National Wildfire Coordinating Group

S-190, Introduction to Wildland Fire Behavior 2008

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Module 1: Basic Concepts of Wildland Fire

Topic 1: Course Introduction

Wildland fire behavior course introduction

During the heat of summer, avoiding news reports of a wildland fire raging somewhere across the country is nearly impossible. Wildland fire is often thought of as something that happens deep in national forests, out in rangelands, or perhaps in crop fields. Unfortunately, the truth is that wildland fires also occur in areas adjacent to residential and commercial development, such as:

- Vacant lots
- Parks
- Golf courses
- Highway medians

When this happens, you are facing an increasingly common scenario—a wildland/urban interface fire.

In either case, you need to understand the basics behind fire behavior in order to begin to anticipate how tactics and safety procedures change according to the conditions at hand.

Course objectives

The course objectives are simple enough to describe - however, attaining these goals will require the professionalism and determination required of all wildland firefighters.

By the end of this course, you should be able to:

- Identify and discuss the three sides of the fire triangle
- Identify the environmental factors of fuels, weather, and topography affecting the start and spread of wildland fire
- Describe the contributing factors indicating potential for increased fire behavior that might compromise your safety

This course provides the foundation to understanding the characteristics and interactions of the wildland fire environment and how those factors influence a fire's behavior. Ultimately, your safety is the top priority.

Course overview

There's a good chance this is your first formal wildland fire behavior training - so we'll give you the basics. The modules you will be working through are:

- Basic Concepts of Wildland Fire - introducing wildland fire terminology, the fire triangle, and heat transfer methods
- Principles of Wildland Fire Behavior - describing fuels and their relation to the rate of spread (ROS) as well as weather and topography impacts
- Wildland Fire Behavior and Safety - discussing the differences between problem and extreme fire behavior and emphasizing the must-follow rules described in the Incident Response Pocket Guide (IRPG)

After each module, there will be a Challenge Review where you'll show you've picked up the required knowledge, so be sure to take your time and feel free to review the material as much as you'd like.

Course prerequisites

There are no prerequisites to the S-190 Introduction to Wildland Fire Behavior course - but completing the course won't necessarily ensure you are ready to hit the fireline immediately. Your local agency determines the requirements for each fire-fighting position. These are all established by your local authority having jurisdiction and may include:

- Minimum educational requirements
- Minimum age requirements
- Local medical requirements
- Local physical requirements

So, be sure to get the basics here and then consult with your local agency. Good luck and good learning!

Topic conclusion

That concludes the Course Introduction Topic. You should now have a good idea of:

- Why you are here
- What we expect you to get out of the course
- How the course is organized

Topic 2: Fire Behavior

Topic introduction

Welcome to the world of wildland fire fighting. You're probably anxious to get started fighting wildland fires, but before you do, you need to have a firm grasp of many key concepts.

As the saying goes, Rome wasn't built in a day—and you won't be prepared to fight wildland fires in a day either. So let us help you build a strong foundation of knowledge to stand on before you head out to the heat of the fireline.

This first topic covers these basics of wildland fire fighting:

- Wildland fire fighting terminology
- Fire triangle
- Heat transfer
- Breaking the fire triangle

Parts of a wildland fire

Part of "talking the talk" is having a diverse wildland fire fighting vocabulary. All firefighters working on wildland fires will use certain terms, and you need to be "in the know." In this section, you'll learn about the parts of a wildland fire. These parts are named for their unique characteristics and locations.

Some of the most common names you'll hear associated with the main fire are:

- Origin
- Head
- Fingers
- Pocket
- Perimeter
- Rear
- Flanks
- Islands

Origin

The origin is the area where the fire started. It is also the point from which the fire spreads, depending on the fuels present and the effects of wind and slope.

When the fire is human caused, you often find the origin next to a trail, road, or highway, but a lightning strike or campfire can result in a very inaccessible point of origin. Protect the area of origin for subsequent investigation of fire cause whenever possible.

Head

The head is the part of a wildland fire with the greatest forward rate of spread (ROS). Because wind and slope affect the rate and direction of spread, the head is normally either on the edge of a fire opposite to the direction from which the wind is blowing or it is toward the upper part of a slope.

The head of a fire often burns intensely and may move with alarming speed. Some large fires may have multiple heads. Ultimately, you have to control the head(s) and prevent the formation of new heads to suppress a wildland fire.

Fingers

Fingers are typically long, narrow strips of fire that extend from the main body of a fire. They form:

- When a fire burns into mixed fuels; slowing in heavy fuel, but spreading quickly in light fuels
- Due to variations in terrain or wind direction
- When the head is split by natural features such as fields, water, or rock outcroppings

Caution - uncontrolled fingers may form new heads. If possible, contain the fingers when they're small and manageable.

Pocket

A pocket is the unburned area between the main fire and any fingers.

Perimeter

The perimeter is the outer boundary - or the distance around the outside edge - of the burning or burned area. Also commonly called the fire edge, don't confuse the perimeter with the control line (an inclusive term for all constructed or natural barriers and treated fire edges used to control a fire) or fireline (the part of the control line that is constructed by firefighters). Obviously, the fire's perimeter continues to grow until you get it controlled and extinguished.

Rear
The rear or heel of a wildland fire is the end opposite the head - that is, relatively closer to the point of origin than to the head. Be aware that a wind shift can quickly change the relative calm of the rear to a new blazing fire front.

Because fire at the heel usually burns into any prevailing wind, it generally:

- Burns with low intensity
- Has a low ROS
- Is generally easier to control than the head

Flanks
The flanks are the sides of a wildland fire, roughly parallel to the main direction of fire spread. Flanks are identified as either left or right as you are looking from the heel of a fire toward the head.

Control flanks as soon as possible, because:

- A shift in wind direction may quickly change a flank into a head.
- Fingers often extend from flanks.

Islands
Islands are unburned areas inside the fire perimeter. Because they are unburned potential fuels, patrol them frequently and check for spot fires. Islands close to a control line may flare up later and start spot fires across the control line. You may want to burn out islands, consuming fuels between the perimeter (fire edge) and the control line.

Additional wildland fire terms

A few other common terms relate to the perimeter and what's inside and outside the fire edge. A few more terms are:

- Spot fire
- Slopover
- Green
- Black

Spot fires
Spot fires are small fires burning beyond the main fire boundary. As gases rise from a fire into the convection column, sparks, embers, and burning twigs are carried aloft. Spot fires result as these hot and burning items fall back to the ground or are blown across a fireline by winds. Spot fires can also result when embers or burning fuels roll downhill across the fireline into unburned fuels beyond the main fire.

If spot fires burn unchecked, they may form a new head or another major fire. If this happens, firefighters could be trapped between two fires, or the fire may move in an unanticipated direction.

Slopover
Also known as breakover, slopover occurs when fire crosses a control line or natural barrier intended to contain the fire. Slopover and spot fires differ mainly in their location relative to the control line:

- Slopover occurs immediately across and adjacent to the control line.
- Spot fires occur some distance from the control line.

The green
Any area that's not burnt - but is adjacent to an involved area - is called the green. Fuels in the green may be:

- Live fuels, including:
  - – Vegetation with a high moisture content that is relatively slow to ignite
  - – Vegetation with lower moisture content and that is highly flammable
  - – Dense, golden - yellow annual grasses and other similar fuels with low moisture content that may burn vigorously
- Dead fuels - dried vegetation that is highly flammable and will go up like kindling

The term green certainly does not define a safe area. It is simply the opposite of the black, or burned, area. The edge of the green is usually where you construct a control line.

The black
The opposite of the green - the black or the burn - is the area (including both surface and aerial fuels) in which the fire has consumed, or "blackened," the fuels.

Whether the black is safe or not depends on a few factors. If it is completely burned over and little, if any, unburned fuel remains, the black is a relatively safe area during a fire. However, the black is not always safe.

Hazards of the Black
The black or burn area may not be safe for a few reasons:

- In steep terrain, exposure from adjacent unburned fuels can cause reburn
- Residual heat and smoke
- Hot spots and smoldering snags (standing dead trees), stumps, and downed trees
- Falling snags

If a surface fire leaves aerial fuels more or less intact in the black, or vice versa, a reburn can occur when burning conditions are more favorable - for example, if the winds shift or humidity drops. This often occurs when fire moving quickly through an area fails to consume all fuels.

Fire spread

The terms you'll learn about in these next few sections refer mostly to how the fire behaves and spreads. Fire spread is simply the movement of the fire, classified as rate of spread (ROS) and given in chains per hour. A chain is a surveying term and equals 66 ft. (20 m).

A good rule of thumb is to watch the fire spread for a minute. Since there are 60 minutes in an hour and just over 60 ft. (18 m) in a chain, using the rule of thumb will give you a reasonably accurate measurement of the fire's forward progress. For example:

1 ft. (0.3 m)/minute = 1 chain/hour
10 ft. (3 m)/minute = 10 chains/hour

A fire that burns an area 10 chains by 10 chains is a 1-acre fire.

Fire behavior terms

So, what are the terms you need to know about that deal with fire spread? We'll take a look at these terms in order in the next few sections:

- Flaming front
- Smoldering
- Creeping
- Running
- Backing
- Spotting
- Torching
- Crowning
- Blowup
- Flare-up
- Firewhirl

Flaming front

The flaming front, also known as the fire front, is the part of a fire within which continuous flaming combustion is taking place. Most of the time, the flaming front is the leading edge of the fire perimeter. However, in surface fires, the flaming front may be mainly smoldering combustion.

Behind this flaming zone, combustion is primarily glowing or involves the burning out of larger fuels (fuels greater than about 3 in. [8 cm] in diameter). Light fuels typically have a shallow flaming front, whereas heavy fuels have a deeper front.

Smoldering and creeping fires

Two terms refer to fires that are spreading very slowly:

- A smoldering fire is one that burns without a flame and is barely spreading.
- A creeping fire burns with a low flame and spreads slowly.

Running and backing fires

A running fire is one that spreads rapidly with a well-defined head. Compare and contrast this to a backing fire, where the fire moves away from the head, downhill, or against the wind. A backing fire, also called a heel fire, is usually a portion of the fire with slower ROS and lower intensity.

Spotting

A fire is spotting when winds or a convection column carries sparks or embers produced by the main fire. Obviously, spotting causes spot fires in advance of the fire's head.

Crowning and torching

A fire is crowning when it advances across the tops of trees or shrubs more or less independent of the surface fire. Crown fires are sometimes classed as running or dependent to distinguish the degree of independence from the surface fire. Use the terms crown fire and crowning carefully because they describe a very serious fire situation.

A term commonly confused with a crowning fire is a torching fire. Unlike a crowning fire, a torching fire periodically ignites the crown of a single or small group of trees or shrubs before returning to the surface. A torching fire is not as serious as a crown fire.

Blowup and flare-up

A blowup occurs when there's a sudden increase in ROS sufficient to prevent or rule out direct control of the fire. Blowups are often accompanied by violent convection, can behave like fire storms, and will most likely set back existing suppression plans. A flare-up is any sudden acceleration in the ROS or intensification of the fire. Unlike blowup, a flare-up is of relativity short duration and does not radically change existing control plans.

Stay alert because:

- Blowups and flare-ups can occur on smaller fires or on isolated portions of large fires.
- Most fires are innocent in appearance before blowups or flare-ups occur, such as fires in the mop-up stage.
- Flare-ups generally occur in deceptively light fuels.
- Blasts of air from low-flying helicopters and air tankers have been known to cause flareups.

Firewhirl

The last fire behavior term we will look up is firewhirl. Firewhirls are spinning, moving columns of rising air and fire gases that carry smoke, debris, and flames aloft. They're usually formed on the leeward side (protected from wind) of elevated terrain features and can cause spotting. Firewhirls range in size from less than 1 ft. (30 cm) to over 500 ft. (150 m) in diameter. Large fire whirls have the size and intensity of a small tornado!

Additional wildland fire terms

Just a few more terms to know and you're on your way to bigger and better training concepts. Here are a few other common terms related to wildland fire fighting:

- Control line
- Fireline
- Anchor point
- Containment and control
- Mop-up

Control line, fireline, and anchor point

The terms control line, fireline and anchor point are closely related.

- Control line refers to all constructed or natural fire barriers. It's also used to describe the treated fire edges used to contain the fire.
- A fireline is any cleared strip or portion of a control line where flammable material has been removed by scraping or digging down to mineral soil.
- The anchor point is any good place where you can start constructing a fireline. Generally, a fire barrier is a safe anchor point. Using an anchor point minimizes the chance of being outflanked by the fire while the line is being constructed.

Containment and control

Containment is the status of a wildfire suppression action that can reasonably be expected to stop the fire spread under prevailing and predicted conditions. Control is the point in time when the perimeter spread of a wildland fire has been halted and can reasonably be expected to hold under foreseeable conditions.

To control a fire means that all of these actions have been taken:

- Complete the control line around a fire, any spot fire from the fire, and any interior island to be saved
- Burn out any unburned area adjacent to the fire side of the control lines
- Cool down all hot spots that are immediate threats to the control line until the lines can reasonably be expected to hold under foreseeable conditions

Mop-up

If you hear the term mop-up, it's a good thing. The mop-up phase marks the final extinguishing of a fire after it has been completely surrounded by control lines. It is a strategy to make a fire safe or to reduce residual smoke. But always be at the ready - blowups and tragedies have occurred in the mop-up stage.

During mop-up, you will extinguish or remove all burning or smoldering material within a specified distance of the control line. A general guideline is to mop up within 100 ft. (30 m) of the control line but follow the control objectives set for the incident. Mop-up involves felling snags and trenching logs to prevent rolling after an area has burned.
Mop-up must be thorough because a small spark or flame left along the line could rekindle hours or days later, starting another and perhaps larger fire.

Combustion process

The remainder of this topic will introduce you to the combustion process in the wildland environment from three perspectives:

- Fire triangle
- Heat transfer
- Breaking the fire triangle

The fire triangle

Fire is actually a by-product of a larger process called combustion. Wildland fuels have an abundant supply of oxygen available in the air. Rapid oxidation occurs in two forms:

- Smoldering fires
- Steady-state fires (unchecked rapid burning) - steady-state fires are sometimes called free-burning fires

The three sides of the triangle consist of oxygen sources, heat sources, and fuel. Read the following for the details.

Caption: The fire triangle's sides represent the three components required for combustion—oxygen, heat, and a fuel source. These components can occur in three states including as a gas, a solid, or a liquid.

Oxygen Sources

A concentration of approximately 16 percent oxygen is required for combustion, but normal air contains 21 percent - more than enough for combustion to occur. However, some fuel materials contain sufficient oxygen within their makeup to support burning.

Heat Sources

Heat sources sufficient to reach ignition temperature may come from:

- Open flame
- Sun
- Lightning
- Hot surfaces
- Sparks and arcs
- Friction
- Chemical action
- Electric energy
- Compression of gases

Fuel

Fuel may exist in any of the three states of matter - solid, liquid, and gas. However, only gases burn. The initiation of combustion of a solid or a liquid fuel requires its conversion into a gaseous state by heating. During combustion, heat and chemical changes in the fuel cause fuel gases to evolve from the fuel. So, even though fuel and oxygen are present in the wildland, heat must be added to liberate the fuel gases and initiate the combustion process.

Fuels in Gas Form
Gas fuels can include:

- Natural gas
- Propane
- Butane
- Hydrogen
- Acetylene
- Carbon monoxide

Fuels in Liquid Form
Liquid fuels can include:

- Gasoline
- Kerosene
- Turpentine
- Alcohol
- Cod liver oil
- Paint
- Varnish
- Lacquer
- Olive oil

Fuels in Solid Form
Solid fuels can include:

- Dust
- Coal
- Wood
- Paper
- Cloth
- Leather
- Plastic
- Sugar
- Grain
- Hay
- Cork

Heat energy
As heat energy is released, further chemical changes occur, adding more fuel and possibly producing a self-sustaining process. Heat activates and sustains the chemical reactions needed for continued combustion.

Heat generated by a fire evaporates the moisture in the fuel and heats the fuel to its ignition temperature. The amount of heat required to reduce the moisture content of the fuel depends upon the physical and chemical makeup of the fuel and the percentage of atmospheric moisture.

If the supply of oxygen available to the combustion process increases, then combustion intensifies. While the percentage of oxygen in the atmosphere does not vary appreciably from place to place, wind can effectively increase the amount of oxygen available to a fire and thereby increase the rate of combustion.

Heat transfer

For sustained combustion, heat must transfer from involved fuels to those that are not involved. Three primary methods for heat transfer are:

- Conduction
- Convection
- Radiation

You will investigate each of these methods in turn.

Conduction

When two objects of different temperatures contact each other directly or through a medium, heat conducts from the warmer object to the cooler one until their temperatures equalize.

Metals such as aluminum, copper, and iron conduct heat readily and can play a significant role in fire spread within structures. However, fibrous materials such as plants and wood are poor conductors of heat. Therefore, heat transfer by conduction has a limited effect on the spread of wildland fires.

Caption: A severely fire-damaged truck from conducted heat from the exhaust system.

Convection

During convection, gases heated in a fire expand, become lighter, and rise. In a wildland fire, fire gases rise in a convection column, and cooler air flows in to replace the rising gases. In some cases, this inflow is sufficiently strong to affect local winds.

As these gases rise up into the column, sparks, embers, and burning twigs are carried aloft. These burning materials fall back to earth up to several miles downwind and can start spot fires well ahead of the main fire. Hot convected gases moving up a slope can dry out fuels, lowering their ignition temperature. These fuels also become preheated by the convected heat, thus increasing their susceptibility to ignition and more rapid fire spread.

Radiation

Heat transfer by radiation is one of the major sources of fire spread in wildland fires. It’s as simple as 1, 2, and 3:

1. Heat waves, sometimes called infrared rays, radiate in all directions from the heat source.
2. Heat waves travel through air until they are totally or partially absorbed by an opaque object.
3. The opaque object gains heat and in turn radiates heat from its surface.

One of the most common examples of radiant heat in a wildland context is fire burning in a narrow canyon. Radiating heat preheats and dehydrates exposed fuels immediately adjacent to the fire and initiates combustion. Another common example is the heat firefighters feel on the fireline - radiant heat is also responsible for many burn injuries to those working near wildland fires.

Breaking the fire triangle

You interrupt the combustion process (and extinguish the fire) by disrupting one or more of the three required elements as shown earlier in the fire triangle.
In other words:

- Removing fuel
- Removing oxygen
- Removing the heat energy that sustains the chemical reactions

Removing Fuel

Clearing a space of all surface fuels down to mineral soil (dirt containing little or no organic material) is a common way of controlling and extinguishing wildland fires. This is the basic idea behind the creation of any fireline.

Removing Oxygen

Wildland fires burn in the open air; therefore, attempting to restrict the oxygen supply to a fire (removing oxygen) is usually limited to smothering relatively small fires with dirt. Of course, make sure the dirt you use doesn’t have a lot of flammable organic material in it, such as pine needles and dead leaves.

Removing the Heat Energy

Cooling the fire with water or Class A foam is one of the most common and effective fire extinguishing methods.

Topic summary

An observer of life once noted that before you can walk, you have to learn how to crawl. We hope this topic did, indeed, help you learn how to crawl - with respect to becoming a wildland firefighter, that is.

In this topic, we covered:

- Wildland fire fighting terminology
- Fire triangle
- Heat transfer
- Breaking the fire triangle

Module 2: Principles of Wildland Fire Behavior

Topic 1: Introduction

Principles of wildland fire behavior introduction

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

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

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

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

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.

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.

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.

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.

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.

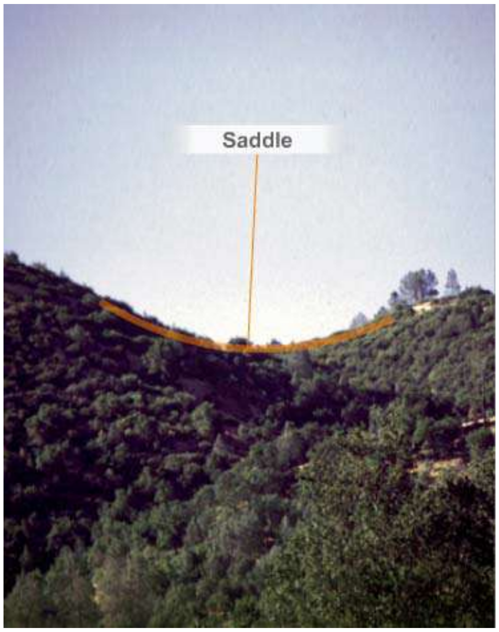
A chute is a steep V-shaped drainage, and a saddle is a common name for the depression between two adjacent hilltops.

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.



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

Box Canyons

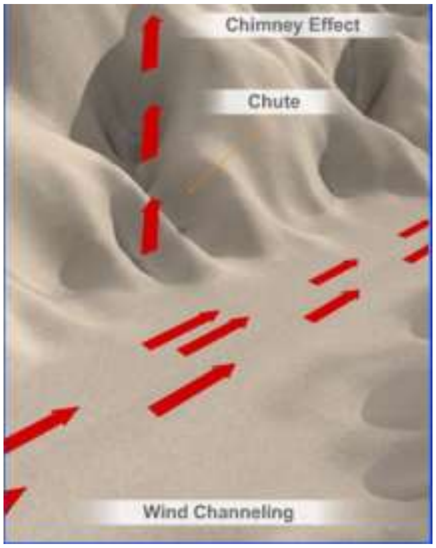
Fires starting near the base of box canyons and narrow canyons may react similar to a fire in a wood burning stove or fireplace. Air will be drawn in from the canyon bottom creating very strong upslope drafts. These upslope drafts create rapid fire spread up the canyon, also referred to as the chimney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



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.

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.

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

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.

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.

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.

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.

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

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

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.

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

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.

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

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

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.

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.

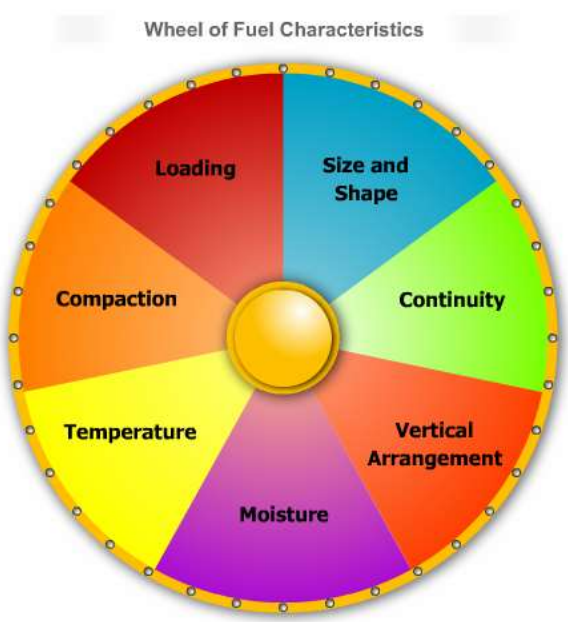
Other examples of man-made fuel sources are:

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

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.

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

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.

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.

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.

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

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.

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.

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

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.

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

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.

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

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.

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

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.

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.

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.

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.

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.

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.

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.

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 it's 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.

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.

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.

Warning!

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.

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.

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.

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.

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.

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.

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

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.

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.

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.

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.

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.

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.

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.

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.

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.

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:

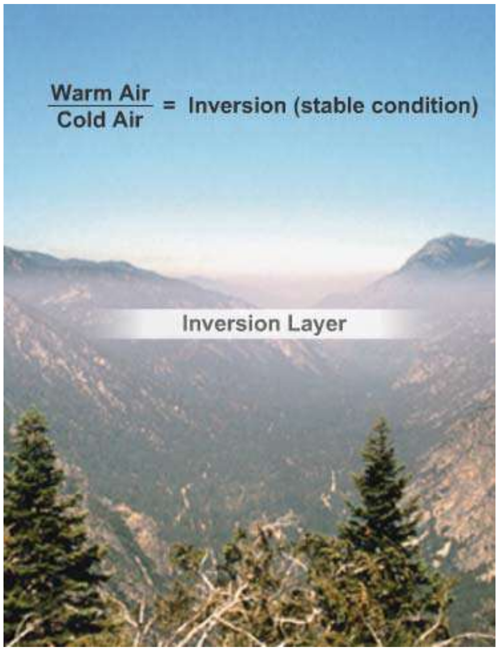
- Increase in temperature
- Decrease in RH
- Increase or shift in wind

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.



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.

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.

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.

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.

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.

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.

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.

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.

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.

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

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.

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 firecontrol efforts.

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

- Direct
- Indirect

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.

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

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

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

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

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.

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.

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.

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.

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.

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.

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

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.

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.

Whirlwinds and firewhirls

While whirlwinds, also known 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.

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

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

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

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- 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

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

Foehn wind characteristics
As we explained earlier, foehn wind is a type of general wind occurring when stable, highpressure 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.

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.

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.

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.

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.

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

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.

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


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

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

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

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.

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

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.

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.

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.

Module 3: Monitoring Fire Behavior

Topic 1: Introduction

Fire behavior

Module introduction

If you've gone through this course in the order it has been presented, you'll recognize some concepts already discussed - but the fundamentals of wildland fire fighting are lessons reflected on over and over throughout the course of a firefighter's career. Even if you're a seasoned veteran of wildland fire fighting, you'll find information in this module you should review and consider carefully.

Specifically, this module describes factors influencing a fire including:

- Fuel characteristics
- Fuel moisture
- Fuel temperature
- Topography
- Wind
- Atmospheric stability
- Fire behavior

Look familiar? These are the seven factors of the Look Up, Down, and Around rule from the Operations section of your Incident Response Pocket Guide (IRPG). A full version of the IRPG is available in the collection of resources available for this course.

Problem vs. extreme fire behavior

One of the overall goals of this course is to get you ready to anticipate and evaluate changes in a fire's behavior based on your evaluation of current conditions. Wildland fire fighting is as much an intellectual and mental exercise as a physical one, and you'll need to stay focused.
Fires rarely go from small fires to extreme blowups without signs pointing the way. Working on the fireline demands your attention to details, and you'll have to monitor your surroundings.

Fires can quickly change between two states:

Problem Fire Behavior
Problem fire behavior has the potential to hurt you or other fireline personnel if the tactics being used to fight the fire are not being adjusted according to conditions. Problem fire behavior can easily go to extreme fire behavior if you don't recognize the indicators that tell you the fire is changing and that it is time to change your game plan.

Extreme Fire Behavior
Extreme fire behavior is also a problem, but kicked up another notch.

Here are some telltale signs that the fire is becoming extreme:

- Rapid rate of spread (ROS) ROS is the relative activity of a fire in extending its horizontal dimensions
- Intense burning
- Spotting
- Crowning

Topic 2: Look Up, Down, and Around

Topic introduction

Wildfires don't just suddenly decide to become unruly. In fact, their behavior is just like anything else's - it's an opposite and equal reaction to an action. If you're paying attention on the fireline, you'll be able to observe those actions firsthand and then predict the fire's consequent reaction.

This topic analyzes two types of fire behavior - problem and extreme. Problem fire behavior is fire activity presenting a potential hazard to fire personnel if the tactics being used are not adjusted.

Extreme fire behavior is the highest level of problem fire behavior and is characterized by:

- Rapid rate of spread (ROS)
- Intense burning
- Spotting
- Crowning

This topic will present a list of factors and related indicators to help you determine when a fire is transitioning to problem, or even extreme, fire behavior.

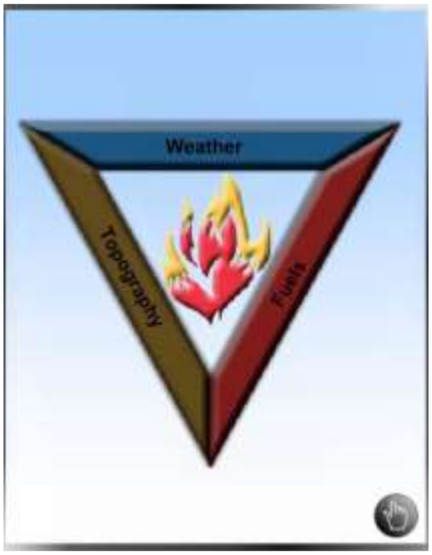
The Incident Response Pocket Guide
Your Incident Response Pocket Guide (IRPG) is a handy tool for field reference for the content we'll cover in this topic.

Much of this topic is based on the Operational section of the IRPG. Use the Look Up, Down, and Around information in this section to help you monitor changing conditions within a fire environment - the conditions, influences, and modifying forces controlling fire behavior.

The seven factors
The Look Up, Down, and Around guidelines contain seven fire environment factors you should monitor every time you're at a wildland fire incident:

1. Fuel characteristics
2. Fuel moisture
3. Fuel temperature
4. Topography
5. Wind
6. Atmospheric stability
7. Fire behavior

Obviously, factors 1 through 3 deal with the fuel side of the fire triangle, factor 4 to the topography side, and factors 5 and 6 with the weather side.



Caption: A three-sided triangle labeled "Weather" on the top side, "Topography" on the left side, and "Fuels" on the right side represents each environmental factor's influence, individually or cumulatively, on fire behavior.

Fuel characteristics
Looking down to observe the fuels around you can help you anticipate changes in fire behavior. When assessing fuel characteristics, pay attention to five key indicators, four of which are:

Continuous Fine Fuels
The indicator of continuous fine fuels (fuels distributed uniformly over an area) is the most critical fuel characteristic indicator as identified in your IRPG. Fire is able to change and spread rapidly in these fuels, especially when combined with slope (incline) or wind.

Heavy Loading of Dead and Down Fuels
Stands of trees that have died and fallen down can provide fires with large amounts of readily available fuel.

Ladder Fuels
Ladder fuels (fuels that provide vertical continuity between strata) allow a fire to readily spread into the canopy, launching firebrands (spots) into the air.

Tight Crown Spacing
When tree tops are less than 20 ft. (7 m) from other tree tops, and bush tops are less than 20 ft. (7 m) from other bush tops, a fire can move more quickly and easily from tree to tree or bush to bush.

Special conditions
The fifth fuel characteristic indicator is special conditions, meaning any of these situations:

Firebrand Sources
Firebrand sources are burning materials carried by the wind ahead of a fire or outside of control lines.

Potential firebrand sources include:

- Pine bark plates
- Manzanita leaves
- Eucalyptus leaves
- Maple leaves
- Oak leaves

Numerous Snags
When a fire becomes established in snags (dead or partially dead trees), it can launch firebrands into the air or cause the snags to fall across control lines or to fall on personnel.

Frost and Bug Kill
Frost and bug kill provides more available fuel for a fire.

Preheated Canopy
A lower intensity fire burning the fuels near the ground can preheat canopies. As heat from the fire dries the fuels above it, it makes those fuels available to burn.

Unusual Fine Fuels
Unusual fine fuels are light, flashy fuels mixed with high-energy fuels, such as continuous grass mixed with sage.

High Dead-to-Live Ratio
Wildland areas having greater amounts of dead-to-live materials can provide additional fuel for a fire.

Fuel moisture
Fuel moisture is another factor to consider. Fuel moistures are important for both fine and large fuels as well as dead and living fuels. For example, relative humidity (RH) affects 1- hour fuels much faster than 1,000-hour fuels. Fuel moistures change at different rates depending on the size of the fuel.

When assessing fuel moisture, pay attention to these indicators:

Low Relative Humidity (RH) - Less Than 25 Percent
Moisture in the air is known as relative humidity. 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. As identified in the IRPG, low RH is the most critical fuel moisture indicator.

RH can add or remove moisture to fuels. The lower the RH, the more available the fine fuels are to carry fire.

Low 10-Hour Fuel Moisture Content (FMC) - Less Than 6 Percent
The diameter of a 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. 10-hour fuels are fuels 1/4 to 1 in. (6 to 25 mm) in diameter, such as small

branches. If the 10-hour fuels in your area have less than 6 percent FMC, they will be more available to burn.

Drought Conditions
Drought conditions can mean fuels are more receptive to ignition and carrying the spread of fire. A 1,000-hour fuel category can indicate long-term drought. When burning, very dry 1,000-hour fuels can release large amounts of energy and are hard to control.

Seasonal Drying
Regardless of size and shape, all fuels are affected by seasonal changes in humidity. After a prolonged period of warm, dry weather, timber (a 1,000-hour fuel) may actually be drier than kiln-dried lumber.

Warning!
A general rule of thumb is that an RH of 25 percent or lower means fire behavior will most likely increase dramatically. Put your head on a swivel when you or someone on the crew identifies an RH level at or below 25 percent. Of course, fuels and your geographic location play some role, so if you're not sure, ask a supervisor! Tactics may change accordingly in this scenario.

Fuel temperature
As you know, 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.

When assessing fuel temperatures, pay attention to three indicators. The first two are temperatures greater than 85° F (29° C) and high percent of fuels in direct sunlight.

High Temperatures
Most wildland fuels require temperatures between 400° and 700° F (200° and 370° C) to ignite. Obviously, 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.

As identified in the IRPG, high temperatures - greater than 85° F (29° C) - are the most critical fuel temperature indicator to observe.

High Percent of Fuels in Direct Sunlight
In the wildland, fuels in the shade are cooler than fuels in the sun, meaning they won't ignite as quickly. As you practice looking down, determine whether the majority of fuels in your area, on any given slope, are in the sun or the shade.

Aspect fuel temperatures
The final fuel temperature indicator is increasing aspect fuel temperatures. Being aware of which slopes are "hotter" throughout the day will allow you to monitor where the potential for the greatest fire behavior is.

To be able to determine aspect fuel temperatures, know which slopes tend to have higher fuel temperatures in the morning and which ones have higher temperatures in the afternoon. Consider slopes facing south and southwest, and north.

South and Southwest Slopes
Generally, south and southwest facing slopes:

- Are more exposed to sunlight
- Have lighter and sparser fuels
- Have higher temperatures, lower humidity, and lower fuel moisture
- Are the most critical in terms of start and spread of fire

North Slopes
Usually, north facing slopes have more shade, causing:

- Heavier fuels
- Lower temperatures
- Higher humidity
- Higher fuel moistures

Topography

Topographic elements (terrain) can be like a roadmap pointing out the path of a fire's direction, and they can also act as warning signs. Be sure to look around and scout the topography to help you anticipate changes in fire behavior.
When assessing the terrain, pay attention to five key indicators:

- Steep slopes
- Chutes
- Saddles
- Box canyons
- Narrow canyons

As identified in the IRPG, steep slopes and chutes are the two most critical terrain indicators. We'll describe each of the five topographic indicators in turn.

Steep Slopes
Pay special attention to slopes with inclines greater than 50 percent. They encourage rapid ROS due to convective heating and increased potential for rollouts below the fire. The flames of a fire on a slope can preheat, dehydrate, and ignite the fuels located uphill much faster than downhill because of their closer proximity. The steeper the slope, the more preheating of fuels—thereby creating a faster moving fire. On the other hand, a fire at the top of a slope is less able to preheat the downhill fuel and tends to burn slower.

Chutes
Chutes are another type of terrain to pay special attention to. A chute is a steep V-shaped drainage area that can easily channel smoke and fire upward at a rapid rate. Slow-burning fires in wide canyons can blow up as they enter a chute. Chutes 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 ROS and direction of spread by acting as chimneys and literally propelling the fire up as if through a stovepipe.

Saddles
A saddle is a common name for the depression between two adjacent hilltops. Slow-burning fires in wide canyons can blow up as they enter a saddle. 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 ROS and direction of spread. They allow heat to rise rapidly, and a chimney effect is created.

Box Canyons
A box canyon is a canyon with three steep sides and only one way in and out. Fires starting near the base of box 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 ROS 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
Radiant and convective heating can increase spotting across narrow canyons. Also, fire can burn down to the bottom of the canyon and then cross over to the other side. This is known as slope reversal. Also, expect wind eddies and strong upslope air movement at sharp bends in the canyon.

Wind
Of the seven fire environment factors you should monitor every time you're at a wildland fire incident, wind is the most variable and least predictable. It is the primary factor influencing wildland fire spread.

Wind adds to the unpredictable nature of fire spread and delivers more oxygen to the fire. When observing the wind, pay attention to seven key indicators:

- Surface winds above 10 mph (16 km/h)
- Battling or shifting winds
- Lenticular clouds
- High, fast moving clouds
- Approaching cold fronts
- Cumulonimbus development
- Sudden calm

As identified in the IRPG, the first two factors in this list are the two most critical wind indicators. You'll investigate each of the seven indicators in turn:

Surface winds above 10 mph (16 km/h)
Pay special attention to surface winds. They:

- Help determine the direction of fire spread
- Help to carry firebrands ahead of the fire
- Increase the supply of oxygen to the fire

Take a moment to review the graphic. It depicts a burnout operation with steady 15 to 20 mph (24 to 32 km/h) winds. Notice how the wind has leaned the column of smoke. Even though the wind speed isn't very high, it still has a serious effect on the fire.

Caption: A section of tall pines to the left of a constructed fire line. Lengthy flames and billowing black smoke are rising from the pines. The black smoke and flames are both leaning heavily to one side, clearly indicating the wind is blowing steadily.

Battling or Shifting Winds

Battling winds change direction and then return to the original direction. Battling or shifting winds indicate a probable change in wind speed and direction.

Pay close attention to these types of winds because changes in wind speed and direction:

- Affect everyone on the fire
- Can cause firebrands to cross control lines

Also, increasing winds can cause previously quiet parts of the fire to intensify.

Lenticular Clouds

Lenticular clouds are:

- Stationary
- Lens shaped
- Formed at high altitudes
- Normally aligned at right angles to the wind direction
- Indicative of high winds aloft with the potential to surface

High, Fast Moving Clouds

High, fast moving clouds indicate a potential for wind shifts.

Approaching Cold Fronts

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 altering natural convection currents, causing longer horizontal flames, and resulting in preheated fuels
- Strong, shifting winds causing erratic wildland fire behavior and increasing the potential for spotting downwind
- Strong winds developing high heat outputs in active fire heads and flanks (sides)

Cumulonimbus Development

Cumulonimbus clouds are anvil shaped and usually accompanied by lightning, thunder, hail, and strong winds. They indicate possible wind speed and direction and the potential for erratic winds.

Sudden Calm
If the wind suddenly dies down, it may spring back up again in a different direction - completely changing the direction of fire spread previously forecasted.

Atmospheric stability
Atmospheric stability is another fire environment factor to monitor when you're at a wildland fire incident. More specifically, you should be on the lookout for clues pointing to atmospheric instability. Unstable air tends to increase the potential for gusty surface winds and, thus, fire activity. When the air is unstable, wildland fires burn hotter and with more intensity.

The seven indicators of atmospheric instability are:

- Good visibility
- Gusty winds and dust devils
- Cumulus clouds
- Castellatus clouds in the morning
- Smoke rising straight up
- Inversion beginning to lift
- Thermal belt

The first five indicators show unstable air mass, meaning a fire has the increased potential to grow rapidly. You'll examine each indicator in turn:

Good Visibility
Your eyes can help you spot atmospheric stability indicators. For instance, when the air is unstable, visibility is good.

Gusty Winds and Dust Devils
Gusty winds make it difficult to accurately predict a fire's movement and behavior. Not only do gusty winds tend to shift erratically - moving the fire in different directions as they do, but gusts can also pick up and spread embers, causing spot fires and producing dust devils.

Dust devils are small, rotating windstorms containing sand or dust. 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.

Cumulus Clouds
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. Cumulus clouds herald the arrival of cold fronts and thunderstorms.

Castellatus Clouds in the Morning
Castellatus clouds consist of separate towers of clouds rising from a flat middle level base. When you see these clouds in the morning, they often indicate an approaching thunderstorm.

Smoke Rising Straight Up
When the air is unstable, smoke will rise vertically, almost in columns.

Inversion Beginning to Lift
Increased wildland fire behavior is almost certain when inversions - warm air over cold - break or lift due to heating the lower atmosphere by the sun or a fire. When the inversion lifts, it indicates the transition from a stable to an unstable atmosphere. 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 the fire fighting effort.

Watch for these indicators when an inversion breaks:

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

Thermal Belt
A thermal belt is the top of an inversion layer. “Thermal” means warm, and the top of the inversion layer contains the warmest air temperature. This area is characterized by the:

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

Wildland fires within the thermal belt can remain quite active during the night.

Fire behavior indicators
Fire behavior is the final fire environment factor to monitor when you’re at a wildland fire incident. By understanding the variables affecting fire behavior, you can reduce the risk involved in fire suppression.

There are eight indicators of a rapidly changing, wind-driven fire with intense burning. The first four pertain to columns of smoke and usually signify an increase in fire behavior:

- Leaning column
- Sheared column
- Well-developed column
- Changing column

As identified in the IRPG, a well-developed column is one of the three most critical fire behavior indicators to watch for. This is because they can make their own weather, affecting winds in the area and the fire area itself. These columns can also lean over (collapse) over unburned areas causing spotting.

Other fire behavior indicators

The remaining four indicators of a rapidly changing, wind-driven fire with intense burning are:

- Torching
- Frequent spot fires
- Smoldering fires picking up
- Small firewhirls beginning

As identified in the IRPG, torching and frequent spot fires are two of the three most critical fire behavior indicators. We’ll describe each indicator in turn.

Torching
A torching fire is a vertical phenomenon where a surface fire periodically ignites the crown of a single or small group of trees or shrubs before returning to the surface. Typically, when trees begin torching, the fire is beginning to transition from a surface fire to a crown fire. Pay close attention when you see trees torching.

If you see trees torching, note:

- Whether just one tree or shrub is torching or small groups of trees or shrubs are catching fire
- Whether wind is blowing - and if it is, how fast it is blowing

Frequent Spot Fires
Spot fires are fires starting outside the perimeter of a main fire. Pay close attention when you see the number of spot fires increasing. Frequent spot fires indicate the fire is:

- Spreading
- Increasing in complexity

Smoldering Fires Picking Up
Smoldering fires are fires burning without flame and barely spreading. Smoldering fires picking up (flaming up) indicate that fire behavior is increasing. Some possible reasons for the pickup include:

- An inversion is lifting
- Wind is increasing
- Shading has decreased on that aspect and temperature is increasing
- RH has decreased

Small Firewhirls Beginning
Firewhirls are spinning vortex columns of ascending hot air and gases rising from a fire and carrying smoke, debris, and flames aloft. When small firewhirls begin forming, the fire is increasing in intensity.

Topic summary

The seven fire environment factors can help you identify and assess problem and extreme fire behavior. By now you should be able to recognize each of the seven “look up, down, and around” factors and their key indicators. Here’s a recap:

1. Fuel characteristics
2. Fuel moisture
3. Fuel temperature
4. Topography
5. Wind
6. Atmospheric stability
7. Fire behavior

And here’s a parting tip: always monitor ALL of the factors, not just one or two of them, and monitor the trends of each indicator as well.