IBHS PRIMER SERIES ON WILDFIRE

PART ONE

THE FIRE BEHAVIOR TRIANGLE

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Wildland fire behavior is governed by three environmental components:

1. Weather
2. Fuel
3. Topography

These three components make up the fire behavior triangle (Figure 1).

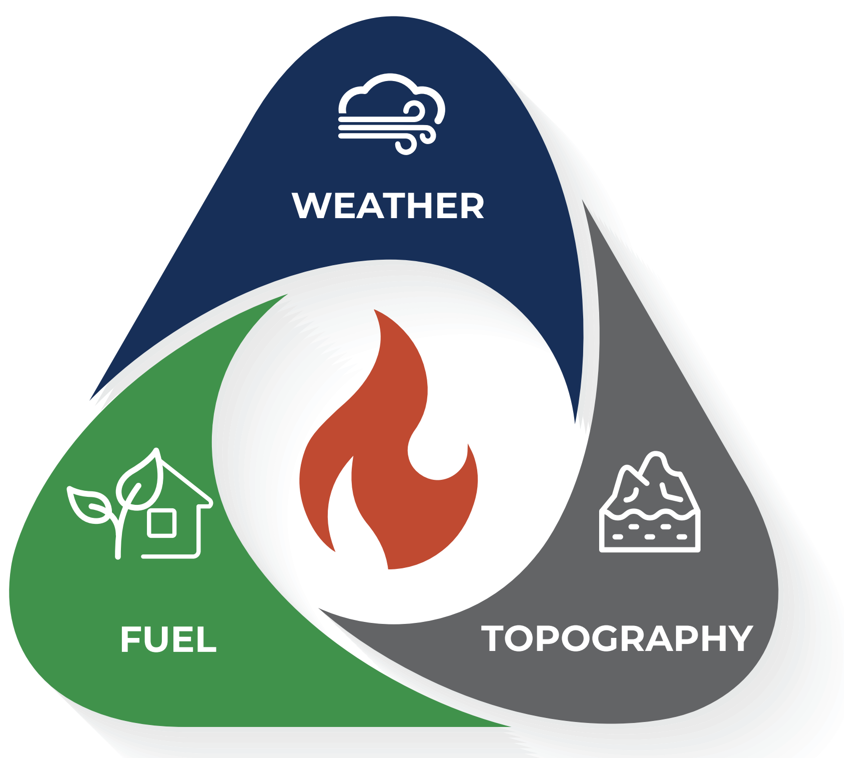

Figure 1. Fire behavior triangle.

When the conditions associated with each component are favorable to fire development, they can create the potential for extreme fire behavior. This behavior can include:

- A high rate of fire spread
- Prolific crown fires
- Ember-driven ignitions ahead of the main fire (spotting)
- Fire whirls
- A strong, deep column of rising air[1]

WEATHER AND CLIMATE

Regional weather and the long-term climate play key roles in determining the number of red flag days. During active fires, weather conditions strongly influence fire behavior. Seasonal trends in temperature, humidity, and precipitation over several years affect the type and growth of vegetation that ultimately becomes the primary fuel for wildland fire.

CLIMATE CYCLES

Adverse climate can be an enabling mechanism for wildfires. The impact of patterns of extreme drought and their linkage to our changing climate is understood.[2] Climate change has also led to more stagnant large-scale weather patterns that have allowed for rapid changes between extreme rainfall and extreme drought. This can lead to rapid vegetation growth followed by warm and dry conditions, creating an abundance of available fuel for wildfires. Climate cycles such as El Nino/La Nina cycles also impact precipitation patterns on time scales of months to a few years. An anthropogenic contribution to wildfire is the number of fires started by human activity, which has increased over those caused by lightning (the only natural means to start a wildfire).

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[1] *National Wildfire Coordinating Group (NWCG) Glossary of Wildland Fire, PMS 205*
[2] *National Academy of Science. 2016. Attribution of Extreme Weather Events in the Context of Climate Change*

SEASONAL TRENDS—WEEKS TO MONTHS

Temperature, precipitation, and relative humidity affect the moisture content of fuels. Low relative humidity and high temperatures result in extremely dry fuels that are susceptible to ignition and signal the potential for rapid fire spread.

Significant precipitation followed by rapid development of drought conditions can change the available fuels. Rapid vegetative growth followed by extreme drought can increase the available fuels and then make them highly susceptible to ignition, increasing the potential for rapid spread.

CURRENT WEATHER

At the time of ignition, wind can be the dominant factor in fire spread. The National Weather Service issues red flag warnings based on forecasts for conditions that are ideal for rapid wildfire spread. Firefighting agencies use fire weather forecasts to manage staffing and resource allocation to accommodate high fire danger.

Red Flag Warnings

These warnings are Issued by local offices of NOAA's National Weather Service to indicate that the conditions for rapid wildfire spread (high winds and low humidity) are ongoing or forecast within the next 24 hours. In 2019, the Extreme Red Flag Warning was added to communicate a "particularly dangerous situation" where conditions are ideal for extreme fire spread and behavior. This includes high winds, low relative humidity, and very dry fuels over a long period of time. The exact criteria for red flag warnings is

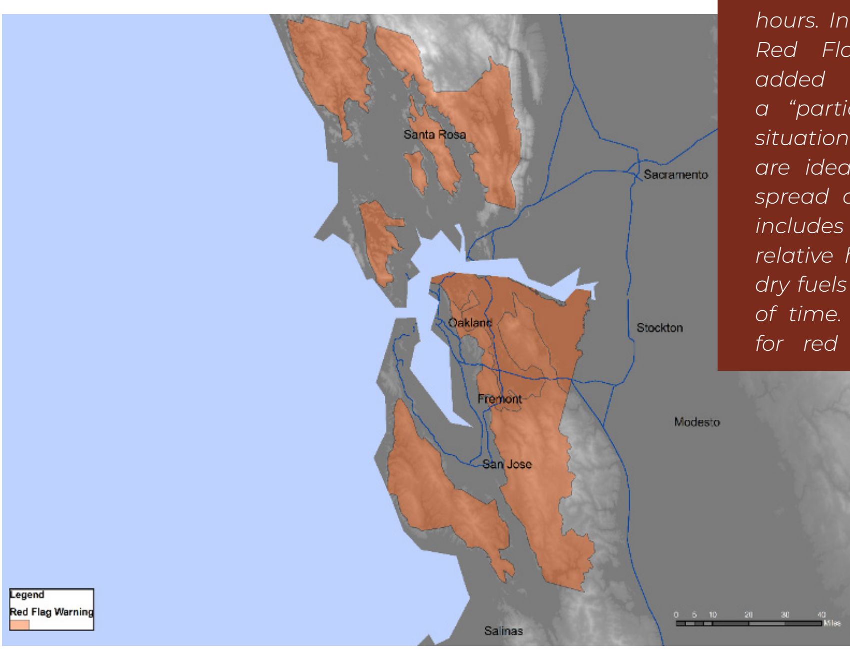

Figure 2. Example of a set of red flag warnings issues by the San Francisco Weather Forecast Office of the National Weather Service during October of 2018.

Downslope winds, such as the Santa Ana and Diablo winds in California, cause some of the most favorable wind conditions for wildfire growth. Other downslope wind events can occur on the eastern side of the Rocky Mountains (Chinook winds). As air descends the sloping terrain, it warms and dries, displacing relatively cooler air. The process can also create a wave-breaking pattern that can lead to extreme turbulence aloft and severe wind gusts at ground level.

Local terrain features such as gaps, canyons, and valleys can further accelerate the downward moving air.

TOPOGRAPHY

Topography describes the shape of the land surface and is a combination of:

- Elevation
- Slope (steepness of the land)
- Aspect (direction a slope faces)
- Features (canyons, valleys, rivers, etc.)

Topographical features influence the spread of fire and affect both the fuel conditions and the local fire behavior. For example, fires burning upslope preheat and dry potential fuel, which can lead to faster spread rates.

Features of topography also influence the wind flow behavior. Complex terrain can result in gap flow scenarios, where the wind accelerates in gaps between mountain tops (Venturi effect). Upstream terrain and vegetation also create barriers and surface friction that affect the wind flow. This results in changes in wind gustiness, in turn changing the behavior and spread of the fire over relatively small distances as the flow adjusts to the terrain and vegetation underneath.

Terrain factors that contribute to a severe downslope wind event are:

- Wind direction at mountain top/ridge line level within 30° of perpendicular to the terrain
- Upstream vertical profile of temperature increases with height (inversion)

Ideal terrain for this behavior consists of long ridges with gentle windward (upwind) slopes and steep leeward (downwind) slopes.

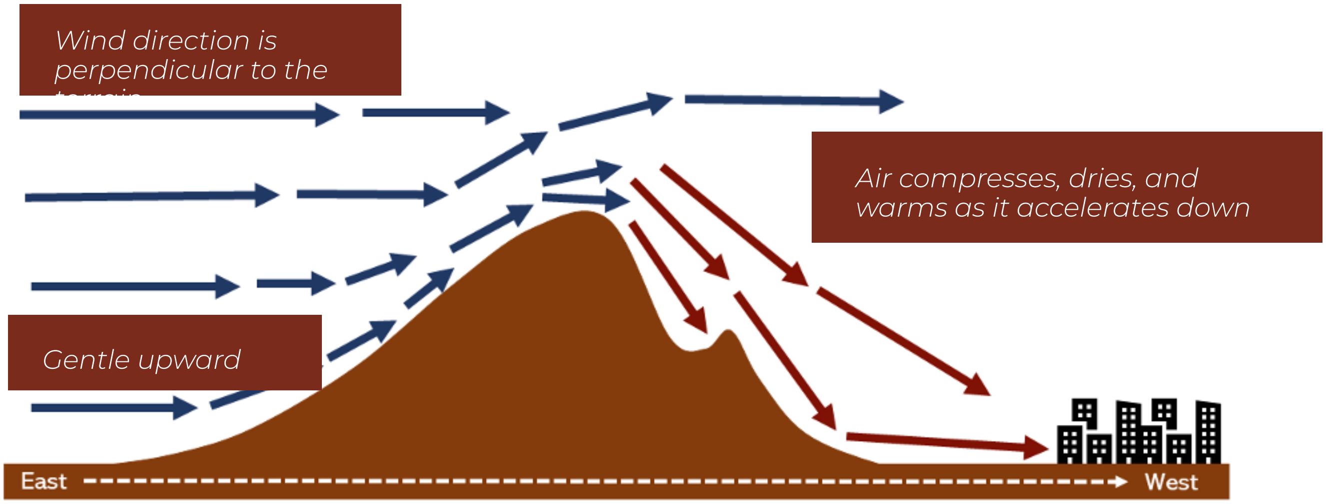

Figure 3. Effects of terrain on wind, humidity, and temperature.

FUEL

Characteristics of the fuel, both vegetative and structural, strongly influence fire behavior. The configuration and orientation of individual fuel categories, such as trees and brush, create paths for fire to move both horizontally and vertically. The material and its moisture content determine the ignition potential. Of the three components of the fire triangle (see Figure 1), fuels are unique because they can be modified (for example, by removal) to change fire behavior. Topography cannot be realistically modified on a large scale and it stays nearly constant over long periods, so its impact on fire behavior can be accounted for. Modifying the weather conditions on a large scale is also not possible. Fires themselves can also create their own environments through the rapidly rising columns of hot air that can increase their severity as it did during the Carr Fire in 2017.

The built environment can also be a source of fuel when a wildland fire spreads into areas of higher population density. This can change the behavior of the fire and create changes in the embers (also called firebrands) that the fire is continually producing. Part 2 of this series explores the vulnerability of the built environment.

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