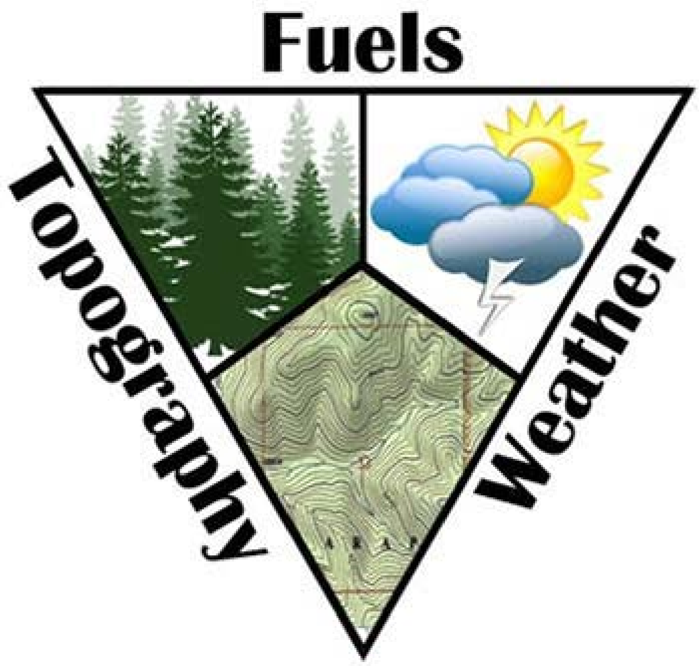
Module 3:
Fire Behavior



Proposed Agenda

Time		Section Name
8:00	8:30	Welcome
8:30	9:00	Course overview and objectives
9:00	10:00	Fire behavior triangle
10:00	10:30	Break
10:30	12:00	Fire intensity, severity, and spread
12:00	1:00	Lunch
1:00	2:00	Fire types
2:00	3:00	Fire regimes
3:00	3:30	Break
3:30	4:30	Effects of climate change
4:30	5:00	Wrap-up
5:00	5:30	Discuss plans for the fire field trip

Overview

This module provides an in-depth review of the fire behavior triangle and its components—topography, fuels, and weather—and the fire tetrahedron for structure fires. Module 3 also addresses fire severity, fire intensity, fire spread, fire types, fire regimes, and the impact of climate change.

Learning Objectives

- Understand how weather, topography, and fuels affect fire behavior
- Compare and contrast fire severity and fire intensity
- Create a landscape and matchstick forest. Hypothesize how a fire will behave on their landscape
- Explain how fire regimes are influenced by fire behavior
- Understand how fuel size and arrangement contribute to fire spread and fire type

Learning Outcomes

Whether there is a wildfire, structure fire, or you're conducting a prescribed burn, utilize concepts in this module to size up the fire, as with wildfire and structure fires for safety and suppression purposes; and utilize fuel, weather, and topographic elements to plan and conduct a safe and effective prescribed burn to achieve predetermined objectives.

Content Outline

- Introduction
- Fire behavior triangle
- Topography
- Fuels
- Weather
- Extreme fire behavior
- Fire intensity and severity
- Fire spread
- Fire types
- Fire regimes
- Potential climate change effects

"From the little spark may burst a mighty flame."

Dante Alighieri
Italian poet

Introduction

Several key variables affect how fires behave. These include weather, topography, and fuels. In this module you will learn some of the many behaviors that occur within a fire and across a landscape as a fire burns. Fire behavior includes such things as how fast a fire burns (rate of spread), how hot it burns (fire intensity), the presence of fire whirls, and ember production and spotting.

In a structure fire, Building Factors, Smoke, Air Track, Heat, and Flame (B-SAHF) are critical fire behavior indicators. Understanding these burn indicators is important, but more important is the ability to integrate these factors in the process of reading the fire as part of size-up and dynamic risk assessment. In structure fires, the process of reading fires involves recognizing the stages of fire development. Remember that fire conditions can vary considerably throughout the building, with one compartment containing a fully developed fire, an adjacent compartment in the growth stage, and still other compartments not yet involved. Recognizing the stages of fire development and likely progression through this process allows firefighters to predict what will happen next if action is not taken. Firefighters can also predict potential changes due to unplanned ventilation, such as failure of a window, and the likely effect of tactical action. This applies to wildland fires as well.

✔ Activity I[1] – Personal and Professional Insights

[1] See Activities section for details on all activities in this curriculum

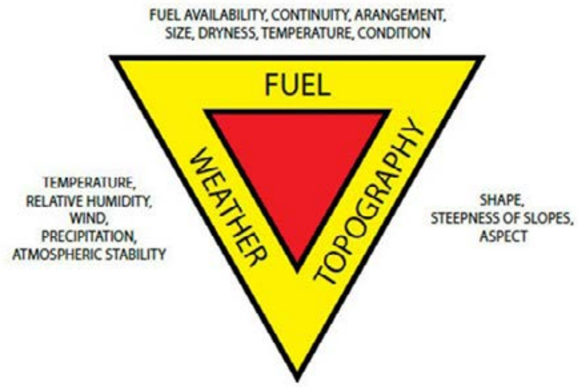


Image: US Forest Service

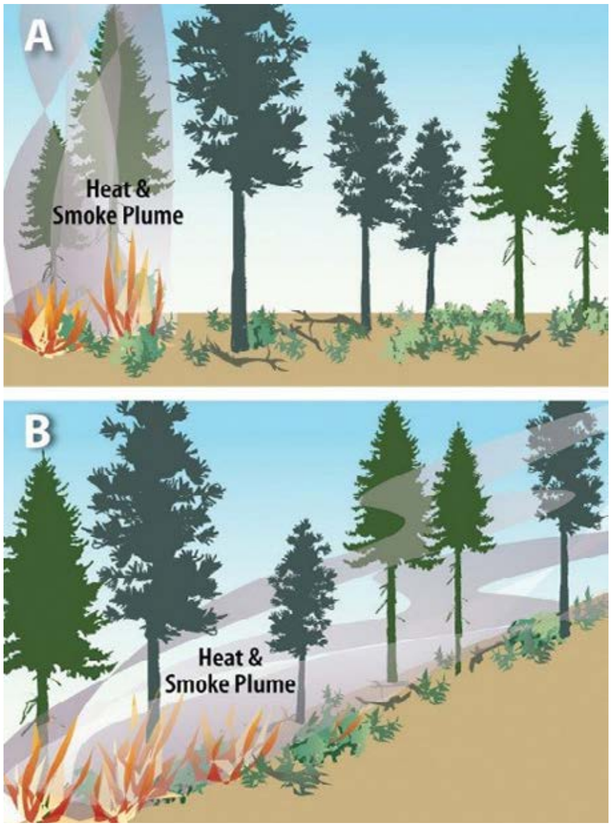
Figure 1. The Fire Behavior Triangle

Fire Behavior Triangle

As mentioned in Module 1: What is Fire?, fire behavior can be broken into a triangle with three main components: topography, fuels, and weather (Figure 1). Each component will be explained in more detail here. Also, refer to Appendix B in the publication *Reducing Fire Risk on Your Forest Property* (PNW 618) listed in "Additional Student Resources" and available in the Oregon State University Extension catalog (https://catalog.extension.oregonstate.edu/pnw618).

Topography

Fire generally spreads faster uphill than downhill because fuels are more efficiently preheated by the uphill-spreading flames and heat (Figure 2). Additionally, the steeper the slope, and the more fuel, the faster the fire will burn and spread. Fuels dry earlier in the season on south slopes compared to north slopes. Low areas that lie between two higher ridges, called saddles, also influence fire behavior. Topographic features such as "chimneys," which are vertical drainages on either side of a hill, can draw fire



Source: National Park Service

Figure 2. Fire is influenced by many factors, including geography, climate, weather, and topography.

up them very rapidly as the hot air rises, even creating their own winds. As a result, topography can alter the normal heat-transfer process in a fire, modify general weather patterns, and result in microclimates with localized moisture conditions. For example, in steep,highly dissected terrain varying slopes and aspects can create cooler temperatures, higher humidity, and protection from prevailing wind resulting in animal and plant refugia.

Fuels (Wildland)

Simply stated, fuels are anything that will burn. Fuels in the wildland environment are measured on horizontal and vertical axes. Vertical fuels include ground fuels, surface fuels, ladder fuels, and crown fuels (Figure 3). Ground fuels include organic matter, duff mounds around trees, peat, and decomposing tree roots. Surface

Topography includes slope steepness and terrain.

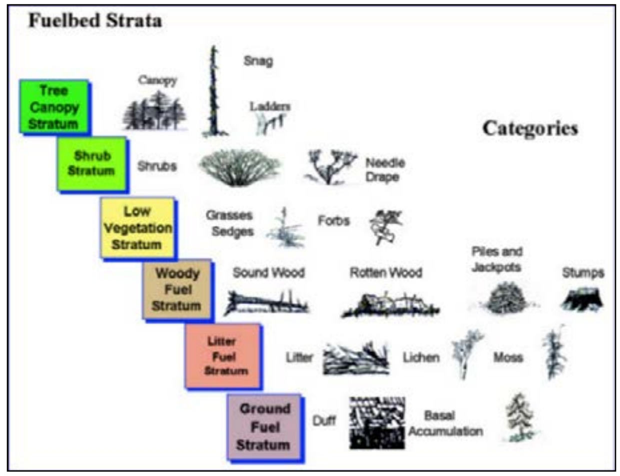


Illustration: Don McKenzie, © US Forest Service

Figure 3. Fuelbed strata and categories

fuels are fuels on the ground, including needles, the herbaceous layer, small shrubs, branches, and tree trunks. Ladder fuels are fuels that convey flames from the ground to the crowns of trees, such as tall shrubs and small and medium-sized trees with low-hanging limbs.

Crown fuels are the fuels contained in the foliage and small branches of the forest canopy. Crown fuels can be connected, as in dense forests, or sparse, as in an open forest. Fuels such as conifer needles that contain oils or resins promote combustion. These fuels ignite and burn more easily, quickly, or intensely than fuels, such as many broadleaf and deciduous trees, that don't have such oils.

Surface fuels in the wildland are characterized by the amount of time it takes to increase or decrease the moisture level within them by 63 percent. In general, these units include 1-hour, 10-hour, 100-hour, and 1,000-hour fuels. One-hour fuels are ¼-inch or less in diameter and are flashy, light vegetation (needles and grasses) that respond very quickly to weather changes. Ten-hour fuels are ¼ to 1 inch in diameter and include small limbs, branches, and other small pieces of organic matter. Hundred-hour fuels are

Table 1. Fuel size categories and their contribution to fire behavior			
Fuel category	Diameter (inches)	Description	Impact on fire behavior
1-hour	0.00–0.25	Needles, twigs, moss, lichens, small shrubs, and grasses	Easily ignited. Supports initial fire spread and the heating and combusiton of larger fuels. Under dry conditions, these fuels are flashy and surface fires spread quickly.
10-hour	0.25–1.00	Small branches, shrubs	Supports fire spread and the heating and combusiton of larger fuels. Under very dry conditions fires spread quickly.
100-hour	1.00–3.00	Medium-sized branches	Supports fire spread and the heating and combusiton of larger fuels.
1,000-hour	3.00–8.00	Large branches, small logs	Supports fire spread. Increases fire duration and influences fire severity, depending on loading.
10,000-hour	>8.00	Large, downed logs that are solid or moderately decayed	Ignites after flaming front has passed. Large fuel pieces do not support fire spread, but can increase fire duration and severity near the log. If fuel loading is high and distributed across the site (such as from beetle-killed trees), high fire severity can be more widespread and can increase both resistance to control and the duration of burning.
Snags	Variable	Bole only or bole with large branches, depending on snag condition	When snags combust, they can torch, lofting embers and firebrands ahead of the main fire, starting additional spot fires. Snags may increase resistance to control.

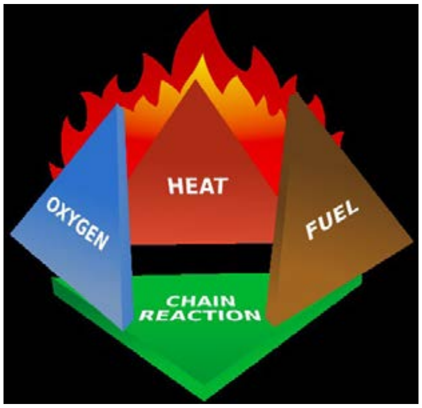
1 to 3 inches in diameter. The combustibility of these fuels is determined by weather patterns averaged over a 24-hour period. Thousand-hour fuels are 3 to 8 inches in diameter. The combustibility of these fuels is determined by averaging weekly weather conditions. Finally, 10,000-hour fuels are small to large logs, greater than 8 inches in diameter. The effect of fuel size on fire behavior is summarized in Table 1.

Fuels (Structures)

Homes and other structures contain a variety of fuels besides wood (Figure 4). Many structure fuels are comprised of synthetic or petroleum-based materials that burn differently than typical wildland fuels. The fire tetrahedron (Figure 5) is the fire triangle with the added element of a chemical chain reaction. Fire extinguishers put out fires by taking away one or more elements, such as oxygen, from the fire tetrahedron. Extinguishing agents used to put out structure fires depend on what type of fuel is burning.

For both wildland and structure fires, there are three generally recognized stages of combustion (Figure 6). The incipient stage, smoldering stage, and flame stage. The incipient stage is a region

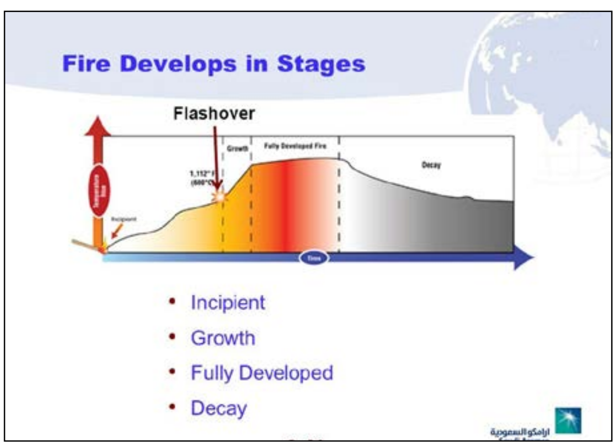
Figure 4: Characteristics Class A,B,C,D and K fuel types.



Source: Jefferson College Campus Fire Departmentr

Figure 5. The fire tetrahedron takes the three elements of the fire triangle (oxygen, heat, and fuel) and adds other passive materials. An uninhibited chain reaction also needs to occur for fire to continue to burn. Different fuels cause different chain reactions within a structure. Depending on the material burning, firefighters use various forms of extinguishing. Ordinary wood-based combustibles; flammable liquids; flammable gases; electrical equipment; combustible metals; and cooking oil or fat all require different extinguishing agents.

where preheating, distillation and slow pyrolysis are in progress. Gas and sub-micron particles are generated and transported away from the source by diffusion, air movement, and weak convection movement, produced by the buoyancy of the products of pyrolysis. The smoldering stage is a region of fully developed pyrolysis that begins with ignition and includes the initial stage of combustion. Invisible aerosol and visible smoke particles are generated and transported away from the source by moderate convection patterns and background air movement. The flaming stage is a region of rapid reaction that starts with the first appearance of flame and continues to a fully developed fire. Heat transfer from the fire occurs predominantly from radiation and convection to the fuels in front of the flame.



Source: International Fire Service Training Association

Figure 6. Stages of fire development

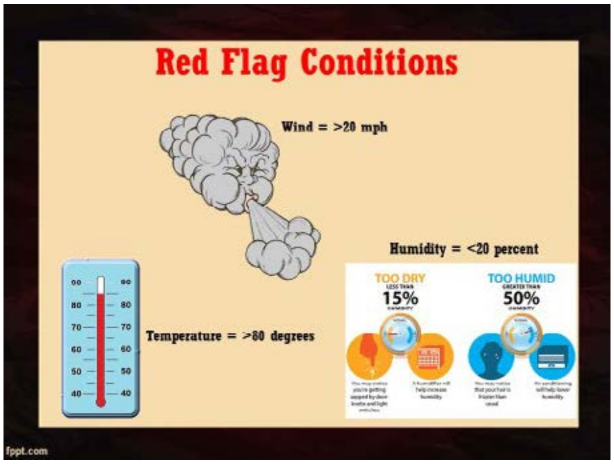
✔ Activity II—Fuels

❍ This demonstration illustrates how size and arrangement of fuels affects combustibility, fire spread, fire duration, and heat transfer to various fuel sizes.

Weather

Weather can affect many aspects of a fire, such as intensity, severity, and fire size. Weather primarily influences fire through wind, temperature, precipitation, and relative humidity. Wind increases oxygen to the fire, carries embers aloft to create spot fires away from the main fire, dries fuels out, and influences the direction and speed of a fire. Temperature influences fire primarily by drying out fuels, but it also affects the temperature of the fuel itself. Thus, fire generally ignites more readily at high temperatures and spreads faster than at low temperatures.

Additionally, if the temperatures are high during the fire, the fire will likely burn more intensely and severely. Precipitation influences moisture content of fuels. If fuels are wet, such as in spring or early summer or after a long rain, fire is less likely to ignite and will burn slower, or will go out. Relative humidity has a major influence on fire behavior. At low humidity levels, fuels become dry, ignite more easily, and burn more quickly than when relative humidity is high. Small fuel particles dry out or absorb moisture more quickly and are most influenced by hourly or daily changes in relative humidity. For example, a fire may escalate as the day heats up and relative humidity goes down, resulting in a smoke plume that builds by late morning



Source: National Weather Service

Figure 7. Red Flag conditions are created under certain weather conditions.

or early afternoon and may persist until early evening. As the day cools and relative humidity goes up—and fine fuel absorbs moisture—the fire's combustion and energy release decreases, resulting in a collapsing of the smoke plume. This pattern may repeat itself for a few to several days until there is a major weather change. It should be noted that other factors, such as wind and topography, can have a greater influence on a given fire's progression and intensity.

Extreme Fire Behavior (Red Flag Warnings)

The three components of a red flag condition are: wind, temperature, and humidity (Figure 7). Red flag weather conditions affect fire behavior to the extreme. A red flag condition occurs when wind speed is greater than 20 miles per hour at slightly above ground level, temperatures reach 80°F or above; and relative humidity is less than 20 percent.

These conditions are also known as a Fire Weather Warning—a forecast issued by the United States National Weather Service to inform area firefighting and land management agencies that conditions are ideal for wildland fire. In these conditions, fires can spread rapidly, making for dangerous conditions for firefighters and the public. Fire whirls (Figure 8) are another example of extreme fire behavior. They represent an unstable atmosphere where superheated air and turbulent wind conditions combine to form whirling eddies of air. Ash and embers are often dispersed by fire whirls. Fire whirls tell firefighters that caution and safety are paramount.

Fire Intensity and Fire Severity

Fire intensity and fire severity both characterize a fire, but they describe entirely different concepts (See sidebox on fire intensity and severity, page 8). Fire intensity is a measure of the heat energy released during flaming combustion. Fire severity is a measure of a fire's impact on the site—in other words, fire effects. Fire intensity is the amount of heat (energy) given off by a forest or house fire at a specific point in time. As a general rule, we can say that fire is hot.

Source: livescience.com

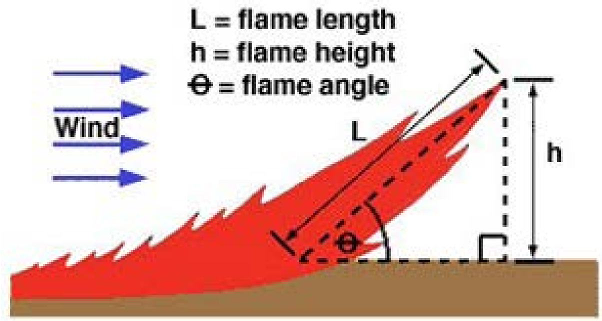
Figure 8. The photos above depict the formation of a fire whirl, in which whirling eddies are created by an unstable atmosphere with superheated air and turbulent wind.

Fire Intensity and Severity

The components of the fire behavior triangle also determine fire intensity, sometimes referred to as "fireline intensity." Fireline intensity is the rate of heat energy released per unit time per unit length of fire front, regardless of the depth of the flame zone (Byram 1959). It is calculated as the product of available fuel energy and the fire's rate of advance. Fireline intensity can be calculated by measuring or estimating flame length.

I = 258 FL2.17
I = energy release (Btu) per unit length (feet) of fire line per unit time (seconds)
FL = flame length (ft.)

Fire severity is a product of fireline intensity and the duration of heat and its effects on vegetation and soil. A given fire may display high, medium, or low fire severity effects.



Source: National Wildfire Coordinating Group

Diagram and photo illustrate what is meant by flame height and flame length.

But how hot? The heat from a Bunsen burner is much greater than the heat from a candle flame. The same is true with forest fires and house fires. Some fires give off much more heat than others. They are more intense. Fire intensity in the wildlands is influenced by weather conditions; amount, size, and moisture content of the fuel (i.e., fuel load); plant chemistry (e.g., conifer needles that emit flammable terpenes contribute more to fire intensity than green maple leaves); and topography. Fire intensity in house fires is also influenced by similar factors like weather (e.g., wind, unstable air, etc.); "topography" (e.g., chimney); and fuels (e.g. fuel type: wood vs. synthetic material).

The intensity of a fire can be low, medium, or high, and different areas within a large wildland fire may burn with different intensities, leaving a mosaic of post-fire conditions. Low-intensity fires occur when conditions are cool or moist, wind speeds are low, or fuel loads are low. Low-intensity fires may help maintain healthy forests by thinning out crowded stands of young trees, reducing the amount of fuel in the understory and on the forest floor, and releasing nutrients in the soil. High-intensity fires occur when conditions are hot, dry, and windy; the fuel load is high; and the topography is steep. High-intensity fires accelerate rapidly and burn through the tree crowns, releasing tremendous smoke and heat and consuming understory vegetation and leaves, branches, bark, and stems

Table 2. Burn severity classification based on postfire appearances of litter, soil, and soil-temperature profiles.

Soil and litter parameter	Low	Burn severity Moderate	High
Litter	Scorched, charred, consumed	Consumed	Consumed
Duff	Intact, surface char	Deep char, consumed	Consumed
Woody debris—small	Partly consumed, charred	Consumed	Consumed
Woody debris—logs	Charred	Charred deeply charred	Consumed,
Ash color	Black	Light colored	Reddish, orange
Mineral soil	Not changed	Not changed	Altered structure, porosity, etc
Soil temp. at 0.4 in (10 mm)	<120° F (<50° C)	210-390° F (100-200° C)	>480° F (>250° C)
Soil organism lethal temp.	To 0.4 in (10 mm)	To 2 in (50 mm)	To 6 in (160 mm)
Proportion of area in each burn severity category	<2% severe <15% moderate Remainder either low or unburned	<10% severe >15% moderate	>10% severe >80% mod. severe

Image: Stephen Fitzgerald, © Oregon State University

on the forest floor. High-intensity fires can be hard to control because they burn extremely hot. High-intensity fires are part of the natural fire regime for some forest types. Coastal forests, for example, have historically burned with a large proportion of high intensity fires, while ponderosa pine forests have historically burned with a large proportion of low-intensity fire (NWFSC 2015).

Fire severity refers to the effects of a fire on the environment. This assessment typically focuses on the loss of vegetation, both aboveground and belowground, and on soil impacts. Fire severity is sometimes called burn severity (Table 2). It is determined by what is burned, what plants were killed, and how much bark was charred and foliage scorched.

Fire severity has both positive and negative effects on plant and ecosystem adaptations. It can result in erosion and socioeconomic impacts on people and communities, but it can also trigger regrowth of vegetation and colonization by wildlife. (NWFSC 2015).

Fire intensity and fire severity are not synonymous or interchangeable.

A fast-moving, wind-driven fire may be intense, but a long-lasting fire creeping through the forest underbrush could transfer more total heat to plants or soil and have much more severe and complex effects on something like forest soil than a faster-moving, higher-intensity fire in the same vegetation. (Hartford and Frandsen 1991).

✔ Activity III—Fire Intensity/Severity

❍ This demonstration illustrates and summarizes the fire behavior triangle (fuel, weather, topography).

Fire Spread

Fire spread is measured or estimated in feet per minute or chains (1 chain = 66 ft) per hour. Fire spread through cured, standing grass is much faster than a surface fire moving through forest fuels. Refer to Table 3 for rate-of-spread comparisons.

Fire spread is influenced by the ratio of the heat source (of combusting fuels) and heat sink (adjacent unburned fuel) (Sugihara et al. 2006). In other words, the more heat that is generated during combustion, the faster adjacent fuels are ignited. Fire spread rates depend on the amount

Table 3. Rate of spread in selected fuel types in eastern Oregon

Fuel type	Rate of spread[1]
grass and bitterbrush	46 chains/hour
ponderosa pine/bitterbrush (4-PP-4)	9 chains/hour
dense ponderosa pine/heavy surface fuels (6-PP4	5 chains/hour

Adapted from U.S. Forest Service General Technical Report PNW105

[1] chain = 66 feet

and arrangement of fuels, wind, weather, and topography.

Fire spreads through convection, radiation, or conduction. Conduction is the transfer of heat from a flame directly to a fuel source through direct contact. For example, a flame touching and lighting a candle wick is an example of conductive heat.

Convection is the transfer of heat from a flame indirectly to a fuel source in the path of the flaming front through the heating of gases or air or both. As the air heats, it rises. In wildland fires, this heated air continues to rise, creating a plume of heat, smoke, and ash. In house fires, this heated air typically makes contact with the ceiling, where it then moves horizontally. As the heated air is trapped, it becomes denser, and then moves down through the air column.

Radiation is the transfer of heat from a flame indirectly to a fuel source via electromagnetic waves. Radiant heat generally travels from the sides or edges of a fire until the heat waves reach another object, such as a tree or house. It is the least efficient method of heat transfer to fuels.

Wet fuels take a long time to dry out and ignite using conduction or radiation. Convection tends to dry and preheat fuels faster, which is why trees at the top of a hill tend to catch fire faster as a fire moves upslope (preheating upslope fuels) than trees at the bottom of a hill as fire moves downslope (backing fire).

✔ Activity IV —Fire Spread

❍ This activity helps students develop critical thinking skills by observing fire indicators, making quick risk assessments, and constantly re-evaluating risk as fire conditions present themselves.

Fire Types

Wildland fire can be described as ground, surface, or crown fires. A wildfire will generally exhibit all three fire types throughout the

Photo: Teresa Brennan, © U.S. Geological Survey

Figure 9. A surface fire burns along the ground.

duration of the fire. However, the proportion of each type can vary greatly day to day depending on fuel, terrain, and weather conditions.

Ground fires burn mostly in the duff and in decayed roots below ground, and they can go undetected as they produce little smoke. Ground fires can emerge and ignite surface fuels or burn beneath firelines and ignite fuels on the other side of the fire line. This is why firefighters often extinguish (mop up) fires in old stumps within 50 feet of the fire line.

Ground fires can exhibit both low and high severity (e.g., peat fires). Surface fires move along the forest floor and consume needles, moss, lichen, herbaceous vegetation, shrubs, small trees, and saplings (Figure 9).

Surface fires can ignite large woody debris and decomposing duff, which can then burn (glowing combustion) long after the surface flames have moved past. Surface fire severity can be categorized as low, medium, or high.

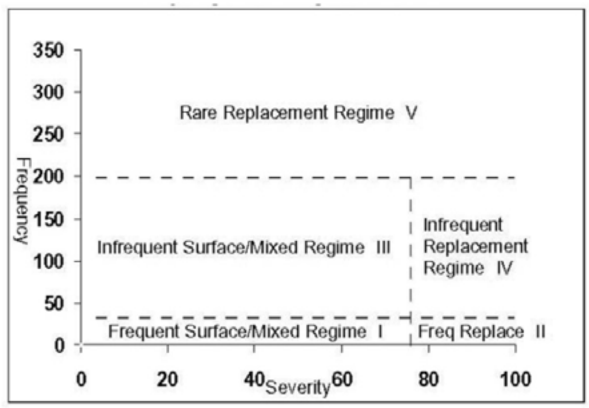
Crown fires move through tree canopies (Figure 10). Factors that influence the transition from a surface fire to crown fire include: surface fuel and foliage moisture content, surface flame length, height to the base of tree crowns, and the density and compactness of tree crowns, known as crown bulk density. Crown bulk density is the weight (in kilograms) of foliage and small branches per cubic foot of crown volume. Forests with crown bulk densities above 0.10 kilograms per cubic meter of crown volume are more prone to crown fires (Graham et al. 2004).

Crown fires are either passive or active. Passive crown fires involve the torching of individual trees or groups of trees. Torching is the precursor to an active crown fire.

Crown fires become active (crown-to-crown combustion) when enough heat from combined surface and ladder fuels preheats and combusts fuels above the surface, followed by active fire spread from tree crown to tree crown through the canopy. Crown fires are usually intense and stand replacing, and are strongly influenced by wind, topography, and crown density. Occasionally crown fires can spread independent of surface fuel combustion, where crown-to-crown combustion is sustained on its own due to combinations of high temperatures, wind, and topography. Independent crown fires are rare and typically last for short periods. But during that time, wildfires can make great lateral advances.

Source: Wikimedia

Figure 10. A crown fire races through the canopy of a ponderosa pine forest.



Source: FRCC Guidebook, Version 3.0

Figure 11. Fire regimes relative to fire frequency and severity.

Fire Regimes

Fire regimes describe the predominant types of fire (frequent or infrequent surface, mixed, stand replacing fire) as well as temporal and spatial patterns of fire on a landscape. These patterns include how frequently an area burns, how many years it takes for a defined area to burn, fire severity, fire intensity, and the fire season (spring, summer, fall). Fire regimes are largely influenced by vegetation, climate, and topography, which in turn affect fire behavior. Fires historically in ponderosa pine forests burned with frequent surface fires of low to mixed severity (Regime I). Wildfires in western Oregon and in Washington Coast Range forests were generally rare and stand-replacing (Regime V, Figure 11).

Fire regimes in some areas of the United States have shifted over time and appear to be associated with changing climatic variables, increased fuel loadings from past fire suppression and more structures built in the forest environment. For example, some forests with historic low severity/frequent fire regime are now experiencing high severity/infrequent fire. Many wildland fires now burn hotter and longer (with higher overall intensity and severity) than 30 years ago. Wildland fire season is starting earlier and lasting longer (Westerling et al. 2006). Wildland fires are harder to extinguish, require more resources, and carry greater risk of damage and costs than two generations ago.

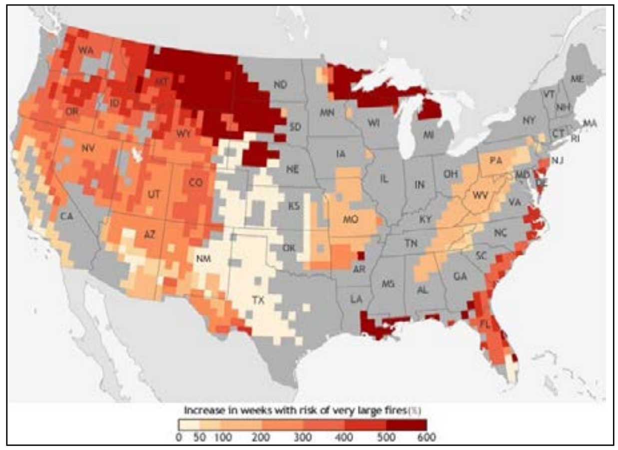
Structure fires are also harder to extinguish than in the ’60s and ’70s, even though methods and equipment to extinguish fires have improved. With new furniture made out of blended synthetic materials and tight, weather-resistant building materials, house fires burn hotter and flash sooner than two generations ago. Where fire crews once had 30 minutes to enter a building to conduct a suppression tactic or carry out a rescue, modern homes can now flashover in 3 minutes or less. Just like the wildland environment, structure fires require more resources with greater risk of damage and loss of life than two generations ago.

For these reasons, dealing with structure fires within wildland areas can be the most dangerous of all conditions.

Potential Climate Change Effects

Climate warming due to increasing greenhouse gas emissions will likely increase the potential for “very large fires”—the top 10 percent of fires, which account for a majority of burned areas in many regions of the United States. Climate change is expected to intensify fire weather conditions and lengthen the season during which very large fires spread. On top of this, fire suppression policies for the last 100 years have allowed fuels to increase, exacerbating and contributing to very large wildfires in the western United States.

Researchers predict that beginning in 2042 the number of weeks in which very large fires could occur will increase by 400 to 600 percent in portions of the northern Great Plains and the Northwest (Figure 12).



Source: National Oceanic and Atmospheric Administration

Figure 12. The projected percentage increase in the number of “very large fire weeks”—weeks in which conditions are favorable to the occurrence of very large fires—by mid-century (2041-2070) compared to the recent past (1971-2000).

Many other areas in the West will see a 50 to 400 percent increase. Red flag conditions will happen earlier, last longer, and be much more common as climate gets warmer.

If these predictions are correct, the effects of climate change are not generations away. Firefighters starting out today will be dealing with this on a large scale during their careers. This will have huge implications for fire-suppression tactics and costs, protection of human infrastructure, and major changes to vegetation across the landscape.

Notes to Instructor

Room Setup

The instructor should secure a room large enough to comfortably accommodate participants. Organize the room in a U with long tables and chairs on the outside. The room should have a large screen to display the presentation. There should be a large table up front for the instructor to use for in-class demonstrations or to display various props.

Total Time Needed

About 8 hours.

Equipment/Materials Needed

- Computer with PowerPoint
- Projector and screen
- Handouts
- Flipcharts and easels or wall space

Delivery Methods

- Presentation from instructors
- In-class demonstrations
- Outdoor demonstration
- Discussion
- Online with Canvas

Prep/Background

Not all instructors for this course will have fire experience. Those who don't could invite a fire professional to the training to provide additional expertise and commentary. Instructors can also review textbooks about fire, fire ecology, and fire management to develop an understanding about fire. Fire investigation reports also provide good insight to understand fire and its aftermath.

Demonstration Set-Up

Simulations help explain fire. The sand table exercise is a proven technique for teaching concepts presented in the module. Try to make it as authentic as possible. Use fire demonstrations (e.g., matchstick forest) whenever it is safe to do so. Safety always comes first.

Handouts

- A copy of the PowerPoint presentation (3 slides per page to allow for note taking)
- Other handouts can be downloaded from the section Additional Student Resources.

PowerPoint

- A scripted PowerPoint presentation for this module is provided.

Photo: Noerthern Bucks Wildland Fire Crew

Northern Bucks Wildland Fire Crew training sand table.

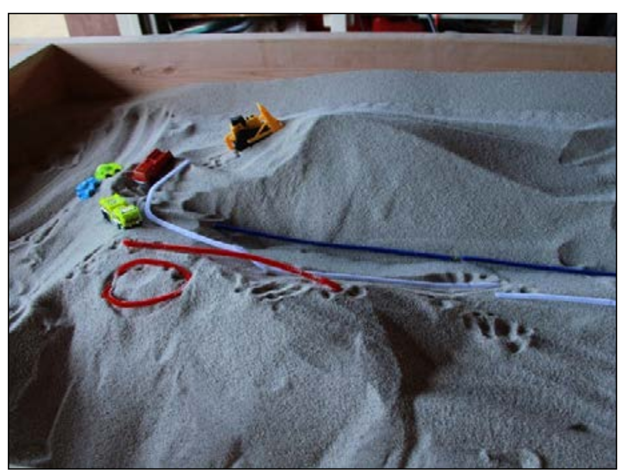


Photo: Studentoffire.org

A sand table training display.

Photo: U.S. Department of Defense

A large-scale depiction of military operations in Afghanistan.

Video

- The 10-minute video, *2017 WFSTAR: Introduction to Fire Behavior*, can be used instead of the PowerPoint, particularly if the instructor is pressed for time. The video covers the fire triangle, fire spread, fire-line intensity and other fire-behavior topics. The video is listed in "Additional Resources for Students" below.

Evaluation Instrument

(For Professional Fire Personnel Only)

To assess student understanding of the topics in this module, students will select an ecosystem, such as a ponderosa-pine-dominated forest, and write a 1,000-word essay about the fire regime of their system.

This essay needs to include information about fire severity, fire intensity, how fire spreads in this system, and how other elements of the fire behavior triangle influence the fire regime in this system. Students will also give a 5-minute presentation about the fire regime of their chosen forest ecosystem.

Class evaluation—Provide a survey for student feedback for each module as a form of formative evaluation.

Activities

I. Personal and Professional Insights

Firefighting has changed since the '60s and '70s. When we started then, our "Personal Protective Equipment" (PPE) was a pair of blue jeans, maybe an orange fire retardant shirt, a metal hardhat, leather or cloth gloves, and boots. The packs we took to the fireline were canvas "FS" haversacks or Army surplus butt packs. Our radios for the field used 12 "D" batteries and weighed 12 to 15 pounds with all the paraphernalia. The lookouts on every mountaintop provided more communication for us than did those heavy radios.

We attacked wildland fires throughout the '60s, '70s, and '80s as soon as we could get to them, and we usually had them out (every ember cold-trailed) within a week or two—the largest fires after a maximum of 4 weeks. It was rare to have a wildland fire burn out of control longer than that. It started to change noticeably in the mid-90s. Snow melted off earlier in the spring in the high country. We kicked up dust on the roads sooner in the year. Leaves changed color and dried out earlier in the season. Humidity fell further and earlier in the day—temperatures rose higher. Night-time temps and humidity didn't recover as much. The trend continued throughout the 2000s.

In 2008, near the Bob Marshall Wilderness in Montana, lightning started a small fire of about 120 acres on a mountaintop. Dispatch sent a Type 1 Hot Shot crew of 20 firefighters to contain and control it. The Type 2 Incident Management Team in charge of the fire sent its operations section chief and safety officer to spike out at the crew mountaintop camp to oversee the operation. No one was worried. Rising bright and early the next morning, crew members improved their fire line and had almost encircled the 120-acre spot. At 0900, the humidity was about 30 percent—same as the previous week. Temperature was 65°F and winds were light at about 1 to 5 miles per hour. Flames burning through the duff at the last corner were about 1½ feet with slow movement. Two hours would be all it took to contain the fire with a solid line. Mop-up would take another couple of hours. Control was imminent.

At 10:30, the world changed. Humidity dropped to single digits, temperature rose to the 80's, and winds kicked up to 40 mph. Red-Flag conditions with no warning. The flame lengths were fanned by hot, dry wind and shot up from 1½ feet to over 200 feet as the crown fire swept up the steep slope like a tornado. We only had minutes to jump into the already-burned-over area, which thankfully served as a safety zone. We were dazed, but safe. We retreated to our camp and were marooned there five days while a thousand freight trains consumed tens of thousands of acres of forest all around us, day and night. When the storm finally abated and we could go back to camp, the 120-acre fire was about 70,000 acres.

The average wildland fire now behaves much like the "extreme" fires of decades ago. Wildland fires now are more extreme, harder to manage, more dangerous, and last longer. Fire seasons start earlier, end later, and cover more parts of the country than they used to. Fire behavior is so extreme so often now that one to two fire-retardant drops that used to quash the fire into a quiet mode now takes a dozen drops.

House fires are more extreme, too. We used to have 30 minutes in an average house fire to conduct rescue, find the fire source, and put it out. Now, because building and furniture materials are made of new, synthetic materials that are more flammable and burn hotter, we have 3 minutes before it's too hot *to enter a building. These factors and the loss of firefighters in both structure and wildland fires have made us more risk adverse and prone to err on the side of protecting firefighter lives.*

II: Fuels

- Provide students with a safe area, such as an outdoor fire pit, fire table or clear area, to burn different sizes and types of fuel.
- Provide students with a variety of 1-hour, 10-hour, 100-hour, and 1,000-hour fuels (e.g., pine needles, small branches, large branches, and a piece of a tree trunk).
- Divide students into three or four groups, one for each fuel type.
- Have students attempt to light their fuel on fire without using kindling, accelerants, or things of that nature.
- You could also have students build a model house with different sizes and types of fuels and see how easily these fuels ignite and burn.
- Have students record how thoroughly their fuel ignited and burned. Then have students regroup into groups containing a representative from the 1-hour, 10-hour, 100-hour, and 1,000-hour groups.
- Students should work together to identify differences in ignitability and combustibility.

III: Fire Intensity/Severity

- Provide students with aluminum pans, clay, matches, a stopwatch, and a lighter.
- Have students work in teams to build their own landscapes, using the clay in the aluminum pans.
- Then have them build their own forest using the match sticks (matchhead up). Use cedar chips (from a pet store) or crinkled up paper shreds to serve as surface fuels beneath the matchsticks.
- Once students have built their own forest, have them hypothesize about how their forest will burn (fire severity and intensity).
- Then have students ignite one of their matchstick trees and time how fast the fire burns.
- Once the fire is out, have them record how many "trees" burned. Discuss the pattern of burning and overall severity.

IV: Fire Spread

- Have students read the excerpts about the Great Chicago Fire (http://ethw.org/images/d/dd/The_Great_Chicago_Fire.pdf) and the Tillamook Fire (http://oregonstate.edu/instruct/geo422/522-Paper%20hoadley.pdf).
- Have students identify the different types of heat (radiation, convection, conduction) that may have influenced how these fires behaved and spread.
- Then have students compare their results with a partner.
- Alternatively, have some students read the excerpt about the Great Chicago Fire and some read the excerpt about the Tillamook Fire. Then pair students from the Great Chicago Fire with students from the Tillamook Fire and have them work together to identify how fuels and fire spread (radiation, convection, conduction) influenced these fires. Have them identify several similarities and differences between these fires and associated fire behavior.

Instructors can also have students do the "Inquiry Lesson" written by David Huss (also in the Additional Resources for Students) and then answer the questions for these two scenarios.

- You have responded to a fire in a one-story, single-family dwelling of wood-frame construction. An incipient fire is burning a bedroom on the corner of the structure. The fire is limited to a plastic trash can containing waste paper, which is located next to the bed.

- ❏ What conditions would you expect to see from the exterior of the structure?
- ❏ What indicators may be visible from the front door as you make entry?
- ❏ What might you observe traveling through the living room and down the hallway?
- ❏ What conditions would you find in the bedroom? It is essential to think about what you are likely to find inside when observing fire behavior indicators from the exterior and performing a risk assessment. After making entry, consider if conditions are different than you anticipated.
- ❏ Why might this be the case?
- ❏ What differences in conditions would be cause for concern?

■ You have responded to a fire in a one-story, single-family dwelling of wood-frame construction. A fire which started in a bedroom on the corner of the structure has gone from fully developed to the decay stage due to a lack of oxygen as building openings (doors and windows) remain closed and intact.

- ❏ What conditions would you expect to see from the exterior of the structure?
- ❏ What indicators may be visible from the front door as you make entry? A fire in the decay stage (particularly when this is due to limited oxygen) still presents a significant threat as conditions can change rapidly.
- ❏ If the door at your entry point remains fully open, how will this influence fire behavior (assuming no other ventilation has been performed)?
- ❏ How would fire behavior be influenced if a window or windows in the fire compartment are opened along with the door at your entry point?
- ❏ What indicators would you anticipate observing as you traveled through the living room to the hallway leading to the bedroom?
- ❏ What conditions would you find in the hallway outside the fire compartment? After making entry, consider if conditions are different than you anticipated. Why might this be the case?
- ❏ What differences in conditions would be cause for concern?

Photo: Oregon State University

Students can build their own matchstick forest.

Additional Resources

Tillamook Fire. Online at: http://oregonstate.edu/instruct/geo422/522-Paper%20hoadley.pdf

Great Chicago Fire. Online at: http://ethw.org/images/d/dd/The_Great_Chicago_Fire.pdf

Inquiry Lesson Plan exploring the roots of the Chicago Fire. Online at: (https://www.uww.edu/Documents/colleges/coeps/cni/social%20studies/lesson%20plans/2009-2010/Inquiry%20Lesson%20Plan-%20Great%20Chicago%20Fire%20tragedy%20to%20occur.pdf)

Fire Regime information from firescience.gov. Online at: https://www.firescience.gov/projects/09-2-01-9/supdocs/09-2-01-9_Chapter_3_Fire_Regimes.pdf

Hartin, E. 2008. Fire Behavior Indicators and Fire Development — Part 1. Retrieved March 28, 2017. http://www.firehouse.com/article/10494291/fire-behavior-indicators-and-fire-development-part-1

Hartin, E. 2007. Fire behavior indicators: Building expertise. Retrieved January 19, 2008 from www.firehouse.com. Fire Development and Fire Behavior Indicators, © Copyright CFBT-US, LLC, Page 15

Hartin, E. 2007. Reading the fire: Building factors. Retrieved March 28, 2017 from: http://www.firehouse.com/article/10501963/reading-the-fire-building-factors

Hartin, E. 2007. Reading the fire: Smoke and air track. Retrieved March 28, 2017 from: http://www.firehouse.com/article/10504806/reading-the-fire-smoke-and-air-track

Reducing Fire Risk on Your Forest Property (PNW 618). Online at: https://catalog.extension.oregonstate.edu/pnw618

All about fire. Online at: http://www.nfpa.org/news-and-research/news-and-media/press-room/reporters-guide-to-fire-and-nfpa/all-about-fire

Northwest Fire Science Consortium, Fire Facts: What is fire intensity? Online at: http://www.nwfirescience.org/biblio/nwfsc-fire-facts-what-fire-intensity

Northwest Fire Science Consortium, Fire Facts: What is fire severity? Online at: http://www.nwfirescience.org/biblio/nwfsc-fire-facts-what-fire-severity

2017 WFSTAR: Introduction to Fire Behavior Video (10 minutes). Online at: https://www.youtube.com/watch?v=L0y4KdgmQU8&index=1&list=PL6li6qFDQR6j8K-NQc-prN74qEoJotenW

Glossary of Terms

Backing fire: A fire burning into the wind.

Backburn: Firefighter technique used to reduce fuels in front of an advancing fire.

Conduction: The transfer of heat from a flame directly to a fuel source through direct contact.

Convection: The transfer of heat from a flame indirectly to a fuel source in the path of the flaming front through the heating of gases or air or both.

Distillation: Conversion of a liquid into vapor that is subsequently condensed back to liquid form.

Pyrolysis: The heating of an organic material, such as biomass, in the absence of oxygen. Because no oxygen is present, the material does not combust. But the chemical compounds (i.e., cellulose, hemicellulose, and lignin) that make up that material thermally decompose into combustible gases and charcoal.

Radiation: The transfer of heat from a flame indirectly to a fuel source via electromagnetic waves.

Spotting: Small fires ignited by fire brands or embers.

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Graham, R.T., S. McCaffrey, T.B. Jain. 2004. Science basis for changing forest structure to modify wildfire behavior and severity. *Gen. Tech. Rep*. RMRS-GTR-120. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

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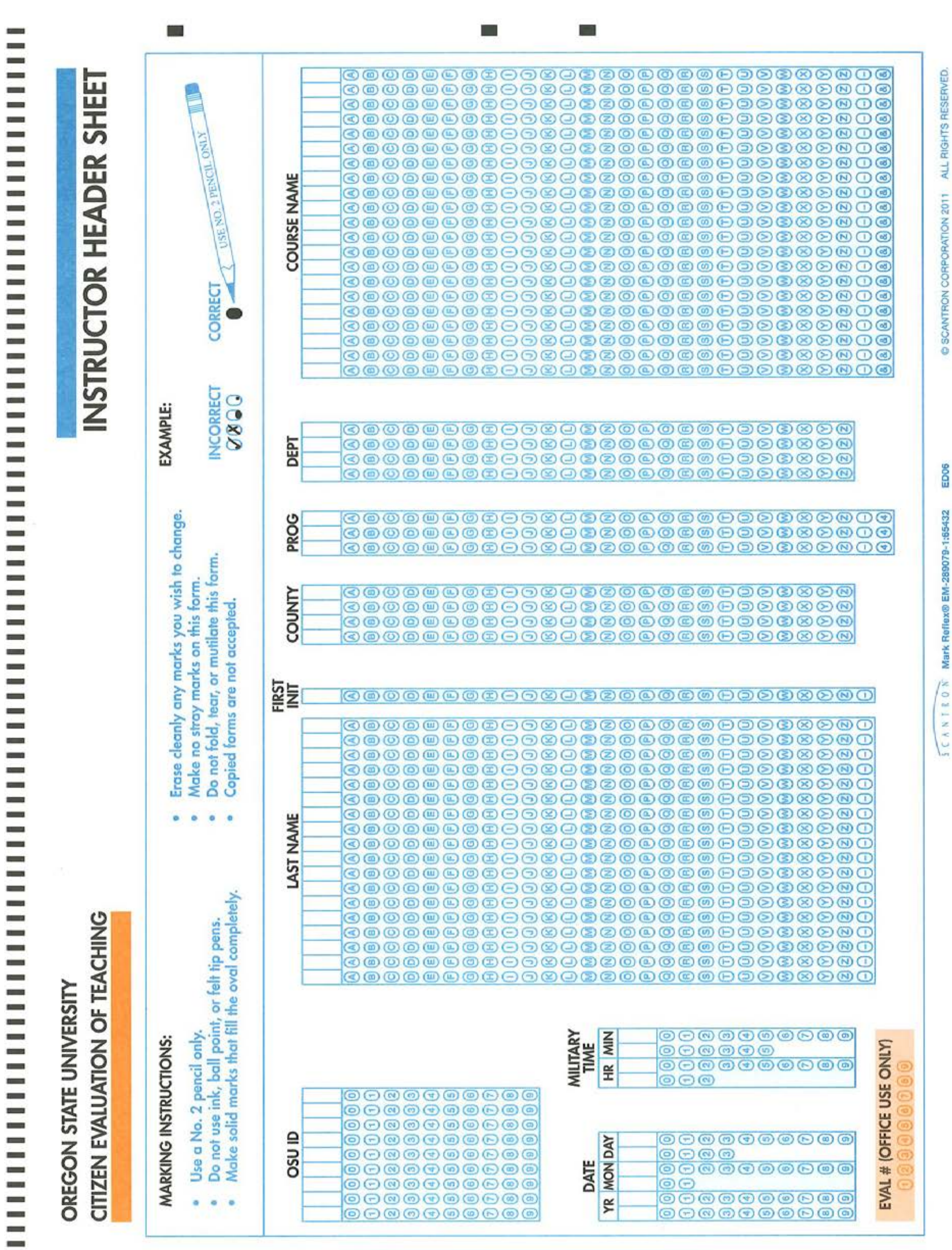
Evaluations


OREGON STATE UNIVERSITY

CITIZEN EVALUATION OF TEACHING

INSTRUCTOR HEADER SHEET

MARKING INSTRUCTIONS:

- Use a No. 2 pencil only.
- Do not use ink, ball point, or felt tip pens.
- Make solid marks that fill the oval completely.
- Erase cleanly any marks you wish to change.
- Make no stray marks on this form.
- Do not fold, tear, or mutilate this form.
- Copied forms are not accepted.

EXAMPLE:

INCORRECT

CORRECT

USE NO. 2 PENCIL ONLY

OSU ID

LAST NAME

FIRST INIT

COUNTY

PROG

DEPT

COURSE NAME

DATE

YR MON DAY

MILITARY TIME

HR MIN

EVAL # (OFFICE USE ONLY)

SCANTRON Mark Reflex® EM-289079-1:65432 ED06

OREGON STATE UNIVERSITY
CITIZEN EVALUATION OF TEACHING

USE NO. 2 PENCIL

INSTRUCTOR'S NAME	EXTENSION EVENT	DATE

YOUR RESPONSES TO THIS QUESTIONNAIRE WILL HELP INSTRUCTORS CONFIRM QUALITY TEACHING AND IMPROVE TEACHING SKILLS AND METHODS.

PLEASE FILL-IN THE APPROPRIATE RESPONSE.
MARK ONLY ONE CIRCLE PER QUESTION/

	VERY POOR	POOR	FAIR	GOOD	VERY GOOD	EXCEL-LENT	UNABLE TO RATE
1. Overall, the quality of the educational event as a whole was	○	○	○	○	○	○	○
2. The quality of instruction in this educational event was	○	○	○	○	○	○	○
3. Clarity of educational objectives was	○	○	○	○	○	○	○
4. Clarity of how you might use this education was	○	○	○	○	○	○	○
5. Teaching organization was	○	○	○	○	○	○	○
6. Instructor's use of examples was	○	○	○	○	○	○	○
7. Instructor's use of teaching aids (slides, overheads, charts, etc.) was	○	○	○	○	○	○	○
8. Instructor's ability to stimulate my thinking more deeply about the subject was	○	○	○	○	○	○	○
9. Instructor's responsiveness to questions was	○	○	○	○	○	○	○
10. Instructor's use of participant discussion to enhance my learning was	○	○	○	○	○	○	○
11. Instructor's ability to develop a welcoming environment for all participants was	○	○	○	○	○	○	○
12. Instructor's skill in making the information useful to me was	○	○	○	○	○	○	○

Your comments will be helpful to improve instruction.

Please comment:

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PowerPoint Slides

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Module 3: Fire Behavior

FIRE SCIENCES CORE CURRICULUM

1

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LEARNING OBJECTIVES

- Understand how weather, topography, and fuels affect fire behavior:
  - Create a landscape and 'matchstick forest' and hypothesize how a fire will behave.
- Understand how fuel size and arrangement contribute to fire spread and fire type
- Compare and contrast fire severity and fire intensity
- Be able to explain what factors produce or influence fire regimes

2

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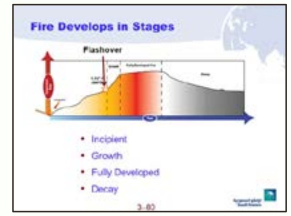

Flashover demonstration: https://www.youtube.com/watch?v=BtMmymOxdjc

3

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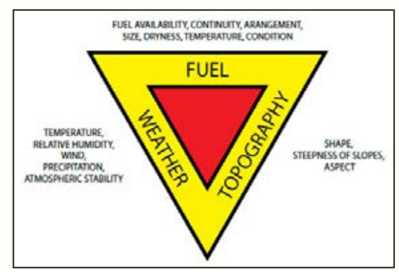
THE FIRE BEHAVIOR TRIANGLE



4

THE FIRE BEHAVIOR TRIANGLE

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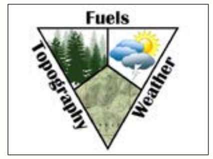
What do we mean by fire behavior? What does it include?



Terminology	Meaning
Rate of spread	How fast a fire moves in ft./min. or chains/hr.
Intensity	How hot a fire burns (heat released in BTUs)
Flame length	Surrogate measure for fire intensity
Torching	Flames moving up from the surface into tree crowns
Crowning	Flames spreading through the main tree canopy
Spotting	Spot fires ignited by embers ahead of main fire front
Whirlwinds	Superheated air and turbulent wind conditions form whirling eddies of fire

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THE FIRE BEHAVIOR TRIANGLE

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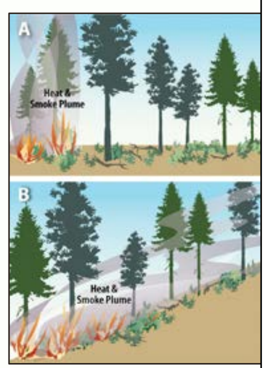
Topography

- Fires spread faster upslope:
  - Slope tilted toward the flames
  - Fuels more effectively preheated by approaching flames



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THE FIRE BEHAVIOR TRIANGLE

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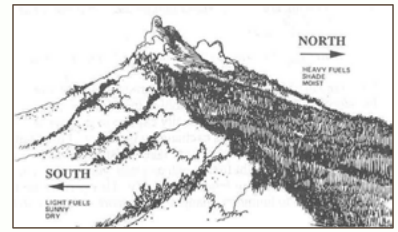
Topography

- Slope angle, aspect, and elevation affects:
  - Drying of fuels on a daily and seasonal basis
  - Air temperature and temperature of fuels



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THE FIRE BEHAVIOR TRIANGLE

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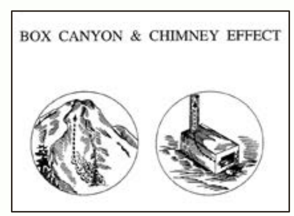
Topography

- Other landscape features
  - Box canyons, saddles, narrow canyons affect:
    - Air flow and wind currents on a daily basis
    - Safety zones for firefighters



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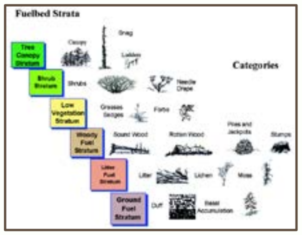
THE FIRE BEHAVIOR TRIANGLE

Fuel

- Fuel is anything that will burn under the right conditions!
- Fuel continuity:
  - Vertical and horizontal dimension to fuels
- Natural vs. activity fuels



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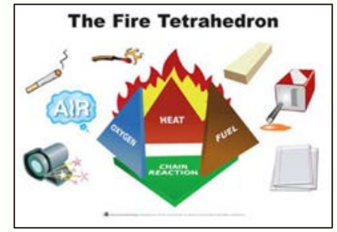
THE FIRE TETRAHEDRON

Structure Fuels

- Fire triangle with the added element of a chemical chain reaction
- Petroleum-based products used in home construction



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THE FIRE BEHAVIOR TRIANGLE

Fuel

- Fuel moisture:
  - Live FM
  - Dead FM
- Fuel size
  - Surface-to-volume ratio
- Chemical makeup
  - Resin, sap, foliar chemicals

Fuel category	Diameter (in.)	Description	Impact on fire behavior
1-hour	0.00–0.25	Needles, twigs, moss, lichens, small shrubs and grasses	Easily ignited. Supports initial fire spread and the heating and combustion of larger fuels. Under dry conditions, these fuels are flashy and surface fires spread quickly.
10-hour	0.25–1.00	Small branches, shrubs	Supports fire spread and the heating and combustion of larger fuels. Under very dry conditions fires spread quickly.
100-hour	1.00–3.00	Medium-size branches	Supports fire spread and the heating and combustion of larger fuels.
1,000-hour	3.00–8.00	Large branches, small logs	Supports fire spread. Increases fire duration and influences fire severity, depending on loading.
10,000-hour	> 8.00	Large downed logs that are solid or moderately decayed	Ignites after flaming front has passed. Large fuel pieces do not support fire spread, but can increase fire duration and severity near the log. If fuel loading is high and distributed across the site (such as from beetle-killed trees), high fire severity can be more widespread and increase resistance to control and the duration of burning.
Snags	Variable	Bole only or bole with large branches, depending on snag condition	When snags combust, they can torch, lofting embers and firebrands ahead of the main fire, starting additional spot fires. Snags may increase resistance to control.

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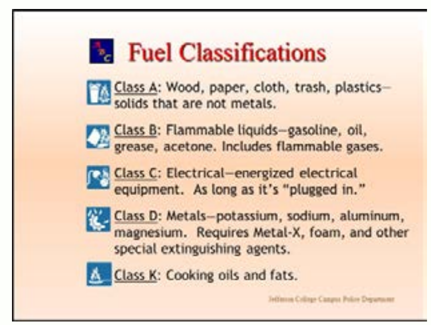
THE FIRE TETRAHEDRON

Structure Fuels



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THE FIRE BEHAVIOR TRIANGLE

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Weather

Wind

Increases oxygen supply

Dries fuels

Causes spot fires

Influence direction of fire spread.

Moves air heated by convection into more fuels

Example: Dry east winds are particularly dangerous during August and September in Oregon.

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THE FIRE BEHAVIOR TRIANGLE

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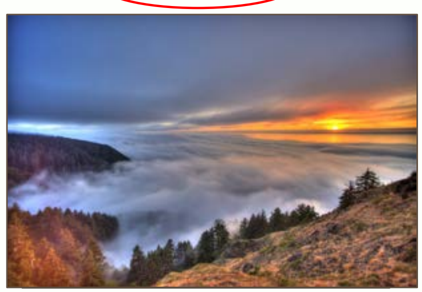
Weather

Precipitation

Duration generally has greater effect than volume



Pattern of yearly precip. affects fuel drying

Other influences, such as a marine layer, can affect relative humidity and fog drip and the wetting and drying of fuels.

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THE FIRE BEHAVIOR TRIANGLE

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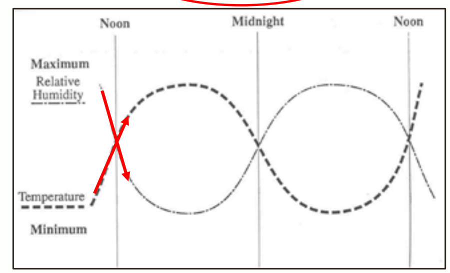
Weather

Relative Humidity



- Affects diurnal wetting and drying of fuel
    - Dependent on fuel surface-to-volume ratio

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THE FIRE BEHAVIOR TRIANGLE

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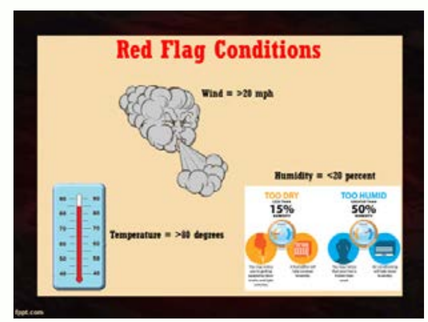
Weather Extremes



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THE FIRE BEHAVIOR TRIANGLE

Weather Extremes

Fire Whirls

- Unstable atmosphere
- Superheated air plus turbulent wind conditions

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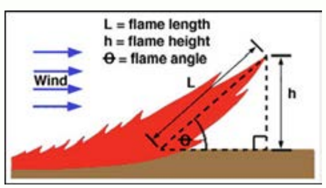
FIRE INTENSITY AND FIRE SEVERITY

Fire Intensity or "Fireline Intensity"

$I = 258$ FL^2.17

I = energy release (Btu) per unit length (ft.) of fire line per unit time (seconds)
FL = flame length (ft.)



- Measure at the midpoint of the flame
- Can be easily observed with proper reference point

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FIRE INTENSITY AND FIRE SEVERITY

Fire Severity

- Refers to the effects of a fire on the environment:
  - Damage to vegetation and trees
  - Damage to soils and watersheds

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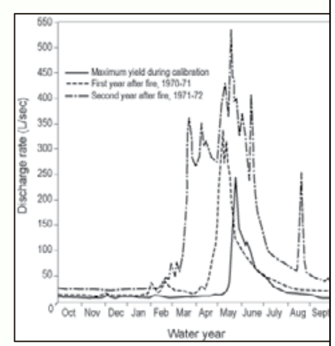
FIRE INTENSITY AND FIRE SEVERITY

Fire Severity

- Fire severity is rated as low, moderate and high base on visual fire effects to soil or vegetation. Example below for soil.



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THE FIRE BEHAVIOR TRIANGLE

Fire Spread

- Fire spread is the movement or progression of fire through a fuel bed
- It is measured by feet per minute or chains (66 ft.) per hour.
- Fire spread is influenced by the type and continuity of fuel, moisture content of fuel, topography, and weather factors, such as wind.

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FIRE SPREAD

Fire Spread

Fuel Type	Rate of spread
Grass and bitterbrush (2-GR)	46 chains/hr. (3,036 ft.)
Ponderosa pine/bitterbrush (4-PP-4)	9 chains/hr. (594 ft.)
Dense ponderosa pine/heavy surf. fuels (6-PP-4)	5 chains/hr. (330 ft.)


Head fire in grass with rapid spread


Backing fire in grass with slow spread


Dense PP with heavy surface fuels

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FIRE TYPES

- **Ground fires**
- **Surface fires**
- **Crown fires**
  - **Passive**
  - **Active**

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FIRE TYPES

Ground fires

- Burn below the surface in duff, roots, buried logs, and peat
  - Peat fires:
    - Slow rate of spread
    - Long duration, high severity
    - Peat fires can last for years
    - Difficult to extinguish
  - Burning in duff around large ponderosa pine trees
    - Long duration smoldering fire
    - Tree mortality

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FIRE TYPES

Surface fires

- Consume litter layer, herbaceous vegetation, shrubs, twigs, and branches
- The higher the fuel loading on the surface, the greater the flame length and the greater the intensity of the fire

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FIRE TYPES

Crown fires:

- Passive
  - "Torching" of individual trees or small groups of trees
- Active
  - Crown-to-crown combustion

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FIRE REGIMES

- Describe the predominant types of fire in ecosystems.
- Fire regimes have the following elements:
  - Frequency
  - Fire intensity and severity
  - Extent
  - Seasonality
  - Synchrony / synergy with other disturbances
- Vegetation, climate, and topography are factors that determine the fire regime in a given area.

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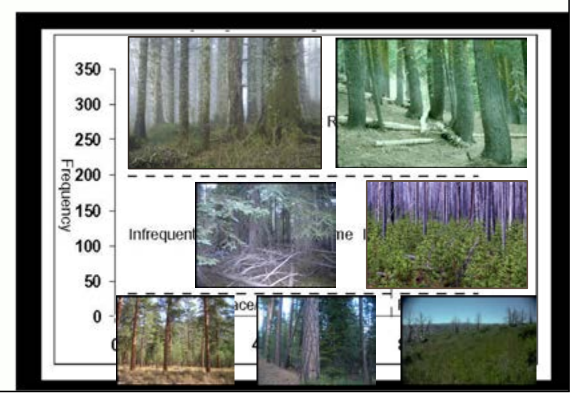
FIRE REGIMES

haracterizing
re regimes by
equency and
verity



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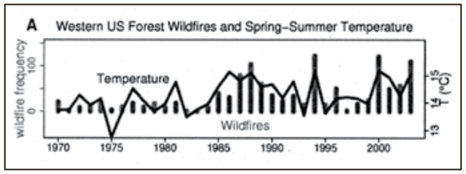
POTENTIAL CLIMATE CHANGE EFFECTS

- CO_2 levels have risen to over 400 ppm and global temperatures are 1.53°F higher than in early industrial times.
- Fire seasons are about 5 weeks longer today, with an uptick in very large wildfires across the western U.S.



- Implications for plant ecology, human infrastructure, and fire suppression tactics and costs.

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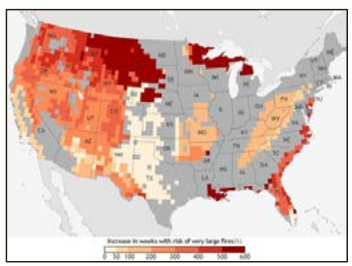
POTENTIAL CLIMATE CHANGE EFFECTS

- The projected percentage increase in the number of "very large fire weeks" by mid-century (2042-2070) compared to recent past (1971-2000). (NOAA)



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POTENTIAL CLIMATE CHANGE EFFECTS

- In addition to climate change potential, other factors that may contribute to very large wildfires now and into the future include:
  - Effects of fire exclusion over the last 100+ years and the build-up of fuel in many of the dry forest types in the western U.S.
  - Changes to firefighting tactics. More conservative fire management approaches will err on firefighter safety rather direct attack at all cost.
  - There is a growing sentiment that in order to get ahead of the wildfire problem, we need to allow wildfires to do more of the work (fuel reduction) by managing wildfires.

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This concludes this module training.

Thank you!

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