but we will learn more about those later. Stable or unstable conditions can be determined by how smoke rises up into the air. Smoke spreads out horizontally in stable air and rises more in a column in unstable conditions.

Cloud formations

If there does not seem to be a wind pushing the smoke in one direction or the other, try looking to the sky. Different cloud formations also indicate atmospheric stability or instability.

There are three types of clouds that you can be on the lookout for:

- *Cumulus clouds*
- *Cumulonimbus clouds*
- **Stratus cloud sheets**

So while your eyes might be focused on the fire, peek up once in a while to check conditions.

Narration Script: Different cloud formations also indicate atmospheric stability or instability. Cumulus clouds are generally easy to spot as they are slightly "fluffy" and have rounded tops with a flat base. These cloud formations have vertical air currents indicating unstable atmospheric conditions and the possibility of gusty or strong winds. The heights of cumulus clouds indicate the depth and intensity of the instability.

Cumulonimbus clouds, often called thunderheads may indicate strong, gusty winds that shift erratically as a storm passes. Gusty winds are a sure sign of unstable air. Watch out for these clouds when they move into a wildland fire area!

Stratus cloud sheets are your friends! They indicate stable layers in the atmosphere with little or no winds.

Knowledge Check 13

Multiple choice—check the box of the answer(s) you choose.

Cloud formations can help identify atmospheric instability.

Select the factors of atmospheric instability that cumulus clouds can aid you in identifying.

- [ ] **Depth and intensity**
- [ ] **Duration and speed**
- [ ] **Direction and vertical movement**
- [ ] **Breadth and span**

The correct answer is depth and intensity.

Inversions

Atmospheric temperature normally gets cooler the further up in the atmosphere it travels. However, in an *inversion* layer, the opposite occurs—the temperature actually increases with height. In such situations, the air is said to be stable. This causes fire activity to remain stable as long as the inversion layer is present.

Under an inversion, fuel moisture content is usually higher, decreasing ROS and fire intensity. Updrafts of smoke and warm gases generated by a fire are typically weak and will only rise until their temperature equals that of the surrounding air. Once this occurs, the smoke flattens out and spreads horizontally. Increased wildland fire behavior is almost certain when inversions break or lift due to heating of the lower atmosphere by the sun or a fire.

Warning

While the breaking up of an inversion is usually gradual, it can occur quite rapidly; when it does, fire activity can increase dramatically and threaten firefighters. Watch for these indicators when an inversion breaks:

- **Increase in temperature**
- **Decrease in RH**
- **Increase or shift in wind**

Narration Script: Inversion layers allow firefighters the opportunity to control fires. Generally, a "normal" atmosphere has temperatures that decrease with height. In other words, it gets cooler the farther up in the atmosphere you travel. But an inversion layer is exactly opposite. The temperature increases with height. This creates a situation where the air is stable and fire activity remains stable as long as the inversion layer is present.

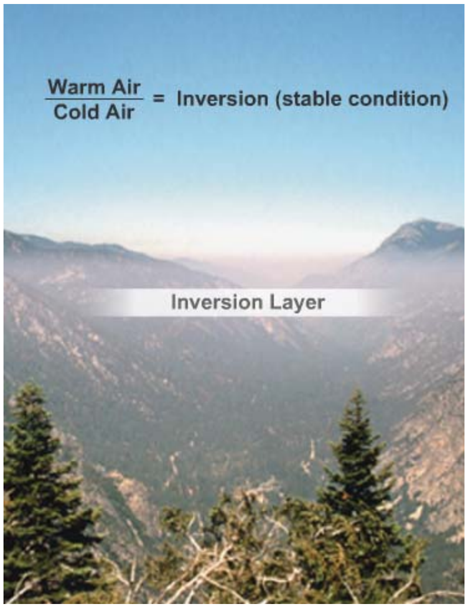
Inversion types

We will investigate these types of inversions and learn how they can affect wildland fires:

- **Night inversions**
- **Subsidence inversions**
- **Marine inversions**

Inversions can often be spotted because you see a layer of clouds or smoke hanging over a surface. Keep reading to learn more about night, subsidence, and marine inversions.

Narration Script: Inversions can often be spotted because you see a layer of clouds or smoke hanging over a surface. You might have noticed the effect of inversions if you've ever ridden a bicycle or motorcycle on a cool winter's night. As you ride, you may cruise through both warm and cool pockets of air. This difference in air temperature is caused by an inversion. You may find that you experience the same type of temperature differences when moving up an incline when fighting a wildfire. Now, there are different types of inversions, so keep reading.



Caption: An example of an inversion layer.

Night inversions

Air cooled at night, primarily by contact with cold surfaces, gradually deepens as the night progresses and forms a surface inversion. Inversions forming at night near the earth's surface are commonly referred to as a radiation or night inversion. Nighttime inversions develop on calm, clear nights when radiational cooling of the earth's surface is greatest, and can differ in strength depending on the time of year. Inversions in the winter are typically stronger than inversions that develop in the summer.

Nighttime inversions are easy to identify because they trap smoke and gases, resulting in poor visibilities in valleys or drainages. After sunrise, night inversions begin to break up—winds increase, temperature rises, and RH decreases. This means that you may have a more active fire on your hands.

Narration Script: Night inversion—is that a rock band? No, as the name implies, these inversions usually occur at night, when the ground cools quickly, cooling the air directly in contact with it. Air is a poor conductor of heat, so the air closest to the surface cools quickly, while the air further up remains warmer. This happens more quickly at night because the sun has gone down and cool air moves in. Because inversions promote atmospheric stability and therefore tend to reduce fire activity, they can be a welcome sight.

Night inversion factors

Before we move on to the other basic types of inversions, let's chat a bit more about night inversions. These types of inversions are not only affected by the cool air moving in during nighttime hours, but also by:

- **Topography**
- **Temperature**
- **Humidity**

Warning

Be especially careful at night because the dangers of fighting an active fire are compounded by the hazard of darkness.

Narration Script: We've mentioned that night inversions can reduce fire activity; but as the sun rises and night inversions dissipate during the morning hours and into the day, unstable air can form around the fire incident causing the fire's behavior to increase. You have to stay on your toes and pocket this information in your weather behavior tool belt. It can help you predict an increase or decrease in fire activity.

Inversions and topography

Hills, valleys, canyons—all that you might call the "lay of the land" have a big influence on inversions. You know this more formally as topography.

For example, surface layers are relatively shallow on mountain slopes and in open canyons or ravines. In these areas, there is little surrounding mass or earth to hold the cold air in; therefore, cold air can simply drain away. This dense, cold air flows downward and gathers in valleys and small depressions where there is more earth to literally hold the cold air in. Another example is patches of ground fog in surface depressions along highways. These patches are small-scale inversions.

Narration Script: The dissipation of air may cause unstable air around the fire area and increase fire activity. Again, understanding the factors affecting inversions will help you predict an increase or decrease in fire activity.

Inversion strength

Knowing the strength of a night inversion is important because it will tell you how quickly the inversion will dissipate and alter fire activity. The stronger the inversion, the more likely it will "hang around." Weaker inversions are more likely to dissipate sooner rather than later.

Measurements of temperature and humidity can indicate the strength of a night inversion. Within an inversion layer, the temperature increases with elevation and may change as much as 25° F (14° C) in 250 vertical ft. (76 m).

In mountainous areas, the height of the top of a night inversion is usually below the main ridges. However, this height can vary from night to night. This is the point at which the temperature begins to decrease again. The height of the warmest air temperature at the inversion top can be found by measuring temperatures along the slope. From this level, the temperatures decrease farther up or down the slope. At this point, we begin to move into what is considered the thermal belt. You will learn more about that in the next discussion.

Narration Script: In the absence of a visible smoke or cloud layer, the top of the inversion can be found by measuring temperatures at various points up and down the slope. The warmest air temperature is at the top of the inversion and temperatures decrease as one goes farther up or down the slope. Both the highest minimum temperatures and the least daily temperature variation of any level along the slope occur at the top of the inversion. The lowest nighttime RH and the lowest nighttime fuel moisture are also found at this level as well.

Thermal belt

Here's a hint; the thermal belt is not a tool to keep your pants up. A *thermal belt* is the top of an inversion layer. "Thermal" means warm (think thermal underwear). The top of an inversion layer is known as the thermal belt because of the somewhat higher temperatures found there. This area is characterized by the:

- **Least amount of variation in daily temperatures**
- **Highest average temperature**
- **Lowest average humidity**

Fires located above, below, and in the thermal belt can all behave differently.

Narration Script: The inversion layer consists of decreased temperatures both above and below the inversion layer. The warmest air temperature is at the top of the inversion, and this is called the thermal belt. Wildland fires within the thermal belt can remain quite active during the night.

However, below the thermal belt, fires are in cool, humid, and stable air, often with downslope winds. Fires located here can remain fairly stable.

Above the thermal belt, temperatures decrease with height. And while generally we would say that the decrease in temperature helps keep the fire activity under control, the effect of the lower temperatures at this level, however, may be offset by stronger winds and less stable air as fires enter the region above the thermal belt

Subsidence inversions

Subsidence is the large-scale sinking of air associated with high-pressure systems and usually contributes in the development of *foehn winds***. As air from higher elevations in high-pressure systems descends to lower elevations, it warms and dries. The warming and drying of air sinking is so pronounced that saturated air (air with 100 percent RH) can produce RH less than 5 percent very quickly.**

If a high-pressure system persists for a period of days, the subsidence inversion may reach the surface with very little external modification or addition of moisture. Burning conditions can become severe during subsidence inversions because:

- **Skies are typically clear or cloudless.**
- **Extended periods of above-average temperatures and below-average RH can dry out fuels.**

Narration Script: Subsidence is the large-scale sinking of air associated with high-pressure systems. As air from higher elevations in high-pressure systems descends to lower elevations, it warms and dries. The warming and drying of sinking air is so pronounced that saturated air with 100 percent RH can produce RH less than 5 percent in a very short period of time.

Marine inversions

Just like a wildfire, not all inversions are alike. Coastal or *marine inversions* occur on both the West and East coasts of North America and are quite different from a nighttime inversion in the Rocky Mountains. Marine inversions are common in the summer and may be caused when winds reverse at night and become a land breeze. Even though the inversions on the West and East coasts are produced by the same weather phenomena, the inversion patterns are different.

Read the following to investigate the differences for each coast.

West Coast Marine Inversions

Cool, moist air from the Pacific spreads inland in a layer that may vary in depth from a few hundred to several thousand feet (meters). It continues to spread inland until stopped by a much warmer, drier, and relatively unstable air mass.

East Coast Marine Inversions

The terrain along the eastern seaboard is not as mountainous as on the West Coast, so the interaction between weather and topography does not produce the same inversion patterns. The daytime sea breezes on the east coast usually extend 5 to 6 mi. (8 to 10 km) inland but may extend as much as 25 mi. (40 km) from the coast.

Narration Script: Marine inversions are the strongest and most noticeable at night although they may persist in some areas even during the day. After sunset, fog and stratus clouds often form in the cool marine air and move inland into coastal basins and valleys. If the layer of cold air is relatively shallow, fog usually forms. If the layer of cold air is deep, stratus clouds are more predominant.

Knowledge Check 14

Multiple choice—check the box of the answer(s) you choose

Let's see if you're feeling a little inverted right about now.

Identify THREE correct statements about inversions.

- ☐ **Air is extremely stable in an inversion layer.**
- ☐ **Inversions on the West Coast are called marine inversions.**
- ☐ **Inversions on the East and West coasts act similarly to inversions in the Rocky Mountains.**
- ☐ **Inversions on the East Coast are called nighttime inversions.**
- ☐ **Temperatures decrease both above and below an inversion layer.**

The correct answers are air is extremely stable in an inversion, inversions on the West Coast are called marine inversions, and temperatures decrease both above and below an inversion layer.

Unstable atmosphere

Now that you know what a stable atmosphere is, let's look at what makes up an unstable atmosphere. These next couple of subjects might even be a recap of some of the conclusions you may have already gathered from the previous discussion.

An unstable atmosphere is defined as an atmosphere that encourages upward motion, pushing cold air over warm air. When the atmosphere is unstable, vertical motions increase, contributing to increased fire activity by:

- **Allowing** *convection columns* **to reach greater heights, producing stronger indrafts and** *convective* **updrafts**
- **Increasing the lofting of flying sparks or embers by updrafts**
- **Increasing the occurrence of** *dust devils* **and** *firewhirls*
- **Increasing the potential for gusty surface winds**

When the air is unstable, wildland fires burn hotter and with more intensity.

<u>Narration Script: Remember, stable air discourages the vertical movement of air and tends to reduce fire activity, while UNstable air encourages the vertical movement of air and tends to increase fire activity.</u>

Atmospheric instability and visual indicators

Visual indicators can reveal important information about local atmospheric conditions. Get to know these indicators of an unstable atmosphere:

- **Clouds grow vertically and smoke rises to great heights**
- **Cumulus clouds and good visibility**
- **Gusty winds and dust devils or firewhirls**

Narration Script: When the air is unstable, you'll experience gusty winds and see cumulus clouds. Both clouds and smoke will spread vertically, almost in columns. You'll also notice you can see for what seems like miles in any direction, with only dust devils and whirlwinds interrupting your line of sight.

Knowledge Check 15

Matching—select the match you choose from the pull down list.

Let's see whether your knowledge of the atmosphere is stable or unstable.

Match the atmospheric terms to the appropriate descriptions. You may use each term more than once.

Stable air	Increases the potential for gusty surface winds
Stable air	Increases the potential for gusty surface winds
Stable air	Increases the potential for gusty surface winds
Unstable air	Increases the potential for gusty surface winds
Unstable air	Increases the potential for gusty surface winds

The correct matches are as follows:
Stable air: Discourages the vertical movement of air
Stable air: Tends to spread smoke horizontally
Stable air: Usually increases fuel moisture content
Unstable air: Tends to increase fire activity
Unstable air: Increases the potential for gusty surface winds

Wind

***Wind* is basically air in motion. It is the horizontal movement of air relative to the surface of the earth and is measured in terms of:**

- **Direction—you'll describe a wind's direction in terms of where it is blowing from so that a "north wind" is blowing from the north to the south**
- **Speed—measure wind in miles per hour (mph)**
- **Turbulence—how gusty is the wind?**

The two most important weather-related elements affecting wildland fire behavior are wind and fuel moisture. Of the two, wind is the most variable and the least predictable. Wind can quickly move a fire in different directions.

Narration Script: Wind is nothing but moving air. You can describe wind in terms of three characteristics: direction, speed, and turbulence or *gustiness*. Surface winds are strongly affected by topography and by local heating and cooling. These factors are responsible for much of the wind's variability, and variability puts the "X factor" into predicting a fire's movement and behavior.

Effects of wind

The rate and direction of fire spread are mostly functions of wind speed and direction. The expected winds must be considered in the development of any wildland fire-control plan. Anticipating these changes increases firefighter safety and helps ensure the success of fire-control efforts.

Wind behavior determines the direction of spread for a wildland fire and has the following effects:

- **Direct**
- **Indirect**

Read the following to learn more.

Direct Effects

The direct effects of winds are caused when wind:

- **Intensifies the burning by increasing the amount of oxygen available to the fire**
- **Bends flames, preheating and drying uninvolved fuels making them more susceptible to ignition**
- **Can carry embers and sparks more than 1 mi. (1.6 km) ahead of the fire into unburned fuels, resulting in spot fires and increasing the ROS**

Indirect Effects

The indirect effects of wind are observed in the following ways:

- **Strong, dry winds absorb the moisture from the fuels. However, cool winds can help wildland fuels retain their moisture.**
- **Because wind speed and direction can change rapidly, wind-induced fire behavior may also change rapidly.**
- **Wind affects how long the flaming front of the fire remains in an area—called the residence time—and influences the amount of fuel consumed by the fire. The stronger the wind, the shorter the residence time and the less fuel is consumed.**

<u>Narration Script: The two most important weather-related elements affecting wildland fire behavior are wind and fuel moisture. Of the two, wind is the most variable and the least predictable. Numerous firefighter deaths have been in some way related to wind behavior. Wind not only adds to the unpredictable nature of fire spread, but also delivers more oxygen to the fire.</u>

Types of wind

Like RH, local topography and regional variability produce different types of winds. We've boiled down three of the essential types of wind here:

- **General winds**
- **Local winds**
- **Convective winds**

We'll cover each type of wind in this order.

Narration Script: Local, general, and convective winds all act to push the fire along the surface at a faster rate and potentially push the fire toward new fuel sources. Each type of wind can pick up fire embers and transfer them to other areas, igniting other fuel sources and creating what are called spot fires. Stay tuned as we investigate each type of wind.

General winds

The terms "high- and low-pressure system" are tossed around frequently on your local weather channel. Two types of *general winds* are associated with high- and low-pressure systems:

- *Frontal winds*
- **Foehn or gravity winds**

We discuss both of these general winds in detail on the next pages so keep moving on.

Narration Script: Let's first turn our attention to general winds. We'll break down general winds a bit further into frontal and foehn winds.

Frontal winds

Air masses **come in two packages—either warm or cold—depending on temperature and moisture content. The leading edges of the two air masses are called** *fronts***—and they create *frontal winds*.**

When cold air masses replace warm air masses, the leading edge of the cold mass is called the *cold front***. Conversely, when a warm air mass replaces a cold air mass, the leading edge of the warm mass is called the** *warm front***. You really want to keep your eyes on cold fronts. Cold fronts have a much more dramatic impact on fires than a warm front, but either one can bring changes in wind direction and intensity.**

You must understand the chilly (and dangerous) reception a cold front can bring you. When a cold front advances on a warm front, it produces dramatic results making a fire extremely difficult to control. A cold front's influence includes:

- **Gusty winds changing direction sharply and distinctly**
- **Surface winds alter natural convection currents and cause longer horizontal flames resulting in preheated fuels**
- **Strong, shifting winds cause erratic wildland fire behavior and increase the potential for spotting downwind**
- **Active head and flanks (sides) with high heat outputs develop because of the strong wind**

Narration Script: The first type of general wind we'll investigate is frontal winds. Frontal winds are the leading edge of either cold or warm fronts. Though both warm and cold fronts cause weather changes affecting a fire's behavior, you really want to beware of a cold front moving in. When a cold front advances on a warm front, it produces strong and gusty winds that change quickly. As the front moves in, surface winds alter natural convection currents and cause longer horizontal flames so you get preheated fuels ahead of the fire preheating. These winds also cause a fire to develop a very active head and flanks, which generate an extremely high heat output. Like any type of wind, embers can be picked up and fly well ahead of the fire producing spot fires. Put these factors together and controlling a fire becomes a monumental task.

Foehn wind

Foehn winds are often named according to their location. So, Santa Ana wind, North wind, Chinook—these are all local terms for *foehn winds* (also called *gravity winds*). These winds result from air being forced over mountain ridges by convection or high barometric pressure and are described as:

- **Strong**
- **Hot**
- **Dry**
- **Persistent**
- **Unfavorable for wildland fire control**

These types of winds are important to you because they can quickly turn a wildland fire into a firestorm.

Common Foehn Winds

The locations of the common foehn winds in the western United States are:

- **Chinook wind—the east side of the Rocky Mountains and east side of the Sierra Nevadas**
- **Wasatch wind—on the west side of the Wasatch Range in Utah**
- **Santa Ana and Sundowner—Southern California**
- **Mono and North wind—central and northern California**
- **East wind—western Washington and Oregon**

Narration Script: Another type of general wind is called foehn or gravity winds. "Chinook," "Santa Ana," and "North" winds are all examples of local names for these types of winds. Foehn winds contribute to rapid wildland fire spread. These winds result from air being forced over mountain ridges by convection or high barometric pressure. The air then cascades downslope as gravity winds. As the air drops in elevation, the atmospheric pressure increases, which causes the air to compress and heat. The resulting winds can create poor conditions for wildland fire control.

Knowledge Check 16

Multiple choice—check the box of the answer(s) you choose

You could probably use a cool breeze right about now. Take a moment to check your knowledge of wind activity.

Identify THREE correct statements about general winds.

- ☐ **Chinook is a local term for frontal winds.**
- ☐ **The leading edges of air masses are called fronts.**
- ☐ **As a cold front moves in, surface winds cause longer vertical flames.**
- ☐ **Foehn winds cause a fire to develop a very active head and flanks.**
- ☐ **Foehn winds are described as strong, hot, and dry.**
- ☐ **Both types of frontal winds can bring changes in wind direction and intensity.**

The correct answers are the leading edges of air masses are called fronts; foehn winds are described as strong, hot, and dry; and both types of frontal winds can bring changes in wind direction and intensity.

Local winds

***Local winds* are a by-product of the daily heating and cooling of the earth's surface referred to as the diurnal cycle. Your local wind pattern is directly related to these factors:**

- **Land masses heat more rapidly than bodies of water during the daytime and cool more rapidly at night.**
- **Darker soils absorb more solar heat than lighter soils.**
- **Bare soil absorbs more solar heat than grass-covered soil.**
- **In hilly or mountainous terrain, heating generally causes upslope winds; cooling causes downslope winds.**
- **In flat terrain, heating can produce whirlwinds or dust devils.**

Narration Script: Hilly terrain causes various changes in local winds. For example, as the terrain, such as a mountain or hill rises, the heat will create an upslope local wind. The air at this point will increase in temperature. As the air moves up and over the mountain and comes down the other side, a downslope, local wind is created by the cooler air. As the wind moves into flat terrain, the heat mixing with the cooler air coming from the downslope wind can create dust devils, whirlwinds, or other unpredictable behaviors.

Convective wind

***Convective winds* are essentially general winds that are affected by the localized heating of air that expands and rises while cooler, denser air comes in to replace it. Examples of convective winds include:**

- **Slope and valley winds**
- **Land and sea breezes**

- **Thunderstorm winds**
- **Whirlwinds**
- **Firewhirls**

As with the other weather factors, each wind type carries a specific danger. We'll describe each type of convective wind in the coming screens.

Narration Script: We've looked at local and general winds, and there is just one other type of wind that we will cover here—convective winds. As you learned earlier in this course, convection is one method of heat transfer. As you might have guessed from your prior knowledge of convection, *convective winds* are caused by the localized heating of air that expands and rises while cooler, denser air descends to replace it. As you'll soon learn, the massive heat from a fire can create its own convective wind system. As we did for general winds, we'll break down convective winds into the sub-types listed here.

Slope wind

In steep terrain, wildland fires are greatly influenced by *slope winds*. Except for foehn conditions mentioned earlier, slope winds:

- **Flow up during the day due to surface heating**
- **Flow down at night because of surface cooling**

Large wildland fires produce their own slope winds by heating the air, causing the hot air to rise rapidly up the slope. To match the speed of the rising warm air, cold air moves down toward the fire.

Narration Script: Slope winds are local winds that develop in mountainous terrain where differences in heating and cooling occur. Typically, the local wind pattern moves upslope during the day and downslope during the night.

Upslope and valley winds

Upslope winds are produced when the air in the valleys rises as it becomes warmer than the air along the mountaintops. East facing slopes receive solar energy at sunrise, so the downslope-to-upslope change takes place first on east aspects. Southwest and west facing slopes receive heat later in the morning, so their upslopes usually take place by late morning. Continued heating throughout the day produces larger and faster upslope winds. By midday, winds may reach 7 to 10 mph (11 to 16 km/h). No longer just localized winds, they become up-canyon or *valley winds*.

Narration Script: Though we keep stressing the unpredictability of wind itself, there are patterns to its development you can rely on. In this case, mountain convective winds follow a daily cycle caused by the heating and cooling of the ground and air. As the sun rises, local winds develop and eventually grow to upslope valley winds with a speed of 7 to 10 miles per hour. Though the steepness of slope also plays a role, stronger upslope winds lead to faster uphill fire spread.

Downslope wind

Downslope and down valley winds are produced when the air along the mountaintops sinks as it becomes cooler than the air in the valleys. Because east aspects lose solar energy first, the change from upslope to downslope occurs on east aspects early in the afternoon.

Southwest and west facing slopes receive solar energy through much of the afternoon, so their downslope wind typically begins just after sunset. After sunset, the downslope winds intensify, flowing into canyons or valleys at an average of 5 to 7 mph (8 to 11 km/h), allowing fires to burn actively throughout the night in the thermal belt.

Warning

The change in wind from downslope to upslope can rapidly change wildland fire behavior from inactive to active in a matter of minutes. Though the steepness of slope also plays a role, stronger upslope winds lead to faster uphill fire spread. Downslope winds seldom produce dangerous conditions; however, strong downslope winds, increased by the steepness of the terrain, can result in downhill runs.

Narration Script: When the sun fades in the afternoon and the air cools, valley winds switch directions and begin a downslope movement of 5 to 7 miles per hour. Downslope winds seldom produce dangerous conditions; however, strong downslope winds, increased by the steepness of the terrain, can result in downhill runs.

Chimneys and wind

Mountains not only have slopes and valleys, but they also have steep V-shaped crevices, *saddles*, and narrow canyons. When wind flows through areas of least resistance, such as a steep V-shaped drainage, a chute, a saddle, or a narrow canyon, wind speeds can increase significantly. These terrain features sometimes referred to as *chimneys* may also create unstable updrafts in response to localized heating, causing a chimney effect. This updraft can increase fire activity or at the very least make fire activity a bit unpredictable.

Warning

Fires in drainages or chutes may spread at an alarming rate, so these formations are always very dangerous locations during wildland fires. Wind-driven fires sweeping through these terrain features have been associated with many firefighter injuries and fatalities. These areas should never be used as safety zones.

Narration Script: Normal valley winds travel through crevices in a fairly predictable fashion until the wind encounters a steep crevice or chute, and dramatically increases. This crevice allows heat to rise rapidly, and a chimney effect is created when heated air rises rapidly as it would in a flue pipe—hence the term, “chimney effect.”

Knowledge Check 17

Multiple choice—check the box of the answer(s) you choose

It's time to make sure you're floatin' in the breeze when it comes to the convective winds we've covered so far.

Identify FOUR correct statements about convective winds.

- ☐ **Chimneys can create unstable updrafts in response to localized heating.**
- ☐ **Upslope winds become valley winds when they reach 7 mph (11 km/h).**
- ☐ **Wildland fires produce their own slope winds.**
- ☐ **Downslope winds often produce dangerous conditions.**
- ☐ **East aspects of mountainsides gain and lose solar energy first.**
- ☐ **Fires in drainages or chutes may spread very quickly.**

The correct answers are chimneys can create unstable updrafts in response to localized heating; upslope winds become valley winds when they reach 7 mph (11 km/h); east aspects of mountainsides gain and lose solar energy first; and fires in drainages or chutes may spread very quickly.

Land and sea breeze

***Land and sea breezes* are found along the ocean shores and around larger inland bays and lakes. Several types of land and sea breezes can form:**

- **Landward sea breeze**
- **Land breezes at night**
- **Pacific coast sea breeze**

Read the following to learn more about each type of land or sea breeze.

Landward Sea Breeze

Landward sea breezes move from the sea to the land beginning around midday, strengthening during the afternoon, and ending around sunset. The timing can vary considerably due to local atmospheric conditions such as cloudiness and general winds. The breezes begin at the coast, gradually pushing farther and farther inland, reaching maximum penetration about the time of highest inland temperatures.

In the eastern and southeastern United States, thunderstorms frequently develop as sea breezes move inland from the coast. The movement inland results in weather similar to cold fronts, and can cause fire control and safety problems. This can cause changing weather conditions, such as:

- **Strong shifting winds**
- **Cooler temperatures**
- **Higher RH**
- **Potential heavy rains**

Land Breezes at Night

Land breezes at night are the opposite of the daytime sea-breeze event. At night, land surfaces cool more quickly than water surfaces, and air in contact with the land then becomes cooler than that over the ocean. A pressure difference develops and causes air to flow from the land to the water instead of from the water to the land.

Pacific Coast Sea Breezes

Along the Pacific coast, sea breezes may attain speeds of 10 to 30 mph (16 to 48 km/h), but fog or low clouds, very cool temperatures, and high humidity often move inland in the process. These winds may initially increase fire activity, but the cooler temperatures and higher humidity eventually cause it to diminish.

<u>Narration Script: Turning from slope and valley winds, let's sail on to the next type of convective wind—these are land and sea breezes. Sea breezes are found along the ocean shores. But the same phenomenon also occurs around larger inland bays and lakes.</u>

Thunderstorm wind

We will give you more information on thunderstorms later in this topic. However, here we're concentrating on the effects of thunderstorm winds. Thunderstorm winds are a good indication of an unstable air mass and generally arise as a result of extreme differences in localized heating of the air near the ground. The winds they produce are very strong, often unpredictable convective winds and can produce whirlwinds and firewhirls.

For more on whirlwinds and firewhirls, proceed to the next page.

<u>Narration Script: Thunderstorms not only produce the high, gusty winds that can quickly affect the direction of fire spread, but they also produce the lightning that can start wildland fires. Thunderstorm winds are another type of convective wind and can produce whirlwinds and firewhirls. When you spot a thunderstorm or know one to be in the area, you and the crew should be on high alert.</u>

Whirlwinds and firewhirls

While whirlwinds, also know as dust devils, are considered less dangerous than firewhirls, they both have a similar beginning. Each is a good indicator of instability as a result of intense local heating.

Whirlwinds

Whirlwinds generally happen on hot days over flat, dry terrain when skies are clear and general winds are light. Because burned-over areas are black or dark gray, they are more susceptible to heating by the sun than unburned areas, so dust devils often form in the

black. Dust devils can not only increase a fire's intensity if they move into the flames, but they can cause spotting by picking up burning materials in the black and depositing them in the green.

The size of dust devils can range from 10 ft. (3 m) to over 100 ft. (30 m) in diameter with heights from 10 ft. (3 m) to 3,000 or 4,000 ft. (914 to 1,219 m). Wind speeds in dust devils are often more than 20 mph (32 km/h) and in some extreme cases have exceeded 70 mph (113 km/h).

Firewhirls

Firewhirls are spinning, moving columns of rising air and fire gases carrying smoke, debris, and flames high into the air and therefore a pose a risk for creating spot fires. Ranging from a foot or two (30 to 60 cm) in diameter to the size of a small tornado, firewhirls are dangerously awe inspiring.

Firewhirls may be caused by the same conditions that create dust devils, but they may also be caused by:

- Thunderstorms
- Intense heating within a fire
- Wind shears

You'll find firewhirls on the protected side of elevated terrain features. Because of the intensity with which firewhirls burn, a direct firefighting tactic is likely to be ineffective *and* unsafe.

Knowledge Check 18

Matching—select the match you choose from the pull down list.

Hopefully, you're not blown away by the variety and types of winds. Let's find out.

Match each wind type with its correct description.

Slope wind	Flows from the ocean toward the inland
Landward sea breeze	Flows from the ocean toward the inland
Thunderstorm winds	Flows from the ocean toward the inland
Whirlwinds	Flows from the ocean toward the inland
Firewhirls	Flows from the ocean toward the inland

The correct matches are as follows:
Slope wind: Flows up during the day and down during the night
Landward sea breeze: Flows from the ocean toward the inland
Thunderstorm winds: Created by cumulus clouds and can be gusty and erratic
Whirlwinds: Tend to develop in blackened, burned, and flat terrain
Firewhirls: Spinning columns of rising air carrying gases, fumes, and debris

Critical fire weather conditions

From a discussion of temperature, RH, precipitation, atmospheric stability, and wind, we now move into a discussion of critical fire weather conditions you should look for at every wildland incident.

Fire seasons occur at different times of the year in different regions of the country, depending on seasonal variations in weather. The typical fire season at any given location has numerous hot and dry days, yet wildfires are usually clustered within relatively short periods. These periods are characterized by one (or a combination of) critical fire weather conditions:

- **Strong and shifting wind**
- **Very low RH**
- **High temperature**
- **Unstable atmosphere**
- **Dry lightning**

Narration Script: Depending on where you live, your fire season may occur at slightly different times of the year than the fire seasons other wildland firefighters face. However, even though the timing may be a little different, all wildland firefighters will face the same types of critical fire weather conditions: strong and shifting winds, very low RH, high temperatures, an unstable atmosphere, and dry lightning.

Weather phenomena

These critical fire weather conditions may occur during one or more of the following weather phenomena:

- **Cold fronts**
- **Foehn winds**
- **Thunderstorms**
- **Dust devils and firewhirls**

You will investigate each weather phenomena in turn.

Narration Script: Cold fronts, foehn winds, thunderstorms, dust devils, and firewhirls are all examples of weather phenomenon in which one or more of the critical fire weather conditions may occur.

Cold front characteristics

As we mentioned earlier, *cold fronts* make fires extremely difficult to control. Cold front characteristics include:

- **Warm and unstable air mass ahead of the front—resulting in an increase in fire behavior**
- **Gusty winds—ranging from 15 to 30 mph (24 to 48 km/h)—just ahead, along, and behind the front**

- **Light southeasterly winds several hundred miles (km) ahead of the front**
- **Moderate to strong southwesterly winds just ahead or along the front—driving the fire head to the northeast**
- **Low or high RH, depending on the origin or location of the system**
- **Winds abruptly shifting from southwest to northwest as the front pushes through—driving the fire head to the southeast and increasing fire behavior on the south flank of the fire**

Narration Script: As you learned earlier in this topic, a cold front is the leading edge of a cold air mass. The most important thing you need to know about cold fronts is that as they pass through, they can produce strong winds and abrupt wind shifts. This can cause significant changes in fire behavior.

However, while you're reading about the seriousness of cold fronts, also keep this thought tucked away in the back of your mind: Fire activity typically decreases after a cold front passes through because the air mass behind the cold front is cooler, more stable, and the RH is higher.

Cold front indicators

Cold front indicators include:

- **A line of cumulus clouds approaching from the west or northwest**
- **Large clouds of dust preceding the front's arrival**
- **Winds shifting from the southeast to the south and southwest and increasing in velocity before the front's arrival**

As the front reaches you, winds will be strongest and gustiest, and they'll continue to shift as the front passes—generally resulting in strong, gusty, cool wind out of the northwest

Knowledge Check 19

Multiple choice—check the box of the answer(s) you choose.

Let's see whether your knowledge of cold fronts can warm you up.

Identify THREE correct statements about cold fronts.

- ☐ **One cold front indicator is a line of cumulus clouds approaching from the southwest.**
- ☐ **Large clouds of dust often precede the arrival of a cold front.**
- ☐ **Wind velocity increases before a cold front arrives.**
- ☐ **A cold front pushes a warm and stable air mass ahead of it.**
- ☐ **A cold front can have low or high RH depending on its origin or location.**

The correct answers are large clouds of dust often precede the arrival of a cold front; wind velocity increases before a cold front arrives; and a cold front can have low or high RH depending on its origin or location.

Foehn wind characteristics

As we explained earlier, *foehn wind* is a type of general wind occurring when stable, high-pressure air is forced across and then down the lee slopes of a mountain range. Foehn winds can persists for days and frequently reach speeds of 40 to 60 mph (64 to 97 km/h) but can be as high as 90 mph (145 km/h). Additionally, the RH will usually drop at the onset of foehn winds. The combination of high wind speeds and low RH can cause high ROS. When a foehn wind occurs after a long period of dry weather, wildland fire behavior can be extreme.

Narration Script: Foehn winds are strong, dry winds caused by the compression of air as it flows down the lee side of a mountain range. They're usually, but not always, warm for the season. When the R-H drops and the wind speeds pick up, foehn winds can quickly turn a wildfire into a firestorm.

Thunderstorms

We've talked the talk with cloud cover and inversions. Let's walk the walk by spotting weather-related activity affecting fire behavior. Thunderstorms are one such meteorological event.

Thunderstorms are violent local storms sometimes spawned by cumulonimbus clouds. They are usually of short duration, seldom lasting over two to three hours for any one storm. They can produce thunder, lightning, heavy rains, and hail. It's their convective activity in the atmosphere generating high-velocity updrafts and downdrafts on the ground that can affect the direction of a fire—but we'll talk more about that in the coming screens.

"Wet" thunderstorms can produce heavy precipitation, moistening fuels and bringing relief to fire activity. "Dry" storms pose more danger. They carry little moisture but do bring lots of wind and lightning, bringing even more hazards to the area.

Narration Script: "A 407-acre fire has destroyed an estimated 75 homes, a major sawmill, and other businesses. Crews battling fierce forest fires in the parched mountains of British Columbia managed to hold their own against the flames yesterday, but they kept a nervous eye on the sky for the forecasted thunderstorms bringing little moisture and high winds and lightning strikes."

Thunderstorm danger

Looking out your window as a kid and seeing lightning is pretty cool. Out in dry fuels or in the heart of a wildland incident, the cool factor hits new lows. Cumulonimbus clouds are often the harbinger of lightning, rain, and hail.

Three factors make thunderstorms important elements in wildland fire behavior:

- **Fire-starting potential of cloud-to-ground lightning strikes**
- **Updrafts**
- **Downdrafts**

Warning

The sudden and often violent changes in wind speed and direction that accompany thunderstorms can radically alter fire behavior.

Read the following to learn more about the dangers thunderstorms carry.

Lightning Strikes

Cloud-to-ground lightning strikes occur approximately 25 million times per year in the United States. On the average, lightning strikes the earth about 100 times every second (now that's something to keep in mind when you are out playing golf during a thunderstorm). It only takes one lighting strike in the "right" batch of fuels to start a wildfire.

Updrafts

Updraft winds are most common when a storm is developing. If a storm is not moving, the wind direction will usually draw the fire toward the thunder cell. This means that if the fire is moving in one direction and a storm moves in, your fire direction may quickly shift.

Downdrafts

Downdrafts produced during thunderstorms create strong, erratic, gusty winds of short duration. As the storm matures and then begins to dissipate, these downdrafts become the prominent wind and can reverse the direction of fire spread.

Narration Script: Each thunderstorm cloud mass is made up of individual cloud groups called cells. Each cell may range up to 10 miles in diameter. And each cell cluster is often in a different stage of weather development. Amazingly, these cell clusters may interconnect to each other to form a cloud mass that can extend over 50 miles. Add a thunderstorm to the mix of a fire's behavior and you can encounter some erratic behavior. Storms can produce fire-starting lightning strikes and cause unpredictable winds.

Lightning

Cloud-to-ground lightning is a common type of lightning and the most dangerous type of lightning for a firefighter and for causing wildland fires. Lightning discharges can occur miles ahead of the main storm and will strike without warning—even on a sunny day. Lightning strikes are signs of an approaching storm and quite often are associated with storms that have little or no precipitation reaching the ground.

Cloud-to-Ground Lightning

These types of storms are sometimes called *dry thunderstorms*, and they occur mainly in the mountains of the West. Hundreds of lightning fires can be started during a single day. Additionally, you are at risk of being struck by positive ground flashes that may reach the

ground as much as 40 mi. (65 km) ahead of the cloud formation. While cloud-to-ground lightning can occur before a storm, most ground flashes occur directly below a cumulonimbus cloud. The bottom line is to keep your eyes toward the sky and know what is coming your way.

Narration Script: The Empire State Building is struck by lightning an average of 100 times per year. While trees are not quite as tall as the Empire State Building, they make excellent lightning rods as well. With lightning striking the earth 100 times every second, it's a force to be reckoned with. Firefighters are at risk of being struck by positive ground flashes that may reach the ground as much as 40 miles ahead of the cloud formation.

Visual indicators of thunderstorms

How many times have you heard people say, "It smells like rain"? As you step outside, you can often smell and feel the rain in the air. Some of the visual indicators of lightning and thunderstorms include:

- **Tall, building cumulus clouds**
- **A cauliflower-shape to the top of clouds**
- **Clouds with dark, flat bases**
- **Rain that evaporates before it reaches the ground (this is called virga) or rain falling from the cloud bottom**
- **Anvil-shaped clouds with a fuzzy appearance**

However, know that heat rising from a fire can itself form a convection column so strong that it triggers the development of a thunderstorm, even on an otherwise cloudless day.

Narration Script: We're NOT saying your trick knee isn't a useful tool for predicting thunderstorms, but try some visual indicators first. They include: tall, building cumulus clouds; a cauliflower-shape to the top of clouds; clouds with dark, flat bases; rain that evaporates before it reaches the ground a phenomena called "virga"; or anvil-shaped clouds with a fuzzy appearance

Thunderstorm movement

The path of a thunderstorm is generally indicated by the direction in which the anvil-shaped cloud top is pointing. Usually the storm is moving in the direction of the winds in the upper area of the storm. This means that your fire may spread in the direction of the downdraft as the storm approaches. Remember the anvil-shaped cloud points in the direction the wind is blowing. Expect your fire to react to that wind movement.

When the storm moves over you and winds reach the ground, they usually spread horizontally in all directions. At this point:

- **Wind velocities are often 25 to 35 mph (40 to 56 km/h)**
- **Wind speeds may reach as high as 60 mph (97 km/h)**
- **Surface winds tend to be strongest in the storm's direction of travel**

Narration Script: Clouds are the best visual indicator of all approaching storms. You cannot only see the cloud formation, but you can often see the direction that the clouds are moving based on the formation of the clouds. When the downdraft winds hit the surface level, they can create gusty conditions that are short in duration. But what does that mean to you? It means that they can create conditions that change the fire direction. As you remember from our discussion about wind, both the speed and direction of these strong surface winds can be altered by topography and vegetation.

Thunderstorm wind spread

Winds can become much more unpredictable as the storm moves overhead and departs. As a storm passes, expect these results:

- **Approach—expect winds to blow from the storm *toward* the fire**
- **Over a fire—expect highly erratic winds that can change direction unpredictably**
- **Departure—expect winds to shift so they're blowing *back* to the fire**

So, although thunderstorm winds tend to spread outward from the center of the storm, expect them to shift as much as 180 degrees between the time of a storm's approach and the time that it leaves.

Narration Script: Keep an eye out for shifting winds so you can predict the direction a fire may move in and so you can keep up with a potential increase in fire activity. Wind direction changes significantly as a storm approaches and moves away. Look to the direction of the moving clouds above to predict the incoming wind direction. When the storm is right over the fire, the wind will be very unpredictable. Then as the storm moves away, know that the wind will be pushing back toward the fire. This will literally switch the direction of the fire as the storm moves out of the fire area.

Knowledge Check 20

Multiple choice—check the box of the answer(s) you choose.

How is the wind blowing now?

Identify THREE TRUE statements about wind direction and thunderstorms.

- ☐ **The anvil-shape of a cumulus cloud generally points away from the direction of the wind.**
- ☐ **As a storm moves over the fire, the wind can spread horizontally in all directions.**
- ☐ **As a storm moves out of the fire area, the wind blows from the fire toward the storm.**
- ☐ **The anvil-shape of a cumulus cloud generally points toward the direction of the wind.**
- ☐ **As a storm approaches the fire, the winds blow away from the fire toward the storm.**
- ☐ **As a storm moves out of the fire area, the wind blows from the storm toward the fire.**

The correct answers are the anvil-shape of a cumulus cloud generally points in the direction of the wind; as a storm moves over a fire, the wind can spread horizontally in all directions; and as a storm moves out of a fire area, the wind blows from the storm toward the fire.

Dust devils and firewhirls

Dust devils **(whirlwinds) and** ***firewhirls*** **are two indicators of critical fire weather conditions. As we mentioned earlier in this topic, dust devils:**

- **Generally occur on hot days over flat, dry terrain when skies are clear and general winds are light**
- **Can increase a fire's intensity if they move into the flames**
- **Can cause spotting by picking up burning materials in the black and depositing them in the green**

Firewhirls:

- **Burn intensely**
- **Can create spot fires**
- **Occur on the protected side of elevated terrain features**
- **Are generally considered far more dangerous than dust devils**

<u>Narration Script: Dust devils are one of the most common indicators of unstable air. They occur on hot days, over dry ground, when skies are clear and winds are light. Under intense heating, air near the ground rises in upward spiraling motions, in columns, or chimneys.</u>

<u>Firewhirls generated by intense fires have been known to twist off trees more than 3 feet in diameter. They can pick up large burning embers and spew them far across the fireline, causing</u>

numerous spot fires. In some extreme cases, firewhirls have moved across safe zones and burned or turned over vehicles.

Caption: An example of a dust devil.

Weather forecast resources

There are a variety of resources you can consult to help you "read" local critical fire weather conditions. Some of these resources include specialized fire weather forecasts, such as:

- **Predictive Services**
- **National Weather Service (NWS)**
- **Other**

You will get the weather forecast by examining each of these forecast types in turn.

Narration Script: We've given you a lot of background information for predicting wind and weather patterns—but we're not asking you to be a meteorologist. Being informed is being safe and we want to equip you with the power to help yourself if you can't get information from your IC or outside resources. Hopefully, you'll be a handset call to base camp or radio signal away from getting all the weather-related information you need to help predict the fire's behavior.

Predictive services

Predictive Services is a combined group of interagency land management fire intelligence coordinators or fire behavior analysts (FBAN), and incident or fire meteorologists (IMET). Predictive Services monitors, analyzes, and predicts fire weather, fire danger, and interagency fire management resource impacts.

Predictive Services offers the following products and services:

- **Seasonal assessments**
- **Seven day significant fire potential**
- **Monthly fire weather and fire danger outlook**
- **Weather briefings**
- **Daily summaries of National Weather Service (NWS) fire weather forecasts—graphical and text**
- **Long-term precipitation monitoring**
- **Smoke management summaries**

Narration Script: Agency fire meteorologists, intelligence coordinators, fire behavior analysts, and fuels specialists produce Predictive Services products, including assessments of seasonal fire potential, 30-day fire potential, and seven-day significant fire potential.

National Weather Service

There are over 120 National Weather Service (NWS) offices nationwide—all providing a variety of different types of forecasts. You can use portable radios to receive continuous 24-hour NWS broadcasts, emergency weather warnings, and other civil defense alerts. You can even program these units for a specific county to reduce the amount of radio traffic.

In addition to the NWS fire weather program, you can also access these standardized NWS products:

- **Fire weather planning forecasts (FWFs)**
- **Spot forecasts**
- **Fire weather watches**
- **Red flag warnings**

Read the following to learn more about these NWS products.

Fire Weather Planning Forecasts

FWFs are offered in tabular or narrative format and include a discussion of the upcoming weather and highlights of any critical fire weather events. They also offer many different forecasted elements, including:

- **Sky and weather**
- **Temperature**
- **RH**
- **Wind**

Spot Forecasts

A spot forecast is a site-specific 24- to 36-hour forecast issued to fit time, topography, and weather of a specific location.

Fire Weather Watches

A Fire Weather Watch is issued to advise of conditions that could result in extensive wildland fire occurrence or extreme fire behavior, which are expected to develop in the next 12 to 48 hours, but not more than 72 hours. In cases of dry lightning, a Fire Weather Watch may be issued for the next 12 hours.

Red Flag Warnings

Fire weather forecasters issue a Red Flag warning to alert forecast users to an ongoing or imminent critical fire weather pattern—a Red Flag event. These warnings denote a high degree of confidence that a Red Flag event will occur in 24 hours or less.

Narration Script: Meteorologists produce NWS products, which are geared toward tactical planning, for fire weather zones. NWS products include FWFs, spot forecasts, fire weather watches, and red flag warnings.

Other weather forecast resources

Other weather forecast resources include:

- **Public weather forecasts**
- **Internet**
- **Newspapers**
- **TV weather channels**
- **National Oceanic and Atmospheric Administration (NOAA) weather radio channels**
- **Portable weather devices and radios—including tiny, battery-operated portable weather radios that weigh less than 0.5 lb. (0.25 kg)**
- **Personal experience and observation—watching cloud and smoke movement, understanding local weather patterns, measuring wind speeds and temperatures, and observing cloud formations**

Go to the next section to learn more about how you can enhance your powers of observation.

Daily weather cycles

Using a wide lens, as *seasonal* weather patterns change, the condition of wildland vegetation also changes. If we tighten up the focus, *daily* weather cycles also affect fire behavior, and like seasonal weather cycles, they tend to be predictable. For every 24-hour period, it is possible to make general predictions about burning conditions.

While reading this information, keep in mind the terrain and weather conditions in your area. The differences in your local terrain and weather conditions may modify the burning conditions.

Read the following to dial into more information about daily weather cycles.

10:00 a.m. to 6:00 p.m.

From mid-morning until late afternoon (10:00 a.m. to 6:00 p.m.) is the time when fire behavior is normally most erratic, and fire intensity is likely to be high. This "heat of the day" period is when the RH is low, the temperature is high, the fuel is dry, and the wind is strong. All of these factors are unfavorable for fire control.

6:00 p.m. to 4:00 a.m.

In the evening and nighttime hours (6:00 p.m. to 4:00 a.m.), the wind usually moderates, the air cools, RH usually rises, and fuels begin to absorb moisture. These factors are favorable for fire control.

4:00 a.m. to 6:00 a.m.

During the early morning hours (4:00 a.m. to 6:00 a.m.), wildland fire activity is usually at its lowest.

6:00 a.m. to 10:00 a.m.

From shortly after dawn until mid-morning (6:00 a.m. to 10:00 a.m.), the intensity of a wildland fire is likely to increase again. The wind usually increases, temperature rises, and controlling the fire becomes increasingly difficult.

Narration Script: If you've spent any time on a fire you've probably consciously or unconsciously noticed a pattern of fire behavior throughout the day. As always, local topography plays a huge role in daily patterns, but there is a bit of clockwork to a fire. As your experience on wildland fires builds, you'll be more and more able to piece together the many variables contributing to a fire's behavior. Daily patterns fit in with seasonal patterns, which are influenced by topography, and on and on and on. Don't worry—keep your head in the books and the overall picture will begin to take shape.

Knowledge Check 21

Multiple choice—check the box of the answer(s) you choose

Some folks might check their watch for siesta time; firefighters check it for expected fire behavior. Let's check your recall of daily weather cycles.

Identify THREE correct statements about daily weather cycles affecting wildland fire behavior.

- ☐ **Wildland fire activity is usually at its lowest between 4:00 a.m. and 6:00 a.m.**
- ☐ **Fire activity can increase between 6:00 a.m. and 10:00 a.m.**
- ☐ **10:00 a.m. to 6:00 p.m. is the best time to get a fire under control.**
- ☐ **6:00 p.m. to 4:00 a.m. is a favorable time to gain control of a wildfire.**
- ☐ **RH and radiant heat is constant, so time of day is of little consequence.**

The correct answers are wildland fire activity is usually at its lowest between 4:00 a.m. and 6:00 a.m.; fire activity can increase between 6:00 a.m. and 10:00 a.m.; and 6:00 p.m. to 4:00 a.m. is a favorable time to gain control of a wildfire.

Topic conclusion

In this topic, we covered the following weather influences on a wildland fire:

- **Temperature and RH**
- **Precipitation**
- **Atmospheric conditions**
- **Winds**
- **Critical fire weather conditions**
- **Forecasting**

Understanding the different weather-condition variables will help you correctly predict wildland fire behavior so you can fight fires more safely and effectively.

<u>Narration Script: This topic took you on a tour of weather elements affecting fire behavior. Now it's up to you to keep an eye on the sky and put this knowledge to work for you.</u>