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NWCG Guide to Fireline Fire Assessment

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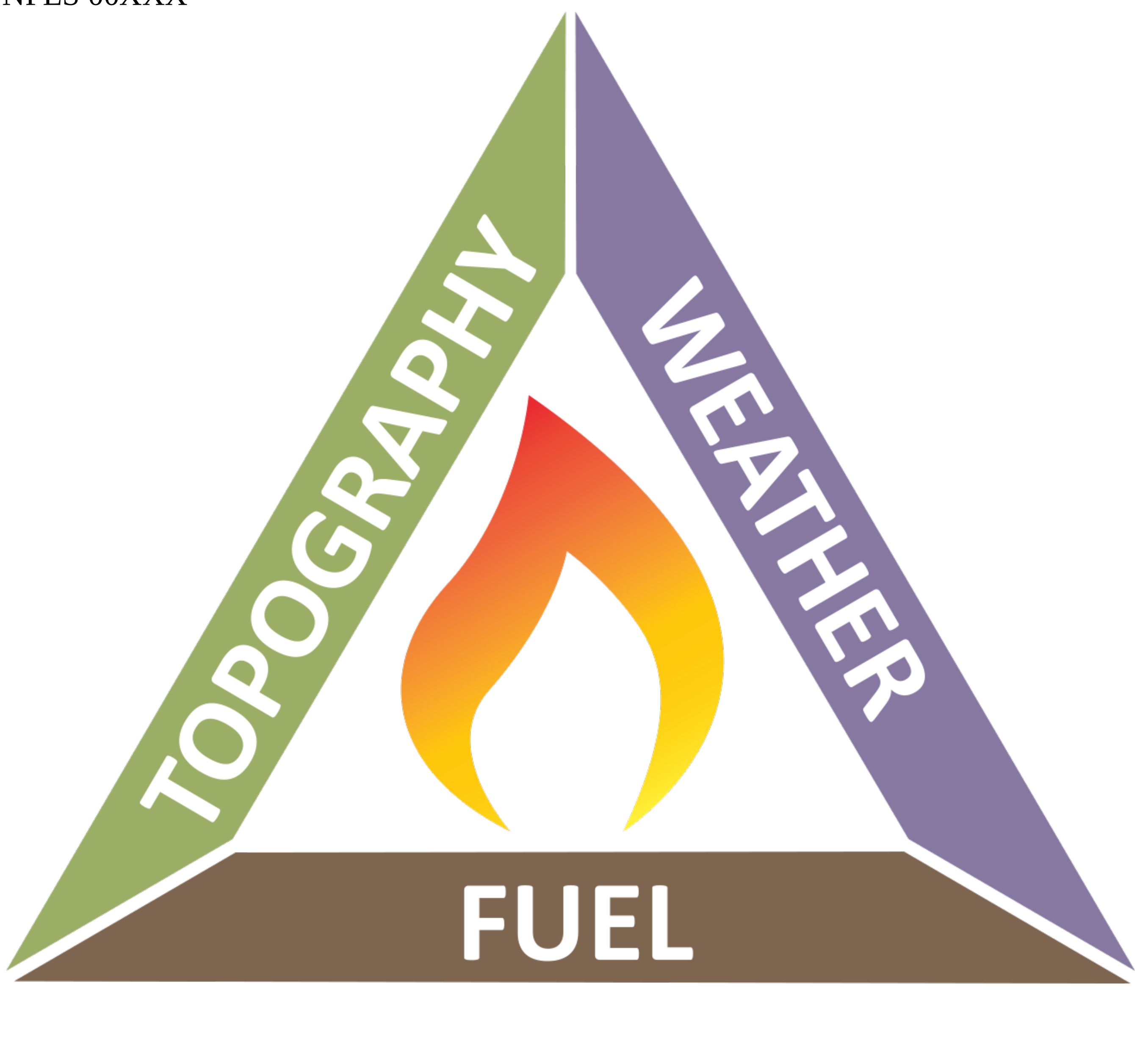

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The *NWCG Guide to Fireline Fire Assessment* offers a firefighter reference to fire behavior assessment. The guide offers a range of descriptions and tools that can support presentation of concepts and practices in training courses and other learning experiences. It can be carried and used as a reference by practitioners on the fireline, providing a concise and versatile resource.

This guide is intended for use as both a learning reference and as a job aid for wildland firefighters in the United States.

As a learning reference, it is most applicable for students enrolled in fire behavior training courses:

- S190 (Introduction to Wildland Fire Behavior)
- S290 (Intermediate Wildland Fire Behavior)
- S390 (Introduction to Wildland Fire Behavior Calculations)

As a job aid, it supports:

- Fireline and offline assessment of the fire environment
- Estimation and interpretation of expected fire behavior
- Safety considerations, such as safety zone size.

The content in this guide is coordinated with the online Fire Behavior Field Reference Guide, intended to supplement that reference in situations where internet and cellular connectivity cannot be assured.

The National Wildfire Coordinating Group (NWCG) provides national leadership to enable interoperable wildland fire operations among federal, state, tribal, territorial, and local partners. NWCG operations standards are interagency by design; they are developed with the intent of universal adoption by the member agencies. However, the decision to adopt and utilize them is made independently by the individual member agencies and communicated through their respective directives systems.

Table of Contents

Introduction

After outlining **A Fire Behavior Assessment Process** on the first page, this guide is divided into three parts.

The first, **Fire Environment Assessment Methods**, begins on page 3. These are a collection of practices that should help inform decision-making on the fireline. Beginning firefighters may be exposed to these practices and fireline leaders may assign them to their lookouts and field observers, as well as others with sufficient skill and experience. These assessments should be communicated to ensure that situation awareness is maintained.

It includes subjects that describe methods for:

- Interpreting Your Weather Forecast,
- Making and Communicating Fireline Observations,
- Anticipate and Interpret Expected Fire Behavior.

The second section outlines methods used to **Estimate Expected Fire Behavior** and begins on page 38.

It includes references and tools used to help quantify fire environment inputs such as:

- Fuel Model Selection
- Determining Elevation/Slope/Aspect
- Dead Fuel Moistures
- Live Fuel Moistures
- Midflame Windspeed

With these inputs:

- Fire Behavior Lookup Tables provide spread rate and flame length estimates,
- Graphs provide crown fire initiation and spread rate estimates,
- Flanking and backing fire behavior can be estimated
- Spotting Distance and Probability of Ignition can be determined
- Fire size and shape of new starts in the early hours can be estimated

These quantitative methods provide the detail necessary for comparing expected changes in the fire environment and how big the change in fire behavior is expected to be.

Part 3, **Other Considerations**, begins on page 87. It offers some additional references for mapping and navigation, unit conversions, and safety considerations.

Together, this guide offers a range of descriptions and tools that can support presentation of concepts and practices in training courses and other learning experiences. It can be carried and used as a reference by practitioners on the fireline, providing a concise and versatile resource.

A Fire Behavior Assessment Process

A Process to Follow

Before an Assignment at the Beginning of the Operational Period

- Evaluate Fire Weather Forecasts and Outlooks, NWS Watches & Warnings, and Predictive Services High Risk Days for local area
- Consider local climatology and critical fire weather patterns
- Review local references for important weather thresholds, fire history, and current season's fire potential.
- Review yesterday's fire activity and notable fire behavior

Once Assigned a Role and While Enroute to the Fire

- Get on scene weather reports from yesterday, overnight and current conditions
- Assess maps and photos of the fire area with current perimeters and recent activity
- Take a local fire weather forecast with you. Consider a Spot Forecast request.
- Interpret Sky and Smoke conditions for stability, windspeed & direction and burning intensity.

On Scene Fire Assessment

- Request current weather observation and validate your forecast. Is your fireline exposed to or sheltered from the expected winds?
- Get a sense of the current fire activity level where firefighters are working and at the head.
- Anticipate today's next big changes. Do you anticipate changes? When? Where?
- Appreciate fuels (carrier fuels, loadings, moistures) adjacent to your fire, especially where firefighters are working and where fire could move.
- Take stock of significant terrain features ahead of the fire. Will it burn upslope or down?
- Continue to monitor the sky for cloud and smoke indicators.
- Estimate the fire behavior you anticipate in view of the current situation and the expected changes. What spread rates do you anticipate? What flame lengths? Do you anticipate crown fire? Spotting across your lines or long range?

Determine Decision Thresholds and Ensure LCES

- Evaluate your strategic plan and fireline tactics in view of expected fire behavior.
- Establish escape routes, time frames, and triggers for escape. What windspeeds or changes in fire behavior will render those time frames insufficient?
- Identify best locations and methods for the lookout to monitor and validate your assessment.
- Ensure that weather & fire behavior observations and implications are communicated.

Document Your Assessment

- Record your observations and assumptions.
- Include worksheets as notes for each assessment.
- Include assessments and decisions in personal logs.

Part 1

Fire Environment Assessment Methods

Interpret Your Weather Forecast

Fire Danger Rating in the US

Fire danger rating systems are used to characterize the current and accumulated influence of weather for the fuels on the landscape you are concerned with. Included are characterizations of fuel moisture (which translates into flammability) and fire behavior characteristics (ignition, spread, and fire intensity potential).

The National Fire Danger Rating System (NFDRS) and the Canadian Forest Fire Weather Index (FWI) system are both used in a variety of ways in the United States. Familiarity with one over another should be secondary to the need to understand and use the local implementation and interpretation. This table compares and contrasts them. Use it to cross reference what you know with what you need to use.

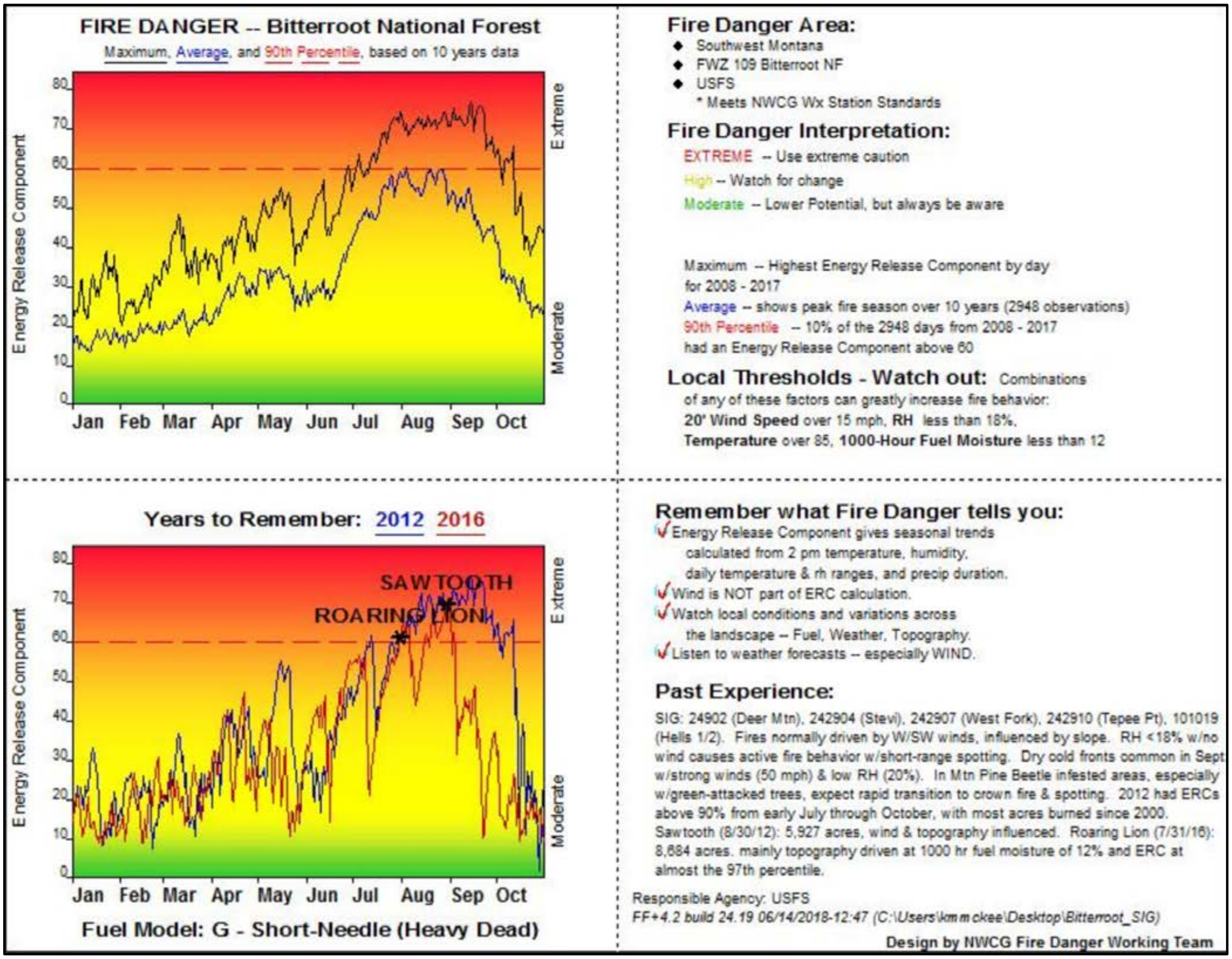
NFDRS 2016	Elements	FWI System
Hourly Observations are Required Temperature Relative Humidity Windspeed Rainfall Solar Radiation	**Weather Observations**	**Daily Observations Required (at solar noon)** Temperature Relative Humidity Windspeed Rainfall
Max/Min Temperatures Max/Min Relative Humidities Precipitation Duration Daylength Vapor Pressure Deficit (VPD) Growing Season Index (GSI)	**Intermediate Weather Inputs**	None
1-hr Fuel Moisture 10-hr Fuel Moisture 100-hr Fuel Moisture 1000-hr Fuel Moisture Herbaceous Fuel Moisture (HFM) Woody Fuel Moisture (WFM) Keetch-Byrum Drought Index (KBDI)	**Fuel Moisture Outputs**	Grass Fuel Moisture Code (GFMC) 1-hr equivalent Fine Fuel Moisture Code (FFMC) 10-hr equivalent Duff Moisture Code (DMC) 360-hr equivalent Drought Code (DC) 1250-hr equivalent
Ignition Component (IC) Spread Component (SC) Energy Release Component (ERC) Burning Index (BI)	**Fire Behavior Outputs**	Initial Spread Index (ISI) Buildup Index (BUI) Fire Weather Index (FWI)
Https://wfas.net https://wfsafe.technosylva.com/	**Current Conditions**	https://akff.mesowest.org https://glff.mesowest.org/
https://www.nwcg.gov/publications/pms437/fire-danger/background	**More info at**	http://www.nwcg.gov/publications/pms437/cffdrs/fire-weather-index-system

Be Mindful of Local Fire Season Climatology

NWCG PocketCards

This is the most basic representation of local fire season climatology that uses fire danger rating codes, components, and indices. Find at https://famit.nwcg.gov/applications/WIMS/PocketCards/PocketCards and use them to determine where you are in the season and how unusual the current conditions are.

Figure 1. Example PocketCard



Upper left quadrant includes a graph of the fire season with the trend for the selected indicator. Notice where you are in the season and what is normal for that time of year.	**Upper right quadrant** defines the area of interest and several of the graphic features to the left. It also includes several important local thresholds.
Lower left quadrant shows a couple of reference years and when important fires occurred in them.	**Lower right quadrant** provides interpretation details including some fire danger watch outs as well as details of past experience.

Critical Fire Weather Patterns

Critical Fire Weather (https://www.nwcg.gov/publications/pms437/weather/critical-fire-weather) can be found in the Fire Behavior Field Reference Guide. The four critical elements that produce extreme fire behavior are **low relative humidity, strong surface winds, unstable air, and drought.**

The critical fire weather patterns that support these conditions can be separated into two primary categories: those that produce strong surface winds, and those that produce atmospheric instability. In both cases, an unusually dry air mass for the region and season must also occur. In brush and timber fuels, drought becomes an important precursor by increasing fuel availability.

Most periods of critical fire weather occur in transition zones between high- and low-pressure systems, both at the surface and in the upper air. The surface pressure patterns of most concern are those associated with cold fronts and terrain-induced foehn winds. Cold front passages are important to firefighters because of strong, shifting winds, and unstable air that can enhance the smoke column or produce thunderstorms. Foehn winds occur on the lee side of mountain ranges and are typically very strong, often occurring suddenly with drastic warming and drying. The area between the upper ridge and upper trough has the most critical upper air pattern because of unstable air and strong winds aloft that descend to ground level.

- **East of the Rocky Mountains**, most critical fire weather patterns are associated with the periphery of *high-pressure* areas, particularly in the prefrontal and post-frontal areas.
- In the **northern plains, Great Lakes, and the northeastern US**, prefrontal *high pressure* from the Pacific, Northwestern Canada, and Hudson Bay all can produce very dry conditions. *Cold fronts* produce relatively short-lived periods of high winds and *instability* that can produce extreme fire behavior.
- In the **southeastern US**, drought is frequently associated with the La Niña state of the southern oscillation pattern or a blocking ridge aloft near the Atlantic coast. Often critical weather patterns follow the frontal passage that brings extremely dry air due to a strong westerly or northwesterly flow. Look for strong winds that accompany the flow. Beware of advancing tropical storms as well.
- In the **southwestern US,** the *breakdown of the upper ridge*, before monsoons develop, is manifest at the surface with breezy, dry, unstable conditions that transition to potentially very windy conditions as it finally breaks down. During transition to the monsoon pattern, *shallow monsoons* can produce gusty wind, low RH, and lightning without much precipitation.
- In the **Rocky Mountain and Intermountain Regions**, the most significant pattern is the *upper ridge-surface thermal trough* that produces a dry and windy surface cold front.
- Along the **eastern slopes of the Rocky Mountains**, weather patterns producing *Chinook winds* bring strong downslope winds that are unusually dry and warm.
- In the **intermountain west**, critical fire weather is associated with *upper troughs* and overhead *jet streams*, or surface *dry cold front* passages.
- Along the **Pacific Coast**, from Washington to California, weather patterns producing *offshore flow* or *foehn wind* are the most important.
- In the **Pacific Northwest,** the *east wind* produces strong winds and dry air west of the cascades. The *upper ridge breakdown* is similar to that described for the rocky mountain & interior west.
- In **California**, the most important are the *north and mono winds* of north & central regions and the *Santa Ana* and *sundowner* winds of southern California. The *subtropical high aloft* brings heat waves.
- In **Alaska**, the primary pattern is the *breakdown of the upper ridge* accompanied by southeast flow. It can bring gusty winds and lightning to the interior of Alaska after a period of hot, dry weather.

These are key words and catchphrases (*italics*) meteorologists typically use to describe critical fire weather growing and slowing patterns. These terms will often be used to explain weather patterns in narrative forecasts and in briefings, though they are not exclusively used. The terminology will often be found in National Weather Service Area Forecast Discussion (AFD) and fire weather planning forecast discussions as well as predictive service 7-day outlook assessments.

Review General Outlooks and Assessment Products

As part of the general information gathering, there are websites that can provide insight about today, tomorrow, and the days and weeks ahead.

The Wildland Fire Assessment System (https://www.wfas.net/), on its home page, offers maps of both North American Fire Danger and the CONUS Severe Fire Weather Potential.

The National Interagency Coordination Center's Predictive Services 7-Day Significant Fire Potential Outlook (https://fsapps.nwcg.gov/psp/npsg/forecast#/outlooks?state=map) offers a day-by-day trend in potential for problem fires. Select the Geographic area and then the area of your fire for specific interpretations.

The US Climate Prediction Center Outlook Products (https://www.cpc.ncep.noaa.gov) page offers outlook trends for temperature and precipitation for days beyond the forecast period.

The National Integrated Drought Information System (https://www.drought.gov/current-conditions) provides a drought assessment site that provides depictions of both current conditions and outlook and forecast trends.

Important Winds for Adapting and Interpreting Forecasts

Critical Winds

Wind Type	Typical Windspeed Ranges	Interpretations
Thunderstorm and Pyrocumulus Induced Outflows and Downdrafts	25 to 35 mph, but can exceed 60 mph	Gusty and erratic in nature. Winds radiate from center of storm, strongest push in direction of storm movement
Frontal Winds	20 to 30 mph, but can exceed 50 mph	Also note timing and significance of shifting wind direction with frontal passage, usually in a clockwise direction
Foehn Winds (Chinook, Santa Ana, Mono, Wasatch, East, and North winds)	20 to 60 mph, but can exceed 90 mph	Warming and drying winds blowing from high elevation downslope, often toward values at risk
Surfacing or Low Level Jets	25 to 45 mph	Generally occurs 100s of feet above the ground, can enhance fire plume
Whirlwinds	50 (and higher) mph	Dust Devils and fire whirls, inflow winds from around the whirl can be significant, strong winds in outer portion of whirl can lift large embers
Glacier Winds	30 to 50 mph	Occur as downslope winds from glaciers and can extend well down from snow and ice cover

Local Winds

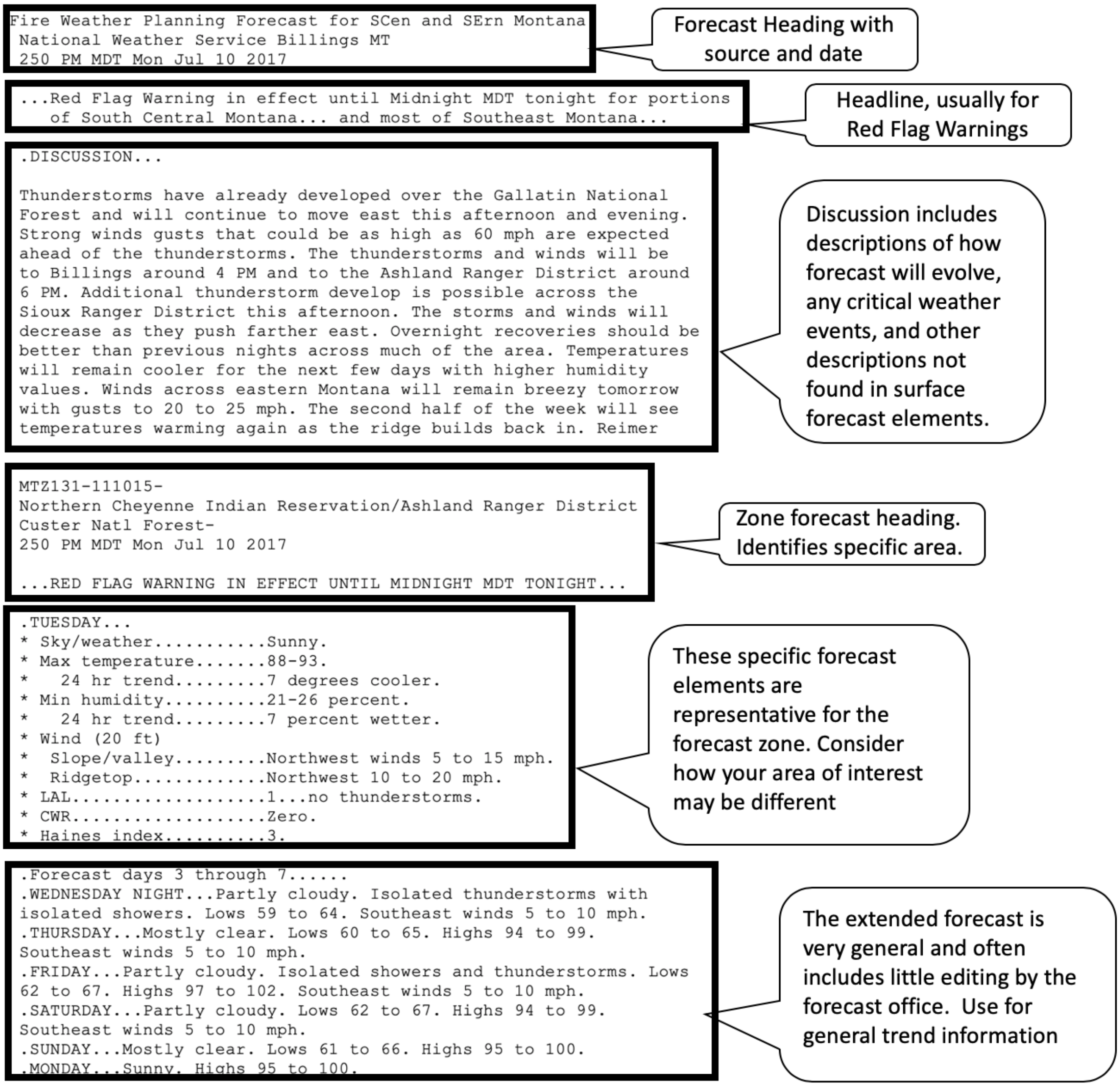
Wind Type	Typical Windspeed Ranges	Interpretations
Upslope	3 to 8 mph	Follows sun on slopes
Upvalley	10 to 15 mph	Peaks in the afternoon with upslopes
Downslope	2 to 5 mph	Follows evening end of upslope winds
Downvalley	5-10 mph	Late night into very early morning
Sea Breeze	10 to 20 mph, can be 30+	Onshore, strongest on sunny days
Land Breeze	3 to 10 mph	Offshore at night, consistent seasonally

NWS Fire Weather Planning and Spot Weather Forecasts

NWS Local Weather Forecast Office Contacts (https://www.weather.gov/stormready/contact)

The daily Fire Weather Planning Forecast and the Spot Weather Forecasts have a lot in common, though there are important differences:

- The formats are similar for planning and spot forecasts, with headings, headlines, discussion, and specific surface forecast elements
- The headline and the discussion in the spot forecast are usually drawn from the planning forecast
- Only the *planning forecast* includes the extended period
- The *spot forecast* is based on a specific request for a specific fire and its specific location. Local factors are more likely considered and local observations are used to calibrate the forecast.



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Fire Weather Planning Forecast for SCen and SErn Montana
National Weather Service Billings MT
250 PM MDT Mon Jul 10 2017

...Red Flag Warning in effect until Midnight MDT tonight for portions
   of South Central Montana... and most of Southeast Montana...

.DISCUSSION...

Thunderstorms have already developed over the Gallatin National
Forest and will continue to move east this afternoon and evening.
Strong winds gusts that could be as high as 60 mph are expected
ahead of the thunderstorms. The thunderstorms and winds will be
to Billings around 4 PM and to the Ashland Ranger District around
6 PM. Additional thunderstorm develop is possible across the
Sioux Ranger District this afternoon. The storms and winds will
decrease as they push farther east. Overnight recoveries should be
better than previous nights across much of the area. Temperatures
will remain cooler for the next few days with higher humidity
values. Winds across eastern Montana will remain breezy tomorrow
with gusts to 20 to 25 mph. The second half of the week will see
temperatures warming again as the ridge builds back in. Reimer

MTZ131-111015-
Northern Cheyenne Indian Reservation/Ashland Ranger District
Custer Natl Forest-
250 PM MDT Mon Jul 10 2017

...RED FLAG WARNING IN EFFECT UNTIL MIDNIGHT MDT TONIGHT...

.TUESDAY...
* Sky/weather...........Sunny.
* Max temperature.......88-93.
*   24 hr trend.........7 degrees cooler.
* Min humidity..........21-26 percent.
*   24 hr trend.........7 percent wetter.
* Wind (20 ft)
*  Slope/valley.........Northwest winds 5 to 15 mph.
*  Ridgetop.............Northwest 10 to 20 mph.
* LAL...................1...no thunderstorms.
* CWR...................Zero.
* Haines index..........3.

.Forecast days 3 through 7......
.WEDNESDAY NIGHT...Partly cloudy. Isolated thunderstorms with
isolated showers. Lows 59 to 64. Southeast winds 5 to 10 mph.
.THURSDAY...Mostly clear. Lows 60 to 65. Highs 94 to 99.
Southeast winds 5 to 10 mph.
.FRIDAY...Partly cloudy. Isolated showers and thunderstorms. Lows
62 to 67. Highs 97 to 102. Southeast winds 5 to 10 mph.
.SATURDAY...Partly cloudy. Lows 62 to 67. Highs 94 to 99.
Southeast winds 5 to 10 mph.
.SUNDAY...Mostly clear. Lows 61 to 66. Highs 95 to 100.
.MONDAY...Sunny. Highs 95 to 100.
```


Figure 2. Example narrative fire weather forecast.

Make and Communicate Fireline Observations

Sky Observations

The firefighter should pay attention to the fire weather forecast and keep an eye on the sky for indicators of instability and other hazards that can influence the fire environment. The weather observer can provide important information to meteorologists by reporting the visual cues and the timing of changes throughout the day. Visual cues are included with a weather observation by recording them in the remarks column. Usually, if a visual cue is worth noting with the weather observation, photography can be very valuable supporting documentation. If a photo is taken, use a photo log or reference the photo number with the location date, time and other identifying comments.

Atmospheric instability tends to enhance convective forces and vertical motion, increasing ventilation of active fires. This generally leads to gusty winds, more intense burning, greater spread, and the possibility of extreme fire events. It can be influenced by the terrain and other local factors to produce more localized effects.

A **stable atmosphere** generally tends to limit vertical motion of a fire's heat and smoke. As a result, cloud build-ups during stable conditions tend to be wider and flatter, sometimes covering much of the sky. Note: strong general winds are possible during stable conditions depending upon the weather pattern.

Lightning and Wind

- Lightning should be reported immediately to alert fireline supervisors to take appropriate precautions and to cue meteorologists to review their lightning detection tools.
- Sudden wind shifts may be important indicators of breaking inversions or frontal passage.

Smoke, Dust, and Fire

- Rising smoke column indicates neutral or instable conditions. Flattening column indicates inversion at that point.
- Smoke column change direction as it rises indicates wind shear or local wind influence.
- Smoke column developing a pyrocumulus cap cloud indicates strong instability and impending down drafts.
- Haze and poor visibility are indicators of inversions. Is this localized (night-time inversion) or more general and persisting throughout the day? Note: if haze or poor visibility abates during the burn period, this is an indicator of increase in fire behavior.
- Dust clouds radiating away from thunderstorms indicate potentially dangerous downdrafts.
- Dust devils are important indicators of surface instability.
- Firewhirls occur when convection from the fire combines with winds influencing the fire, adjacent terrain features that create eddies, instability from cold fronts, and/or multiple interacting fire plumes. Firewhirls are difficult to predict.

Note: Be aware of the potential for gusty erratic winds and firebrand transport when dust devils and firewhirls are observed.

Clouds, Fog, and Precipitation

Clouds occur when moisture in the atmosphere condenses into visible droplets or ice crystals. This usually occurs when moist air becomes cooled by lifting. The shape and texture of clouds reveals much about whether the lifting process has been gradual and gentle or rapid and potentially violent. Paying attention to the sky can help the firefighter stay aware of the current fire environment as well as anticipation of potential changes:

- Cloud cover, in percent, is an important input for fuel moisture shading.
- Building cumulus, towering cumulus, or thunderstorms are all indicators of significant instability that is probably already influencing surface winds.
- Showers or virga may also be indicators of instability.

The Fire Weather Cloud Identification Chart

The NWCG Fire Weather Cloud Chart (https://www.nwcg.gov/publications/438), depicts sky signs of interest for wildland firefighters that are valuable tools in revealing the atmosphere's current state and how it relates to fire behavior as well as foretelling potential changes. Clouds are an important indicator of instability and its influence on fire behavior.

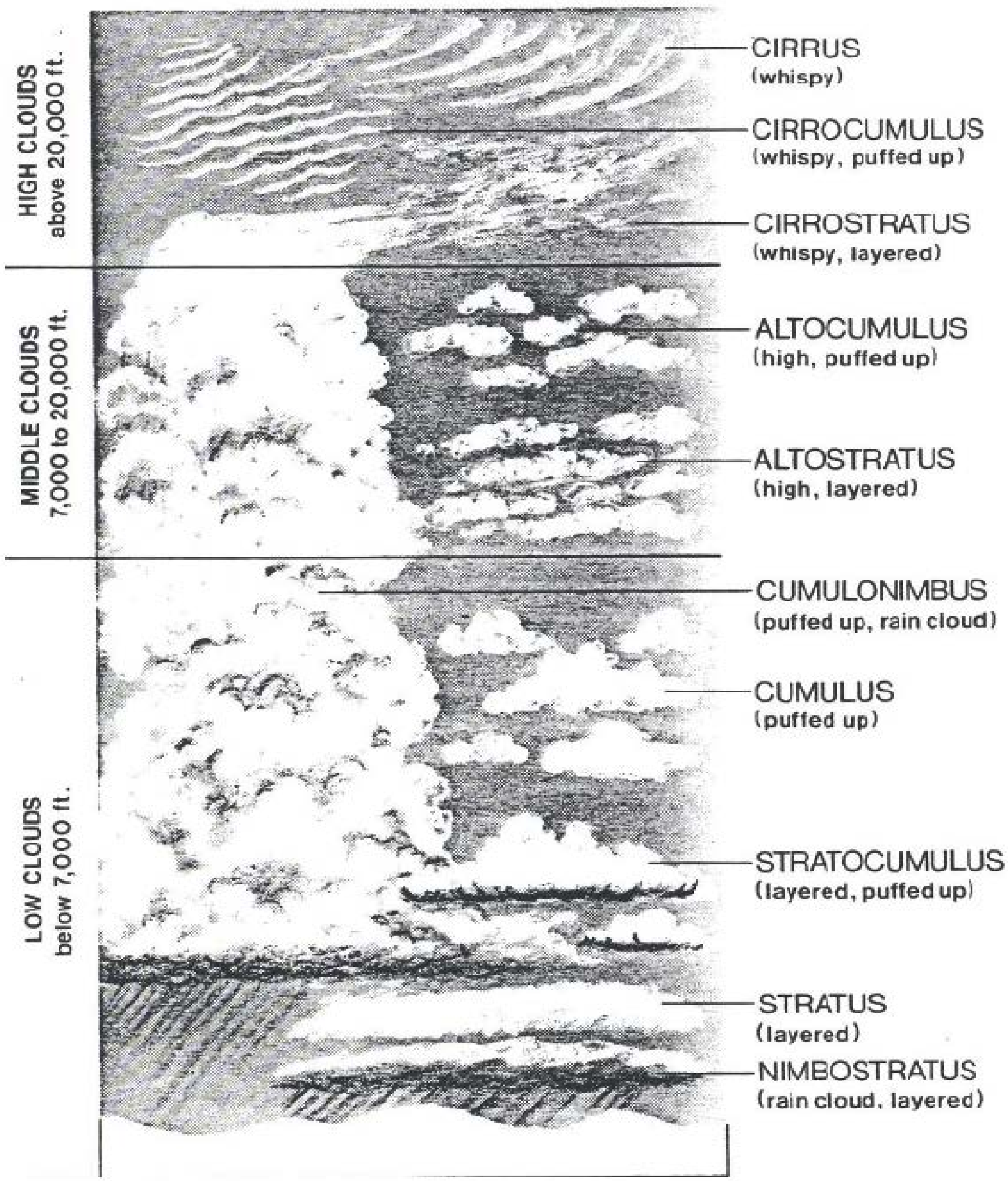


Figure 3. Cloud Classification Chart

Clouds that reveal variations of instability in the atmosphere, as follows:

- **Cumulus (several varieties)** - Weak instability. Normally not a concern for firefighters. However, when cumulus continues growing, firefighters are advised to keep an eye on the buildups due to the potential for sudden downdrafts and gusty winds.
- **Alto Cumulus (several varieties, e.g., castellanus)** - Upper atmosphere instability and possible weather change. These indicate increasing moisture and instability with the potential for thunderstorms.
- **Cumulonimbus** - Very unstable. Fully developed mature thunderstorms contain extreme vertical motion and the strong likelihood of gusty, erratic winds that can arise suddenly miles away from the cloud buildup. Localized wind gusts over 100 mph are possible with very strong thunderstorms along with lightning, virga, and hail. Very strong thunderstorms may also be accompanied by shelf clouds or tornados. Clearly, cumulonimbus clouds portend many hazards to the firefighter exposed on the fireline.
- **Pyrocumulus** - Very unstable. Pyrocumulus clouds grow above ongoing wildfires drawing energy from the heat of combustion and condensation of moisture in the fire’s convection column. A white-capped pyrocumulus cloud is a concern for firefighters for the same reason as a thunderstorm - strong, gusty erratic winds can arise suddenly near a pyrocumulus. Virga, light raindrops, and even some lightning is possible with well-developed pyrocumulus clouds.

Clouds that indicate a stable atmosphere, as follows:

- **Stratus (several varieties)** - Stable and moist. Stratus clouds can cover much of the sky and blot out sunlight or even bring rain. Stratus clouds tend to mean higher humidity and decreased fire behavior. Normally not a concern for firefighters.
- **Cirrostratus (several varieties)** - High level stratus clouds formed of ice crystals. Cirrostratus clouds are normally not a concern for firefighters. However, if these clouds increase from the west or northwest, a front may soon be approaching with strengthening general winds. Check the fire weather forecast.
- **Altostratus (several varieties)** - Mid- to high-level stratus clouds that are a good indicator of an approaching front with strengthening general winds. Check the fire weather forecast.
- **Wave cloud or Lenticular cloud** - Smooth, almond-shaped clouds that sometimes form over mountainous terrain in patterns similar to stacked dishes. These clouds tend to remain fixed over one peak and are a good indicator of strong general winds in the upper atmosphere that may descend to the surface. Wave clouds are sometimes seen during foehn wind events. Check the fire weather forecast.

Monitoring Precipitation on the Fireline

Water bottles can be repurposed like this:

- Cut the top off and connect, inverted, inside to limit splashing.
- Fill with water to level that is full diameter.
- Mark the zero line at that level.
- The weight of the water will help hold it steady. You can reinforce it with dirt, rocks and sticks around the base.

A network of these on a division and at spike camp can provide valuable information that can be reported up the chain of command and included on the spot forecast request.

Temp and Humidity Observation

Estimating temperature, relative humidity, and dew point can provide insight to critical fire behavior thresholds for ignition and crown fire potential.

Sling Psychrometer Use

The following are instructions for determining wet and dry bulb temperatures using the sling psychrometer. These instructions are based on guidance from the Belt Weather Kit Tutorial (https://www.nwcg.gov/publications/training-courses/rt-130/fire-environment/fe401) in the WFSTAR Catalog.

1. If your sling has been in your pack, you may need to hang it in a tree, in the shade, to let it adjust to the outside air temperature. This may be a good time to take the wind observation.
2. Stand in a shaded, open area away from objects that might be struck during whirling. If in open country, use your body shade to shade the psychrometer. If possible, take weather observations over a fuelbed that is representative of the fuel that the fire is burning in. Pick a site away from the fireline or burned area to minimize influence of indrafts and excessive heating.
3. Face the wind to avoid the influence of body heat on the thermometers.
4. Saturate the wick of the wet bulb with clean, clean or distilled water at air temperature.
5. Ventilate thermometers by whirling at full arm's length. Your arm should be parallel to the ground. Whirl for one minute.
6. Note the wet bulb temperature. Whirl for another 40 or 50 times (or another minute or so). and read again. If the wet bulb is lower than the first reading, continue to whirl and read until it will go no lower. Read and record the lowest point. If the wet bulb is not read at the lowest point, the calculated relative RH will be too high. Calculate dew point each time. If it is changing significantly it may suggest a bad observation.
7. Read the dry bulb immediately after the lowest wet bulb reading is obtained.
8. Determine the RH from the tables.

Important Tips - sometimes beginners do not take accurate psychrometer readings because of the following common mistakes:

- Using a psychrometer with a dirty wick.
- Changing psychrometers from one observation to the next, try to use the same throughout.
- Not ventilating the psychrometer long enough to reach equilibrium.
- Not getting the wick wet enough, or letting it dry out.
- Holding it too close to the body or taking too long to read the thermometers.
- Touching the bulb ends with the hands while reading.
- Not facing into the breeze.

Handheld Electronic Weather Instruments

- Allow to acclimate out of pack or pocket for 3-5 minutes. Calibrate instrument periodically.
- **Advantages** include easy-to-read user displays, light, compact package, real-time data with averages and trends in stored records as additional features. **Disadvantages** include environmental damage and degradation if not protected from dirt and damage, battery failure, calibration drift of sensors, and cost.

Estimating Relative Humidity and Dew Point from Psychrometric Tables

Psychrometric tables (https://www.nwcg.gov/publications/pms437/weather/temp-rh-dp-tables#TOC-Full-Set-PDF-) are included in the belt weather kit and provided with the fire behavior field reference guide. The tables allow you to estimate RH and dew point from dry bulb and wet bulb temperatures.

1. Find the correct table based on elevation at your observing location.
2. Use your DB Temp and WB Temp to find the intersecting cell on the page.
3. Read the resulting RH (below) and dew point (above) in that cell.

Example Table (Figure 4)

Each Table is labeled with an Elevation Range, including an adjustment for Alaska.

Dry bulb Temperature is located on the left axis and the wet bulb temp is located at the top of each column. Cell at their intersection includes the resulting RH and dew point.

Elevations between 1,901 and 3,900 feet

Wet Bulb Temperatures 39 to 79 F (Read Down)

Dry Bulb Temperatures 61 to 80 F (Read Across)

DP / RH

DB \ WB	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60
61	-17 / 4	-3 / 7	6 / 11	12 / 14	18 / 18	22 / 22	26 / 26	29 / 30	33 / 34	35 / 38	38 / 42	40 / 47	43 / 51	45 / 56	47 / 60	49 / 65	51 / 69	53 / 74	55 / 79	56 / 84	58 / 89	59 / 95
62	-31 / 2	-9 / 5	2 / 9	9 / 12	15 / 16	20 / 20	24 / 23	28 / 27	31 / 31	34 / 35	37 / 39	39 / 43	42 / 48	44 / 52	46 / 56	48 / 61	50 / 65	52 / 70	54 / 75	56 / 80	57 / 85	59 / 90
63		-18 / 3	-3 / 7	6 / 10	12 / 14	18 / 17	22 / 21	26 / 25	30 / 28	33 / 32	36 / 36	38 / 40	41 / 44	43 / 48	45 / 53	47 / 57	49 / 61	51 / 66	53 / 70	55 / 75	57 / 80	58 / 85
64		-32 / 1	-9 / 5	2 / 8	9 / 11	15 / 15	20 / 18	24 / 22	28 / 26	31 / 29	34 / 33	37 / 37	40 / 41	42 / 45	45 / 49	47 / 53	49 / 57	51 / 62	53 / 66	54 / 71	56 / 75	58 / 80
65			-18 / 3	-3 / 6	6 / 9	13 / 13	18 / 16	23 / 20	27 / 23	30 / 27	33 / 30	36 / 34	39 / 38	41 / 42	44 / 46	46 / 50	48 / 54	50 / 58	52 / 62	54 / 67	55 / 71	57 / 76
66			-32 / 1	-9 / 4	2 / 8	10 / 11	16 / 14	21 / 17	25 / 21	29 / 24	32 / 28	35 / 31	38 / 35	40 / 39	43 / 43	45 / 47	47 / 51	49 / 55	51 / 59	53 / 63	55 / 67	57 / 72
67				-18 / 3	-3 / 6	6 / 9	13 / 12	18 / 15	23 / 19	27 / 22	30 / 25	34 / 29	37 / 32	39 / 36	42 / 40	44 / 43	46 / 47	48 / 51	50 / 55	52 / 59	54 / 63	56 / 68
68				-32 / 1	-9 / 4	2 / 7	10 / 10	16 / 13	21 / 17	25 / 20	29 / 23	32 / 26	35 / 30	38 / 33	41 / 37	43 / 41	45 / 44	48 / 48	50 / 52	52 / 56	54 / 60	55 / 64
69					-17 / 3	-3 / 6	7 / 9	13 / 12	19 / 15	23 / 18	27 / 21	31 / 24	34 / 27	37 / 31	40 / 34	42 / 38	45 / 41	47 / 45	49 / 49	51 / 53	53 / 56	55 / 60
70					-31 / 1	-9 / 4	3 / 7	10 / 10	16 / 13	21 / 16	26 / 19	29 / 22	33 / 25	36 / 28	39 / 32	41 / 35	44 / 39	46 / 42	48 / 46	50 / 49	52 / 53	54 / 57
71						-17 / 3	-2 / 5	7 / 8	14 / 11	19 / 14	24 / 17	28 / 20	31 / 23	35 / 26	38 / 29	40 / 33	43 / 36	45 / 39	47 / 43	49 / 46	51 / 50	53 / 54
72						-30 / 1	-8 / 4	3 / 7	11 / 9	17 / 12	22 / 15	26 / 18	30 / 21	33 / 24	36 / 27	39 / 30	42 / 34	44 / 37	46 / 40	49 / 44	51 / 47	53 / 51
73							-16 / 3	-1 / 5	8 / 8	15 / 11	20 / 13	24 / 16	28 / 19	32 / 22	35 / 25	38 / 28	41 / 31	43 / 34	46 / 38	48 / 41	50 / 44	52 / 48
74							-28 / 1	-7 / 4	4 / 6	12 / 9	18 / 12	23 / 14	27 / 17	31 / 20	34 / 23	37 / 26	40 / 29	42 / 32	45 / 35	47 / 38	49 / 42	51 / 45
75								-14 / 3	0 / 5	9 / 8	15 / 10	21 / 13	25 / 16	29 / 18	33 / 21	36 / 24	39 / 27	41 / 30	44 / 33	46 / 36	48 / 39	51 / 42
76								-26 / 1	-6 / 4	5 / 6	13 / 9	18 / 11	23 / 14	27 / 17	31 / 19	35 / 22	38 / 25	40 / 28	43 / 31	45 / 34	48 / 37	50 / 40
77								-54	-13 / 3	1 / 5	9 / 7	16 / 10	21 / 12	26 / 15	30 / 18	33 / 20	36 / 23	39 / 26	42 / 29	45 / 32	47 / 34	49 / 37
78									-23 / 1	-4 / 4	6 / 6	13 / 9	19 / 11	24 / 13	28 / 16	32 / 19	35 / 21	38 / 24	41 / 27	44 / 29	46 / 32	48 / 35
79									-45	-11 / 3	2 / 5	10 / 7	17 / 10	22 / 12	27 / 14	30 / 17	34 / 20	37 / 22	40 / 25	43 / 27	45 / 30	48 / 33
80										-20 / 2	-3 / 4	7 / 6	14 / 8	20 / 11	25 / 13	29 / 15	33 / 18	36 / 20	39 / 23	42 / 26	44 / 28	47 / 31

DB \ WB	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79
61																			
62	60 / 95																		
63	60 / 90	61 / 95																	
64	59 / 85	61 / 90	63 / 95																
65	59 / 80	60 / 85	62 / 90	64 / 95															
66	58 / 76	60 / 81	61 / 85	63 / 90	65 / 95														
67	58 / 72	59 / 76	61 / 81	63 / 86	64 / 90	66 / 95													
68	57 / 68	59 / 72	60 / 77	62 / 81	64 / 86	65 / 90	67 / 95												
69	56 / 64	58 / 69	60 / 73	62 / 77	63 / 81	65 / 86	66 / 91	68 / 95											
70	56 / 61	58 / 65	59 / 69	61 / 73	63 / 77	64 / 82	66 / 86	67 / 91	69 / 95										
71	55 / 58	57 / 61	59 / 65	60 / 69	62 / 73	64 / 78	65 / 82	67 / 86	68 / 91	70 / 95									
72	55 / 54	56 / 58	58 / 62	60 / 66	62 / 70	63 / 74	65 / 78	66 / 82	68 / 86	69 / 91	71 / 95								
73	54 / 51	56 / 55	58 / 59	59 / 62	61 / 66	63 / 70	64 / 74	66 / 78	67 / 82	69 / 87	70 / 91	72 / 95							
74	53 / 48	55 / 52	57 / 55	59 / 59	61 / 63	62 / 67	64 / 70	65 / 74	67 / 78	68 / 83	70 / 87	71 / 91	73 / 95						
75	53 / 46	55 / 49	56 / 52	58 / 56	60 / 60	62 / 63	63 / 67	65 / 71	66 / 75	68 / 79	69 / 83	71 / 87	72 / 91	74 / 96					
76	52 / 43	54 / 46	56 / 50	58 / 53	59 / 57	61 / 60	63 / 64	64 / 67	66 / 71	68 / 75	69 / 79	70 / 83	72 / 87	73 / 91	75 / 96				
77	51 / 41	53 / 44	55 / 47	57 / 50	59* / 54	61 / 57	62 / 61	64 / 64	66 / 68	67 / 71	69 / 75	70 / 79	71 / 83	73 / 87	74 / 91	76 / 96			
78	51 / 38	53 / 41	55 / 44	56 / 48	58 / 51	60 / 54	62 / 57	63 / 61	65 / 64	67 / 68	68 / 72	70 / 76	71 / 79	73 / 83	74 / 87	75 / 91	77 / 96		
79	50 / 36	52 / 39	54 / 42	56 / 45	58 / 46	60 / 51	61 / 55	63 / 58	65 / 61	66 / 65	68 / 68	69 / 72	71 / 76	72 / 80	74 / 84	75 / 88	76 / 92	78 / 96	
80	49 / 34	51 / 37	53 / 40	55 / 43	57 / 46	59 / 49	61 / 52	62 / 55	64 / 58	66 / 62	67 / 65	69 / 69	70 / 72	72 / 76	73 / 80	75 / 84	76 / 88	77 / 92	79 / 96

Figure 4. Example Psychrometric Table

Vapor Pressure Deficit (VPD)

While fuel moisture estimates integrate temperature and humidity factors, Vapor Pressure Deficit increases the importance of temperature in its characterization. With increasing temperature, the atmosphere can hold more moisture. If it does not, the atmospheric moisture deficit becomes even more severe as the temperature rises. VPD is increasingly being used in wildfire assessments.

°C	°F	95%	90%	85%	80%	75%	70%	65%	60%	55%	50%	45%	40%	35%	30%	25%	20%	15%	10%	5%
0	32	0	1	1	1	2	2	2	2	3	3	3	4	4	4	5	5	5	5	6
1	34	0	1	1	1	2	2	2	3	3	3	4	4	4	5	5	5	6	6	6
2	36	0	1	1	1	2	2	2	3	3	4	4	4	5	5	5	6	6	6	7
3	37	0	1	1	2	2	2	3	3	3	4	4	5	5	5	6	6	6	7	7
4	39	0	1	1	2	2	2	3	3	4	4	4	5	5	6	6	6	7	7	8
5	41	0	1	1	2	2	3	3	3	4	4	5	5	6	6	7	7	7	8	8
6	43	0	1	1	2	2	3	3	4	4	5	5	6	6	7	7	7	8	8	9
7	45	0	1	1	2	2	3	3	4	4	5	5	6	6	7	7	8	8	9	9
8	46	1	1	2	2	3	3	4	4	5	5	6	6	7	7	8	9	9	10	10
9	48	1	1	2	2	3	3	4	5	5	6	6	7	7	8	9	9	10	10	11
10	50	1	1	2	2	3	4	4	5	6	6	7	7	8	9	9	10	10	11	12
11	52	1	1	2	3	3	4	5	5	6	7	7	8	9	9	10	10	11	12	12
12	54	1	1	2	3	3	4	5	6	6	7	8	8	9	10	10	11	12	13	13
13	55	1	1	2	3	4	4	5	6	7	7	8	9	10	10	11	12	13	13	14
14	57	1	2	2	3	4	5	6	6	7	8	9	10	10	11	12	13	14	14	15
15	59	1	2	3	3	4	5	6	7	8	8	9	10	11	12	13	14	14	15	16
16	61	1	2	3	4	5	5	6	7	8	9	10	11	12	13	14	14	15	16	17
17	63	1	2	3	4	5	6	7	8	9	10	11	12	13	14	14	15	16	17	18
18	64	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	20
19	66	1	2	3	4	5	7	8	9	10	11	12	13	14	15	16	17	19	20	21
20	68	1	2	3	5	6	7	8	9	10	12	13	14	15	16	17	19	20	21	22
21	70	1	2	4	5	6	7	9	10	11	12	14	15	16	17	19	20	21	22	23
22	72	1	3	4	5	7	8	9	11	12	13	14	16	17	18	20	21	22	24	25
23	73	1	3	4	6	7	8	10	11	13	14	15	17	18	20	21	22	24	25	27
24	75	1	3	4	6	7	9	10	12	13	15	16	18	19	21	22	24	25	27	28
25	77	2	3	5	6	8	9	11	13	14	16	17	19	20	22	24	25	27	28	30
26	79	2	3	5	7	8	10	12	13	15	17	18	20	22	23	25	27	28	30	32
27	81	2	4	5	7	9	11	12	14	16	18	19	21	23	25	27	28	30	32	34
28	82	2	4	6	8	9	11	13	15	17	19	21	23	24	26	28	30	32	34	36
29	84	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38
30	86	2	4	6	8	11	13	15	17	19	21	23	25	27	29	32	34	36	38	40
31	88	2	4	7	9	11	13	16	18	20	22	25	27	29	31	33	36	38	40	42
32	90	2	5	7	9	12	14	17	19	21	24	26	28	31	33	35	38	40	42	45
33	91	2	5	7	10	12	15	17	20	22	25	27	30	32	35	37	40	42	45	47
34	93	3	5	8	11	13	16	18	21	24	26	29	32	34	37	40	42	45	47	50
35	95	3	6	8	11	14	17	20	22	25	28	31	33	36	39	42	45	47	50	53
36	97	3	6	9	12	15	18	21	24	27	29	32	35	38	41	44	47	50	53	56
37	99	3	6	9	12	16	19	22	25	28	31	34	37	40	44	47	50	53	56	59
38	100	3	7	10	13	16	20	23	26	30	33	36	39	43	46	49	53	56	59	62
39	102	3	7	10	14	17	21	24	28	31	35	38	42	45	49	52	55	59	62	66
40	104	4	7	11	15	18	22	26	29	33	37	40	44	48	51	55	58	62	66	69

Figure 5. Vapor Pressure Deficit (VPD) in Hectopascals (hPa). Integrates temperature, in either Celsius or Fahrenheit, on left axis, and Relative Humidity across the top. Colors generally represent vegetative stress, with blues (low) as too cold and wet for vegetative activity, and orange (high) too hot and dry. Local interpretations may differ.

Estimating Surface Wind Speed and Direction

Visual Estimate of Surface (20ft) Wind Speed – Modified Beaufort Land Scale for Firescapes

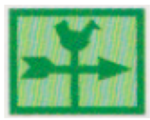
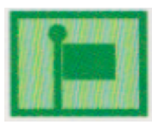
Class	Wind Speed	Terminology	Example	Visible Effect
0	Less than 1mph	Calm		Calm, smoke rises vertically.
1	1 to 3 mph	Very Light Breeze		Leaves of quaking aspen in constant motion, small branches sway, tall grasses and weeds sway and bend with wind, wind vane barely moves.
2	4 to 7 mph	Light Breeze		Trees of pole size in the open sway gently, wind felt distinctly on face, leaves rustle, loose scraps of paper move, wind flutters small flag.
3	8 to 12 mph	Light Wind		Leaves, small twigs in constant motion, tops of trees in dense stands sway, light flags extended.
4	13 to 18 mph	Windy		Trees of pole size in the open sway violently, whole trees in dense stands sway noticeably, dust is raised in the road.
5	19 to 24 mph	Very Windy		Branchlets are broken from trees, inconvenience is felt in walking against wind.
6	25 to 31 mph	Strong Wind		Tree damage increases with occasional breaking of exposed tops and branches, progress impeded when walking against wind.
7	32 to 38 mph	Very Strong Wind		Severe damage to tree tops, very difficult to walk into wind.
8	39 to 46 mph	Slightly Damaging Wind		Surfaced strong Santa Ana, intense stress on all exposed objects, vegetation, buildings, canopy offers virtually no protection.
9	47 mph or more	Dangerous Wind		Structural damage occurs, slate blown from roofs.

Figure 6. Modified Beaufort Wind Scale for Land Application

Surface Wind Definitions

Surface wind is the wind measured at specific locations near the Earth's surface. It is commonly measured by an anemometer (speed) and wind vane (wind direction), usually at a standard height of 10 m or 20 ft above the ground, in an area where the distance between the instrument and obstructions is at least 10 times the height of the obstruction. It is generally assumed to integrate general atmospheric and local factors that contribute to that measured windspeed.

- Fire behavior assessments call for these standard **surface wind estimates** so that **midflame wind speeds** can be derived from them.
- Generally, handheld anemometers can estimate **eye-level** surface winds if they are taken in open, unobstructed conditions. Make sure to average them over a minute or so. Report as eye level.
- If you expect a **critical wind** event during your assessment period based on the forecast or are encountering one, it can be used as your surface wind.
- **Wind Gust** is a sudden, brief increase in speed of the wind. According to U.S. weather observing practice, gusts are reported when the peak wind speed reaches at least 16 knots and the variation in wind speed between the peaks and lulls is at least 9 knots. The duration of a gust is usually less than 20 seconds.

Critical Winds as Surface Winds

Critical winds dominate the fire environment and easily override local wind influences. Examples include frontal winds, Foehn winds, thunderstorm winds, whirlwinds, surfacing or low-level jets (reverse wind profiles), and glacier winds. Use as the surface wind estimate if you anticipate it.

<u>Breakdown of the Upper Ridge and Cold Frontal Passage</u>

Three main stages:

- First stage represents warmer-drier-breezy and unstable conditions.
- Second stage wind speeds will increase while conditions remain warm-dry and unstable.
- Third stage is defined by a cold frontal passage.

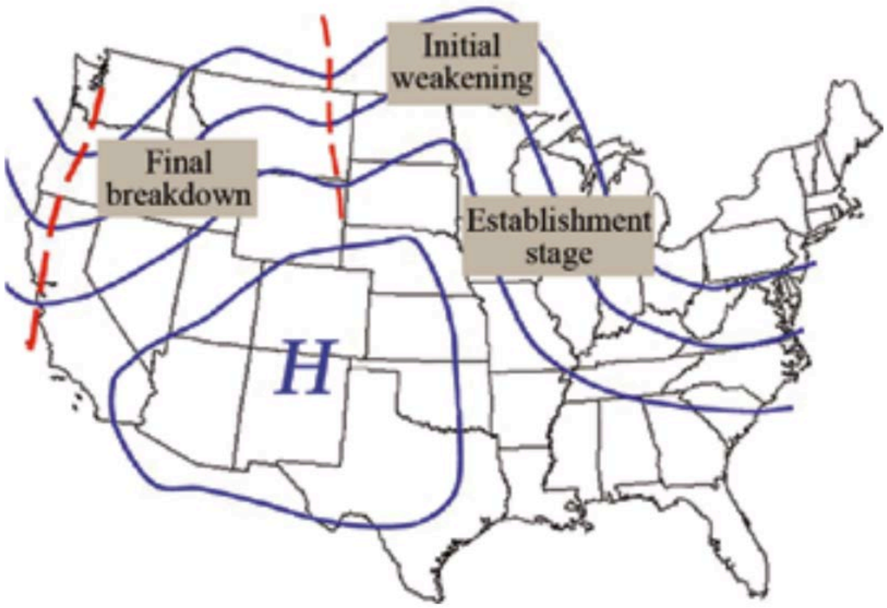


Figure 7. Life cycle stages of an upper level ridge.

Thunderstorm Dynamics, Outflows, and Downbursts

Thunderstorms in the vicinity of a fire have the potential to produce outflow gust fronts or downbursts, regardless of whether the updraft is fed by the fire, or not. Any evidence of precipitation means the storm has developed to the point where it can produce these types of winds, as well as lightning. Rain at the ground or virga is a potential warning sign. Outflow gust fronts are winds radiating outward but primarily in the direction of storm motion, from the base of the convection. They are present in all well-developed convection and last tens of minutes to an hour or more. They can travel tens to hundreds of kilometers. Downbursts are much less common, shorter lived, and affect a much smaller area. Either type of wind has the potential to abruptly change the speed and direction of fire spread.

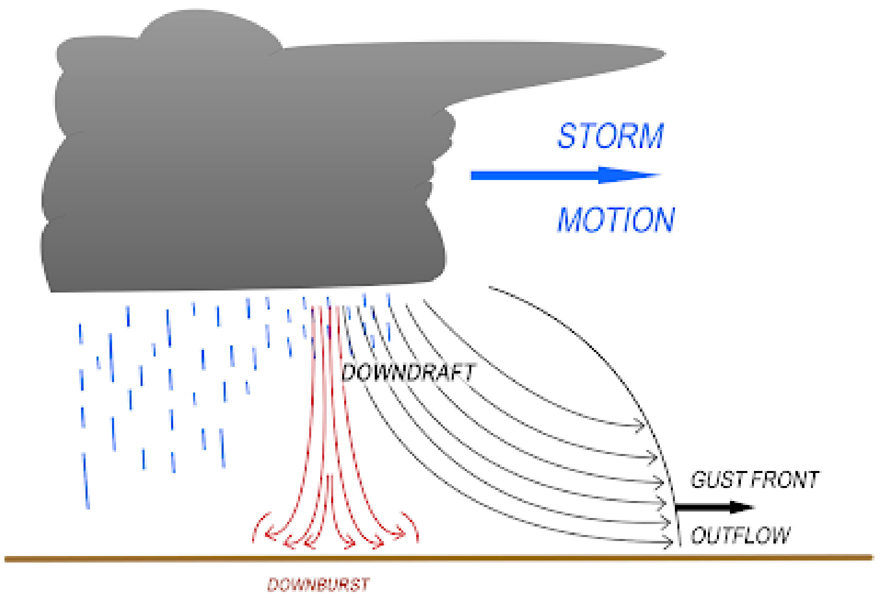


Figure 8. Thunderstorm downburst, outflow, and gust front.

Foehn or Downslope Winds

Foehn or downslope wind events have many regional names. You might recall that foehn or downslope winds are caused by air forced over mountain ranges and through mountain passes in association with stable conditions. Common examples are Santa Ana and Chinook winds.

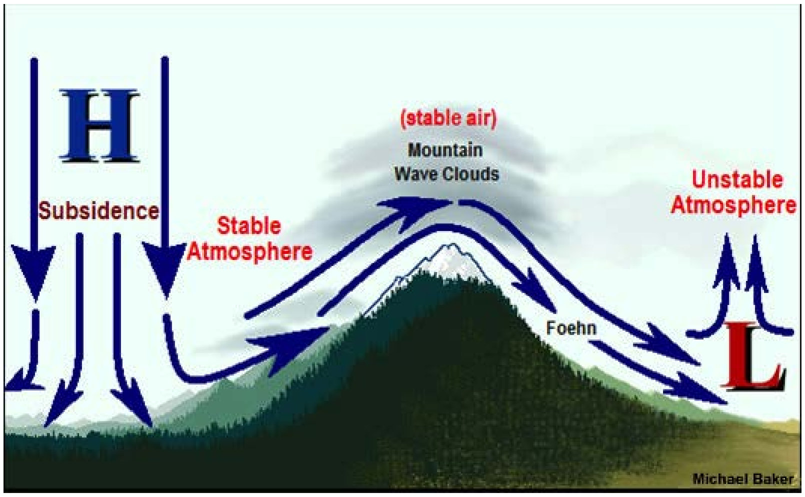


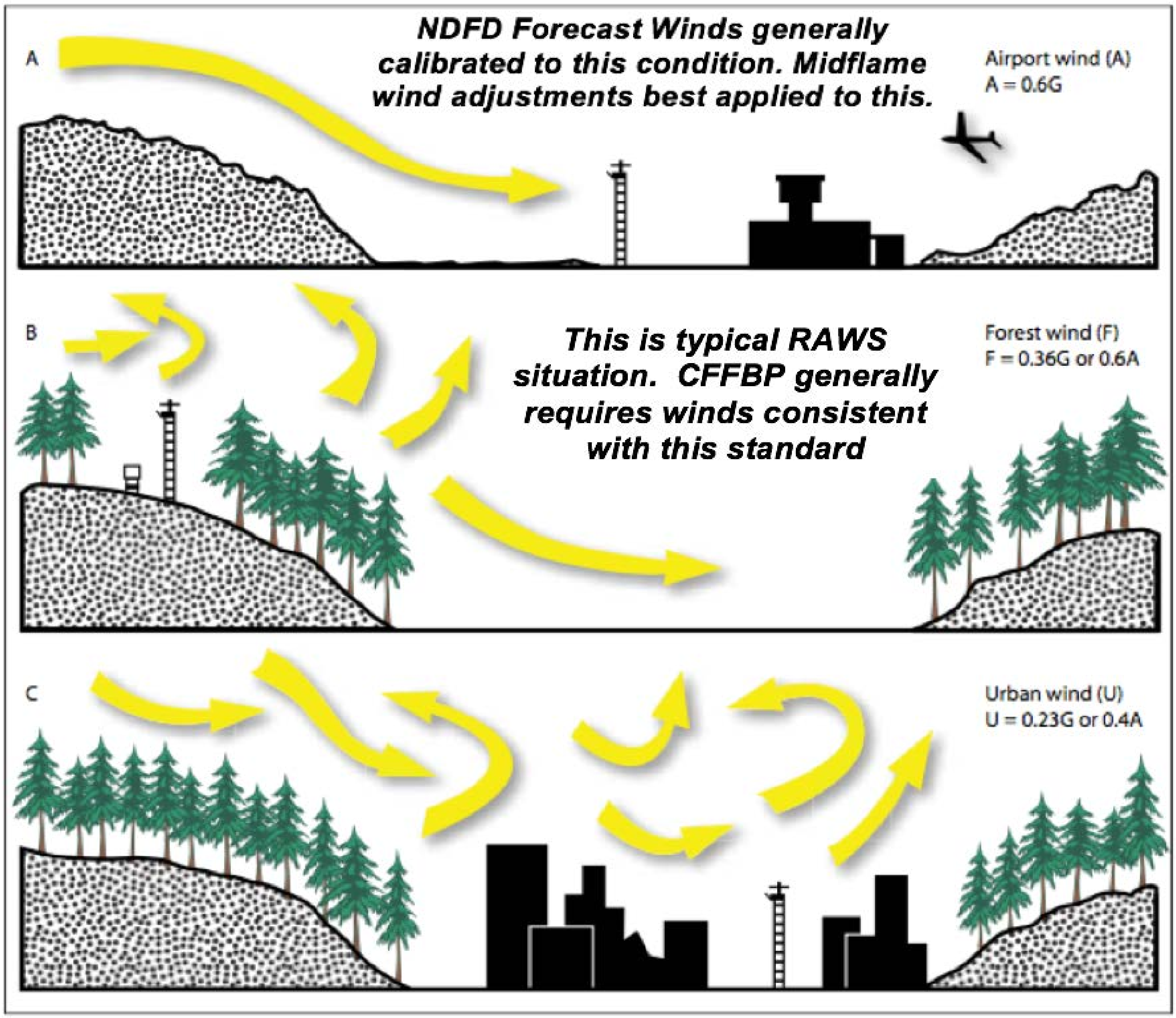
Figure 9. Atmospheric pressure and windflows that produce Foehn Winds.

Observed Surface Windspeed

Generally, three factors govern the surface wind estimate produced by automated weather observing sensors and handheld anemometers.

1. **Surface characteristics** that produce differing friction factors - forests and cities vs airports and agricultural regions. Generally, gradient winds are reduced by friction from the earth's surface. The surface friction in areas surrounded by large flat smooth surfaces (airports and agricultural areas) is less than that experienced in forest openings and among buildings and structures.

Figure 10. Surface winds and friction factors. In this graphic, "G" references general wind, NDFD references the National Weather Service National Digital Forecast Database, RAWS stands for Remote Automated Weather Station, and CFFBP is the acronym for the Canadian Forest Fire Behavior Prediction System. (Lawson & Armitage, 2008).



2. **Sensor standards for timing and duration of observation** - fire weather standard averages wind speed over 10 minutes while International standard averages wind speed over two minutes. How long do you hold your handheld anemometer into the wind?

3. **Sensor height above the prevailing cover.** In this table, “rough” surface represents forest clearings covered in low brush or slash whereas the “smooth” surface is used for clearings where the ground is smooth or covered in mowed grass or cropped brush. (Lawson & Armitage, 2008)

The adjustment factors provided here can be used to adjust observations at the sensor location to the surface windspeed at the international standard 10m height above prevailing cover. Simply multiply the local wind measurement by the adjustment factor based on the sensor’s height above prevailing cover and the surface roughness.

Mast Height (m)	Mast Height (ft)	Rough Surface Adjustment Factor	Smooth Surface Adjustment Factor
1.5	5	1.94	1.48
2.0-2.9	7-10	1.54	1.31
3.0-3.9	10-13	1.37	1.22
4.0-4.9	13-17	1.26	1.16
5.0-6.9	17-23	1.18	1.11
7.0-8.9	23-30	1.06	1.03
9.0-11.9	30-40	1.00	1.00

Using forecasted windspeeds and RAWS observations in your fire behavior estimates
In most cases, the standard Fire Weather Planning Forecasts prepared and distributed by your local National Weather Service (NWS) Weather Forecast Office (WFO) include forecasted wind speed labeled as a 20 ft Surface wind speed. As such, these forecasts are derived from models that coarsely consider the terrain and vegetation. They are also adjusted based on wind observations and trends in the forecast zone.

- Generally, the **forecast surface wind speed** (usually stated as 20ft in the US) is provided and qualified based on influences like terrain (elevation, slope and aspect) and mix of vegetation. *If your situation is as qualified in the forecast, midflame wind speeds is determined by applying wind adjustment factors (detailed later in the guide) directly to the forecasted surface wind.*
- In many cases, **standard fire RAWS** installations measure wind speeds that are lower than forecasted and lower than wind speeds reported at nearby airport locations due to terrain and surrounding trees and shrubs. It can be as much as a 40% reduction. In these situations, applying midflame wind adjustment factors to the RAWS wind speed can significantly underestimate the midflame wind speed and negatively impact your fire behavior assessment. *Consider adjusting RAWS windspeeds to estimate the standard 20ft surface windspeed, multiplying by as much as 1.5 as a first try.*
- The Canadian Fire Weather Index (FWI) system and its associated Fire Behavior Prediction (FBP) system calls from **winds based on a forest RAWS standard**. Estimating Initial Spread Index (ISI) and fire behavior directly from forecast surface wind speeds can produce significant overestimates. *Consider adjusting forecast windspeeds if the fire is located in a typical forested landscape, multiplying by 0.7 as a first try to improve CFFDRS FWI and FBP estimates.*

Adjusting Surface Wind Speed Forecasts for Your Situation

Forecasted winds may relate to specific locations or broad general areas. The user needs to understand what wind forces (General, Local, Critical) are integrated into the forecast provided and adjust if needed.

General (Synoptic Scale) Winds

General, or synoptic scale, winds (*gradient, free air, ridgetop)* are large-scale winds produced by broad scale pressure gradients between high- and low-pressure systems. They are influenced and modified considerably in the lower atmosphere by terrain and vegetative structure.

The image below (Figure 11) demonstrates the effect of terrain on general winds in different positions with respect to slopes, including sheltered, lee slope conditions (Bishop, 2010).

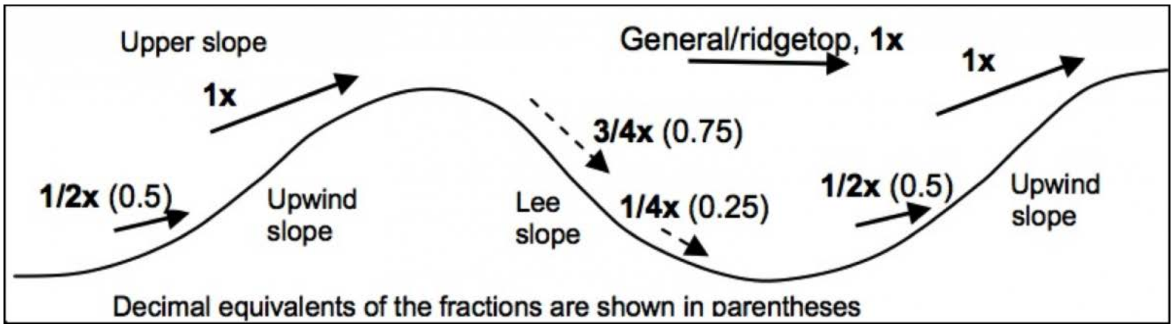


Figure 11. Effects of terrain on surface windspeeds at different locations with respect to slope and position.

Local (Mesoscale) Winds

Thermal, convective, orographic, and gravity winds are all caused by local temperature differences generated over a comparatively small area by terrain and weather. They differ from General winds in that they are limited to near surface and are controlled by the strength of the daily solar cycle.

- **Slope Winds** are driven by heat exchange at the slope surface. They can react quickly to sun on the slope, with upslope breezes starting within a few minutes. The strength of upslope winds is influenced by the length and steepness of the slope as well as the exposure. *Upslope winds generally range from 3-8mph.* Transition from upslope to downslope wind begins soon after the first slopes go into afternoon shadow and cooling of the surface begins. The transition period consists of (1) dying of the upslope wind, (2) period of relative calm, and (3) gentle flow downslope. *Downslope winds are very shallow and of a slower speed than upslope winds, generally 2-5mph*.
- **Valley Winds** are linked with slope winds. Their development each day generally lags 1-3 hours behind that of slope winds. They may be confined to lower slopes and valley bottom, depending on the valley length and steepness. Peak up-valley speeds can be as much as double those of upslope winds, reaching up to 10-15mph. Downvalley winds may reach 5-10 mph.
- **Land and Sea Breeze Circulations:** During the day, the offshore sea/lake breeze can reach 10-20 mph at the peak of solar heating in the afternoon and can exceed 30 mph in extreme cases. The alternate onshore land breeze at night is lighter, perhaps 3-10mph.

NOTE: There are additional topographic considerations that affect surface windspeed in very localized terrain. They are detailed in the section on Terrain Features and Alignments later in the guide.

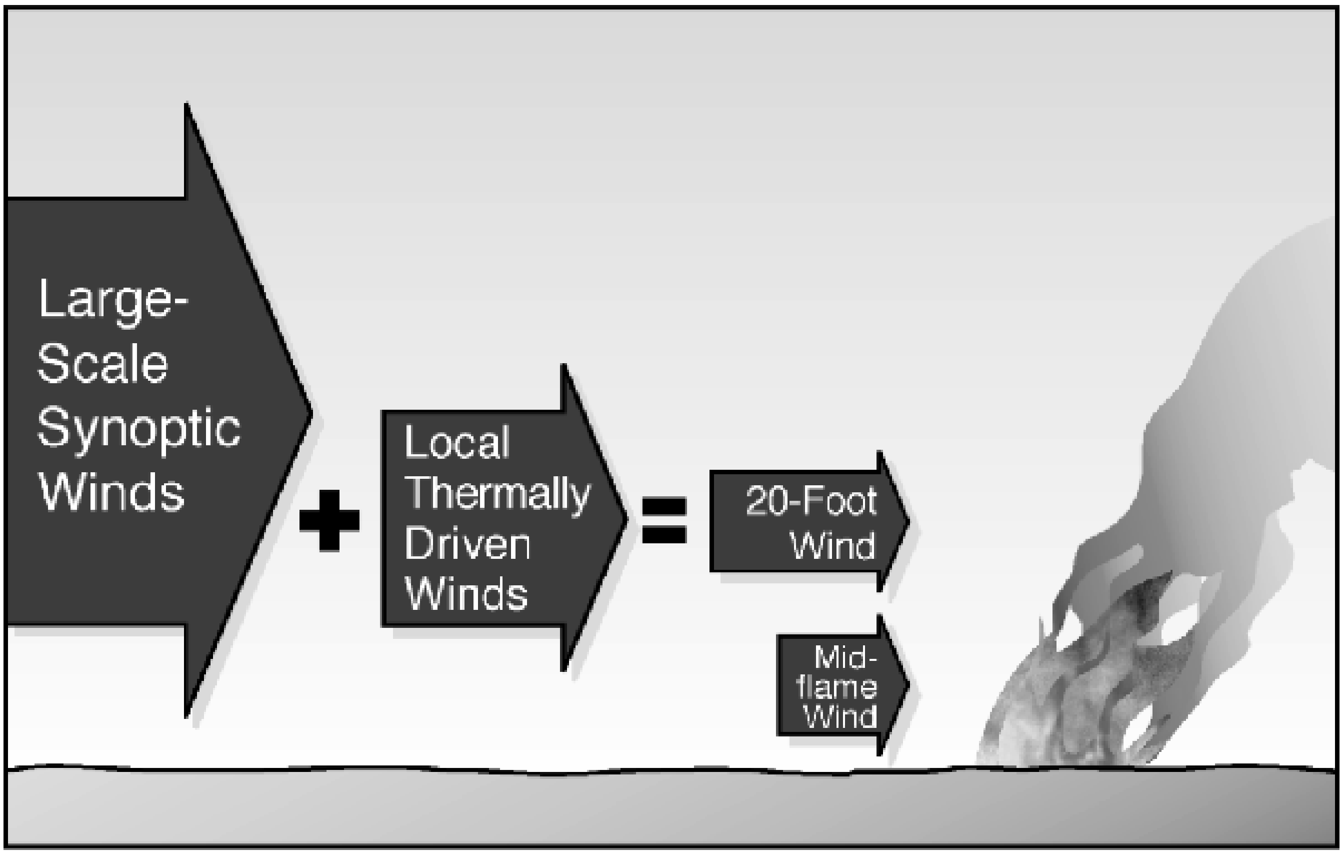
Combining Critical, General, and Local Winds into your Surface Wind Speed Forecast

Wind Ninja (https://www.firelab.org/project/windninja) is an app for computers and mobile devices that can help evaluate the influence of terrain on windspeed and direction. It can account for some thermal effects of terrain, especially when grided forecast winds are applied.

Both Planning and Spot Weather forecasts attempt to tailor windspeed forecasts to the area of concern identified in the heading. Some represent winds for several situations (e.g., ridge, slope, valley locations) in the forecast. However, it is impossible to characterize every situation in mountainous terrain in a narrative or in typical gridded forecast products. WindNinja is a smart device app that can help answer this question.

Figure 12 shows the relationship between General (Synoptic) and Local (Thermally Driven) winds and how they combine to produce the Surface (20 ft) wind measured at a specific location.

Figure 12. Surface Wind factors including large-scale general (synoptic) winds and local (thermally driven) winds



Employ the Surface Wind Speed Worksheet process to estimate forecast winds for your location if narrative forecast appears unrepresentative:

- Determine whether Critical wind will dominate your fire area today.
- Evaluate your position in the terrain or other local features. Are you on a windward or lee slope? Upper or lower slope? What time of day is it? Large body of water or heated basin? Near Glacier? Use Surface Wind Worksheet guidelines to reinforce your estimate.
- In mountainous terrain, consider "Ridge" wind forecast as the General wind component. Use this as your spotting distance input wind.
- In flat and gently rolling terrain, forecast wind is the surface wind.
- Do general and local winds work together or oppose each other? Will that mean gustiness?

Surface Wind Speed Worksheet

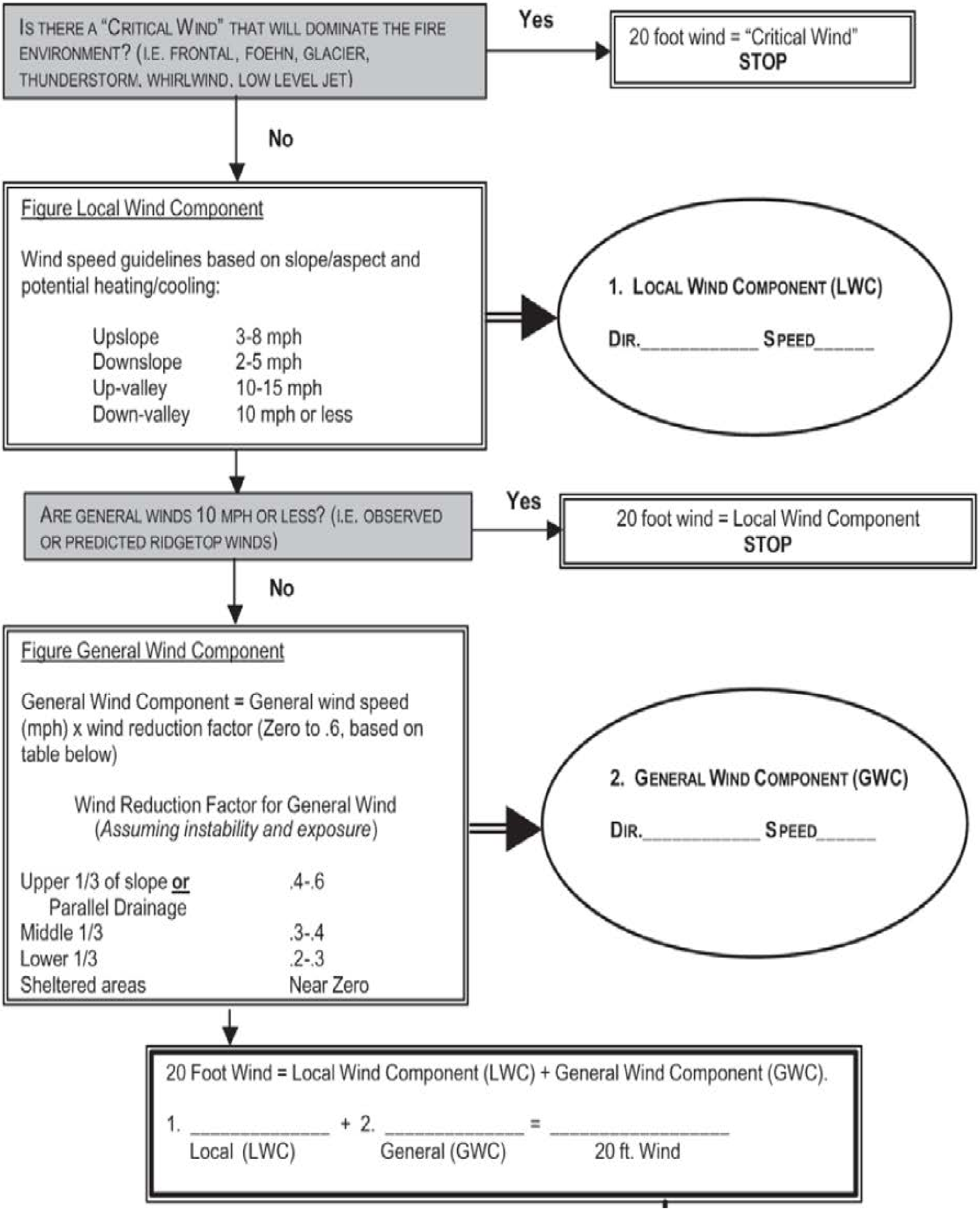


Figure 13. Surface Windspeed Worksheet

Fuel Characteristics

What surface fuels are, and will be, burning at the fire's leading edges?

Size, continuity and loading of dead fine fuels: Flammability of dead fine fuels is necessary for active fire spread. **Grasses** and **Litter** fuels differ in their response to hot and dry weather over the burn period.

Beware of **potential spread rates in dry grass fuels** and keep an updated wind forecast in hand. **Shaded litter fuels may burn with less intensity** and may provide opportunities for direct attack at the head of a fire.

Fuelbed Depth: Surface fuel bed depth usually limits potential fire behavior. Tall and erect surface fuels, like warm season grasses, have greater fuel loads and are more influenced by wind.

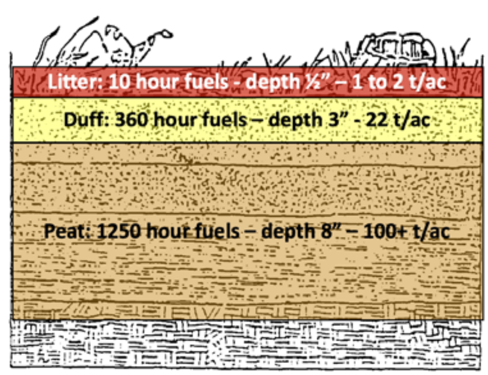
If fine fuels are a foot or more tall (likely for grass, grass-shrub, and shrub fuels), **anticipate greater spread rates and flame lengths**, especially under significant wind. Consider carefully whether direct attack at the head is appropriate.

Mix of live and dead fuels: Fine dead surface fuels generally carry fire spread. Live fuels tend to reduce fire behavior unless stressed due to seasonal drying or drought conditions.

Identify whether live fuels are a significant part of surface fuels. **Observe and review** whether they are resisting or contributing to fire behavior. **Decide** whether they will cause problems in areas you are concerned about during the forecast period.

Duff fuels below the surface: In many situations, the surface fuelbed is shallow, with mineral soil directly beneath it. But **on wetter and colder landscapes**, there are accumulations of fuel that become compacted into organic soil layers that burn under **drought conditions**.

In these situations, **holdover fire** is more likely, **mopup more difficult**, and **reburn potential** increases.



Are Trees and Shrubs Expected to Burn?

Heavy dead fuel loads and ladder fuels: Transition from surface fires into the crowns of trees and shrubs requires sufficient surface fire intensity, ladder fuels and low crown branches. Under dry conditions, even litter fuels can produce sufficient fire intensity if there is good loading and ladder fuels to connect to the crowns. Be aware of holdover fire and mopup problems.	
Tight tree and shrub crown spacing (<20ft): If the forest canopy looks like this, crown to crown fire spread will not be difficult. Fire intensity increases as well if the foliage is flammable. Under closed stands like these, surface fuels will be shaded and have higher moisture content. Winds will be reduced dramatically at the surface fuel level under the trees. Intensely burning fires that reach tight canopies like this can become active crown fires, especially under dry conditions and on steep slopes.	
Foliage flammability: Conifers, like lodgepole pine, are recognized for their flammable needles. But burnable resins exist in a wide variety of broadleaf species as well, like Chamise and Manzanita in California, Gamble Oak in Colorado, and ground cover like leatherleaf and sweetfern. Take note of species and communities that burn readily from local experts and make sure you can identify what they say will burn.	
Old and decadent stands of trees and shrubs: Dead trees and sparse crowns allow more sunlight and wind on the surface fuels below. Anticipate heavy fuel loads due to breakage and deadfalls from the canopy. Dead trees can be especially dry and burn high into the boles, exposing embers to the wind. Increased dead and down fuels increase fire intensity and decrease the effect of live fuels at the surface.	

Is there damage to fuels ahead of the fire?

Blowdown and Activity Fuels: Abnormally heavy fuel loads can result from commercial harvests and non-commercial treatments, as well as blowdown from critical wind events. Fuel loads depend on the method of harvest and utilization, the amount of blowdown damage, and the age of the added fuel load at the surface.

Fires in these fuels do not spread quickly, but can burn intensely and will be difficult to suppress.

Bug Kill (Tree and shrub mortality): While many trees and shrubs are impacted by leaf-eating critters, defoliators usually don't kill them. Systemic damage from bark beetles, wood borers, and budworms can kill trees slowly. Often the damage will be hard to see at first, with green needles obscuring the change. With red needles and gray snags, as shown here, the damage and flammability are more apparent.

Frost Damage: The sensitivity of living foliage to frost damage varies widely, based on each species' adaptation to temperature changes and extremes.

Early in the growing season, new growth may be sensitive to frost damage that can result in increased dead fuel loads, usually until new leaves come out or sometimes for the rest of the season.

Later in the year, cold can damage leaves that are already changing due to drought or fall dormancy.

Fire Damage and Preheated Canopy: A stand like this may not cause concern initially. But under dry conditions, scorched leaves and needles dry and fall onto holdover fire in heavy fuel loads. Unburned and partially burned fuels can provide sufficient fine fuel load to carry fire spread again.

Be alert for increased **reburn potential** that can encourage new spread through burned areas.

Fuel Moisture Observations; Field Estimation

The speed with which fine fuels respond to changes in humidity depends on fuel bed characteristics such as whether the fuel bed consists of compacted hardwood leaves or jack-strawed pine needles. Different fuel types can reach different moisture contents under the same humidity conditions. For example, grassy openings containing cured material can be burned within hours of a drenching rain if good drying conditions exist. Because of these natural variations, recommended fine-fuel moisture values are only guidelines. On-the-ground knowledge of fuel conditions must be incorporated into the interpretations and decisions.

Estimating Fine Dead Fuel Moisture in Shaded Long Needle Pines (10-hr)

Randomly select a cured brown pine needle from the forest floor. Hold needle between thumbs and forefingers. Slowly bend ends of the needle in a circle. Move thumbs down and together.

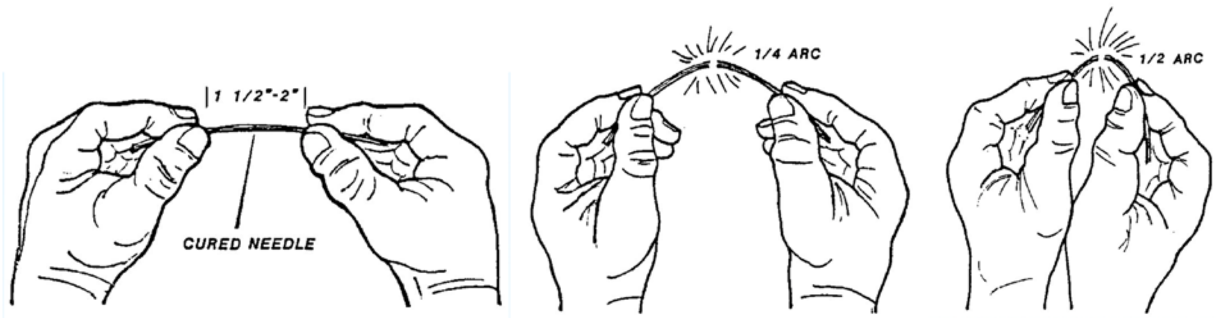


Figure 14. Field method for estimating dead ponderosa pine needle moisture.

- If needle breaks before ¼ arc, moisture content 4-7%. Burning conditions very favorable.
- If needle breaks before ½ arc, moisture contents 8-11%. Burning conditions favorable.
- If needle bends beyond ½ arc and not break, burning conditions marginal or unsatisfactory.

NFDRS Fuel moisture sticks that respond to weather changes like 10-hour fuels may be available. With a good set of scales and proper placement of the sticks, acceptable fuel moisture estimates can be obtained just before ignition. These values will differ slightly from actual fine-fuel moistures, but are fairly representative of most southern fuel types. They are much closer to actual fine fuel moistures than are calculated or tabular values.

Duff Moisture

Lower litter should always be checked before prescription burning to see if it feels damp. This will help identify if some will remain, even though charred, to leave a protective covering over the soil.

If lower litter and duff layers are dry, fires often burn more intensely than would be expected from just looking at the upper-litter-layer moisture content. When burning in deep duff, this phenomenon can have important consequences. If the fire dries the moist surface layer of peat, the organic soil will ignite. These fires can impact an area for many weeks in spite of control efforts, causing extensive smoke problems.

Generally, the moisture content increases from the litter surface down through the duff layer to the soil. Exceptions can occur after a light shower or in the morning after heavy dew.

Fuel Moisture Observations; Oven Sampling

General Guidelines

- Record site name, date, time, observer name, observed weather, general site description.
- DO NOT collect samples if water drops or dew are present on samples.
- Keep samples in a cool and dry location.
- Seal containers with tape that will not leave residue.

Live Fuel Samples

- Only collect foliage or needles and very small twigs remove flowers, seeds, nuts, or berries.
- Pack containers loosely to avoid spillage but ensure the container is full.
- Include stems of herbaceous plants.
- Replace lid on container immediately after collecting the sample.

Dead Fuel Samples

- Samples should not be attached to live trees or shrubs.
- Avoid decayed samples that crumble or splinter when rubbed.
- Collect samples from several different plants.
- Ensure the container is full or about 20 grams.
- Do not collect buried samples.
- Pick samples of different size within the time lag class.
- Recently fallen material should be avoided.
- Remove all lichen, moss, and very loose bark from sample.

Duff and Soil Samples

- Remove all soil and live tree or plant roots from the sample.
- Avoid any soil particles in duff samples and vice versa.

Litter Samples

- Collect only uncompacted dry litter from both sunny and shady areas.

Handling and Measuring Samples

- Preheat drying oven between 60°C (140°F) – 100°C (212°F). Be sure to note temp used.
- Place sample cans with closed lids on scale and record wet weights.
- Remove lid just prior to placing in oven. If material is lost, re-weigh sample
- Dry sample for 24 hours (very wet samples 48 hours).
- Replace Lids immediately after sample is removed from oven and weigh
- Calculate fuel moisture using worksheet provided here:

$$\%\ Moisture\ Content = \frac{wet\ weight\ of\ sample - dry\ weight\ of\ sample}{dry\ weight\ of\ sample - container\ tare\ weight}\ X\ 100$$

Gross Weight		C. Container Weight	D. Water Weight	E. Dry Weight	F. % Moisture
A. Wet Wt	B. Dry Wt.		**(D = A – B)**	**(E = B – C)**	**F=(D/E) X 100**

Figure 15. Equation and table for estimation of gravimetric live fuel moisture.

Terrain Features and Alignments

Flammability Alignment based on Aspect and Time of Day

Use Figure 16 to help you identify when, where, and how much fire behavior will change based on the aspect of a slope.

- **South** aspects get sun by late morning, resulting in greatest fuel heating at the beginning of the peak burn period.
- **West** aspects get sun by midday and get heating late into the day.
- **East** aspects are shaded by midday, reducing flammability during peak burn period.
- **North** slopes often have more live vegetation and receive less heating than the other aspects.

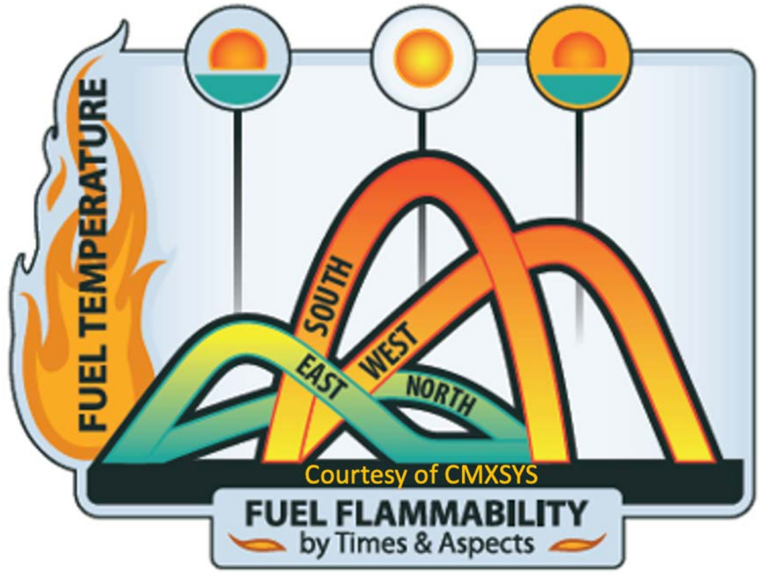


Figure 16. Effects of aspect, time of day, and solar radiation on fuel temperature.

Steep Slopes

If your fire is burning on a steep slope, consider its aspect for when the sun will reach it during the day. Be ready for fire to become active and exhibit rapid increase in uphill spread and intensity.

The slope steepness will influence how fast the fire spreads beyond the wind it supports. Fuels on slopes above a fire are exposed more directly to its heat. You can think of its influence like a wind. In Figure 17, a 40% slope has the same effect on fire spread as if it were a 2 mile per hour midflame windspeed. This makes it easy to combine midflame windspeed and slope into an **effective windspeed**.

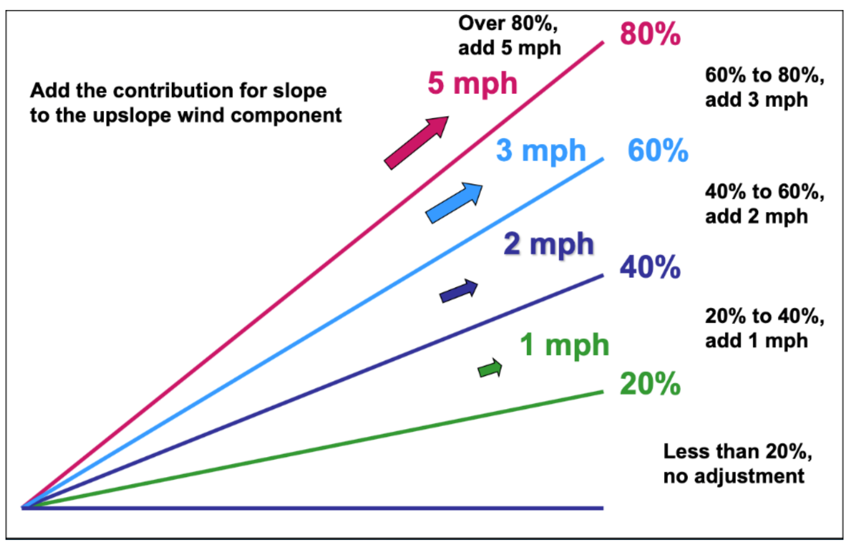


Figure 17. Slope steepness as an equivalent midflame windspeed (Bishop 2007).

Be aware of fire below you on slopes and consider safety warnings about working above them.

- For every 20% slope change, uphill spread rate could double
- For every 20% slope change, downhill spread rate could be cut in half

Slope Reversals

If fire is backing downslope toward the bottom of narrow canyons, beware of rollout and spotting that can move fire to the upslope side (Bishop, 2007). Anticipate rapid increase in spread and intensity. **Avoid working on slopes with unburned fuels above active fires.**

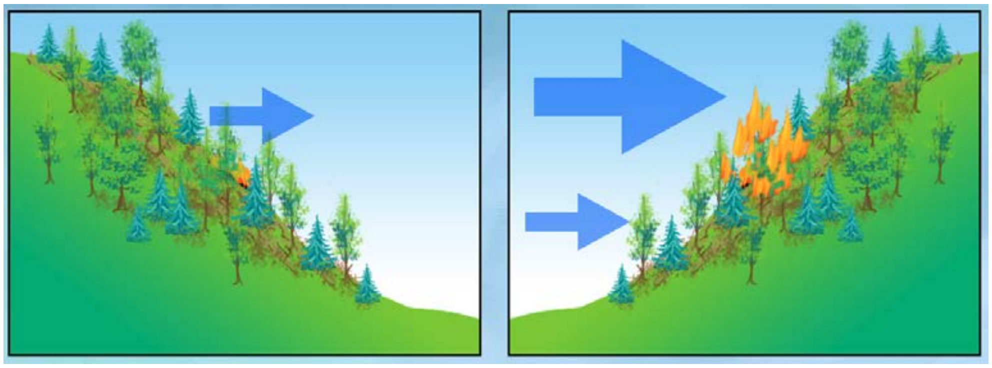


Figure 18. Benign, backing fires (left) burning downslope can rapidly change to intense fires burning upslope (right).

Narrow Canyons

Narrow, steep canyons have produced many extreme fire events.

- They can intensify heating on both sides when sunlight reaches lower slopes.
- They can channel winds, raising windspeed significantly.
- And when inversions break in them, fire behavior can increase rapidly.

These narrow canyons can produce slope reversals from rollout sending fires across at the bottom and from spotting across to the other side.

Maintain your **lookouts** with good vantage points when working in steep canyons. Be careful to keep an **escape route** open down-canyon from the fire.

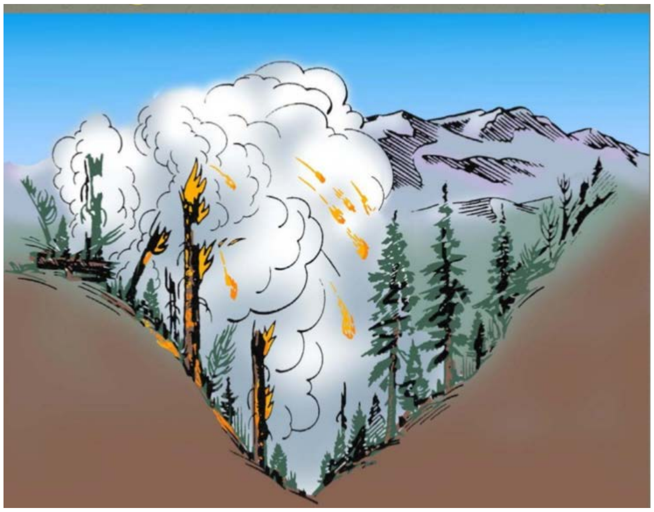


Figure 19. Fire behavior in a steep canyon.

Box Canyons and Chutes as Chimneys

Box canyons and chutes can produce extreme spread rates, intense burning, impressive pyrocumulus smoke plumes and long-range spotting from fires burning low on their slopes. *Especially as they steepen*!

Be very aware of **fire below you** that can reach these chimneys. Consider the aspect of these features and consider what time of the day they will be in the sun and become most flammable.

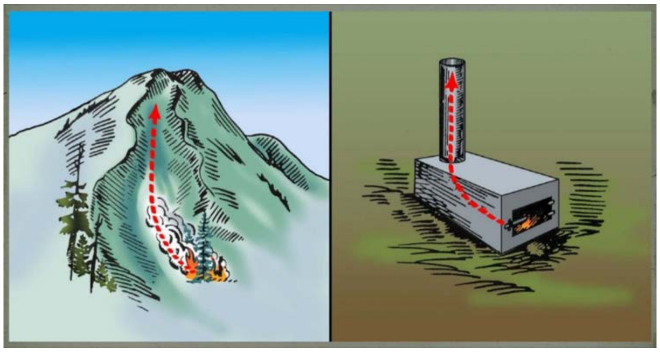
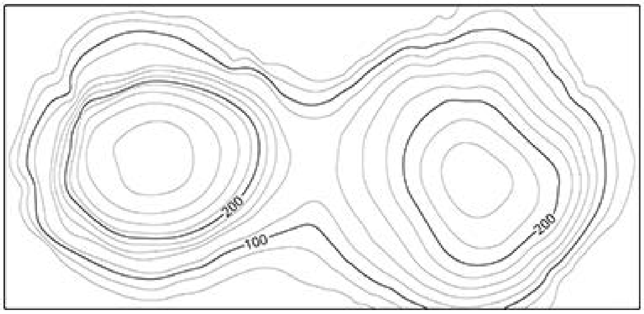


Figure 20. Chute (left) and its chimney effect (right).

Saddles, Passes and Gaps Increase windspeed and gustiness

These are different versions of the same topographic influence. Any of these depressions within blocking terrain will permit winds to be forced through at increasing speed and turbulence, with eddying winds on the other side. They differ primarily in the depth of the depression and how they are encountered in fire operations.

WARNING: These features, and their influence on winds, are generally not considered in production of general forecast products. Knowledge of these features and the importance of their influence on fireline operations is critical to your safety. Tools like WindNinja (https://www.firelab.org/project/windninja) and experiential context are best means of assessing them.



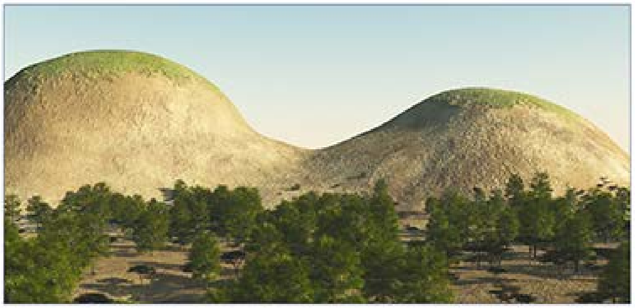


Figure 21. Saddles and Passes are similar features, high elevation dips in mountains and ridge lines.

Saddles are generally considered the shallowest of these features, usually as dips in ridgelines. Because they are smaller and more frequent, they are harder to avoid in control operations. Often, they are the weakest points in control lines along ridges. Mitigating the hazards associated with higher, turbulent winds in these locations is commonly the focus of ridgeline control operations.

Passes are usually deeper, and are named to represent locations where it is easiest to cross mountain ridges because they are significantly lower. When identified as named features, passes can be the locations of significant roads, trails, and traffic. But like saddles and gaps, passes permit wind to pass through blocking ridges at higher speeds and with greater turbulence. Because of upslope and valley winds mixing from both sides with general winds, passes are usually windy and gusty places.

Gaps are the deepest of these depressions in mountain ridges. It is not uncommon for them to drop to the valley bottom with sharp steep sides associated with old geologic fault lines and deep river cuts. But because these are frequently abrupt features in otherwise unbroken terrain, they are sites of strongest winds primarily with winds that align through them. It is difficult to construct line on their steep sidewalls, so they are often considered only as natural breaks or barriers when winds cannot easily push fires through to breach them.

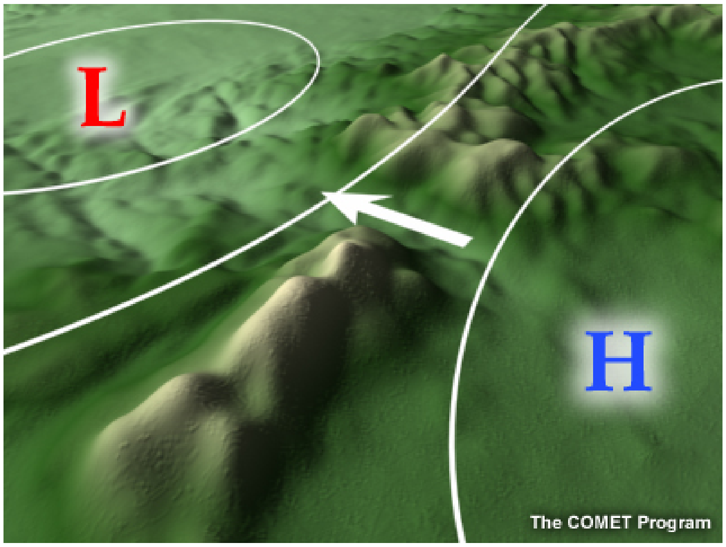


Figure 22. Gaps

Visual Fire Behavior Observation & Description

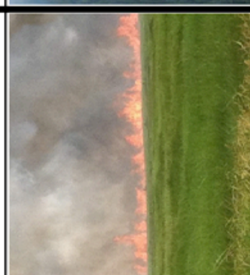
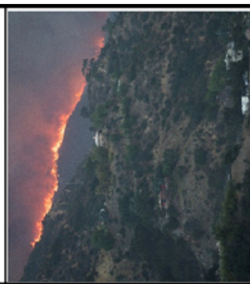
Surface Fire When fire is on the ground			**Crown Fire** When trees & shrubs burn		
Smoldering	**Creeping & Spreading**	**Running**	**Torching & Spotting**	**Crowning**	**Erratic & Extreme**
					
Little fire spread Minimal flaming, less than 1 ft White smoke Combustion of ground fuels	***Intermittent surface fire*** Slow spread Visible open flames 1-4 ft. Little torching Generally white smoke	***Vigorous surface fire.*** Flames 4-8 ft. Flammable canopy can ignite Moderate to fast (grasses) spread	***Single tree to group tree torching*** Surface flames 8-12 ft Moderate to fast spread. Gray to black smoke	***Crown fire front at head*** Fast spread rates Black to copper smoke Long range spotting	***Extreme fire environment*** Extreme intensity Turbulent fire Chaotic spread Interface fuel involvement

Figure 23. Fire Observation/Description Guide.

Flame Length vs Flame Height

Observing Flames, as proxy for fireline intensity and indicator of tactical limitations, requires careful observation of flame length versus flame height. It is also important to identify whether the observation is for head, flank, or back of the fire.

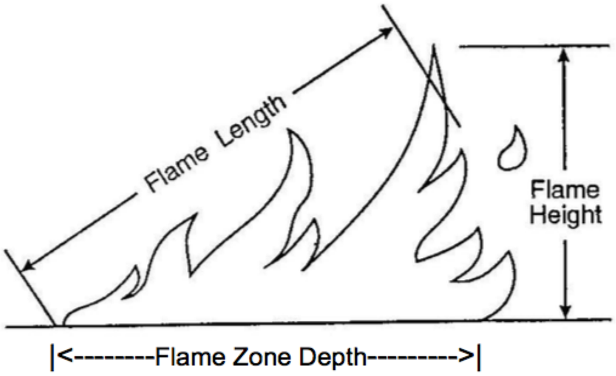


Figure 24. Flame length and flame height.

Flame Length: The distance measured from the average flame tip to the middle of the active flaming zone at the base of the fire. It is measured on a slant when the flames are tilted due to effects of wind and slope.

Flame Height: The average height of flames as measured vertically, up, and down. It is estimated by comparing the flame to a nearby object of known height. Flame height is needed to estimate spot distance from a burning pile.

Rate of Spread Estimator

Fireline observers can use this table to look up a spread rate based on how long it takes the flaming front to move a given distance.

Spread Distance (ft)				
1	3	5	10	ROS ch/hr (ft/min)
Time in Minutes (') and seconds (")				
3'38"	10'55"	18'10"	36'22"	¼ (¼)
1'49"	5'27"	9'05"	18'10"	½ (½)
55"	2'44"	4'33"	9'05"	1 (1)
36"	1'49"	3'02"	6'04"	1.5 (1-2)
27"	1'22"	2'16"	4'33"	2 (2)
18"	55"	1'31"	3'02"	3 (3)
14"	41"	1'08"	2'16"	4 (4-5 ft)
11"	33"	55"	1'49"	5 (5-6)
9"	27"	45"	1'31"	6 (6-7)
8"	23"	39"	1'18"	7 (7-8)
7"	20"	34"	1'08"	8 (9)
6"	18"	30"	1'01"	9 (10)
5"	16"	27"	55"	10 (11)
4"	11"	18"	36"	15 (16-17)
3"	8"	14"	27"	20 (22)
2"	7"	11"	22"	25 (27-28)
2"	5"	9"	18"	30 (33)
2"	5"	8"	16"	35 (38-39)
1"	4"	7"	14"	40 (44)
1"	3"	5"	11"	50 (55)
Spread Distance (ft)				

Use this chart to help estimate rate of spread

Here's how:

1. Measure out 1, 3, 5 or 10 feet. Mark distance with two points.
2. Time fire as it spreads between your two points and record this time.
3. Using the appropriate spread distance column (1, 3, 5 or 10), place your time on the sheet between two times listed, your "bracketed" times.
4. Move to the right with the bracket times. This is your ROS range.

Time Key
1' 49" = 1 minute and 49 seconds
36" = 36 seconds

Example: Say you're monitoring a backing fire burning in light ponderosa needle cast. You measure out 3 feet, and place two stones at each of the points. You time the fire as it moves between the stones. In this case, say the fire takes 1 minute 6 seconds (1'6") to move 3 feet. Looking at the 3 column, you move down until you see two times which bracket our time: 1'22" and 55". You then scroll right and see that the rate of spread is between 2 and 3 chains per hour.

Observation Report

Fire Name:____ Fire #____________

Management Unit:____________________________________ Date:___________ Time:______

Current Fire Size:__________ Observation Location (map grid/elev.etc.):_____________________

Attach current map indicating active fire perimeter, spread direction and other significant information.

Fuel Model/Vegetation Type (of active area):____

Fire Activity: Creeping, Running, Torching, or Crowning._________________________________

- Rate of Spread_________ch/h Type of spread Head Flanking Backing Average (select any that apply)
- Perimeter growth___________chains, direction_________Growth Rate (chains/time)_____________
- Percent of perimeter actively burning?_________.Location(s)______________________________
- Max temp/time_____Min temp/time_____ Min RH/time_____ Max RH/time
- Wind: Max sustained dir/time____
- Smoke: (describe column: color, shape, etc)_____________________________________
- Distance to MMA, Trigger Points, other values at risk (note on attached map also)______________

Other notes (i.e. influencing factors – topography, shading, etc., potential fuel model changes, resistance to control efforts, structures (if applicable), more on observations above.)

Prepared by:____ Date____________

Name, Module, and Qualification

Reviewed by:____ Date____________

Name, Module, and Qualification

Attached Products: (check)

☐ **FIRE BEHAVIOR OBSERVATIONS**

☐ **SMOKE OBSERVATIONS**

☐ **SPOT WEATHER FORECAST REQUEST**

☐ **FIRE PERIMETER/ AREA MAP**

☐ **FIRE WEATHER OBSERVATIONS**

☐ **FUEL MOISTURE SAMPLING SHEET**

☐ **ICS 214 UNIT LOG**

☐ **PHOTO LOG**

Anticipate and Interpret Expected Fire Behavior

Fire Behavior Classes, Interpretation

These fire behavior classes correspond to the shading in the Fire Characteristics Chart (Figure 25) and the categories in the Fire Observation/Description Guide (Figure 23). Fire behavior estimation tables include these classes as colors in the tables. Use these interpretations, along with anticipation of spotting spread and active crown fire to evaluate strategy and tactics and to inform LCES practices during the assignment.

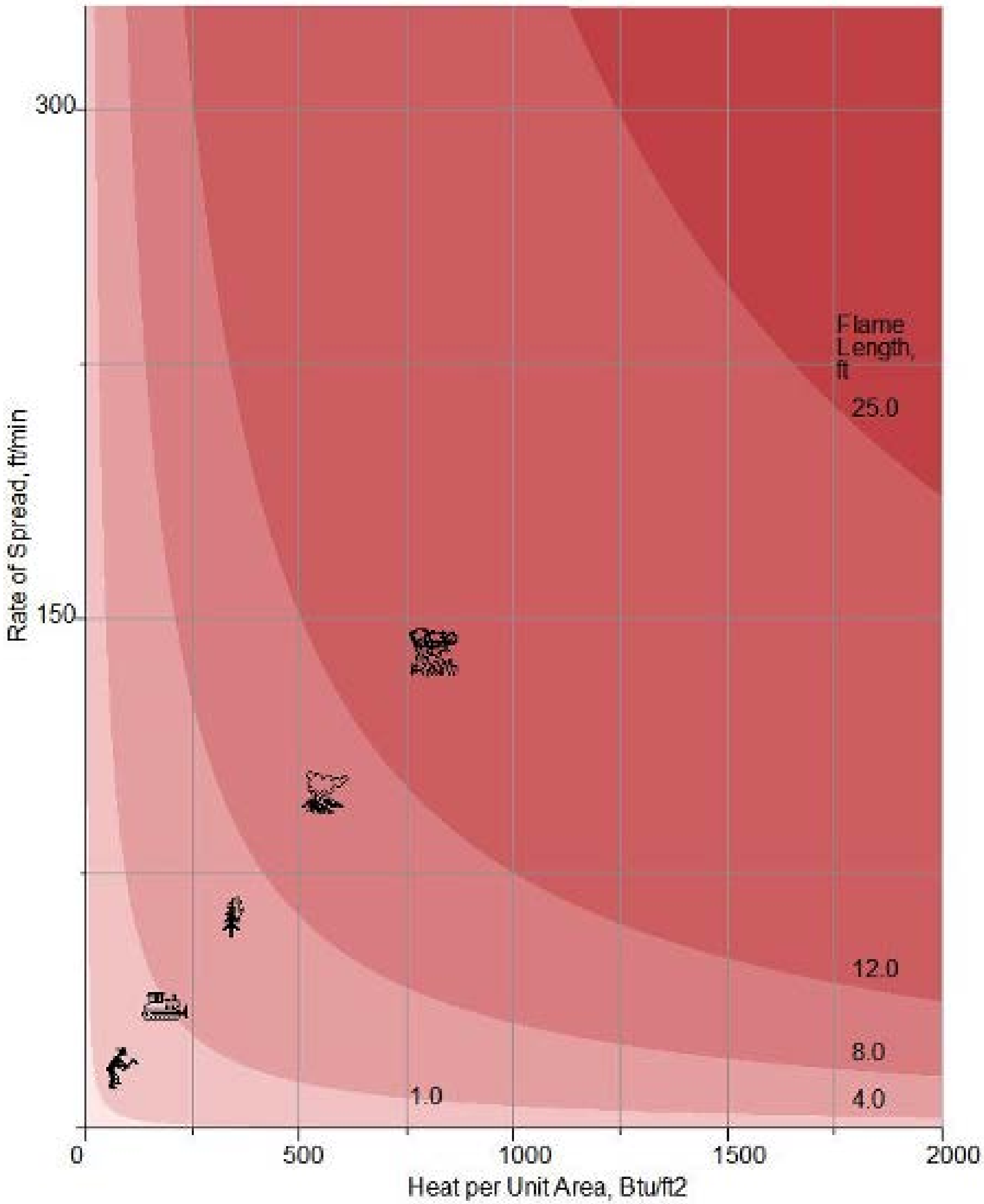
Table 1. Fire Behavior Class Descriptions (Scott and Burgan, 2005)

Fire Behavior Class	Rate of Spread (ch/hr)	Flame Length (ft)	Tactical Interpretation
Very Low, Smoldering	0-2	0-1	Fires are generally not spreading and open flames are only intermittently observed along the perimeter. Handline should hold the fire.
Low, Creeping and Spreading	2-5	1-4	Fires can generally be attacked at the head or flanks by persons using hand tools. Handline should hold the fire.
Moderate, Running	*5-20*	*4-8*	*Fires are too intense for direct attack on the head by persons using hand tools.* *Handline cannot be relied on to hold fire. Equipment such as dozers, engines, and retardant aircraft can be effective.*
High, Torching and Spotting	**20-50**	**8-12**	**Fires may present serious control problems - torching out, crowning, and spotting.** **Control efforts at the head of the fire will probably be ineffective.**
Very High, Active Crown Fire	**50-150**	**12-25**	**Crowning, spotting, and major runs are common.** **Control efforts at the head of the fire are ineffective.**
Extreme and Erratic	**150+**	**25+**	**Extreme intensity, turbulent fire, chaotic spread.** **Escape to safety is the primary objective.**

Fire Characteristics Chart

Plot your fire using anticipated rate of spread and flame length to rate the potential fire behavior, the expected changes in the burn period, and the suppression difficulty, based on the forecast predictions or fireline observations. Shading corresponds to the fire behavior classes in Table 1.

Figure 25. Fire Behavior Characteristics Chart.



Fine Fuel Moisture and Fire Behavior

These classifications of dead fine fuel moisture help suggest how receptive the fuels that carry fire spread are to ignition, spread, and more extreme behavior. These colors correspond to the fire behavior classes in Table 1. Use these interpretations, along with anticipation of spotting spread and active crown fire to evaluate strategy and tactics and to inform LCES practices during the assignment.

Though these thresholds are helpful, suggesting different levels of ignition potential and burning conditions, they are *not applicable equally everywhere you fight fire*. Make sure you ask about local thresholds and how conditions relate to recent fire activity

Table 2. Fire ignition Potential Factors.

Relative Humidity	NFDRS & NFBPS	CFFDRS FFMC	Prob of Ignition	Interpretation
>60%	1hr >20% 10hr>15%	<80	<10%	Very Low: Very little ignition, some spotting may occur with winds above 9 mph
45-60%	1hr - 15-19% 10hr - 12-15%	80-84	10-20%	Low: Low ignition hazard, campfires become hazardous, glowing brands cause ignition when RH is less than 50%
30-45%	*1hr - 11-14%* *10hr - 10-12%*	*85-88*	*20-30%*	*Moderate: Medium ignition hazard, matches become hazardous, “easy” burning conditions*
26-40%	**1hr - 8-10%** **10hr - 8-9%**	**89-92**	**30-50%**	**High: High ignition hazard, matches are dangerous, occasional spotting caused by gusty winds, “medium burning conditions.**
15-30%	**1hr - 5-7%** **10hr - 6-7%**	**93-95**	**50-70%**	**Very High: Quick ignition, rapid buildup, extensive crowning, any increase in wind causes increased spotting, crowning and loss of control. Fire moves up ladder fuels. Long distance spotting in conifers. “Dangerous” burning conditions.**
<15%	**1hr < 5%** **10hr < 6%**	**>95**	**80-100%**	**Extreme: All sources of ignition are dangerous. Aggressive burning, spot fires occur often and spread rapidly. Extreme fire behavior is probable. “Critical” burning conditions.**

Fire Behavior Quick Tips

Crossover and the 20/20 Rule: Potentially Severe Fire Weather

The combination of temperature and relative humidity, falling below the orange line in Figure 26, signals potentially severe fire behavior.

The 20/20 Rule is a specific example of this when Temperature is at 20 C (68 F) and Relative Humidity is at or below 20%

This concept is very similar to that represented by Vapor Pressure Deficit (VPD).

Beware that severe conditions may exist even if crossover doesn't occur.

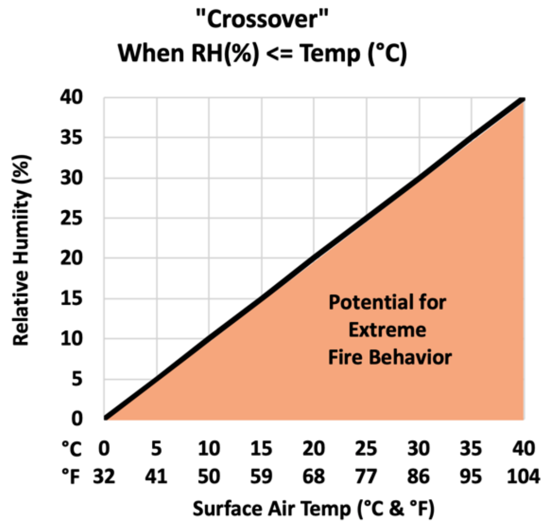


Figure 26. Crossover highlights potential for extreme fire behavior.

Estimating Rate of Spread from Surface Windspeed (use for active wildfires during peak seasons)

Use only with grass and shrub/crown fire fuel types carrying the fire. For large, multi-hour runs in dry dead fine fuels on flat to gently rolling terrain. Error up to 50% ±.

Use **unsheltered surface windspeed** (Forecasted 20ft or measured Eye Level)

20 foot Surface (Open) Windspeed	5 mph	10 mph	15 mph	20 mph	25 mph	30 mph	35 mph	40 mph	45 mph	50 mph
Eye Level Surface (Open) Windspeed	2 mph	4 mph	6 mph	8 mph	10 mph	12 mph	14 mph	16 mph	18 mph	20 mph

For fast moving fires, measured in miles per hour (grass spread may be wind limited for "?")

Grass, in mph	0.9	2.2	3.6	5.1	6.7	8.3	?	?	?	?
Brush/Crown, in mph	0.6	1.2	1.7	2.3	2.9	3.5	4.0	4.6	5.2	5.8

Table 3. Rate of Spread based on surface windspeed.
Alexander and Cruz (2019), Bishop (2007), Lawson and Armitage (2008).

Slope and Fire Spread

- For every 20% steeper upslope, double spread rate (e.g., 40% upslope 4X faster than flat.
- For every 20% steeper downslope, halve spread rate (e.g., 40% down, 0.25X flat ground).

Fire Size Estimates

Perimeter Length = 2.5 x Forward Spread Distance

Firebreak Effectiveness

In the absence of spotting, required firebreak width = 1.5 x flame length

Part 2

Estimate Expected Fire Behavior

Estimate Expected Fire Behavior

You cannot use a single factor or use a single scale to describe or rate wildfire behavior. There are several aspects that you must consider describing to provide an accurate picture of the fire behavior you anticipate:

- **Ignition potential**, often described using the Probability of Ignition (PIG) to evaluate the potential for fires to start and to spread actively once they do.
- **Rate of Spread**, estimated and classified using the fire behavior classes above.
- **Flame Length**, estimated and classified using the fire behavior classes above.
- Potential for **Spotting Spread** and **Active Crown Fire**.
- Anticipation of **Erratic and Extreme Fire Events**.

Identify the Next Big Changes in the Fire Environment

In Jim Bishop's Fireline Assessment Method (FLAME) explanations, he focused on the next big changes in the fire environment and identified these

- Change in Wind Speed and/or Direction
- Fuel type (grass, litter, and crown) and fire behavior change (potential for crown fire)
- Slope Reversal
- Change in Slope Steepness
- Weather getting hotter and drier
- Spotting Spread
- Surface Fire Transitioning to Active Crown Fire

Critical fire weather factors highlighted in forecasts can be important indicators. And evaluation of the fire environment at the beginning and throughout the operational period can help anticipate and predict the result of these oncoming "big changes" as the "NEXT BIG CHANGE" estimation of fire behavior.

Gather and Prepare the Inputs

The Fire Behavior Worksheet, found below, provides a process to follow in attempting to make estimates of expected fire behavior in the field.

On it, there are a series of assessment steps that require evaluation of the fire environment in advance of a fire behavior prediction.

- Identify **Times** and **Places** of Interest. Think about **fire spread direction**.
- Select Representative **Fuel Models**
- Estimate **elevation, slope and aspect** for places of interest
- Estimate **Dead and Live Fuel Moistures** based on the fuel, terrain and weather inputs
- Estimate **Midflame and Effective Wind speeds**

Fire Behavior Estimation

- Determine **Rate of Spread** and **Flame Length** from app or lookup tables
- Determine **Probability of Ignition** and estimate **Spotting Distance**
- **Calibrate** and **Interpret** these results against observed fire weather/behavior yesterday.
- Consider **fire size and shape** for initial attack fires

Use the Right Tool for Your Estimate

How will the tool help answer your question?	How will fire behavior change with the next big change in fire environment? Sensitivity Analysis	Where will fire go today and how long will it take? How will fire behavior vary across areas of interest during the burn period?	Where will fire go over several days given changing weather as well as fuel and terrain?	What risk do identified values face over a given planning period?
Tool or Model	• BehavePlus • Lookup Tables • Nomograms • Nomographs • Nexus • FLAME/CPS	Short-Term Fire Behavior (STFB) or FlamMap Minimum Travel Time (MTT), (Finney 2002).	Near-Term Fire Behavior (NTFB) or FARSITE (Finney 1998).	• Fire Spread Probability (FSPro). • Burn Probability • Use Minimum Travel Time (MTT), (Finney 2002).
Best Use, Calc Time	Fireline	Incident or Event, 15 min to 1 hour.	Incident Planning, 1 to 3 hours.	Risk Assessment, 2 or more hours.
Forecast Horizon	Single Period	Up to 3 days if weather persistent.	Up to 6 days (evaluate forecast confidence).	One week to 30 days.
Weather	Single weather (wind and fuel moisture) scenario.	Single weather (wind and fuel moisture) scenario over duration of run.	Hourly, variable weather (wind and fuel moisture) over duration of run.	Short term forecast plus ERC seasonal trend after that produce range of daily weather scenarios.
Gridded Wind	No	Yes (WindNinja)	No	No
Spotting	Yes Max Spot Distance, Probability of Ignition.	Yes Spotting Distance/Frequency (one ember per node; spotting probability value higher than NTFB; start with .10% spotting probability).	Yes Spotting Distance/Frequency (16 embers per vertex; spotting probability value lower than STFB; start with .05%).	Yes (like STFB)
Principal Outputs	Not Spatial • Rate of Spread. • Flame Length.	Spatial • Major flow paths and arrival time perimeters. • Fire behavior grids.	Spatial • Progression perimeters.	Spatial • Probability contours.

Figure 27. Analysis questions and the best tool(s), purpose, scope, inputs, and outputs to apply.

Fire Behavior Worksheet

Fire Behavior Worksheet (with Size & Shape)

Incident/Project: **Observer/Analyst:** **Date:**

	Time and Place				**Briefing/Notes**
1	Projection Point Identifier				
2	Projection Month/Day				
3	Projection Hour of the Day				
4	Burn Period/Duration (hr or min)				
	Fuel/Terrain				
5	**Surface Fuel Model**				
6	Canopy Cover, %				
7	Aspect (N, E, S, W)				
8	**Slope, %**				
	Dead Fuel Moisture – add 1-2 % each for 10-hr and 100-hr				
9	Cloud Cover, %				
10	Dry Bulb Temperature, °F				
11	Wet Bulb Temperature, °F				
12	Relative Humidity, %				
13	Reference Fuel Moisture, %				
14	(S)haded or (U)nshaded				
15	Elevation Difference (B, L, A)				
16	Fuel Moisture Correction, %				
17	**1-hr Moisture Content (L13 + L16)**				
	Live Fuel Moisture				
18	**Herbaceous Moisture Content, %**				
19	**Woody Moisture Content, %**				
	Windspeed and Wind Direction				
20	Wind Direction				
21	Surface (20ft) Windspeed, mph				
22	(S)heltered or (U)nsheltered				
23	Wind Adjustment Factor				
24	Midflame Windspeed, mph				
25	**Effective Windspeed, mph**				
	Fire Behavior				
26	**Probability of Ignition**				
27	Spread Direction				(H)ead, (B)ack, (F)lank
28	Direction of Max Spread				Up/Cross/Down
29	Head Fire Rate of Spread (HFROS)				Chains (66ft)/hour
30	Head Fire Flame Length (HFFL)				Feet
31	Fraction of HFROS				From flanking & backing
32	Fraction of HFFL				nomograph
33	**ROS in Spread Direction**				Chains (66ft)/hour
34	**FL in Spread Direction**				Feet
35	**Spotting Distance**				
	Fire Size and Shape				**Notes**
36	Spread Distance, chains (66ft)				
37	**Fire Size, acres**				
38	**Fire Perimeter, chains (66ft)**				

Fuel Model Selection

There are 53 standard fuel models used in US fire spread models, each with a label (and a numeric code in parentheses). Only the ***13 original "Anderson" models*** (with FM prefix) are provided as lookup tables in this reference. These were developed for estimating fire behavior under peak season burning conditions with active fire spread. This smaller set of fuel models simplifies the choice for fireline users. And in most situations where fireline assessment of active to critical conditions is needed, these assumptions are generally appropriate.

Some descriptive and comparative information about the newer ***"40" (Scott and Burgan) fuel models*** is included for more advanced users. Mobile apps are becoming more available and they are in wide use in analysis products and fuel treatment applications. They offer access to a full set of fuel models.

Fuel Model Selection Guide

- Start with the conventional local fuel model selections. Compare to what this tool suggests.
- First, make sure that live fuels are an important factor.
- Second, determine which of the fuel carriers is most responsible for fire spread. Grass, Grass-Shrub, Shrub, and Timber Understory for live fuel loads. Timber Litter and Slash/Blowdown for dead fuels only. Categories are grouped for similarity and overlap.
- Third, consider how much heat the fire might produce as low, moderate, or high.
- Try several alternatives and both low and high moisture of extinction choices when calibrating.

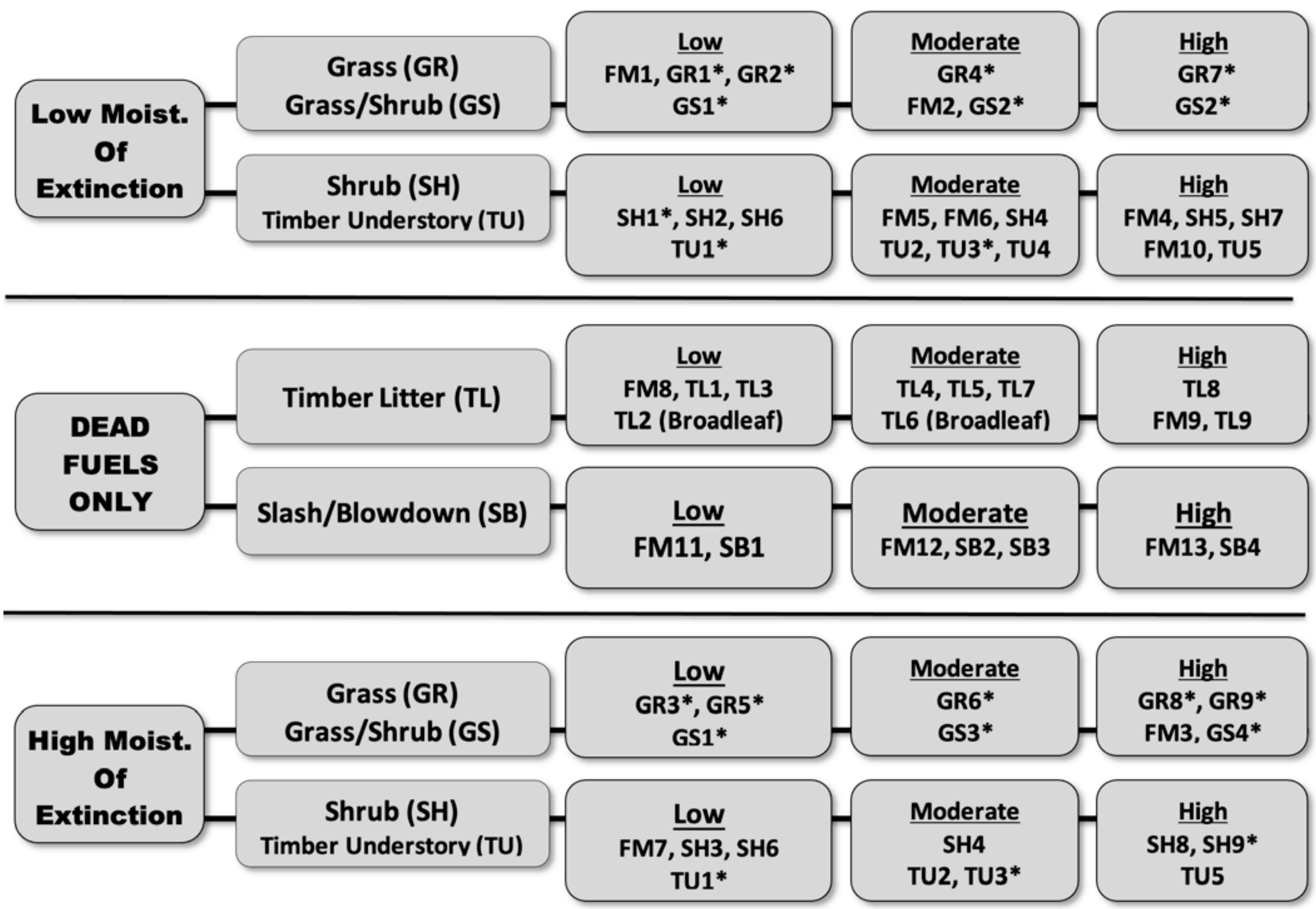


Figure 28. Quick fuel model selector tool. Uses moisture of extinction, primary carrier fuel category, and potential flammability to suggest fuel models. Asterisk (*) denotes a dynamic fuel model with live herbaceous load transfer potential.

Grass and Grass-Shrub Fuels

Anderson (1982) Fuel Models

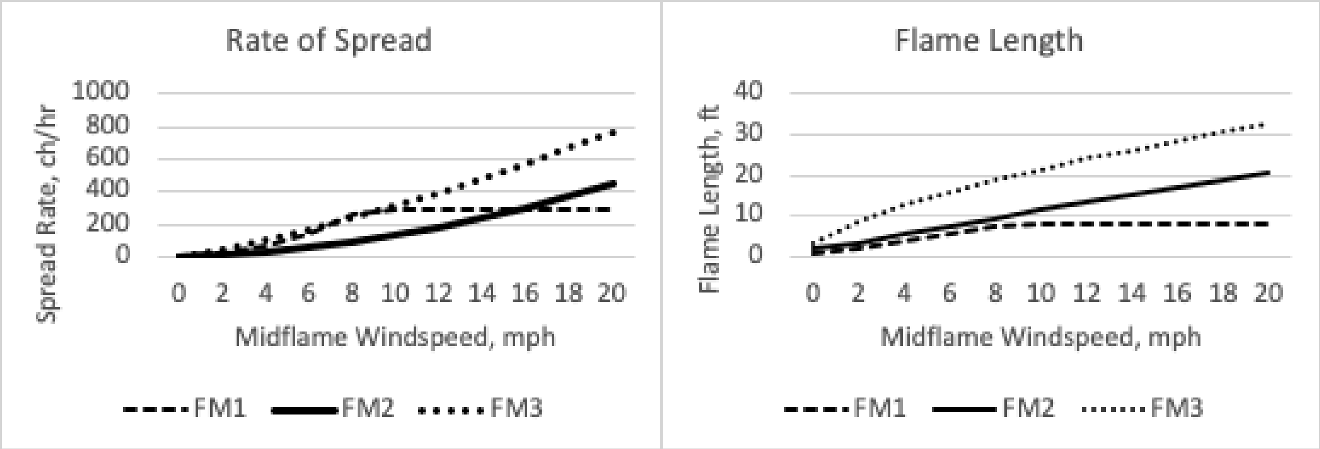


Figure 29. Comparative Fire Behavior for Grass and Grass-Shrub Fuel Models

	**FM1 (01)**: Fire spread is governed by the fine herbaceous fuels that are cured or nearly cured. Fires move rapidly through cured grass & associated material. Very little shrub or timber is present, generally less than one-third of the area. Grasslands & savanna are represented along with stubble, grass tundra, & grass-shrub combinations that meet the above area constraint. Annual & perennial grasses are included fuels.
	**FM2 (02)**: Fire spread is primarily through the fine herbaceous fuels, either curing or dead. These are surface fires where the herbaceous material, besides litter and dead-down stem wood from the open shrub or timber overstory, contribute to the fire intensity. Open shrub lands and pine stands or scrub oak stands that cover one-third or two thirds of the area may generally fit this model, but may include clumps of fuels that generate higher intensities and may produce firebrands. Some pinyon-juniper may be in this model.
	**FM3 (03)**: Fires in this fuel are the most intense of the grass group and display high rates of spread under the influence of wind. The fire may be driven into the upper heights of the grass stand by the wind and cross standing water. Stands are tall, averaging about 3 ft., but may vary considerably. Approximately one-third or more of the stand is considered dead or cured and maintains the fire. Wild or cultivated grains that have not been harvested can be considered similar to tall prairie and marshland grasses.

Scott and Burgan (2005) Fuel Models

All of these fuel models use **dynamic** transfer of herb fuel load from live to dead as live fuel moisture falls below 120%. More information in the live fuel moisture section.

Low Moisture of Extinction

- **GR1 (101):** The primary carrier of fire is sparse grass, though small amounts of fine dead fuel may be present. The grass in GR1 is generally short, either naturally or by heavy grazing, and may be sparse or discontinuous. Moisture of extinction of GR1 is indicative of dry climate fuelbeds, but may also be applied in high-extinction moisture fuelbeds, because in both cases predicted spread rate and flame length are low compared to other GR models.
- **GR2 (102):** Primary carrier of fire is grass, though small amounts of fine dead fuel may be present. Load is greater than GR1. Fuelbed may be more continuous. Shrubs do not affect fire behavior.
- **GR4 (104):** The primary carrier of fire is continuous, dry-climate grass. Load and depth are greater than GR2 fuelbed depth is about 2-feet.
- **GR7 (107):** Primary carrier is continuous dry-climate grass. Load and depth greater than GR4. Grass about 3-feet tall.
- **GS1 (121):** The primary carrier of fire is grass and shrubs combined. Shrubs are about 1 foot high; grass load is low. Spread rate is moderate; flame length low. Moisture of extinction is low.
- **GS2 (122):** Primary carrier is grass and shrubs combined. Shrubs are 1-3-feet high; grass load is moderate. Spread rate is high; flame length moderate. Moisture of extinction low.

High Moisture of Extinction

- **GR3 (103):** The primary carrier of fire is continuous, coarse, humid-climate grass. Grass and herb fuel load is relatively light; fuelbed depth is about 2 feet. Shrubs are not present in significant quantity to affect fire behavior.
- **GR5 (105):** The primary carrier of fire is humid-climate grass. Load is greater than GR3 but depth is lower, about 1-2-feet.
- **GR6 (106):** The primary carrier of fire is continuous humid-climate grass. Load is greater than GR5 but depth is about the same. Grass is less coarse than GR5.
- **GR8 (108):** The primary carrier of fire is continuous, very coarse, humid-climate grass. Load and depth are greater than GR6. Spread rate and flame length can be extreme if grass is fully cured.
- **GR9 (109):** The primary carrier of fire is dense, tall, humid-climate grass. Load and depth are greater than GR8, about 6-feet tall. Spread rate and flame length can be extreme if grass is fully or mostly cured.
- **GS3 (123):** The primary carrier of fire is grass and shrubs combined. Moderate grass/shrub load, average grass/shrub depth less than 2-feet. Spread rate is high; flame length moderate. Moisture of extinction is high.
- **GS4 (124):** The primary carrier of fire is grass and shrubs combined. Heavy grass/shrub load, depth greater than 2-feet. Spread rate high; flame length very high. Moisture of extinction is high.

Carrier	FM #	FM Code	Fuel Model Name	***Wind Adj***	1hr Load	10hr Load	100hr Load	Herb Load	Woody Load	***Total Load***	1hr SAV	Herb SAV	Woody SAV	***Bed Depth***	***Moist Extinct***	Dead Heat	Live Heat
Dry Climate Fuel Models																	
GR	1	FB1	Short grass	***0.36***	0.7	--	--	--	--	***0.7***	3500	--	--	***1.0***	***12***	8000	--
GR	2	FB2	Timber grass and understory	***0.36***	2.0	1.0	0.5	0.5	--	***4.0***	3000	1500	--	***1.0***	***15***	8000	8000
GR	101	GR1	Short, sparse dry climate grass	***0.31***	0.1	--	--	0.3	--	***0.4***	2200	2000	--	***0.4***	***15***	8000	8000
GR	102	GR2	Low load dry climate grass	***0.36***	0.1	--	--	1.0	--	***1.1***	2000	1800	--	***1.0***	***15***	8000	8000
GR	104	GR4	Moderate load dry climate grass	***0.42***	0.3	--	--	1.9	--	***2.2***	2000	1800	--	***2.0***	***15***	8000	8000
GR	107	GR7	High load dry climate grass	***0.46***	1.0	--	--	5.4	--	***6.4***	2000	1800	--	***3.0***	***15***	8000	8000
GS	121	GS1	low load dry climate grass-shrub	***0.35***	0.2	--	--	0.5	0.7	***1.4***	2000	1800	1800	***0.9***	***15***	8000	8000
GS	122	GS2	moderate load dry climate grass-shrub	***0.39***	0.5	0.5	--	0.6	1.0	***2.6***	2000	1800	1800	***1.5***	***15***	8000	8000
Humid Climate Fuel Models																	
GR	3	FB3	tall grass	***0.44***	3.0	--	--	--	--	***3.0***	1500	--	--	***2.5***	***25***	8000	--
GR	103	GR3	Low load very coarse humid climate grass	***0.42***	0.1	0.4	--	1.5	--	***2.0***	1500	1300	--	***2.0***	***30***	8000	8000
GR	105	GR5	low load humid climate grass	***0.39***	0.4	--	--	2.5	--	***2.9***	1800	1600	--	***1.5***	***40***	8000	8000
GR	106	GR6	moderate load humid climate grass	***0.39***	0.1	--	--	3.4	--	***3.5***	2200	2000	--	***1.5***	***40***	9000	9000
GR	108	GR8	High load very coarse humid climate grass	***0.49***	0.5	1.0	--	7.3	--	***8.8***	1500	1300	--	***4.0***	***30***	8000	8000
GR	109	GR9	very high load humid climate grass	***0.52***	1.0	1.0	--	9.0	--	***11.0***	1800	1600	--	***5.0***	***40***	8000	8000
GS	123	GS3	moderate load humid climate grass-shrub	***0.41***	0.3	0.3	--	1.5	1.3	***3.3***	1800	1600	1600	***1.8***	***40***	8000	8000
GS	124	GS4	high load humid climate grass-shrub	***0.42***	1.9	0.3	0.1	3.4	7.1	***12.8***	1800	1600	1600	***2.1***	***40***	8000	8000

Figure 30. Grass and Grass-Shrub Fuel Model Parameter Table

Shrub and Timber Understory Fuels

Anderson (1982) Fuel Models

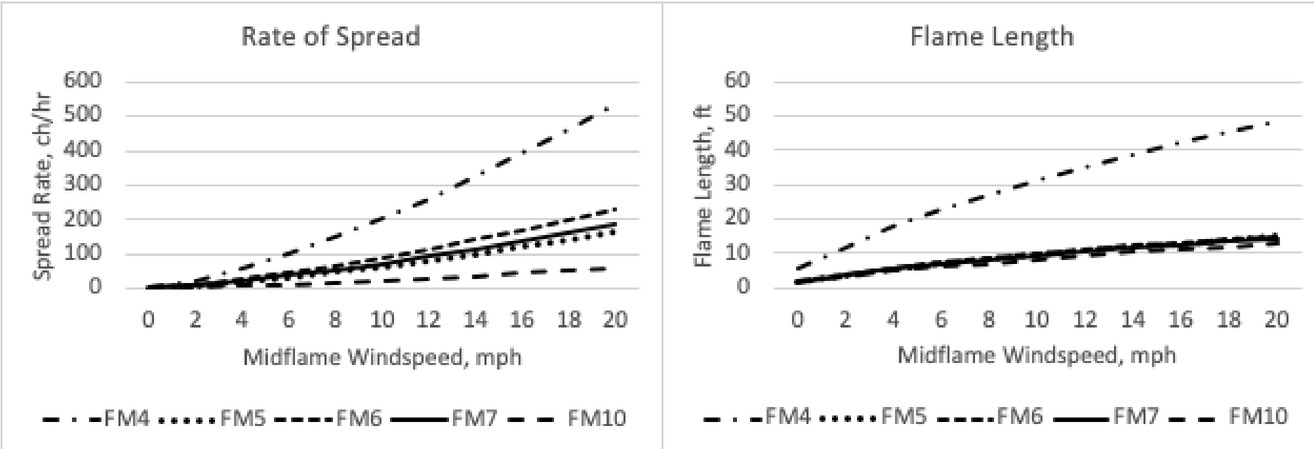


Figure 31. Shrub and Timber Understory Fuel Models

	**FM4 (04):** Fire intensity and fast-spreading fires involve the foliage and live and dead fine woody material in the shrub layer. Besides flammable foliage, there is dead woody material that significantly contributes to fire intensity. Deep litter layer may also confound suppression efforts.
	**FM5 (05):** Primary carrier is litter cast by the shrubs, and the grasses or forbs in the understory. Shrubs not tall, but have nearly total coverage of the area. Young, green stands with no deadwood.
	**FM6 (06):** Fire carries through the shrub layer, requiring at least moderate winds. Fire will drop to the ground at low windspeeds or openings in the stand. The shrubs are older. A broad range of shrub conditions is included here.
	**FM7 (07):** Fires burn through the surface and shrub strata with equal ease and can occur at higher dead fuel moisture contents because of the flammable nature of live foliage and other live material. Stands of shrubs are generally between 2 and 6 ft. high. Palmetto-gallberry understory within pine overstory sites are typical and low pocosins may be represented. Black spruce-shrub combinations in Alaska may also be represented.
	**FM10 (10):** Dead, down fuels include greater quantities of 3-inch or larger limb wood resulting from decadence or natural events that create a large load of dead material. Crown fire and spotting is more frequent in this fuel situation.

Scott and Burgan (2005) Fuel Models

Low Moisture of Extinction

- **SH1 (141):** This model uses **dynamic** transfer of herb fuel load from live to dead. The primary carrier of fire in SH1 is woody shrubs and shrub litter. Low shrub fuel load, fuelbed depth about 1 foot; some grass may be present. Spread rate very low; flame length very low.
- **SH2 (142):** The primary carrier of fire in SH2 is woody shrubs and shrub litter. Moderate fuel load (higher than SH1), depth about 1 foot, and no grass fuel present. Spread rate is low; flame length low.
- **SH5 (145):** The primary carrier of fire in GS4 is grass and shrubs combined. Heavy grass/shrub load, depth greater than 2-feet. Spread rate very high; flame length very high. Moisture of extinction is high.
- **SH7 (147):** The primary carrier of fire is woody shrubs and shrub litter. Very heavy shrub load, depth 4-6-feet. Spread rate lower than SH5, but flame length similar. Spread rate is high; flame length very high.
- **TU1 (161):** This model uses **dynamic** transfer of herb fuel load from live to dead. The primary carrier of fire is low load of grass and/or shrub with litter. Spread rate is low; flame length low.
- **TU4 (164):** The primary carrier of fire is grass, lichen or moss understory plants. If live woody moisture content is set to 100 percent, this fuel model mimics the behavior of Norum's (1982) empirical calibration for Alaska Black Spruce. Spread rate is moderate; flame length moderate.
- **TU5 (165):** The primary carrier of fire in TU5 is heavy forest litter with a shrub or small tree understory. Spread rate is moderate; flame length moderate.

High Moisture of Extinction

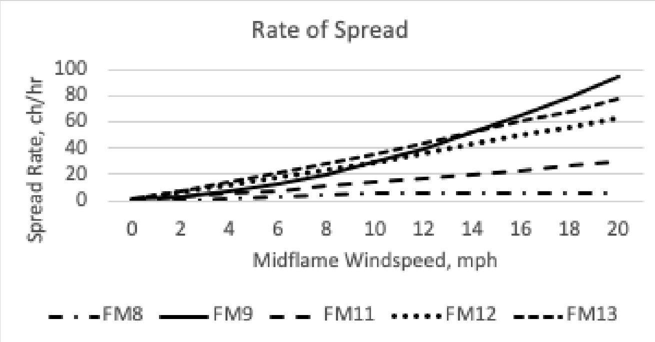
- **SH3 (143):** The primary carrier of fire in SH3 is woody shrubs and shrub litter. Moderate shrub load, possibly with pine overstory or herbaceous fuel, fuel bed depth 2-3-feet. Spread rate is low; flame length low.
- **SH4 (144):** The primary carrier of fire in SH4 is woody shrubs and shrub litter. Low to moderate shrub and litter load, possibly with pine overstory, fuel bed depth about 3-feet. Spread rate is high; flame length moderate.
- **SH6 (146):** The primary carrier of fire in SH6 is woody shrubs and shrub litter. Dense shrubs, little or no herbaceous fuel, fuelbed depth about 2-feet. Spread rate high; flame length high.
- **SH8 (148):** The primary carrier of fire in SH8 is woody shrubs and shrub litter. Dense shrubs, little or no herbaceous fuel, fuelbed depth about 3-feet. Spread rate high; flame length high.
- **SH9 (149):** This model uses **dynamic** transfer of herb fuel load from live to dead. The primary carrier of fire in SH9 is woody shrubs and shrub litter. Dense, finely branched shrubs with significant fine dead fuel, about 4-6-feet tall; some herbaceous fuel may be present. Spread rate is high, flame length very high.
- **TU2 (162):** The primary carrier of fire in TU2 is moderate litter load with shrub component. High extinction moisture. Spread rate is moderate; flame length low.
- **TU3 (163):** This model uses **dynamic** transfer of herb fuel load from live to dead. The primary carrier of fire in TU3 is moderate forest litter with grass and shrub components. Extinction moisture is high. Spread rate is high; flame length moderate.

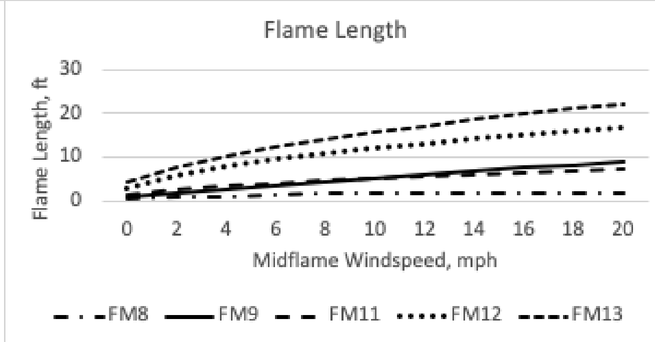
Carrier	FM #	FM Code	Fuel Model Name	***Wind Adj***	1hr Load	10hr Load	100hr Load	Herb Load	Woody Load	***Total Load***	1hr SAV	Herb SAV	Woody SAV	***Bed Depth***	***Moist Extinct***	Dead Heat	Live Heat
			Dry Climate Fuel Models														
SH	4	FB4	chaparral	***0.55***	5.0	4.0	2.0	--	5.0	***16.0***	2000	--	1500	***6***	***20***	8000	8000
SH	5	FB5	brush	***0.42***	1.0	0.5	--	--	2.0	***3.5***	2000	--	1500	***2***	***20***	8000	8000
SH	6	FB6	dormant brush	***0.44***	1.5	2.5	2.0	--	--	***6.0***	1750	--	--	***2.5***	***25***	8000	--
SH	141	SH1	low load dry climate shrub	***0.36***	0.3	0.3	0.0	0.2	1.3	***2.0***	2000	1800	1600	***1***	***15***	8000	8000
SH	142	SH2	mod. load dry climate shrub	***0.36***	1.4	2.4	0.8	--	3.9	***8.4***	2000	--	1600	***1***	***15***	8000	8000
SH	145	SH5	high load dry climate shrub	***0.55***	3.6	2.1	--	--	2.9	***8.6***	750	--	1600	***6***	***15***	8000	8000
SH	147	SH7	very high load dry climate shrub	***0.55***	3.5	5.3	2.2	--	3.4	***14.4***	750	--	1600	***6***	***15***	8000	8000
TU	161	TU1	light load dry climate timber-grass-shrub	***0.33***	0.2	0.9	1.5	0.2	0.9	***3.7***	2000	1800	1600	***0.6***	***20***	8000	8000
TU	164	TU4	dwarf conifer with understory	***0.32***	4.5	--	--	--	2.0	***6.5***	2300	--	2000	***0.5***	***12***	8000	8000
TU	165	TU5	very high load dry climate timber-shrub	***0.33***	4.0	4.0	3.0	--	3.0	***14.0***	1500	--	750	***1***	***25***	8000	8000
TU	10	FB10	timber litter and understory	***0.36***	3.0	2.0	5.0	--	2.0	***12.0***	2000	--	1500	***1***	***25***	8000	8000
			Humid Climate Fuel Models														
SH	7	FB7	southern rough	***0.44***	1.1	1.9	1.5	--	0.4	***4.9***	1750	--	1500	***2.5***	***40***	8000	8000
SH	143	SH3	mod. load humid climate shrub	***0.44***	0.5	3.0	--	--	6.2	***9.7***	1600	--	1400	***2.4***	***40***	8000	8000
SH	144	SH4	low load humid climate timber-shrub	***0.46***	0.9	1.2	0.2	--	2.6	***4.8***	2000	--	1600	***3***	***30***	8000	8000
SH	146	SH6	low load humid climate shrub	***0.42***	2.9	1.5	--	--	1.4	***5.8***	750	--	1600	***2***	***30***	8000	8000
SH	148	SH8	high load humid climate shrub	***0.46***	2.1	3.4	0.9	--	4.4	***10.7***	750	--	1600	***3***	***40***	8000	8000
SH	149	SH9	very high load humid climate shrub	***0.50***	4.5	2.5	--	1.6	7.0	***15.5***	750	1800	1500	***4.4***	***40***	8000	8000
TU	162	TU2	Moderate load humid climate timber-shrub	***0.36***	1.0	1.8	1.3	--	0.2	***4.2***	2000	--	1600	***1***	***30***	8000	8000
TU	163	TU3	moderate load humid climate timber-grass-shrub	***0.38***	1.1	0.2	0.3	0.7	1.1	***3.3***	1800	1600	1400	***1.3***	***30***	8000	8000

Figure 32. Shrub and Timber Understory Fuel Model Parameter Table

Timber Litter and Slash/Blowdown Fuels

Anderson (1982) Fuel Models





	**FM8 (08):** Slow-burning ground fires with low flame heights, although the fire may encounter occasional "jackpot" or heavy fuel concentration that can flare up. Only under severe weather conditions involving high temperatures, low humidities, and high winds do the fuels pose fire hazards. This layer is mainly needles, leaves, and some twigs. Little undergrowth is present in the stand.
	**FM9 (09):** Fire runs through surface litter faster than FM8 and has a higher flame height. Both long-needle conifer & hardwood stands, especially oak-hickory types, are typical. Fall fires in hardwoods are representative, but spotting by rolling and blowing leaves in high winds will cause higher spread rates than predicted. Concentrations of dead-down woody material contribute to torching & spotting.
	**FM11 (11):** Fires are active in the slash and intermixed herbaceous material. The spacing of the rather light fuel load, shading from overstory, or the aging of the fine fuels can contribute to limiting the fire potential. The less-than-3-inch material load is less than 12 tons per acre. The greater-than-3-inch material is represented by not more than 10 pieces, 4 inches in diameter, along a 50-ft transect.
	**FM12 (12):** Rapidly spreading fires with high intensities can generate firebrands. When fire starts, it is generally sustained until a fuel break or change in fuels is encountered. Visual impression dominated by slash, most less than 3 inches in diameter. Fuels total less than 35 tons per acre and well distributed.
	**FM13 (13):** Fire generally carried across the area by a continuous layer of slash. Large quantities of greater-than-3-inch material present. Active flaming sustained for long periods and firebrands of various sizes may be generated. These contribute to spotting problems. Situations where slash still has "red" needles attached but the total load is lighter, more like model 12, can be represented because of the earlier high intensity and quicker area involvement.

Scott and Burgan (2005) Fuel Models

Timber Litter Fuel Models

- TL1 (181): The primary carrier of fire is compact forest litter. Light to moderate load, fuels 1-2 inches deep. May be used to represent a recently burned forest. Spread rate is very low; flame length very low.
- TL2 (182): The primary carrier of fire is broadleaf (hardwood) litter. Low load, compact litter. Spread rate is very low; flame length very low.
- TL3 (183): The primary carrier of fire is moderate load conifer litter, light load of coarse fuels. Spread rate is very low; flame length low.
- TL4 (184): The primary carrier of fire is moderate load of fine litter and coarse fuels. Includes small diameter downed logs. Spread rate is low; flame length low.
- TL5 (185): The primary carrier of fire is High load conifer litter; light slash or mortality fuel. Spread rate is low; flame length low.
- TL6 (186): The primary carrier of fire is moderate load broadleaf litter, less compact than TL2. Spread rate is moderate; flame length low.
- TL7 (187): The primary carrier of fire is heavy load forest litter, including larger diameter downed logs. Spread rate low; flame length low.
- TL8 (188): The primary carrier of fire is moderate load long-needle pine litter, may include a small amount of herbaceous load. Spread rate is moderate; flame length low.
- TL9 (189): The primary carrier of fire is very high load, fluffy broadleaf litter. Can also be used to represent heavy needle-drape. Spread rate is moderate; flame length moderate.

Slash Blowdown Fuel Models

- SB1 (201): Primary carrier of fire is light dead and down activity fuel. Fine fuel load is 10 to 20 t/ac, weighted toward fuels 1-3 in diameter class, depth is less than 1 foot. Spread rate is moderate; flame length low.
- SB2 (202): The primary carrier of fire is moderate dead and down activity fuel or light blowdown. Fine fuel load is 7 to 12 t/ac, evenly distributed across 0-0.25, 0.25-1, and 1-3 inch diameter classes, depth is about 1 foot. Blowdown is scattered, with many trees still standing. Spread rate is moderate; flame length moderate.
- SB3 (203): The primary carrier of fire is heavy dead and down activity fuel or moderate blowdown. Fine fuel load is 7 to 12 t/ac, weighted toward 0-0.25 inch diameter class, depth is more than 1 foot. Blowdown is moderate; trees compacted to near the ground. Spread rate is high; flame length high.
- SB4 (204): The primary carrier of fire is heavy blowdown fuel. Blowdown is total, fuelbed not compacted, most foliage and fine fuel still attached to blowdown. Spread rate very high; flame length very high.

Carrier	FM #	FM Code	Fuel Model Name	Wind Adj	1hr Load	10hr Load	100hr Load	Herb Load	Woody Load	Total Load	1hr SAV	Herb SAV	Woody SAV	Bed Depth	Moist Extinct	Dead Heat	Live Heat
Timber Litter Fuel Models																	
TL	8	FB8	compact timber litter	0.28	1.5	1.0	2.5	--	--	5.0	2000	--	--	0.2	30	8000	--
TL	9	FB9	hardwood litter	0.28	2.9	0.4	0.2	--	--	3.5	2500	--	--	0.2	25	8000	--
TL	181	TL1	Low load compact conifer litter	0.28	1.0	2.2	3.6	--	--	6.8	2000	--	--	0.2	30	8000	--
TL	182	TL2	low load broadleaf litter	0.28	1.4	2.3	2.2	--	--	5.9	2000	--	--	0.2	25	8000	--
TL	183	TL3	moderate load conifer litter	0.29	0.5	2.2	2.8	--	--	5.5	2000	--	--	0.3	20	8000	--
TL	184	TL4	Small downed logs	0.31	0.5	1.5	4.2	--	--	6.2	2000	--	--	0.4	25	8000	--
TL	185	TL5	high load conifer litter	0.33	1.2	2.5	4.4	--	--	8.1	2000	--	--	0.6	25	8000	--
TL	186	TL6	moderate load broadleaf litter	0.29	2.4	1.2	1.2	--	--	4.8	2000	--	--	0.3	25	8000	--
TL	187	TL7	Large downed logs	0.31	0.3	1.4	8.1	--	--	9.8	2000	--	--	0.4	25	8000	--
TL	188	TL8	long-needle litter	0.29	5.8	1.4	1.1	--	--	8.3	1800	--	--	0.3	35	8000	--
TL	189	TL9	very high load broadleaf litter	0.33	6.7	3.3	4.2	--	--	14.1	1800	--	--	0.6	35	8000	--
Slash/Blowdown Fuel Models																	
SB	11	FB11	light slash	0.36	1.5	4.5	5.5	--	--	11.5	1500	--	--	1.0	15	8000	--
SB	12	FB12	medium slash	0.43	4.0	14.0	16.5	--	--	34.6	1500	--	--	2.3	20	8000	--
SB	13	FB13	heavy slash	0.46	7.0	23.0	28.1	--	--	58.1	1500	--	--	3.0	25	8000	--
SB	201	SB1	low load activity fuel	0.36	1.5	3.0	11.0	--	--	15.5	2000	--	--	1.0	25	8000	--
SB	202	SB2	moderate load activity or low load blowdown	0.36	4.5	4.3	4.0	--	--	12.8	2000	--	--	1.0	25	8000	--
SB	203	SB3	high load activity fuel or moderate load blowdown	0.38	5.5	2.8	3.0	--	--	11.3	2000	--	--	1.2	25	8000	--
SB	204	SB4	high load blowdown	0.45	5.3	3.5	5.3	--	--	14.0	2000	--	--	2.7	25	8000	--

Figure 33. Timber Litter and Slash-Blowdown Fuel Model Parameter Table

Determine Elevation, Slope, and Aspect

Elevation and Lapse Rate

Though not often the focus of fire behavior assessments, consider whether the weather observation or forecast represent the same elevation (within 1000') that the fire is and will be burning in.

- It may be necessary to adjust RH up if fire is burning at elevations more than 2000 feet above the weather observation location. Assume same dew point and lower temperature based on lapse rate of 3-5 degrees per 1000 ft elevation change.
- Conversely, it may be necessary to adjust RH down if fire is burning at elevations more than 2000 feet below the weather observation location. Assume same dew point and higher temperature based on lapse rate of 3-5 degrees Fahrenheit per 1000 ft elevation change.
- If your weather observation at night is below the inversion boundary, it is probably not possible to use it to estimate fuel moisture in the ***Thermal Belt*** and above.

Slope and Effective Windspeed

Estimates of slope steepness are converted to equivalent windspeeds for fire behavior estimation. This slope equivalent windspeed is combined with observed or forecast windspeed, adjusted for sheltering, into an ***effective windspeed*** for use as the wind input.

Estimate effective windspeed using one of Tables 7, 8, and 9 below for upslope fire spread. It will only help you with adjustments **for upslope spread.**

- It requires you to choose the **fuel model** of interest, the **slope** that you are concerned about (in percent), and the **midflame windspeed** that you have estimated from observation or forecast.
- Generally, only slopes of 30% or more are important here.

Aspect and Fine Fuel Moisture

Solar heating and drying impacts fuels most dramatically and unevenly on steeper terrain. South and southwest aspects are most exposed to the sun's heat during the peak burning period:

- This results in the lowest dead fuel moistures.
- Vegetation and fuels on those slopes will also be more open and more cured than their north and east counterparts.
- Assuming other factors are equal, spread will be fastest on these south and southwest aspects during the peak afternoon burn period.

Slope Estimation

Slope steepness is an important factor in fire behavior estimation. Slope reversals or other "big changes" in slope can dramatically change your fire behavior. You will need to estimate the steepness of the slope. It can be estimated as:

- an eyeball estimate of the terrain or of contour spacing on a map,
- estimated from a leveling app on your smart phone,
- or calculated using the instructions below.

For field analysis, slope estimation can be coarsely categorized into these categories and values.

- Flat or gently rolling terrain, 0% slope
- Moderate slope, 20%
- Steep slope, 40%

Calculate Slope Percent from a Map

1. **Determine Map Scale** from Legend (verify if map is reproduced) or from known distance measurement (Side of a square mile section).
    - You will need a map measurement (in inches) for the known distance of 1 mile (*use one side of a representative land survey section*) in feet (5280/mile). Table Reference for several different map scales found in Map Use Section.
    - Divide 5280 by the number of inches for the 1-mile side of the section. Your **map scale** is represented as the number of feet (ground distance) per 1 inch of map distance.
2. Identify two representative points on either end of a slope on the map and draw a straight line between them. The line or span that connects them will provide the ground distance (run) and the elevation change (rise) for your calculation.
3. **Elevation change (rise), in feet**, is determined by multiplying the contour interval by the number of contour lines between the two endpoints of your line.
4. **Ground distance (run), in feet,** is determined by multiplying the map distance of your line (in inches) by the map scale (in feet/inch) determined in the first step.
5. **Slope Percent** is determined by dividing the Elevation Change (in feet) by the Ground Distance (now in feet) and multiplying by 100.

Slope Arc/Angle vs Percent

Slope (Degrees)	Slope (Percent)
10°	17.6%
20°	36.4%
30°	57.7%
40°	83.9%
45°	100%
50°	119.2%
60°	173.2%
70°	274.7%
80°	567.1%
90°	Not defined

Estimate Dead Fuel Moistures

Michael A. Fosberg and John E. Deeming (1971) documented procedures for estimating 1 and 10-hour Timelag Fuel Moistures. The methodology for 1-hr, along with seasonal adjustment tables, were integrated into Richard Rothermel's (1983) tools and methods for surface fire behavior predictions. 78/88 NFDRS uses this.

Their work has been superseded by Nelson (2000), with a dead fuel moisture model that is now applied variously in both fire danger and spatial fire behavior estimations. However, simple fireline lookup tables are not yet in widespread use. For that reason, this dead fuel moisture estimation process is offered here for use in the field.

Dead Fuel Moisture Size Classes

1-hr: less than ¼" in diameter	**10-hr:** ¼" to 1" in diameter	**100-hr:** 1" to 3" in diameter	**1000-hr:** 3" to 8" in diameter

Daytime Estimation Procedure (Using Fosberg and Deeming)

- Using **Figure 34**, determine Reference Fuel Moisture (RFM). Percentage from intersection of temperature and relative humidity. Record this RFM percentage.
- Select **Figure 36, 37, or 38** to adjust RFM for local conditions by referencing current month.
- Is the fine fuel more than 50% shaded by canopies and/or clouds? If yes, use the bottom **(shaded)** portion of the table. If no, use the top **(exposed)** portion of the table.
- **Determine the appropriate row based on aspect and slope**.
- **Determine the appropriate column based on time of day and elevation** of area of concern when compared to the wx site elevation. Use **(A)bove** if the fire is 1000-2000' above your location, **(B)elow** if the fire is 1000-2000' below you, and **(L)evel** if the fire is within 1000' above or below you.
- Obtain the 1-hr Moisture Content Correction (%) from the intersection of row and column.
- Add the resulting 1-hr Moisture Content Correction (%) to the Reference Fuel Moisture (%).

Nighttime Estimates of 1-hr Fuel Moisture

Published Reference Fuel Moisture and Correction Tables for Nighttime Conditions are not included here. Instead use the daytime correction factors using these steps:

- Estimate Dry Bulb Temperature and RH for the location of interest.
- Use **Figure 34** to estimate the Reference Fuel Moisture.
- Use the appropriate 1-hr Moisture Content Correction Table (**Figure 36, 37, or 38**) based on the month of the year.
- Obtain the correction for 0800, shaded conditions, and appropriate aspect from that table and add it to the Reference Fuel Moisture to estimate 1-hr moisture content for nighttime conditions.

10-hr and 100-hr Fuel Moisture Estimates

Generally, 10-hr and 100-hr fuel moistures do not have a large influence on surface fire behavior estimation using the Rothermel model. For quick estimates:

- 10-hr fuel moisture is estimated by adding 1% (W. US) or 2% (E. US) to the 1-hr estimate.
- 100-hr fuel moisture is estimated by adding 2% (W. US) or 4% (E. US) to the 1-hr estimate.

Figure 34. Reference Fuel Moisture (in %).

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

Figure 35. Elevation of the fire compared to the position of the weather observation or applying the forecast.

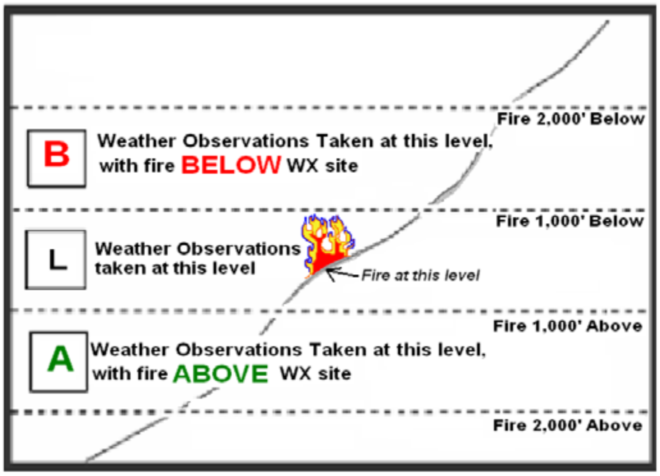


Figure 36. 1-hr Fuel Moisture Corrections (in %); May-June-July.

Unshaded – Less than 50% shading of surface fuels

Aspect	Slope	0800-0959			1000-1159			1200-1359			1400-1559			1600-1759			1800-1959		
		B	L	A	B	L	A	B	L	A	B	L	A	B	L	A	B	L	A
N	0-30	2	3	4	1	1	1	0	0	1	0	0	1	1	1	1	2	3	4
	31%	3	4	4	1	2	2	1	1	2	1	1	2	1	2	2	3	4	4
E	0-30	2	2	3	1	1	1	0	0	1	0	0	1	1	1	2	3	4	4
	31%	1	2	2	0	0	1	0	0	1	1	1	2	2	3	4	4	5	6
S	0-30	2	3	3	1	1	1	0	0	1	0	0	1	1	1	1	2	3	3
	31%	2	3	3	1	1	2	0	1	1	0	1	1	1	1	2	2	3	3
W	0-30	2	3	4	1	1	2	0	0	1	0	0	1	0	1	1	2	3	3
	31%	4	5	6	2	3	4	1	1	2	0	0	1	0	0	1	1	2	2
Shaded – 50 % or more shading of surface fuels due to canopy and/or cloud cover																			
N	All	4	5*	5	3	4	5	3	3	4	3	3	4	3	4	5	4	5	5
E	All	4	4*	5	3	4	5	3	3	4	3	4	4	3	4	5	4	5	6
S	All	4	4*	5	3	4	5	3	3	4	3	3	4	3	4	5	4	5	5
W	All	4	5*	6	3	4	5	3	3	4	3	3	4	3	4	5	4	4	5

B = Area of concern is 1000'to 2000'below the weather site location
L = Area of concern is within 1000'of the weather site location
A = Area of concern is 1000'to 2000'above the weather site location

Figure 37. 1-hr Fuel Moisture Corrections (in %); Feb-Mar-Apr and Aug-Sept-Oct.

Unshaded – Less than 50% shading of surface fuels																			
Aspect	Slope	0800-0959			1000-1159			1200-1359			1400-1559			1600-1759			1800-1959		
		B	L	A	B	L	A	B	L	A	B	L	A	B	L	A	B	L	A
N	0-30	3	4	5	1	2	3	1	1	2	1	1	2	1	2	3	3	4	5
	31%	3	4	5	3	3	4	2	3	4	2	3	4	3	3	4	3	4	5
E	0-30	3	4	5	1	2	3	1	1	1	1	1	2	1	2	4	3	4	5
	31%	3	3	4	1	1	1	1	1	1	1	2	3	3	4	5	4	5	6
S	0-30	3	4	5	1	2	2	1	1	1	1	1	1	1	2	3	3	4	5
	31%	3	4	5	1	2	2	0	1	1	0	1	1	1	2	2	3	4	5
W	0-30	3	4	5	1	2	3	1	1	1	1	1	1	1	2	3	3	4	5
	31%	4	5	6	3	4	5	1	2	3	1	1	1	1	1	1	3	3	4
Shaded – 50 % or more shading of surface fuels due to canopy and/or cloud cover																			
N	All	4	5*	6	4	5	5	3	4	5	3	4	5	4	5	5	4	5	6
E	All	4	5*	6	3	4	5	3	4	5	3	4	5	4	5	6	4	5	6
S	All	4	5*	6	3	4	5	3	4	5	3	4	5	3	4	5	4	5	6
W	All	4	5*	6	4	5	6	3	4	5	3	4	5	3	4	5	4	5	6

B = Area of concern is 1000'to 2000'below the weather site location
L = Area of concern is within 1000'of the weather site location
A = Area of concern is 1000'to 2000'above the weather site location

Figure 38. 1-hr Fuel Moisture Corrections (in %); Nov-Dec-Jan.

Unshaded – Less than 50% shading of surface fuels																			
Aspect	Slope	0800-0959 (+ night)			1000-1159			1200-1359			1400-1559			1600-1759			1800-1959		
		B	L	A	B	L	A	B	L	A	B	L	A	B	L	A	B	L	A
N	0-30	4	5	6	3	4	5	2	3	4	2	3	4	3	4	5	4	5	6
	31%	4	5	6	4	5	6	4	5	6	4	5	6	4	5	6	4	5	6
E	0-30	4	5	6	3	4	4	2	3	3	2	3	3	3	4	5	4	5	6
	31%	4	5	6	2	3	4	2	2	3	3	4	4	4	5	6	4	5	6
S	0-30	4	5	6	3	4	5	2	3	3	2	2	3	3	4	4	4	5	6
	31%	4	5	6	2	3	3	1	1	2	1	1	2	2	3	3	4	5	6
W	0-30	4	5	6	3	4	5	2	3	3	2	3	3	3	4	4	4	5	6
	31%	4	5	6	4	5	6	3	4	4	2	2	3	2	3	4	4	5	6
Shaded – 50 % or more shading of surface fuels due to canopy and/or cloud cover																			
N	All	4	5*	6	4	5	6	4	5	6	4	5	6	4	5	6	4	5	6
E	All	4	5*	6	4	5	6	4	5	6	4	5	6	4	5	6	4	5	6
S	All	4	5*	6	4	5	6	4	5	6	4	5	6	4	5	6	4	5	6
W	All	4	5*	6	4	5	6	4	5	6	4	5	6	4	5	6	4	5	6

B = Area of concern is 1000'to 2000'below the weather site location
L = Area of concern is within 1000'of the weather site location
A = Area of concern is 1000'to 2000'above the weather site location

Canadian Forest Fire Danger Rating System Grass Fuel Moisture

Wotton (2009) published a new grass moisture model for exposed fully cured grass fuels, to better represent moisture and flammability in cured grasses in Canada. This new model is based on the general structure of the FWI System's Fine Fuel Moisture Code (FFMC) however it includes explicit adjustment for the exposure of the fuel layer to solar radiation and a response time appropriate for fine grass fuels.

Though the full estimation process incorporates precipitation, Figure 39 of *equilibrium moisture content* can be used in situations where the atmospheric moisture influences have remained stable for several hours. Consider it as an alternative estimate.

Figure 39. CFFDRS Cured Grass Fuel Equilibrium Moisture Content (%). Assumes that atmospheric moisture conditions have been relatively stable for last several hours.

CFFDRS Grass Fuel Moisture		Relative Humidity (%)							
Solar Radiation	Temp	10%	20%	30%	40%	50%	60%	80%	100%
Overcast Or Shaded	41°F	10	13	16	17	19	21	25	38
	50°F	9	12	14	16	17	19	23	37
	59°F	8	11	13	15	16	17	23	37
	68°F	7	10	12	13	15	17	21	34
	77°F	6	8	10	12	14	15	20	32
	86°F	5	7	9	11	12	14	19	32
Broken Clouds and/or Shading > 50% of sky	41°F	7	10	12	14	15	16	19	21
	50°F	6	9	11	13	14	15	17	20
	59°F	6	8	10	11	13	14	16	19
	68°F	5	7	9	10	12	13	15	17
	77°F	4	6	8	9	10	11	14	17
	86°F	3	5	6	8	9	10	13	16
Scattered Clouds and/or Shading < 50% of sky	41°F	5	8	10	11	12	13	15	17
	50°F	5	7	9	10	11	12	14	15
	59°F	4	6	7	9	10	11	13	14
	68°F	4	5	6	8	9	10	11	13
	77°F	3	4	5	6	7	8	10	12
	86°F	2	3	4	5	6	7	9	11
Clear Skies And Unshaded Fuelbed	41°F	4	6	7	8	9	10	12	13
	50°F	3	5	6	7	8	9	11	12
	59°F	3	4	5	6	7	8	9	11
	68°F	3	4	4	5	6	7	8	10
	77°F	2	3	4	4	5	6	7	9
	86°F	2	2	3	3	4	5	6	7

Estimate Live Fuel Moistures

Live fuel moistures differ for herbaceous fuels (primarily grasses) and woody fuels (shrubs and trees). Use this table to set live fuel moisture estimates and to interpret current status of live fuels in the field.

Live Moisture Content(%)	Herbaceous/Dynamic	Woody/Foliar/Original 13
>150 to 300%	Maturing foliage still developing. Fresh foliage fully expanded and vigorously growing, early in growing cycle	
>120 to 150%	*Mature foliage, new growth complete and comparable to older perennial foliage. Shrubs and grasses resist spread.*	
>100 to 120%	**Mature foliage, new growth complete and comparable to older perennial foliage. Flammable shrubs should burn, grasses resist spread**	
>80 to 100%	**Grasses become less resistant to spread, avoid 90 to 100% as inputs**	**Anticipate flammable shrubs burning aggressively.**
>50 to 80%	**Near dormancy, coloration starting, leaves may have dropped from stems on shrubs, live fuels now contributing to fire intensity**	
>30 to 50%	**Mostly to completely cured, treat as dead fuels**	**Dormant, leafless deciduous shrubs, increased dead fuel loads**

Figure 40. Live Fuel Moisture Content Levels

Herbaceous Fuel Moisture

The newer Standard Fuel Models (Scott and Burgan, 2005) include a number of grass (9), grass-shrub (4), shrub (2), and timber-understory (2) models that are influenced by herbaceous fuel moisture.

- In the first graph (Figure 41), between 30% and 120%, herbaceous fuel moisture transfers fractional live fuel loads to dead and uses the lower dead fuel moisture for that load. Herbaceous fuel moisture above 120% usually limits fire spread in dynamic fuels.
- The second graph (Figure 42), points out the dramatic drop in spread rate that is noted when herbaceous fuel moisture input is just below 100%. Be careful to avoid small increments between 90% and 100% for those "dynamic" fuel models.

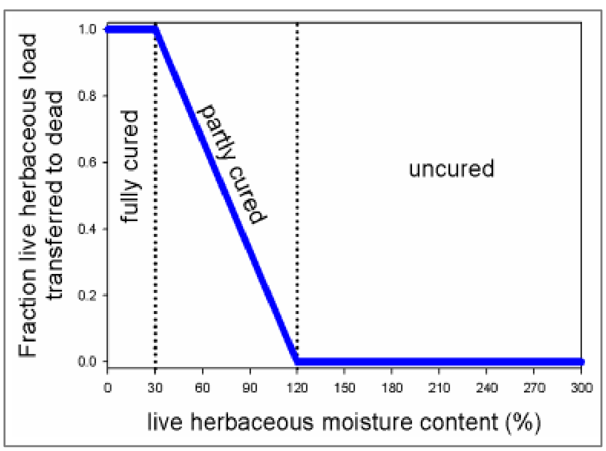


Figure 41. Herbaceous fuel load transfer

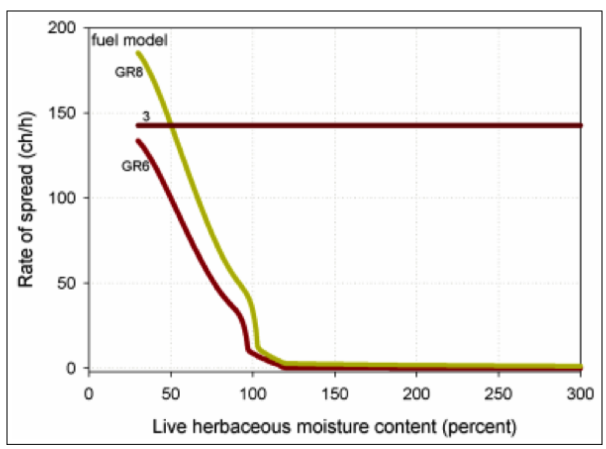
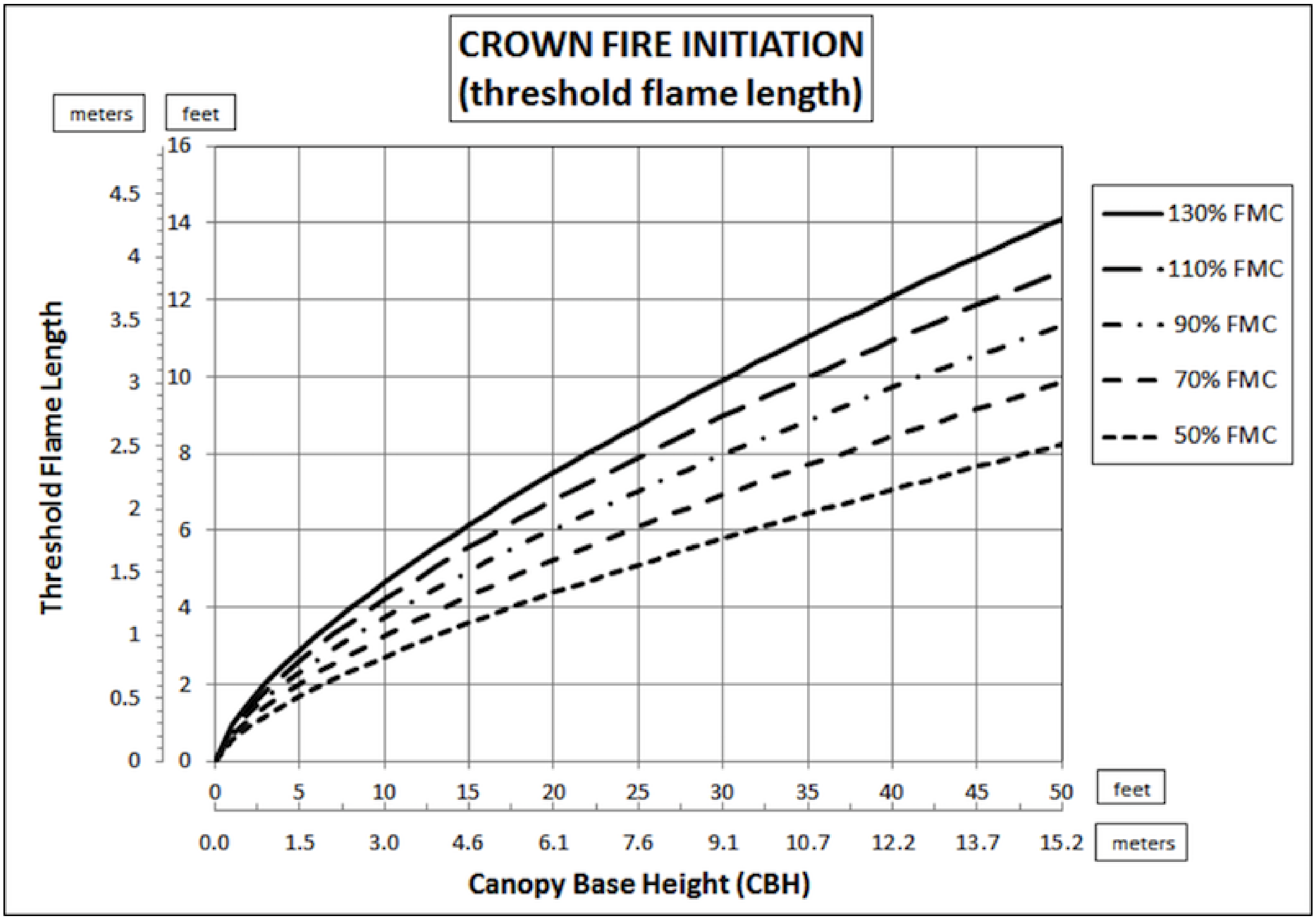


Figure 42. Effect of herbaceous fuel load transfer.

Woody Fuel Moisture and Foliar Moisture Content

Moisture content estimates of needles, leaves and live stems of woody shrubs and trees provide two important inputs for estimation of fire behavior when grass-shrub, shrub, and timber-understory fuels are used. These live fuels, when not transitioning between dormant and growing seasons, resist day to day changes much better than herbaceous fuels.

Figure 43. Threshold (minimum) flame length for crown fire initiation, based on canopy base height, surface flame length from a spreading wildfire, and foliar moisture content. Graphic based on work by Charles Van Wagner in 1977.



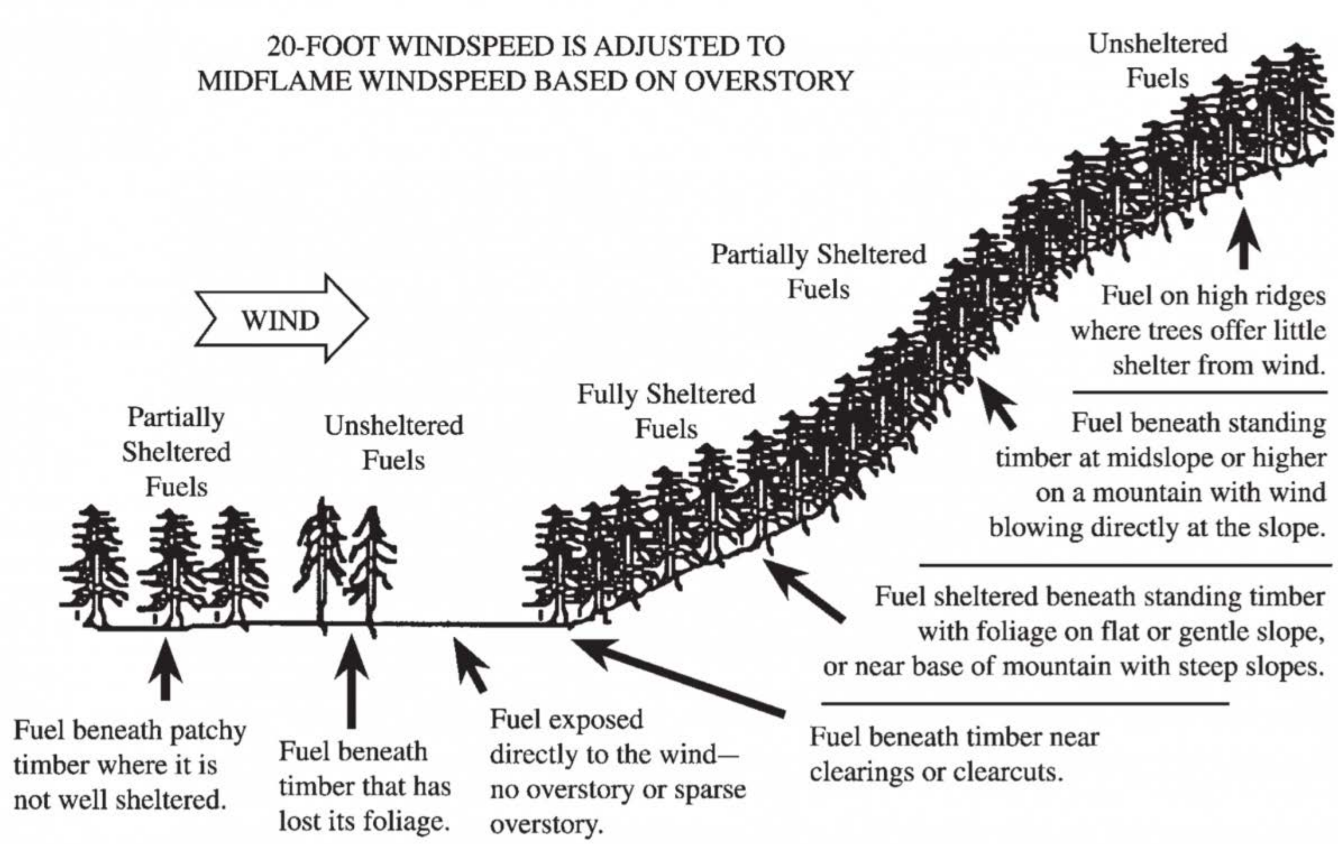
As with herbaceous fuel moisture, woody fuels with moistures above 120% reduce fire spread estimates where understory trees and shrubs are a significant part of the surface fuels. Mature needle moistures will rarely be much above that. Higher woody fuel moistures are generally only found in deciduous trees and shrubs, shortly after full greenup.

Reference fuel moisture sampling estimates for woody fuel moistures in the area of interest. The *National Fuel Moisture Database* (http://wfas.net/index.php/national-fuel-moisture-database-moisture-drought-103) may provide insight for seasonal trends and current conditions of specific vegetation types.

Midflame Wind Speed

Once estimates of general, local, and critical winds are determined and adapted to a 20 ft surface windspeed (either in the forecast, from a WindNinja analysis or from the surface windspeed worksheet in Figure 13 based on terrain and other local factors), adjustment of 20 ft windspeed to midflame windspeed depends on canopy sheltering and surface fuel bed depth. Note how the effect of sheltering varies based on fires position in terrain.

Figure 44. Wind Adjustment Factor (WAF) criteria.



- All Canopy covers less than 20% and all Crown Ratios less than 0.2 are considered unsheltered. Wind Adjustment Factor (WAF) for unsheltered fuel is a function of fuel bed depth only.
- WAF for sheltered fuels is based on a combination of Canopy Cover, Canopy Height, and Average Crown Ratio for the site. As combinations of these factors increase, WAF becomes partially sheltered, then fully sheltered.

Unsheltered Fuels

- Openings on level ground.
- On high ridges where trees offer little shelter from wind.
- Leafless canopy.
- Surface with average Crown Ratio less than 0.2 (crowns less than 20% of tree height) and Canopy Cover less than 20%.

Wind Adj. Factor (WAF)	Fuel Models	Bed Depth
0.5	Grass (gr7, gr8, gr9) Shrub (FM4, sh4, sh5, sh7, sh8, sh9) Slash (13, sb4)	More than 2.7 feet
0.4	Grass & Grass-Shrub (FM1, FM2, FM3, gr2, gr3, gr4, gr5, gr6, gs1, gs2, gs3, gs4) Shrub (FM5, FM6, FM7, sh1, sh2, sh3, sh6) Timber-Understory (FM10, tu2, tu3) Slash (FM11, FM12, sb1, sb2, sb3	0.9 to 2.7 feet
0.3	All Timber Litter Fuels (FM8, FM9, tl1 thru tl9) gr1, tu1, tu4, tu5	Less than 0.9 foot

Partially Sheltered Fuels

- Patchy timber.
- Beneath canopy at midslope or higher with wind blowing directly at the slope.

Wind Adj. Factor (WAF)	Fuel Models	Bed Depth
0.3	All Fuel Models	Any

Fully Sheltered Fuels

- Under standing timber on flat or gentle slopes.
- Under standing timber near the base of the mountain with steep slopes above.

Wind Adj. Factor (WAF)	Fuel Models	Bed Depth
0.2	Open Canopy	Any
0.1	Dense Canopy	Any

Fire Behavior Lookup Tables

Follow this process outline to use the following Fire Behavior Lookup Tables to estimate expected fire behavior.

Determine Effective Wind Speed

Effective wind speed is the way that fire behavior calculations incorporate slope steepness and its effect on spread and intensity.

In many cases, when the fireground is flat or gently rolling and slope can be considered 0%, Effective Wind Speed is simply the midflame wind speed estimate.

If slope is 10% or more, use the Effective Wind Speed tables below to determine the new wind speed for fire behavior estimates.

- On the next page Select Table 4, 5, or 6, referencing the **fuel model**(s) identified for the situation.
- Use the **midflame wind speed** and **slope %** estimated earlier.
- Estimate **Effective Windspeed** from the selected table.
- use this enhanced **Effective Windspeed** with Fire Behavior Tables 10-22 to estimate fire spread rate and flame length, fire size, fire shape, and fire perimeter estimation.
- Color codes in the Effective Windspeed Table can be interpreted as well.

Crown fire anticipated for:	**Sparse Stands**	**Open Stands**	Closed Stands

Estimate Rate of Spread and Flame Length

- Select the appropriate fire behavior table (Tables 10-22) for the **fuel model**(s) identified in the following pages.
- Using the **effective wind speed** and **1-hr fuel moisture** as inputs, find the intersecting cell and read the estimates in the SPREAD and FLAME sections on the page.
- If the page you selected includes **live fuel moistures** and ranges of outputs in individual cells, 80% live fuel moisture represents significantly cured and 120% live fuel moisture as mature foliage that is still slowing fire spread somewhat.

Interpret the results

Color/font distinctions in the fire behavior lookup tables are there to aid in interpretation. Review the section on anticipating and interpreting expected fire behavior to aid in the assessment.

Figure 45. Fire behavior classes.

Low	*Moderate*	**High**	**Very High**	**Extreme**

Crown fire anticipated for:	**Sparse Stands**	**Open Stands**	Closed Stands

Table 4. Effective Windspeed (EWS), in mph. Fuel Models 1, 2, 9.

	Slope Steepness									
MFWS	**10%**	**20%**	**30%**	**40%**	**50%**	**60%**	**70%**	**80%**	**90%**	**100%**
0	1	1	2	3	3	4	5	5	6	7
2	2	2	3	3	4	4	5	6	6	7
4	4	4	5	5	5	6	6	7	7	8
6	6	6	6	7	7	7	8	8	9	9
8	8	8	8	8	9	9	9	9	10	11
10	10	10	10	10	11	11	11	12	12	13
12	12	12	12	12	13	13	13	14	14	14
14	14	14	14	14	15	15	15	15	16	16
16	16	16	16	16	16	17	17	17	18	18
18	18	18	18	18	18	19	19	19	19	20
20	20	20	20	20	20	21	21	21	21	22

Table 5. Effective Windspeed (EWS), in mph. Fuel models 3, 4, 5, 6, 7, 8, 10.

	Slope Steepness									
MFWS	**10%**	**20%**	**30%**	**40%**	**50%**	**60%**	**70%**	**80%**	**90%**	**100%**
0	0	1	1	2	3	3	4	5	6	7
2	2	2	3	3	4	5	5	6	7	8
4	4	4	5	5	5	6	7	8	8	9
6	6	6	7	7	7	8	9	9	10	11
8	8	8	8	9	9	10	10	11	12	12
10	10	10	10	11	11	11	12	13	13	14
12	12	12	12	13	13	13	14	15	15	16
14	14	14	14	15	15	15	16	16	17	18
16	16	16	16	17	17	17	18	18	19	20
18	18	18	18	19	19	19	20	20	21	21
20	20	20	20	21	21	21	21	22	23	23

Table 6. Effective Windspeed (EWS), in mph. Fuel models 11, 12, 13.

	Slope Steepness									
MFWS	**10%**	**20%**	**30%**	**40%**	**50%**	**60%**	**70%**	**80%**	**90%**	**100%**
0	0	1	1	2	3	4	5	6	7	9
2	2	2	3	3	4	5	6	7	9	10
4	4	4	5	5	6	7	8	9	10	12
6	6	6	7	7	8	9	10	11	12	14
8	8	8	9	9	10	11	12	13	14	15
10	10	10	11	11	12	13	14	15	16	17
12	12	12	13	13	14	15	16	17	18	19
14	14	14	15	15	16	17	18	19	20	21
16	16	16	17	17	18	19	19	21	22	23
18	18	18	19	19	20	20	21	22	24	25
20	20	20	21	21	22	22	23	24	25	26

Fuel Model 1, Short Grass (1 foot bed depth)

SPREAD Ch/hr		Effective Windspeed(EWS), mph *Use 20ft/FCST wind only if EWS = MFWS and assumes unsheltered wind adjustment (0.4)												
*20ft/FCST		NWNS-0	Back - ½	Flank - 1	5	10	15	20	25	30	35	40	45	50
EWS					2	4	6	8	10	12	14	16	18	20
1-hr Moisture, %	1	8	9	14	32	111	247	442	697	1014	1145	1145	1145	1145
	2	6	7	11	26	90	201	360	568	666	666	666	666	666
	3	5	6	9	22	77	172	307	446	446	446	446	446	446
	4	5	6	8	20	69	154	275	345	345	345	345	345	345
	5	4	5	8	19	64	143	255	297	297	297	297	297	297
	6	4	5	7	18	61	135	242	270	270	270	270	270	270
	7	4	5	7	17	57	127	228	242	242	242	242	242	242
	8	4	4	6	15	52	117	199	199	199	199	199	199	199
	9	3	4	6	13	45	101	136	136	136	136	136	136	136
	10	2	3	4	10	35	65	65	65	65	65	65	65	65
	11	1	2	2	6	13	13	13	13	13	13	13	13	13
	12	0	0	0	0	0	0	0	0	0	0	0	0	0

Low	*Moderate*	<u>High</u>	**Very High**	**Extreme**

FLAME Feet		Effective Windspeed(EWS), mph *Use 20ft/FCST wind only if EWS = MFWS and assumes unsheltered wind adjustment (0.4)												
*20ft/FCST		NWNS-0	Back - ½	Flank - 1	5	10	15	20	25	30	35	40	45	50
EWS					2	4	6	8	10	12	14	16	18	20
1-hr Moisture, %	1	2	2	2	3	6	9	11	14	17	18	18	18	18
	2	1	2	2	3	5	7	10	12	13	13	13	13	13
	3	1	1	2	3	4	6	8	10	10	10	10	10	10
	4	1	1	2	2	4	6	8	9	9	9	9	9	9
	5	1	1	2	2	4	6	7	8	8	8	8	8	8
	6	1	1	1	2	4	5	7	7	7	7	7	7	7
	7	1	1	1	2	4	5	7	7	7	7	7	7	7
	8	1	1	1	2	3	5	6	6	6	6	6	6	6
	9	1	1	1	2	3	4	5	5	5	5	5	5	5
	10	1	1	1	1	2	3	3	3	3	3	3	3	3
	11	0	1	1	1	1	1	1	1	1	1	1	1	1
	12	0	0	0	0	0	0	0	0	0	0	0	0	0

Fuel Model 2, Timber Grass and Understory (1 foot bed depth)

SPREAD Ch/hr		Effective Windspeed(EWS), mph *Use 20ft/FCST wind only if EWS = MFWS and assumes unsheltered wind adjustment (0.4)												
*FCST/20ft		NWNS-0	Back - ½	Flank - 1	7	13	20	27	33	40	47	53	60	67
EWS					2	4	6	8	10	12	14	16	18	20
1-hr Moisture, %; (Herbaceous moist. 120%-80%)	1	3-4	4-5	6-7	12-14	36-41	71-82	118-136	176-202	245-281	324-371	412-473	511-586	619-710
	3	3	3-4	5	10-11	28-32	56-64	93-106	138-158	192-220	253-290	323-370	400-458	484-555
	5	2-3	3	4-5	8-10	24-27	48-55	79-91	118-135	164-188	217-248	277-316	343-392	415-475
	7	2	3	4	8-9	22-25	44-50	73-83	108-123	150-171	198-226	253-288	313-357	379-432
	9	2	2-3	3-4	7-8	20-23	40-46	66-76	99-113	138-157	182-207	232-264	287-327	348-396
	11	2	2	3	6-7	17-20	34-39	57-65	85-97	118-134	155-177	198-226	245-280	297-339
	13	1	1-2	2	4-5	12-14	24-27	40-45	60-68	83-94	110-124	140-159	173-196	210-238
	15	0	0-1	0-1	0-2	0-4	0-9	0-13	0-13	0-13	0-13	0-13	0-13	0-13
	17	0	0	0	0	0	0	0	0	0	0	0	0	0

Low	Moderate	High	Very High	Extreme

FLAME Ch/hr		Effective Windspeed(EWS), mph *Use 20ft/FCST wind only if EWS = MFWS and assumes unsheltered wind adjustment (0.4)												
*20ft/FCST		NWNS-0	Back - ½	Flank - 1	7	13	20	27	33	40	47	53	60	67
EWS					2	4	6	8	10	12	14	16	18	20
1-hr Moisture, %; (Herbaceous moist. 120%-80%)	1	2-3	3	3-3	5	7-8	10-11	13-14	15-16	18-19	20-22	23-24	25-27	27-29
	3	2	2	3-3	4	6	8-9	10-11	12-13	14-16	16-18	18-20	20-22	22-24
	5	2	2	2-3	3-4	5-6	7-8	9-10	11-12	13-14	15-16	16-18	18-19	20-21
	7	2	2	2	3	5	7	9	10-11	12-13	14-15	15-16	17-18	18-20
	9	2	2	2	3	5	6-7	8-9	10	11-12	13-14	14-16	16-17	17-19
	11	1	2	2	3	4	6	7-8	9	10-11	11-12	13-14	14-15	15-17
	13	1	1	1	2	3	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12
	15	0	<1	<1	0-1	0-1	0-2	0-2	0-2	0-2	0-2	0-2	0-2	0-2
	17	0	0	0	0	0	0	0	0	0	0	0	0	0

Fuel Model 3, Tall Grass (2.5 foot bed depth)

SPREAD Ch/hr — **Effective Windspeed(EWS), mph**

*Use 20ft/FCST wind only if EWS = MFWS and assumes unsheltered wind adjustment (0.4)

*20ft/FCST				5	10	15	20	25	30	35	40	45	50
EWS	**NWNS/0**	**Back - ½**	**Flank - 1**	**2**	**4**	**6**	**8**	**10**	**12**	**14**	**16**	**18**	**20**
1-hr Moisture, %													
1	8	18	32	68	157	261	377	502	636	776	923	1076	1234
3	6	14	25	52	121	201	290	387	490	598	712	829	951
5	5	11	20	42	97	162	234	312	395	482	574	669	767
7	4	9	17	36	82	137	198	264	335	409	486	566	650
9	4	8	15	32	73	122	176	234	296	362	430	501	575
11	3	8	14	29	67	111	161	214	271	331	393	458	526
13	3	7	13	27	62	103	149	198	251	306	364	425	487
15	3	6	12	25	57	95	137	182	231	282	335	391	448
17	3	6	10	22	51	85	122	163	207	252	300	350	401
19	2	5	9	19	43	71	103	137	174	212	253	294	338
21	2	4	7	14	32	53	77	103	130	159	189	194	194
23	1	2	4	8	18	30	43	54	54	54	54	54	54

Low	*Moderate*	High	**Very High**	**Extreme**

FLAME feet — **Effective Windspeed(EWS), mph**

*Use 20ft/FCST wind only if EWS = MFWS and assumes unsheltered wind adjustment (0.4)

*20ft/FCST				5	10	15	20	25	30	35	40	45	50
EWS	**NWNS/0**	**Back - ½**	**Flank - 1**	**2**	**4**	**6**	**8**	**10**	**12**	**14**	**16**	**18**	**20**
1-hr Moisture, %													
1	5	7	9	12	18	23	27	31	35	38	41	44	47
3	4	5	7	10	15	19	22	25	28	31	34	36	38
5	3	5	6	9	13	16	19	22	24	26	28	31	33
7	3	4	5	8	11	14	17	19	21	23	25	27	29
9	3	4	5	7	10	13	15	18	20	21	23	25	27
11	2	4	5	7	10	12	15	17	19	20	22	24	25
13	2	3	5	6	9	12	14	16	18	19	21	23	24
15	2	3	4	6	9	11	13	15	17	19	20	22	23
17	2	3	4	6	8	10	12	14	16	17	19	20	21
19	2	3	4	5	7	9	11	12	14	15	16	17	19
21	1	2	3	4	6	7	8	10	11	12	13	13	13
23	1	1	2	2	3	4	5	6	6	6	6	6	6

Fuel Model 4, Chaparral (6 foot bed depth)

SPREAD Ch/hr — **Effective Windspeed(EWS), mph**

*Use 20ft/FCST wind only if EWS = MFWS and assumes unsheltered wind adjustment (0.5)

1-hr Moisture, %; (Woody moist. 120%-80%)	*20ft/FCST				4	8	12	16	20	24	28	32	36	40
	EWS	NWNS-0	Back - ½	Flank - 1	2	4	6	8	10	12	14	16	18	20
	1	5-6	8-11	13-18	27-37	65-88	111-151	165-224	225-306	290-394	359-489	433-589	511-695	593-807
	3	4-6	7-9	11-16	24-32	56-76	97-132	144-195	196-266	253-343	313-425	378-513	446-605	517-702
	5	4-5	6-8	10-14	21-29	51-69	88-118	130-176	178-239	229-309	284-383	343-462	404-545	469-632
	7	4-5	6-8	10-13	20-27	48-64	83-110	122-163	167-222	215-286	267-355	322-429	380-506	440-587
	9	3-4	6-7	9-12	19-25	46-61	79-104	118-155	160-211	206-271	256-337	309-406	365-479	423-556
	11	3-4	5-7	9-12	19-24	44-58	76-100	113-148	154-201	199-259	247-322	298-388	351-458	408-531
	13	3-4	5-7	8-11	17-23	41-55	71-95	105-140	143-191	184-246	229-306	276-369	325-435	377-504
	15	2-4	4-6	6-10	13-21	30-50	52-87	77-129	105-175	135-226	167-281	202-338	238-399	276-463
	17	1-3	2-5	3-8	6-16	14-38	25-65	37-96	50-130	65-168	80-209	97-252	114-297	133-344
	19	1	1	2	3-4	8-10	14-17	20-25	27-34	35-44	44-55	53-66	62-78	72-90

Low	*Moderate*	**High**	**Very High**	**Extreme**

FLAME feet — **Effective Windspeed(EWS), mph**

*Use 20ft/FCST wind only if EWS = MFWS and assumes unsheltered wind adjustment (0.5)

1-hr Moisture, %; (Woody moist. 120%-80%)	20ft/FCST				4	8	12	16	20	24	28	32	36	40
	EWS	NWNS-0	Back - ½	Flank - 1	2	4	6	8	10	12	14	16	18	20
	1	6-7	8-9	10-11	13-16	20-24	26-30	31-36	36-42	40-47	44-52	48-57	52-61	56-66
	3	5-6	7-8	9-10	12-14	18-21	23-27	27-32	32-37	36-42	39-46	43-50	46-54	49-58
	5	5-6	6-7	8-9	11-13	16-19	21-25	25-30	29-34	33-38	36-42	39-46	43-50	46-53
	7	5	6-7	8-9	10-12	16-18	20-23	24-28	28-32	31-36	34-40	37-43	40-47	43-50
	9	5	6-7	7-8	10-12	15-17	19-22	23-27	27-31	30-35	33-38	36-42	39-45	42-48
	11	4-5	6-6	7-8	10-11	15-17	19-22	23-26	26-30	29-34	32-37	35-40	38-44	41-47
	13	4-5	5-6	7-8	9-11	14-16	18-21	21-25	24-29	28-32	30-36	33-39	36-42	38-45
	15	3-5	4-6	5-7	7-10	10-15	13-19	16-23	18-27	21-30	23-33	25-36	27-39	29-42
	17	2-3	2-3	3-6	4-8	5-12	7-15	8-18	9-21	11-23	12-25	13-28	14-30	15-32
	19	1	1	2	2	3	4	5	5-6	6-7	7	7-8	8-9	9

Fuel Model 5, Brush (2 foot bed depth)

SPREAD Ch/hr		Effective Windspeed(EWS), mph *Use 20ft/FCST wind only if EWS = MFWS and assumes unsheltered wind adjustment (0.4)												
*20ft/FCST		NWNS-0	Back - ½	Flank - 1	5	10	15	20	25	30	35	40	45	50
EWS					2	4	6	8	10	12	14	16	18	20
1-hr Moisture, %; (Woody moist. 120%-80%)	1	1–2	2-3	4-6	8-12	20-28	34-48	50-70	67-95	86-122	107-151	128-181	151-214	175-247
	3	1-2	2-3	3-5	7-11	17-25	28-43	42-63	57-86	73-110	90-136	109-164	128-193	148-223
	5	1	2-3	3-5	5-10	13-23	22-40	32-59	44-79	56-102	70-126	84-152	98-178	114-206
	7	<1	1-2	1-4	3-9	6-22	10-37	15-54	20-74	22-95	22-117	22-141	22-165	22-191
	9	<1	1-2	1-4	2-8	6-18	10-32	14-47	19-63	20-81	20-100	20-120	20-142	20-164
	11	<1	1	1-2	2-4	5-9	9-16	14-23	19-32	19-41	19-46	19-46	19-46	19-46
	13	<1	1	1	2-3	5-7	9-12	13-17	17-22	17-22	17-22	17-22	17-22	17-22
	15	<1	<1	1	2-3	5-6	8-10	11-15	12-16	12-16	12-16	12-16	12-16	12-16
	17	<1	<1	<1	1-2	3-5	6-8	7-9	7-9	7-9	7-9	7-9	7-9	7-9
	19	<1	<1	<1	1	1-2	1-2	1-2	1-2	1-2	1-2	1-2	1-2	1-2

Low	*Moderate*	**High**	**Very High**	**Extreme**

FLAME feet		Effective Windspeed(EWS), mph *Use 20ft/FCST wind only if EWS = MFWS and assumes unsheltered wind adjustment (0.4)												
*20ft/FCST		NWNS-0	Back - ½	Flank - 1	5	10	15	20	25	30	35	40	45	50
EWS					2	4	6	8	10	12	14	16	18	20
1-hr Moisture, %; (Woody moist. 120%-80%)	1	2	2-3	3	4-5	6-7	8-9	9-11	11-13	12-14	13-16	14-17	15-19	17-20
	3	1-2	2	3	4	5-7	7-9	8-10	9-12	10-13	11-14	12-16	13-17	14-18
	5	1-2	2	2-3	3-4	4-6	5-8	6-10	7-11	8-12	9-14	10-15	10-16	11-17
	7	1-2	1-2	1-3	1-4	2-6	3-7	3-9	4-10	4-12	4-13	4-14	4-15	4-16
	9	1	1-2	1-2	1-3	2-5	3-7	3-8	3-9	3-10	3-11	3-12	3-13	3-14
	11	1	1	1	1-2	2-3	2-4	3-4	3-5	3-5	3-6	3-6	3-6	3-6
	13	1	1	1	1	2	2-3	3	3-4	3-4	3-4	3-4	3-4	3-4
	15	0-1	1	1	1	2	2	2-3	3	3	3	3	3	3
	17	<1	0-1	0-1	1	1	2	2	2	2	2	2	2	2
	19	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1

Fuel Model 6, Dormant Brush/Hardwood Slash (2.5 foot bed depth)

SPREAD Ch/hr

Effective Windspeed(EWS), mph

*Use 20ft/FCST wind only if EWS = MFWS and assumes unsheltered wind adjustment (0.4)

*20ft/FCST	NWNS/0	Back - ½	Flank - 1	5	10	15	20	25	30	35	40	45	50
EWS				2	4	6	8	10	12	14	16	18	20
1-hr Moisture, % 1	3	5	9	19	42	71	103	138	175	215	257	300	345
3	2	4	7	15	34	56	82	110	139	171	204	239	274
5	2	4	6	12	28	47	68	91	115	141	168	197	226
7	2	3	5	10	24	40	58	78	99	121	145	169	181
9	1	3	5	9	21	36	52	69	88	108	129	150	150
11	1	2	4	8	19	33	47	63	81	99	118	132	132
13	1	2	4	8	18	30	44	59	75	92	109	120	120
15	1	2	4	7	17	28	41	55	70	85	102	109	109
17	1	2	3	7	15	26	38	50	64	78	93	96	96
19	1	2	3	6	14	23	33	45	57	70	78	78	78
21	1	1	3	5	12	19	28	38	48	55	55	55	55
23	1	1	2	4	9	15	21	29	31	31	31	31	31
25	< 1	1	1	2	5	9	10	10	10	10	10	10	10

Low	*Moderate*	**High**	**Very High**	**Extreme**

FLAME feet

Effective Windspeed(EWS), mph

*Use 20ft/FCST wind only if EWS = MFWS and assumes unsheltered wind adjustment (0.4)

*20ft/FCST	NWNS/0	Back - ½	Flank - 1	5	10	15	20	25	30	35	40	45	50
EWS				2	4	6	8	10	12	14	16	18	20
1-hr Moisture, % 1	2	3	4	5	8	10	12	14	15	17	18	19	21
3	2	2	3	5	7	8	10	11	13	14	15	16	17
5	2	2	3	4	6	7	9	10	11	12	13	14	15
7	2	2	2	4	5	7	8	9	10	11	12	13	13
9	1	2	2	3	5	6	7	8	9	10	11	12	12
11	1	2	2	3	5	6	7	8	9	10	10	11	11
13	1	2	2	3	4	6	7	7	8	9	10	10	10
15	1	2	2	3	4	5	6	7	8	9	10	10	10
17	1	2	2	3	4	5	6	7	8	8	9	9	9
19	1	1	2	3	4	5	5	6	7	8	8	8	8
21	1	1	2	2	3	4	5	5	6	6	6	6	6
23	1	1	1	2	3	3	4	4	4	4	4	4	4
25	0	1	1	1	2	2	2	2	2	2	2	2	2

Fuel Model 7, Southern Rough (2.5 foot bed depth)

SPREAD Ch/hr		Effective Windspeed(EWS), mph *Use 20ft/FCST wind only if EWS = MFWS and assumes unsheltered wind adjustment (0.4)												
*20ft/FCST		NWNS-0	Back - ½	Flank - 1	5	10	15	20	25	30	35	40	45	50
EWS					2	4	6	8	10	12	14	16	18	20
1-hr Moisture, %; (Woody moist. 120%-80%)	3	1-2	3	5-6	10-12	23-28	38-47	56-68	74-91	94-115	116-141	138-168	161-197	185-226
	6	1	2-3	4-5	9-10	20-24	33-40	48-58	64-78	81-99	100-121	119-144	139-169	160-194
	9	1	2-3	4-5	8-9	17-21	29-35	42-51	57-68	72-87	88-106	105-127	123-148	141-170
	12	1	2	3-4	7-8	16-19	26-32	38-46	51-62	65-78	80-96	95-114	112-134	119-147
	15	1	2	3-4	6-8	15-17	25-29	36-42	48-57	60-72	74-88	88-105	103-123	105-129
	18	1	2	3	6-7	14-16	23-27	33-40	45-53	57-68	70-83	83-99	96-115	96-117
	21	1	2	3	6-7	13-15	22-26	32-37	42-50	54-64	66-78	79-93	89-108	89-108
	24	1	2	3	5-6	12-15	21-24	30-35	40-47	51-60	63-74	75-88	82-100	82-100
	27	1	1-2	2-3	5-6	12-14	19-23	28-33	38-44	48-56	59-69	70-83	74-91	74-91

Low	*Moderate*	**High**	**Very High**	**Extreme**

FLAME feet		Effective Windspeed(EWS), mph *Use 20ft/FCST wind only if EWS = MFWS and assumes unsheltered wind adjustment (0.4)												
*20ft/FCST		NWNS-0	Back - ½	Flank - 1	5	10	15	20	25	30	35	40	45	50
EWS					2	4	6	8	10	12	14	16	18	20
1-hr Moisture, %; (Woody moist. 120%-80%)	3	2	2	3	4	6	7-8	8-9	10-11	11-12	12-13	13-14	14-15	15-16
	6	1-2	2	2-3	3-4	5-6	6-7	8	9-10	10-11	11-12	11-13	12-14	13-14
	9	1	2	2-3	3	5	6	7-8	8-9	9-10	10-11	10-12	11-12	12-13
	12	1	2	2	3	4-5	5-6	6-7	7-8	8-9	9-10	10-11	10-11	11-12
	15	1	2	2	3	4	5-6	6-7	7-8	8-9	9	9-10	10-11	10-11
	18	1	2	2	3	4	5	6	7	7-8	8-9	9-10	9-10	9-11
	21	1	1-2	2	3	4	5	6	6-7	7-8	8-9	9	9-10	9-10
	24	1	1-2	2	2-3	4	5	5-6	6-7	7-8	8	8-9	9-10	9-10
	27	1	1	2	2-3	3-4	4-5	5-6	6-7	7	7-8	8-9	8-9	8-9

Fuel Model 8, Closed Timber Litter (0.2 foot bed depth)

SPREAD Ch/hr		Effective Windspeed(EWS), mph *Use 20ft/FCST wind only if EWS = MFWS and assumes sheltered wind adjustment (0.2)												
*20ft/FCST		NWNS/0	Back - ½	Flank - 1	10	20	30	40	50	60	70	80	90	100
EWS					2	4	6	8	10	12	14	16	18	20
1-hr Moisture, %	1	0	1	1	1	3	4	*6*	*9*	*11*	*13*	*13*	*13*	*13*
	3	0	<1	1	1	2	3	*5*	*7*	*8*	*8*	*8*	*8*	*8*
	5	0	<1	<1	1	2	3	4	*6*	*6*	*6*	*6*	*6*	*6*
	7	0	<1	<1	1	1	2	4	4	4	4	4	4	4
	9	0	0	<1	1	1	2	3	3	3	3	3	3	3
	11	0	0	<1	1	1	2	3	3	3	3	3	3	3
	13	0	0	<1	0	1	2	3	3	3	3	3	3	3
	15	0	0	<1	0	1	2	2	2	2	2	2	2	2
	17	0	0	0	0	1	2	2	2	2	2	2	2	2
	19	0	0	0	0	1	1	2	2	2	2	2	2	2
	21	0	0	0	0	1	1	2	2	2	2	2	2	2

Low	*Moderate*	**High**	**Very High**	**Extreme**

FLAME feet		Effective Windspeed(EWS), mph *Use 20ft/FCST wind only if EWS = MFWS and assumes sheltered wind adjustment (0.2)												
*20ft/FCST		NWNS/0	Back - ½	Flank - 1	10	20	30	40	50	60	70	80	90	100
EWS					2	4	6	8	10	12	14	16	18	20
1-hr Moisture, %	1	1	1	1	1	1	2	2	2	3	3	3	3	3
	3	1	1	1	1	1	2	2	2	2	2	2	2	2
	5	0	1	1	1	1	1	2	2	2	2	2	2	2
	7	0	<1	1	1	1	1	1	2	2	2	2	2	2
	9	0	<1	1	1	1	1	1	1	1	1	1	1	1
	11	0	<1	<1	1	1	1	1	1	1	1	1	1	1
	13	0	<1	<1	1	1	1	1	1	1	1	1	1	1
	15	0	<1	<1	1	1	1	1	1	1	1	1	1	1
	17	0	<1	<1	0	1	1	1	1	1	1	1	1	1
	19	0	<1	<1	0	1	1	1	1	1	1	1	1	1
	21	0	<1	<1	0	1	1	1	1	1	1	1	1	1

Fuel Model 9, Hardwood Litter (0.2 foot bed depth)

SPREAD Ch/hr		**Effective Windspeed(EWS), mph** *Use 20ft/FCST wind only if EWS = MFWS and assumes prtly shelterd wind adjustment (0.3)												
*FCST/20ft		NWNS-0	Back - ½	Flank - 1	7	13	20	27	33	40	47	53	60	67
EWS					2	4	6	8	10	12	14	16	18	20
1-hr Moisture, %	1	1	2	2	4	11	20	33	47	64	83	104	127	152
	3	1	1	2	3	8	16	25	36	49	64	80	98	118
	5	1	1	2	3	7	13	20	29	40	52	65	79	95
	7	1	1	1	2	6	11	17	25	34	44	55	67	80
	9	1	1	1	2	5	10	15	22	30	39	49	60	71
	11	1	1	1	2	5	9	14	20	27	36	45	54	65
	13	1	1	1	2	4	8	13	19	25	33	41	50	60
	15	1	1	1	2	4	7	12	17	23	30	38	46	56
	17	0	1	1	1	4	7	11	15	21	27	34	42	48
	19	0	1	1	1	3	6	9	13	18	23	29	33	33
	21	0	<1	1	1	2	4	7	10	13	17	17	17	17
	23	0	<1	<1	1	1	2	4	4	4	4	4	4	4

Low	Moderate	High	Very High	Extreme

FLAME feet		**Effective Windspeed(EWS), mph** *Use 20ft/FCST wind only if EWS = MFWS and assumes prtly shelterd wind adjustment (0.3)												
*FCST/20ft		NWNS-0	Back - ½	Flank - 1	7	13	20	27	33	40	47	53	60	67
EWS					2	4	6	8	10	12	14	16	18	20
1-hr Moisture, %	1	2	2	2	3	4	5	6	8	9	10	11	12	13
	3	1	1	2	2	3	4	5	6	7	8	9	10	11
	5	1	1	1	2	3	4	4	5	6	7	8	8	9
	7	1	1	1	2	2	3	4	5	5	6	7	7	8
	9	1	1	1	1	2	3	4	4	5	6	6	7	7
	11	1	1	1	1	2	3	3	4	5	5	6	6	7
	13	1	1	1	1	2	3	3	4	4	5	6	6	7
	15	1	1	1	1	2	3	3	4	4	5	5	6	6
	17	1	1	1	1	2	2	3	3	4	4	5	5	6
	19	1	1	1	1	2	2	3	3	3	4	4	5	5
	21	0	1	1	1	1	2	2	2	3	3	3	3	3
	23	0	<1	<1	0	1	1	1	1	1	1	1	1	1

Fuel Model 10, Timber Litter and Understory (1 foot bed depth)

SPREAD Ch/hr		Effective Windspeed(EWS), mph *Use 20ft/FCST wind only if EWS = MFWS and assumes prtly shelterd wind adjustment (0.3)												
*20ft/FCST		NWNS-0	Back - ½	Flank - 1	7	13	20	27	33	40	47	53	60	67
EWS					2	4	6	8	10	12	14	16	18	20
1-hr Moisture, %; (Woody moist. 120%-80%)	1	1	1-2	2	3-4	8-10	13-17	19-25	25-33	33-43	41-53	49-64	58-76	67-88
	3	1	2	2	3-4	7-9	11-15	16-22	22-29	29-38	35-47	43-56	50-66	59-77
	5	1	1	1-2	3-3	6-8	10-13	15-19	20-26	26-34	32-42	38-50	45-59	52-69
	7	1	1	1-2	2-3	5-7	9-12	13-18	18-24	24-31	29-38	35-46	42-54	48-63
	9	1	1	1-2	2-3	5-7	9-11	13-16	17-22	22-29	27-36	33-43	39-51	45-59
	11	1	1	1-2	2-3	5-6	8-11	12-16	16-21	21-27	26-34	32-41	37-48	43-56
	13	1	1	1-2	2-3	5-6	8-10	12-15	16-20	20-26	25-32	30-39	36-46	41-53
	15	1	1	1	2-3	4-6	8-10	11-14	15-19	19-25	24-31	29-37	34-43	40-50
	17	1	1	1	2	4-5	7-9	11-13	14-18	18-23	23-29	28-34	33-41	38-47
	19	<1	1	1	2	4-5	7-8	10-12	13-16	17-21	21-26	25-32	30-37	35-43
	21	<1	1	1	1-2	3-4	5-7	8-11	11-14	14-19	17-23	21-28	25-33	29-38

Low	*Moderate*	**High**	**Very High**	**Extreme**

FLAME feet		Effective Windspeed(EWS), mph *Use 20ft/FCST wind only if EWS = MFWS and assumes prtly shelterd wind adjustment (0.3)												
*20ft/FCST		NWNS-0	Back - ½	Flank - 1	7	13	20	27	33	40	47	53	60	67
EWS					2	4	6	8	10	12	14	16	18	20
1-hr Moisture, %; (Woody moist. 120%-80%)	1	2	2-3	3	4	5-6	7-8	8-9	9-11	11-12	12-13	13-15	14-16	15-17
	3	2	2	3	3-4	5-6	6-7	7-8	8-10	9-11	10-12	11-13	12-14	13-15
	5	2	2	2-3	3-4	4-5	6	7-8	8-9	9-10	9-11	10-12	11-13	12-14
	7	2	2	2-3	3	4-5	5-6	6-7	7-8	8-9	9-10	10-11	10-12	11-13
	9	1-2	2	2	3	4	5-6	6-7	7-8	8-9	8-10	9-11	10-11	11-12
	11	1-2	2	2	3	4	5-6	6-7	7-8	7-8	8-9	9-10	10-11	10-12
	13	1-2	2	2	3	4	5	6	6-7	7-8	8-9	9-10	9-11	10-11
	15	1-2	2	2	2-3	4	5	5-6	6-7	7-8	8-9	8-10	9-10	10-11
	17	1	2	2	2-3	3-4	4-5	5-6	6-7	7-8	7-8	8-9	9-10	9-10
	19	1	1-2	2	2	3-4	4-5	5	6	6-7	7-8	8	8-9	9-10
	21	1	1	1-2	2	3	3-4	4-5	5-6	5-6	6-7	6-8	7-8	7-9

Fuel Model 11, Light Logging Slash (1 foot bed depth)

SPREAD Ch/hr		Effective Windspeed(EWS), mph *Use 20ft/FCST wind only if EWS = MFWS and assumes unsheltered wind adjustment (0.4)												
*20ft/FCST		NWNS/0	Back - ½	Flank - 1	5	10	15	20	25	30	35	40	45	50
EWS					2	4	6	8	10	12	14	16	18	20
1-hr Moisture, %	1	1	2	2	4	*8*	*12*	*16*	**20**	**25**	**29**	**34**	**39**	**43**
	3	1	1	2	3	*6*	*9*	*13*	*16*	**20**	**23**	**27**	**31**	**35**
	5	1	1	2	3	*5*	*8*	*11*	*14*	*17*	**20**	**23**	**26**	**30**
	7	1	1	1	2	*5*	*7*	*10*	*12*	*15*	*18*	**21**	**24**	**27**
	9	<1	1	1	2	4	*7*	*9*	*11*	*14*	*17*	*19*	**22**	**25**
	11	<1	1	1	2	4	*6*	*8*	*10*	*12*	*15*	*17*	*19*	**22**
	13	<1	1	1	2	3	*5*	*6*	*8*	*10*	*12*	*14*	*16*	*16*
	15	<1	<1	1	1	2	3	4	*5*	*6*	*7*	*7*	*7*	*7*

Low	*Moderate*	**High**	Very High	Extreme

FLAME feet		Effective Windspeed(EWS), mph *Use 20ft/FCST wind only if EWS = MFWS and assumes unsheltered wind adjustment (0.4)												
*20ft/FCST		NWNS/0	Back - ½	Flank - 1	5	10	15	20	25	30	35	40	45	50
EWS					2	4	6	8	10	12	14	16	18	20
1-hr Moisture, %	1	2	2	3	3	*4*	*5*	*6*	*7*	*7*	**8**	**9**	**9**	**10**
	3	1	2	2	3	*4*	*4*	*5*	*6*	*6*	*7*	*7*	**8**	**8**
	5	1	2	2	2	3	*4*	*5*	*5*	*6*	*6*	*6*	*7*	*7*
	7	1	1	2	2	3	*4*	*4*	*5*	*5*	*6*	*6*	*6*	*7*
	9	1	1	2	2	3	*4*	*4*	*5*	*5*	*5*	*6*	*6*	*6*
	11	1	1	2	2	3	3	*4*	*4*	*5*	*5*	*5*	*6*	*6*
	13	1	1	1	2	2	3	3	*4*	*4*	*4*	*4*	*5*	*5*
	15	1	1	1	1	2	2	2	2	3	3	3	3	3

Fuel Model 12, Medium Logging Slash (2.3 foot bed depth)

SPREAD Ch/hr	Effective Windspeed(EWS), mph *Use 20ft/FCST wind only if EWS = MFWS and assumes unsheltered wind adjustment (0.4)											
*20ft/FCST	NWNS-0	Back - ½	Flank - 1	5	10	15	20	25	30	35	40	45	50
EWS				2	4	6	8	10	12	14	16	18	20
1-hr Moisture, % 1	2	4	5	9	17	25	34	43	52	62	72	82	92
3	2	3	4	7	14	20	28	35	43	50	58	66	75
5	2	2	4	6	11	17	23	30	36	43	50	56	63
7	1	2	3	5	10	15	21	26	32	38	44	50	56
9	1	2	3	5	9	14	19	24	29	34	40	45	51
11	1	2	3	5	9	13	17	22	27	32	37	42	47
13	1	2	3	4	8	12	16	21	25	30	34	39	44
15	1	2	2	4	7	11	15	19	23	27	31	36	40
17	1	1	2	3	6	10	13	17	20	24	28	31	35
19	1	1	2	3	5	8	11	14	16	19	23	26	29
21	1	1	1	2	4	6	8	10	12	14	16	18	21
23	<1	<1	1	1	2	3	4	5	6	7	8	9	9

Low	*Moderate*	High	Very High	Extreme

FLAME ft	Effective Windspeed(EWS), mph *Use 20ft/FCST wind only if EWS = MFWS and assumes unsheltered wind adjustment (0.4)											
*20ft/FCST	NWNS-0	Back - ½	Flank - 1	5	10	15	20	25	30	35	40	45	50
EWS				2	4	6	8	10	12	14	16	18	20
1-hr Moisture, % 1	4	5	6	8	10	12	14	16	17	19	20	21	22
3	3	4	5	7	9	11	12	14	15	16	17	18	19
5	3	4	5	6	8	9	11	12	13	14	15	16	17
7	3	4	4	5	7	9	10	11	12	13	14	15	16
9	3	3	4	5	7	8	9	10	11	12	13	14	15
11	3	3	4	5	6	8	9	10	11	12	13	13	14
13	2	3	4	5	6	7	9	10	10	11	12	13	14
15	2	3	3	4	6	7	8	9	10	11	11	12	13
17	2	3	3	4	5	6	7	8	9	10	10	11	12
19	2	2	3	3	5	5	6	7	8	8	9	9	10
21	1	2	2	3	3	4	5	5	6	6	7	7	7
23	1	1	1	1	2	2	2	3	3	3	3	4	4

Fuel Model 13, Heavy Logging Slash (3 foot bed depth)

SPREAD Ch/hr		Effective Windspeed(EWS), mph *Use 20ft/FCST wind only if EWS = MFWS and assumes unsheltered wind adjustment (0.5)												
*20ft/FCST		NWNS-0	Back - ½	Flank - 1	4	8	12	16	20	24	28	32	36	40
EWS					2	4	6	8	10	12	14	16	18	20
1-hr Moisture, %	1	3	5	6	11	20	30	41	52	63	75	86	98	111
	3	2	4	5	9	16	25	34	43	52	61	71	81	91
	5	2	3	5	7	14	21	28	36	44	52	60	69	77
	7	2	3	4	6	12	18	25	31	38	45	52	60	67
	9	2	2	4	6	11	16	22	28	34	41	47	54	60
	11	1	2	3	5	10	15	20	26	32	37	43	49	55
	13	1	2	3	5	9	14	19	24	29	35	40	46	51
	15	1	2	3	5	9	13	18	23	27	33	38	43	48
	17	1	2	3	4	8	12	17	21	26	30	35	40	45
	19	1	2	2	4	8	11	15	19	24	28	32	37	42
	21	1	2	2	4	7	10	14	18	21	25	29	33	37
	23	1	1	2	3	6	9	12	15	18	22	25	29	32
	25	1	1	2	3	5	7	10	12	15	18	21	23	26
	27	1	1	1	2	3	5	7	9	11	13	15	17	19
	29	<1	<1	<1	1	2	3	4	5	6	7	8	9	10

Low	*Moderate*	**High**	**Very High**	**Extreme**

FLAME feet		Effective Windspeed(EWS), mph *Use 20ft/FCST wind only if EWS = MFWS and assumes unsheltered wind adjustment (0.5)												
*20ft/FCST		NWNS-0	Back - ½	Flank - 1	4	8	12	16	20	24	28	32	36	40
EWS					2	4	6	8	10	12	14	16	18	20
1-hr Moisture, %	1	5	7	8	10	13	16	18	20	22	24	26	27	29
	3	5	6	7	9	11	14	16	18	19	21	22	24	25
	5	4	5	6	8	10	12	14	16	17	19	20	21	22
	7	4	5	5	7	9	11	13	14	16	17	18	19	20
	9	4	4	5	6	9	10	12	13	15	16	17	18	19
	11	3	4	5	6	8	10	11	13	14	15	16	17	18
	13	3	4	5	6	8	9	11	12	13	14	15	16	17
	15	3	4	5	6	8	9	10	12	13	14	15	16	17
	17	3	4	4	5	7	9	10	11	12	13	14	15	16
	19	3	3	4	5	7	8	10	11	12	13	13	14	15
	21	3	3	4	5	6	8	9	10	11	12	13	13	14
	23	2	3	3	4	6	7	8	9	10	10	11	12	13
	25	2	2	3	4	5	6	7	7	8	9	9	10	11
	27	2	2	2	3	4	4	5	6	6	7	7	8	8
	29	1	1	1	2	2	2	3	3	3	4	4	4	4

Crown Fire Initiation & Propagation

Crown Characteristics

Canopy Cover

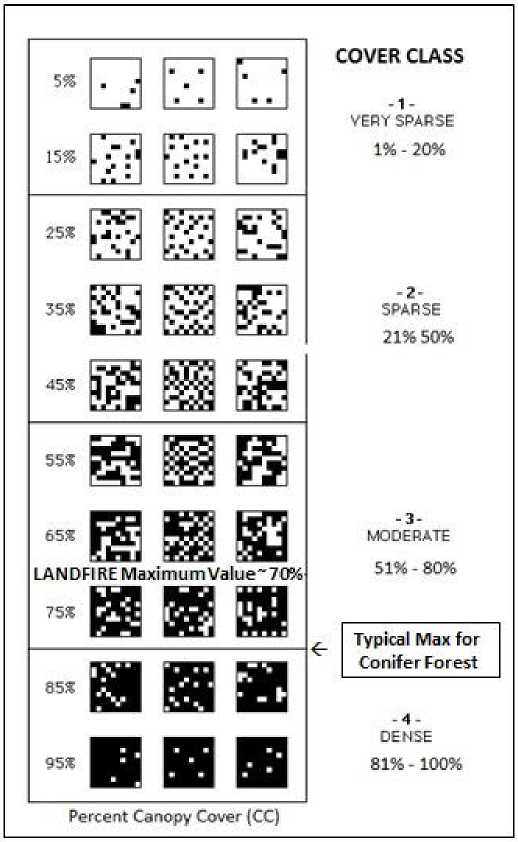


Figure 46. Canopy cover ocular estimation.

The forest Canopy Cover (CC) describes the percent cover or cover class of the tree canopy in a stand. Specifically, CC describes the vertical projection of the tree canopy onto an imaginary horizontal surface representing the ground's surface. Estimate of CC is used in adjustment of 20 foot winds to mid-flame, fuel moisture conditioning and spotting distance models.

- CC ≤ 5%, unsheltered
- 5% < CC ≤ 15%, partially sheltered
- 15% < CC ≤ 50%, fully sheltered, open
- CC > 50%, fully sheltered, closed.

The scale (Figure 46) illustrates representative CC percentages and ranges within each cover class.

Canopy Bulk Density

The forest Canopy Bulk Density (CBD) describes the density of available canopy fuel in a stand. It is defined as the mass of available canopy fuel per canopy volume unit. Typical units are either kg/m3 (LANDFIRE default) or lb/ft3 (BehavePlus default). CBD estimates are used to determine the threshold spread rate, or surface wind speed (Figure 48), used to determine the likelihood of active crown fire.

Stand (Canopy) Height

The Stand or Canopy Height (SH) describes the average height of the top of the vegetated canopy. SH estimates are used in adjustment of 20 foot winds to mid-flame and in spotting distance models.

Canopy Base Height

The forest Canopy Base Height (CBH) describes the average height from the ground to a forest stand's canopy bottom. Specifically, it is the lowest height in a stand at which there is a sufficient amount of forest canopy fuel to propagate fire vertically into the canopy. Using this definition, ladder fuels such as lichen, dead branches, and small trees are incorporated. Estimate of CBH is used in the Crown Fire Initiation model (Figure 47).

Figure 47. Crown Fire Initiation. Considers surface flame length, height to flammable canopy fuels, and foliar moisture content. Resulting intersection on the left axis represent minimum conditions for at least passive crown fire.

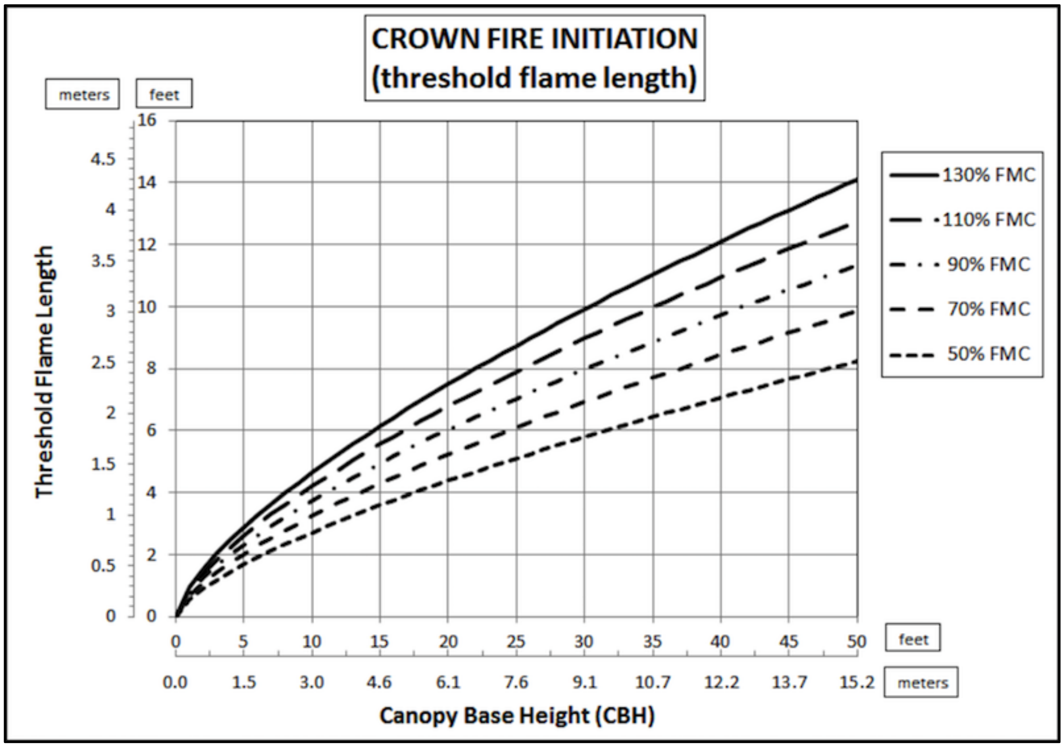
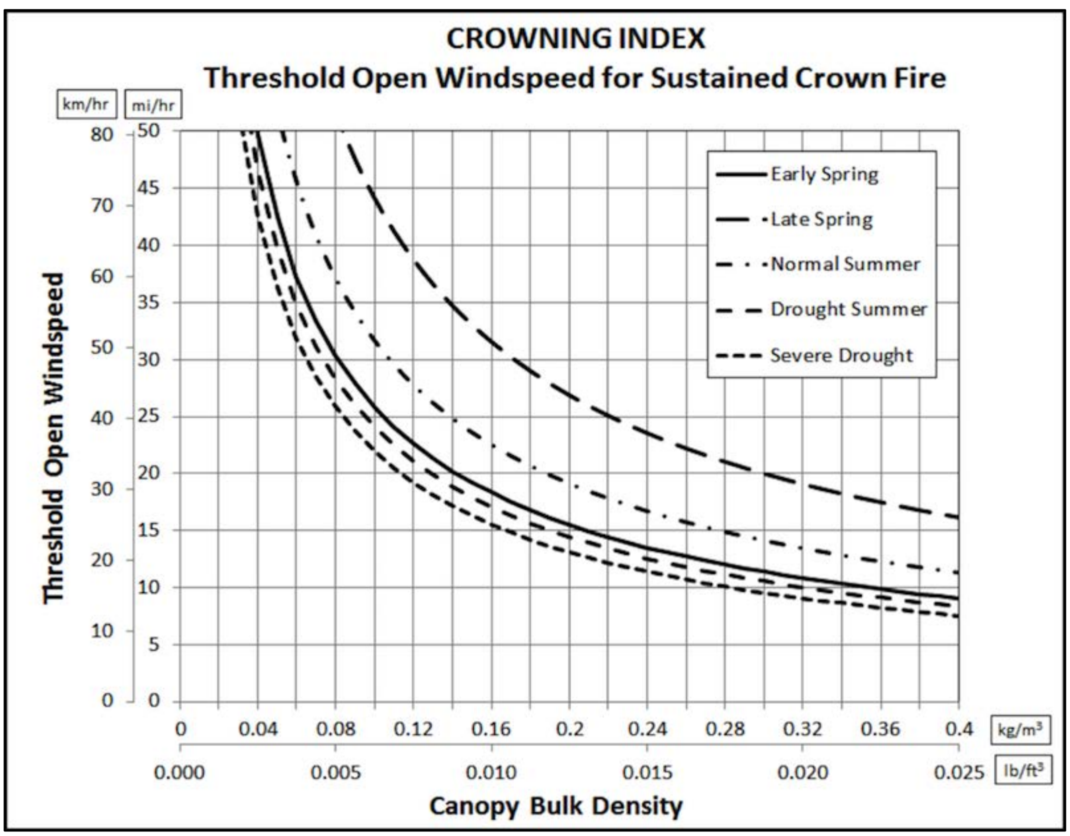


Figure 48. Crowning Index suggests windspeed needed to sustain an active crown fire based on how dense the flammable tree canopy is. Intersecting conditions on the left axis represent minimum conditions for active crown fire activity.



Estimating Active Crown Fire Spread

In fireline assessments, it may be necessary to make quick estimates of crown fire spread based on simple inputs. Simple lookup tables like those provided in this guide can provide rough estimates. Anderson (1982), when describing the original 13 surface fuel models, identified several shrub models as representative of crown fire behavior in several classic types:

- FM4 (Chaparral) for New Jersey Pine Barrens and Lake States Jack Pine.
- FM6 (Dormant Brush) for Alaska Spruce Taiga.
- FM7 (Southern Rough) for Alaska Black Spruce/Shrub Communities.
- Bishop (2010), in developing the Fireline Assessment Method (FLAME), averaged spread rates for fuel models FM5, FM6, and FM7 to estimate crown fire spread.
- Fuel Models sh5 (145) and sh7 (147) have been used in the same manner in spatial modeling in different situations.

Crown Fire flame length will be underestimated when using the surface fire spread model in this way. The surface fuel model does not represent the height of the canopy fuel layer and the fuel loading in the canopy layer. This does not detract from the utility of the spread rate estimates and the intensities, though low, are still extreme.

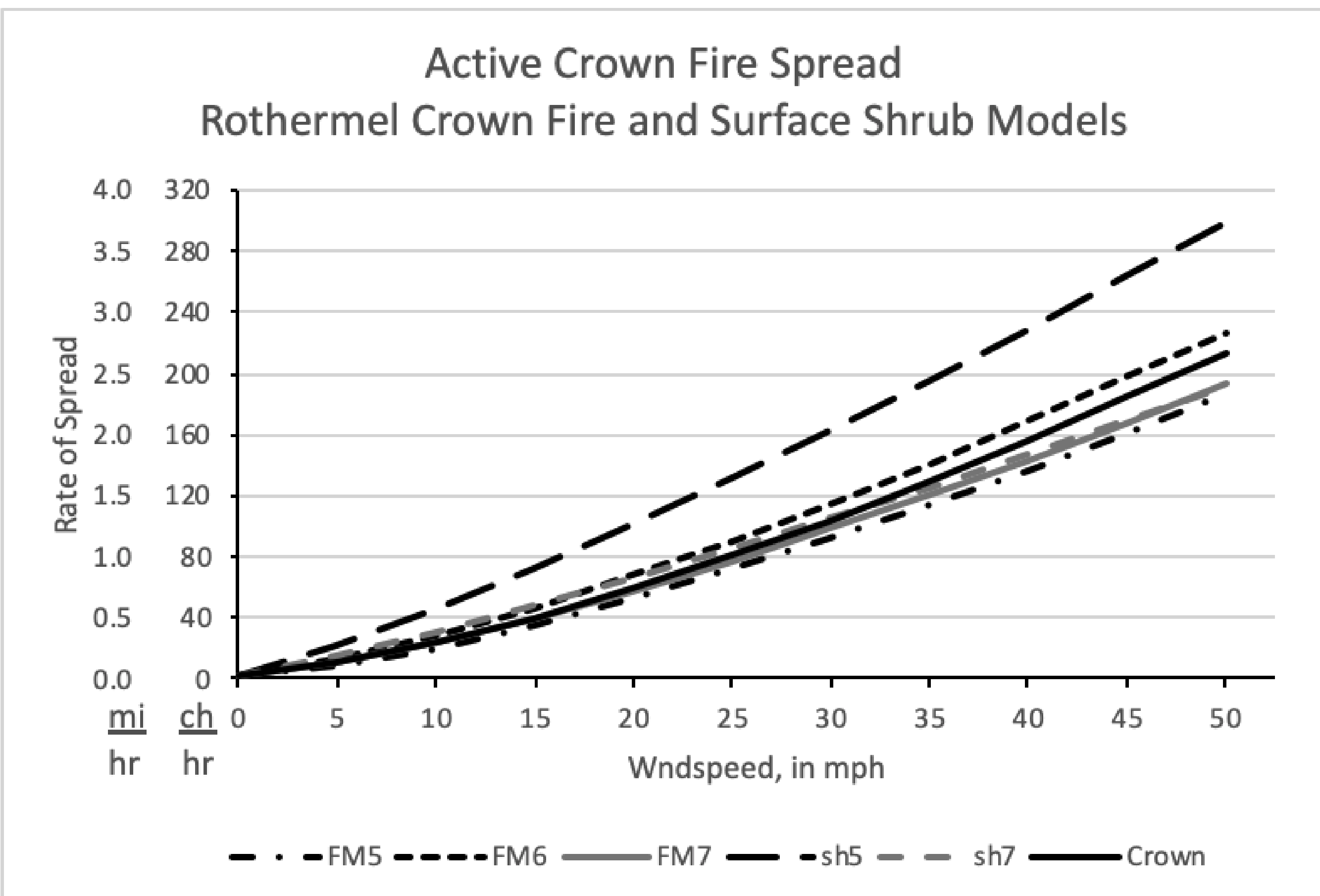


Figure 49. Active Crown Fire Spread. This graphic demonstrates the similarity in spread rates produced by the Rothermel Crown Fire Spread Rate (crown) and several surface shrub fuel models.

Flanking and Backing Fire Behavior

Estimating the spread rate and flame length for flanking and backing fire behavior can be important to tactical decisions on the fireline.

The Fire Behavior lookup tables have columns for backing and flanking fire behavior, based on assumed windspeed of ½ and 1 mph, respectively (Bishop, 2007).

Figure 50 (Scott, 2007) provides a tool for estimating the fire's length to breadth ratio, as well as fractional multipliers for estimating spread rates and flame lengths for backing, flanking, and "hanking" (near head fire on the flank).

1. Estimate effective midflame windspeed from tables on page 62 above.
2. Draw vertical line to read length-to-breadth ratio on scale at the top. (a)
3. Turn and draw a horizontal line from where the vertical line intersects either backing, flanking or hanking curves. (b) (c)
4. Read fractional multiplier for spread rate from scale on left side of chart. Multiply by your estimate of head fire spread rate to get estimate of either backing, flanking, or hanking spread rate. (d)
5. Where horizontal line intersects unitless curve in left half of chart, turn and draw vertical line down to the bottom edge. (e)
6. Read fractional multiplier where it intersects the scale at the bottom of the chart. Multiply by your estimate of head fire flame length to get estimate of either backing, flanking, or hanking flame length. (f)

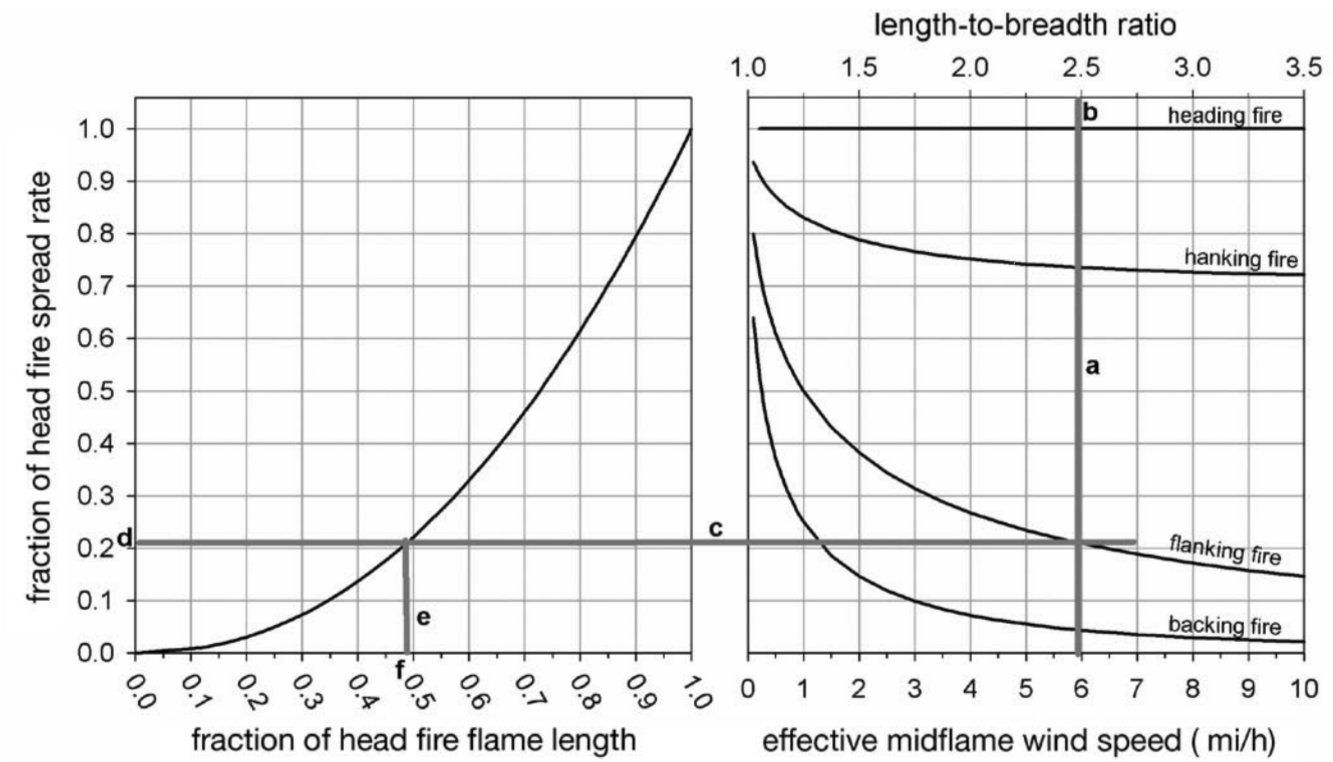


Figure 50. Nomogram for estimation of backing, flanking and hanking spread and intensity.

Estimate Spotting Distance and Probability of Ignition

Spotting Distance

In most cases, it is best to use a program like BehavePlus to estimate spotting distance from using specific inputs from the situation encountered. These tables are offered as a general reference when that is not possible.

Western Tree Species Quick Reference Lookup Table, results in miles.

This table assumes three torching trees 50 ft tall and 10-inch diameter at breast height (DBH) with downwind cover and an open stand of 50 ft tall trees. Read the result in miles.

Tree Species/20ft wind, mph	5	10	15	20	25	30	35	40	45	50
Balsam Fir	0.1	0.3	0.4	0.6	0.7	0.8	1	1.1	1.3	1.4
Grand Fir	0.1	0.3	0.4	0.6	0.7	0.8	1	1.1	1.3	1.4
Subalpine Fir	0.1	0.2	0.4	0.5	0.6	0.7	0.9	1	1.1	1.2
Lodgepole Pine	0.1	0.2	0.3	0.5	0.6	0.7	0.8	0.9	1	1.1
Engelmann Spruce	0.1	0.3	0.4	0.5	0.7	0.8	0.9	1	1.2	1.3
Ponderosa Pine	0.1	0.2	0.3	0.5	0.6	0.7	0.8	0.9	1	1.1
Douglas-Fir	0.1	0.2	0.4	0.5	0.6	0.7	0.9	1	1.1	1.2

Southern Pine Species Quick Reference Lookup Table, results in miles.

This table assumes three torching trees 50 ft tall and 10-inch DBH with downwind cover and an open stand of 50 ft tall trees. Read the result in miles.

Tree Species/20 ft wind, mph	5	10	15	20	25	30	35	40	45	50
Shortleaf Pine	0.1	0.2	0.2	0.3	0.4	0.5	0.6	0.6	0.7	0.8
Slash Pine	0.1	0.2	0.3	0.3	0.4	0.5	0.6	0.7	0.8	0.8
Longleaf Pine	0.1	0.2	0.3	0.3	0.4	0.5	0.6	0.7	0.8	0.8
Pond Pine	0.1	0.2	0.2	0.3	0.4	0.5	0.6	0.6	0.7	0.8
Loblolly Pine	0.1	0.2	0.2	0.3	0.4	0.5	0.6	0.6	0.7	0.8

Probability of Ignition (PIG)

Shading	DB Temp (°F)	1-hr Moisture Content (%) 2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
0-10% shading	110+	100	100	90	80	70	60	50	40	40	30	30	30	20	20	20	10
	100-109	100	90	80	70	60	60	50	40	40	30	30	20	20	20	10	10
	90-99	100	90	80	70	60	50	50	40	30	30	30	20	20	20	10	10
	80-89	100	90	80	70	60	50	40	40	30	30	20	20	20	20	10	10
	70-79	100	80	70	60	60	50	40	40	30	30	20	20	20	10	10	10
	60-69	90	80	70	60	50	50	40	30	30	30	20	20	20	10	10	10
	50-59	90	80	70	60	50	40	40	30	30	20	20	20	10	10	10	10
	40-49	90	80	70	60	50	40	40	30	30	20	20	20	10	10	10	10
	30-39	90	70	60	60	50	40	40	30	30	20	20	20	10	10	10	10
10-50% shading	110+	100	100	80	70	60	60	50	40	40	30	30	20	20	20	20	10
	100-109	100	90	80	70	60	50	50	40	40	30	30	20	20	20	10	10
	90-99	100	90	80	70	60	50	40	40	30	30	30	20	20	20	10	10
	80-89	100	90	80	70	60	50	40	40	30	30	20	20	20	10	10	10
	70-79	100	80	70	60	50	50	40	40	30	30	20	20	20	10	10	10
	60-69	90	80	70	60	50	50	40	30	30	20	20	20	20	10	10	10
	50-59	90	80	70	60	50	40	40	30	30	20	20	20	10	10	10	10
	40-49	90	80	70	60	50	40	40	30	30	20	20	20	10	10	10	10
	30-39	80	70	60	50	50	40	30	30	20	20	20	10	10	10	10	10
60-90% shading	110+	100	90	80	70	60	50	50	40	40	30	30	20	20	20	10	10
	100-109	100	90	80	70	60	50	50	40	30	30	30	20	20	20	10	10
	90-99	100	80	80	70	60	50	40	40	30	30	20	20	20	10	10	10
	80-89	100	80	70	60	60	50	40	40	30	30	20	20	20	10	10	10
	70-79	90	80	70	60	50	50	40	30	30	30	20	20	20	10	10	10
	60-69	90	80	70	60	50	40	40	30	30	20	20	20	10	10	10	10
	50-59	90	80	70	60	50	40	40	30	30	20	20	20	10	10	10	10
	40-49	90	70	60	50	50	40	30	30	30	20	20	20	10	10	10	10
	30-39	80	70	60	50	50	40	30	30	20	20	20	10	10	10	10	10
100% shading	110+	100	90	80	70	60	50	50	40	30	30	30	20	20	20	10	10
	100-109	100	90	80	70	60	50	40	40	30	30	20	20	20	20	10	10
	90-99	100	80	70	60	60	50	40	40	30	30	20	20	20	10	10	10
	80-89	90	80	70	60	60	50	40	30	30	30	20	20	20	10	10	10
	70-79	90	80	70	60	50	40	40	30	30	20	20	20	10	10	10	10
	60-69	90	80	70	60	50	40	40	30	30	20	20	20	10	10	10	10
	50-59	90	70	60	60	50	40	40	30	30	20	20	20	10	10	10	10
	40-49	80	70	60	50	50	40	30	30	20	20	20	10	10	10	10	10
	30-39	80	70	60	50	40	40	30	30	20	20	20	10	10	10	10	10

Figure 51. Probability of Ignition. Uses estimated 1-hr fuel moisture (%), shading from cloud cover or tree/shrub canopy, and ambient surface dry bulb (DB) temperature.

Calibrating Fire Behavior Estimates

On the fireline, diurnal (hour to hour) changes during an operational period are most important. However, when estimating fire behavior, it is important to compare the prediction to recent observations. Use the table below to help identify key factors that may need adjustment:

- Begin by evaluating the ***fixed factors***, which frame the analysis overall
- ***Seasonal situation*** inputs will generally not change on a day to day basis
- Consider what ***day to day changes*** were most significant when comparing yesterday to today
- Finally, use the forecast and fireline observations to consider your ***diurnal*** assumptions.

Variability	Large Scale	Medium Scale	Small Scale
Fixed Fire Environment	Analysis Barriers Crown Fire Method Spotting Frequency Fuel Model Canopy Cover Terrain: Slope, Aspect, Elevation	Canopy Base Height Canopy Bulk Density Stand Height	
Seasonal Trends	Burn Period Length Burn Day frequency Herbaceous Fuel Moisture	Woody Fuel Moisture	
Day-to-Day Variability	Wind Speed & Wind Direction Burn Period length Burn Day frequency	1-hr fuel moisture	10-hr fuel moisture 100-hrs fuel moisture
Diurnal Changes	Burn Period length Wind Speed & Wind Direction Cloud Cover Precipitation 1-hr fuel moisture (when considered over 24 hours in ***primarily grass*** landscapes)	1-hr fuel moisture (when considered over 24 hours in ***mixed forest, shrub and grass*** landscapes)	1-hr fuel moisture (if burn period only includes peak hours)

Fire Size and Shape

These tools are intended for use with initiating fires only. Multiply your estimated spread rate times a number of hours you think significant to determine a *spread distance*. Consider using:

- Number of hours from ignition until the end of the expected burn period.
- Number of hours from ignition until you arrive at the fire.

Elliptical Fire Shapes

These fire shapes are based only on the effective windspeed (midflame windspeed and slope combined). The length to width ratio is shown in parentheses within each shape. Use these shapes (Figure 52) in combination with your estimate of spread distance to overlay the expected fire perimeter on your map.

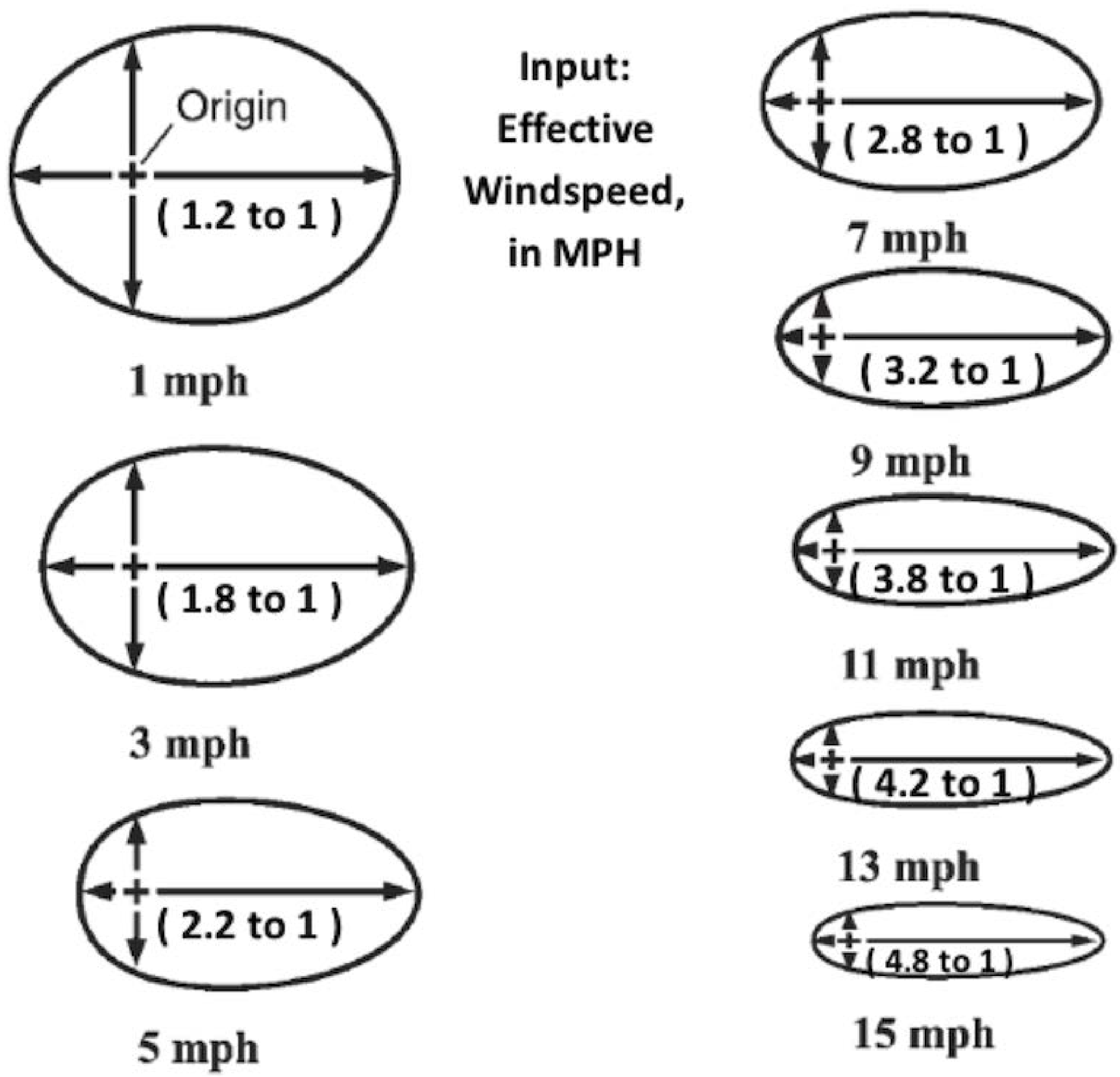


Figure 52. Elliptical Fire Shapes. Based solely on the estimated effective windspeed (midflame windspeed and slope factors combined). Ratio in parentheses provide representative comparisons between length and width (e.g., 1.2 to 1).

Surface Fire Area Estimation from Point Source Fire, in Acres

Spread Distance, in Chains	Effective Windspeed, in mph									
	1	3	5	7	9	11	13	15	17	19
	Acres									
1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	0.4	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1
3	1	1	0.3	0.3	0.2	0.2	0.2	0.2	0.1	0.1
4	2	1	1	1	0.4	0.3	0.3	0.3	0.2	0.2
5	3	1	1	1	1	1	1	0.4	0.4	0.3
6	4	2	1	1	1	1	1	1	1	1
7	5	3	2	2	1	1	1	1	1	1
8	6	4	3	2	2	1	1	1	1	1
9	8	4	3	3	2	2	2	1	1	1
10	10	5	4	3	3	2	2	2	2	1
11	12	7	5	4	3	3	2	2	2	2
12	14	8	6	4	4	3	3	2	2	2
13	17	9	7	5	4	4	3	3	3	2
14	19	11	8	6	5	4	4	3	3	3
15	22	12	9	7	6	5	4	4	3	3
16	25	14	10	8	7	6	5	4	4	4
17	28	16	11	9	7	6	6	5	4	4
18	32	18	13	10	8	7	6	6	5	5
19	35	20	14	11	9	8	7	6	6	5
20	39	22	16	12	10	9	8	7	6	6
21	43	24	17	14	11	10	8	8	7	6
22	48	26	19	15	12	11	9	8	7	7
23	52	29	21	16	13	12	10	9	8	7
24	57	31	22	18	15	13	11	10	9	8
25	61	34	24	19	16	14	12	11	10	9
26	66	37	26	21	17	15	13	11	10	9
28	77	43	31	24	20	17	15	13	12	11
30	88	49	35	28	23	20	17	15	14	13
32	101	56	40	31	26	22	20	17	16	14
34	114	63	45	35	29	25	22	20	18	16
36	127	70	50	40	33	28	25	22	20	18
38	142	78	56	44	37	31	28	24	22	20
40	157	87	62	49	41	35	30	27	24	22
42	173	96	69	54	45	38	34	30	27	25
44	190	105	75	59	49	42	37	33	30	27
46	208	115	82	65	54	46	40	36	32	29
48	226	125	90	71	59	50	44	39	35	32
50	245	135	97	77	64	54	48	42	38	35

Table 7. Fire area for Spread Distances 1-50 chains.

Spread Distance, in Chains	Effective Windspeed, in mph									
	1	3	5	7	9	11	13	15	17	19
	Acres									
52	266	146	105	83	69	59	51	46	41	38
54	286	158	113	89	74	63	55	49	44	40
56	308	170	122	96	80	68	60	53	48	44
58	330	182	131	103	85	73	64	57	51	47
60	353	195	140	110	91	78	68	61	55	50
62	377	208	149	118	98	84	73	65	59	53
64	402	222	159	125	104	89	78	69	62	57
66	428	236	169	133	111	95	83	74	66	60
68	454	250	180	142	117	100	88	78	71	64
70	481	265	190	150	124	106	93	83	75	68
72	509	281	201	159	132	113	99	88	79	72
74	538	297	213	168	139	119	104	93	83	76
76	567	313	224	177	147	126	110	98	88	80
78	597	330	236	186	154	132	116	103	93	84
80	628	347	249	196	162	139	122	108	98	89
82	660	364	261	206	171	146	128	114	103	93
84	693	382	274	216	179	153	134	119	108	98
86	726	401	287	227	188	161	141	125	113	103
88	760	419	301	237	197	168	147	131	118	107
90	795	439	315	248	206	176	154	137	123	112
92	831	458	329	259	215	184	161	143	129	117
94	868	479	343	271	224	192	168	149	135	123
96	905	499	358	282	234	200	175	156	140	128
98	943	520	373	294	244	209	183	162	146	133
100	982	542	389	306	254	217	190	169	152	139
105	1082	597	428	338	280	240	210	187	168	153
110	1188	655	470	371	307	263	230	205	184	168
115	1298	716	514	405	336	287	251	224	202	183
120	1414	780	559	441	366	313	274	244	219	200
125	1534	846	607	478	397	339	297	264	238	217
130	1659	915	657	518	429	367	321	286	258	234
135	1789	987	708	558	463	396	347	308	278	253
140	1924	1062	761	600	498	426	373	332	299	272
145	2064	1139	817	644	534	457	400	356	320	292
150	2209	1219	874	689	571	489	428	381	343	312
155	2359	1301	933	736	610	522	457	406	366	333
160	2513	1386	995	784	650	556	487	433	390	355
165	2673	1474	1058	834	691	591	518	460	415	378

Table 8. Fire Area (in acres) for spread distance 52-165 chains.

Fire Perimeter Estimation from Point Source Fire, in Chains

Spread Distance, in Chains	Effective Windspeed, in mph									
	1	3	5	7	9	11	13	15	17	19
	Chains									
1	4	3	2	2	2	2	2	2	2	2
2	7	6	5	5	5	4	4	4	4	4
3	11	8	7	7	7	7	6	6	6	6
4	14	11	10	9	9	9	9	9	8	8
5	18	14	12	12	11	11	11	11	11	10
6	21	17	15	14	14	13	13	13	13	13
7	25	19	17	16	16	15	15	15	15	15
8	28	22	20	19	18	18	17	17	17	17
9	32	25	22	21	20	20	19	19	19	19
10	35	28	25	23	23	22	22	21	21	21
11	39	30	27	26	25	24	24	23	23	23
12	43	33	30	28	27	26	26	26	25	25
13	46	36	32	30	29	29	28	28	27	27
14	50	39	35	33	32	31	30	30	30	29
15	53	41	37	35	34	33	32	32	32	31
16	57	44	40	37	36	35	35	34	34	34
17	60	47	42	40	38	37	37	36	36	36
18	64	50	45	42	41	40	39	38	38	38
19	67	52	47	44	43	42	41	41	40	40
20	71	55	50	47	45	44	43	43	42	42
21	74	58	52	49	47	46	45	45	44	44
22	78	61	55	51	50	48	48	47	46	46
23	82	64	57	54	52	51	50	49	49	48
24	85	66	60	56	54	53	52	51	51	50
25	89	69	62	59	56	55	54	53	53	52
26	92	72	65	61	59	57	56	55	55	54
28	99	77	70	66	63	62	61	60	59	59
30	106	83	74	70	68	66	65	64	63	63
32	113	88	79	75	72	70	69	68	68	67
34	121	94	84	80	77	75	73	73	72	71
36	128	99	89	84	81	79	78	77	76	75
38	135	105	94	89	86	84	82	81	80	80
40	142	110	99	94	90	88	86	85	84	84
42	149	116	104	98	95	92	91	90	89	88
44	156	122	109	103	99	97	95	94	93	92
46	163	127	114	108	104	101	99	98	97	96
48	170	133	119	112	108	106	104	102	101	101
50	177	138	124	117	113	110	108	107	106	105

Table 9. Fire Perimeter (in chains) for spread distances 1-50 chains.

Spread Distance, in Chains	Effective Windspeed, in mph									
	1	3	5	7	9	11	13	15	17	19
	Chains									
52	184	144	129	122	117	114	112	111	110	109
54	191	149	134	126	122	119	117	115	114	113
56	199	155	139	131	126	123	121	119	118	117
58	206	160	144	136	131	128	125	124	122	122
60	213	166	149	140	135	132	130	128	127	126
62	220	171	154	145	140	136	134	132	131	130
64	227	177	159	150	144	141	138	137	135	134
66	234	182	164	154	149	145	143	141	139	138
68	241	188	169	159	153	150	147	145	144	142
70	248	193	174	164	158	154	151	149	148	147
72	255	199	179	169	162	158	156	154	152	151
74	262	204	184	173	167	163	160	158	156	155
76	269	210	189	178	171	167	164	162	160	159
78	277	215	194	183	176	172	169	166	165	163
80	284	221	199	187	180	176	173	171	169	168
82	291	227	204	192	185	180	177	175	173	172
84	298	232	209	197	189	185	182	179	177	176
86	305	238	214	201	194	189	186	183	182	180
88	312	243	219	206	198	194	190	188	186	184
90	319	249	223	211	203	198	194	192	190	189
92	326	254	228	215	207	202	199	196	194	193
94	333	260	233	220	212	207	203	200	199	197
96	340	265	238	225	217	211	207	205	203	201
98	347	271	243	229	221	216	212	209	207	205
100	355	276	248	234	226	220	216	213	211	210
105	372	290	261	246	237	231	227	224	222	220
110	390	304	273	257	248	242	238	235	232	230
115	408	318	286	269	259	253	249	245	243	241
120	425	331	298	281	271	264	259	256	253	251
125	443	345	310	293	282	275	270	267	264	262
130	461	359	323	304	293	286	281	277	275	272
135	479	373	335	316	304	297	292	288	285	283
140	496	387	348	328	316	308	303	299	296	293
145	514	401	360	339	327	319	313	309	306	304
150	532	414	372	351	338	330	324	320	317	314
155	550	428	385	363	350	341	335	331	327	325
160	567	442	397	374	361	352	346	341	338	335
165	585	456	410	386	372	363	357	352	348	346

Table 10. Fire Perimeter (in Chains for spread distances 52-165 chains.

Part 3

Other Resources

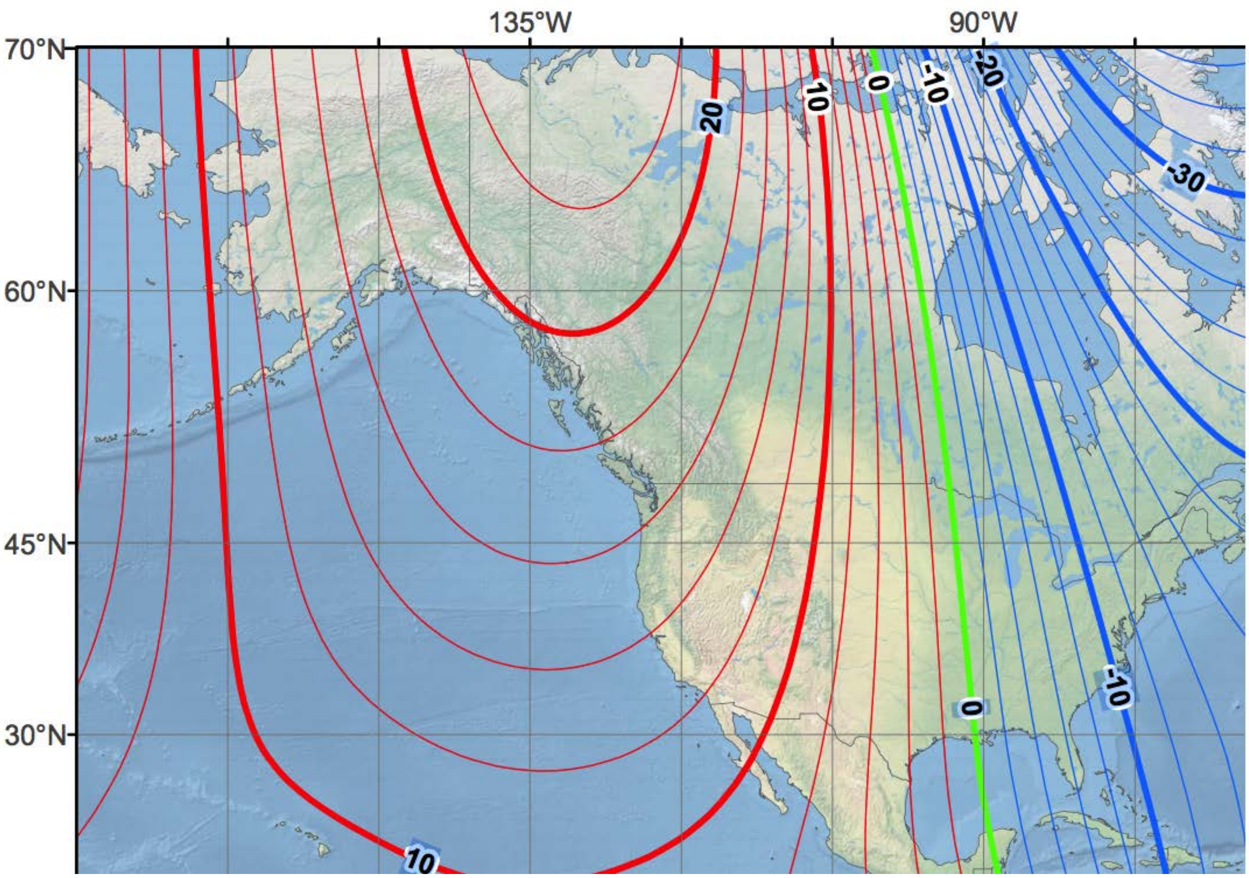
Map Use

Converting Ground Distance to a Map Distance

Scale	Rep. fraction	Map (in/mi)	Map (in/ch)	Feet per map inch
1:253,440	253.44	0.25	0.0031	21120
1:126,720	126.72	0.50	0.0063	10560
1:63,360	63.36	1	0.0125	5280
1:62,500	62.50	1.01	0.0127	5208
1:31,680	31.68	2	0.025	2640
1:24,000	24	2.64	0.033	2000
1:21,120	21.12	3	0.0375	1760
1:15,840	15.84	4	0.05	1320
1:7,920	7.92	8	0.1	660

Magnetic Declination (as of 2018)

Find the declination on the map image here. Negative declinations, in blue, are subtracted from the azimuth of the direction of travel. Positive declinations, in red, are added to the azimuth of the direction of travel.



Measurement Unit Conversions

More about conversions at Firefighter Math (https://www.nwcg.gov/course/ffm) learning website.

Linear Measure, Distance and Speed

Measure Unit	Multiply by	Measure Unit	Multiply by	Measure Unit
Meters/min	3.28084	Ft/min	0.3048	Meters/min
Meters/min	2.982582	Ch/hr	0.33528	Meters/min
Meters/min	0.03728	Miles/hr	26.8224	Meters/min
Meters	0.049709	Chains	20.117	Meters
Meters	0.3048	Feet	3.28084	Meters
Millimeters	0.0393701	Inches	25.4	Millimeters
Kilometers	0.62137	Miles	1.6093	Kilometers
Feet	0.0001894	Miles	5280	Feet
Chains	0.125	Miles	80	Chains

Land Area

Measure Unit	Multiply by	Measure Unit	Multiply by	Measure Unit
hectares	2.4711	acres	0.40469	hectares
Acres	43560	Square Feet	0.000023	Acres
Acres	0.0015625	Square Mile	640	Acres

Weight/Mass

Measure Unit	Multiply by	Measure Unit	Multiply by	Measure Unit
Kg/m2	4.460897	Tons/ac	0.22417	Kg/m2
Kg/m2	0.062	lb/ft2	16.129	Kg/m2
Tonnes/ha	0.44609	Tons/ac	2.2417	Tonnes/ha
Gram	0.035274	Ounce	28.34955	Gram
Kilogram	2.204625	Pound	0.45359	Kilogram

Energy/Power

Measure Unit	Multiply by	Measure Unit	Multiply by	Measure Unit
Kw/m	0.28909	BTU/ft/sec	3.4592	Kw/m

Temperature

Measure Unit	Multiply by	Measure Unit	Multiply by	Measure Unit
Celsius	1.8*C+32	Fahrenheit	(F-32)*0.56	Celsius

Safety Considerations

Fire Orders

1. Keep informed on fire weather conditions and forecasts.
2. Know what your fire is doing at all times.
3. Base all actions on current and expected behavior of the fire.
4. Identify escape routes and safety zones and make them known.
5. Post lookouts when there is possible danger.
6. Be alert. Keep calm. Think clearly. Act decisively.
7. Maintain prompt communications with your forces, your supervisor, and adjoining forces.
8. Give clear instructions and ensure they are understood.
9. Maintain control of your forces at all times.
10. Fight fire aggressively, having provided for safety first.

18 Watchouts

1. Fire not scouted and sized up.
2. In country not seen in daylight.
3. Safety zones and escape routes not identified.
4. Unfamiliar with weather and local factors influencing fire behavior.
5. Uninformed on strategy, tactics, and hazards.
6. Instructions and assignments not clear.
7. No communication link between crew members and supervisors.
8. Constructing line without safe anchor point.
9. Building line downhill with fire below.
10. Attempting frontal assault on fire.
11. Unburned fuel between you and the fire.
12. Cannot see main fire, not in contact with anyone who can.
13. On a hillside where rolling material can ignite fuel below.
14. Weather gets hotter and drier.
15. Wind increases and/or changes direction.
16. Getting frequent spot fires across line.
17. Terrain or fuels make escape to safety zones difficult.
18. Feel like taking a nap near fireline.

Common Denominators of Fire Behavior on Tragedy Fires

There are five major common denominators of fire behavior on fatal and near-fatal fires. Such fires often occur:

1. On relatively small fires or deceptively quiet areas of large fires.
2. In relatively light fuels, such as grass, herbs, and light brush.
3. When there is an unexpected shift in wind direction or in wind speed.
4. When fire responds to topographic conditions and runs uphill.
5. Critical burn period between 1400 and 1700.

Alignment of topography and wind during the critical burning period should be considered a trigger point to reevaluate tactics. Blowup to burnover conditions generally occur in less than 60 minutes and can be as little as 5 minutes. A tactical pause may be prudent around 1400 for reevaluating your situational awareness of topography, weather, and fuel.

Common Tactical Hazards

Position

- Building fireline downhill.
- Building undercut or mid-slope fireline.
- Building indirect fireline or unburned fuel is between you and the fire.
- Attempting frontal assault on the fire or you are delivered by aircraft to the top of the fire.
- Establishing escape routes that are uphill or difficult to travel.

Situation

- Poor communication due to a rapidly emerging small fire or an isolated area of a large fire.
- Suppression resources are fatigued or inadequate.
- Assignment or escape route depends on aircraft support.
- Nighttime operations.
- Wildland Urban Interface operations.

When selected tactics put firefighters in these positions or situations, a higher level of risk is involved. Consider additional hazard controls that may be needed.

Lookouts/Communications/Escape Routes/Safety Zones (LCES)

Lookout(s) or scouts (roving lookouts) need to be in a position where both the objective hazard and the firefighter (s) can be seen. Lookouts must be trained to observe the wildland fire environment and to recognize and anticipate wildland fire behavior changes. Each situation determines the number of lookouts that are needed. Because of terrain, cover and fire size one lookout is normally not sufficient. The whole idea is when the objective hazard becomes a danger the lookout relays the information to the firefighter so they can reposition to the safety zone. Actually, each firefighter has the authority to warn others when they notice an objective hazard which becomes a threat to safety.

Communications(s) is the vehicle which delivers the message to the firefighters, alerting of the approaching hazard. As is stated in current training, communications must be prompt and clear. Radios are limited and, at some point, the warning is delivered by word of mouth. Although more difficult, it is important to maintain promptness and clearness when communication is by word of mouth.

Escape Routes are the path the firefighter takes from their current locations, exposed to the danger, to an area free from danger. Notice that escape routes is used instead of escape route(s). Unlike the other components, there always must be more than one escape route available to the firefighter. Battlement Creek 1976 is a good example of why another route is needed between the firefighter's location and a safety zone. Escape routes are probably the most elusive component of LCES. Their effectiveness changes continuously. As the firefighter works along the fire perimeter, fatigue and spatial separation increases the time required to reach the safety zone. The most common escape route (or part of an escape route) is the fireline. On indirect or parallel fireline, situations become compounded. Unless safety zones have been identified ahead, as well as behind, firefighters retreat may not be possible.

Safety Zone(s) are locations where the threatened firefighter may find refuge from the danger. Unfortunately shelter deployment sites have been incorrectly called safety zones. Safety zones should be conceptualized and planned as a location where no shelter is needed. This does not intend for the firefighter to hesitate to deploy their shelter if needed, just if a shelter is deployed the location is not a tree safety zone. Fireline intensity and safety zone topographic location determine safety zone effectiveness.

Safety Zone Guidelines

Based on recent research for Firefighter Safety (https://www.firelab.org/project/firefighter-safety), safety zones need to account for the influence of windspeed and slope. These factors produce the greater heat felt due to convective heat transfer. A new mobile app, Wildfire Safety Evaluator – WiSE (https://wise.wildfireanalyst.com), is available to calculate safety zone size. Find it at

Safe Separation Distance (SSD) represents the safe distance from an approaching wildfire that firefighters must maintain for protection in a safety zone.

Escape Routes

- Use trigger points & thresholds to help determine whether it is time to disengage.
- Keep escape route steepness to less than 20% (11°).
- Flag escape route for easier navigation in heavy smoke.

Safe Separation Distance (SSD) based on Forecast and Fire Environment

- SSD = 8 X Vegetation Height X Slope-Wind Factor (Δ)

Slope-Wind Factor (Δ)			
	Terrain Slope (%)		
Wind Speed (mph)	Flat (< 15%)	15-30%	>35%
Light (0-6)	1/0.7/**0.7**	1/1/**1**	4/2/**2**
Moderate (7-15)	2/1/**1**	4/2/**1**	6/3/**2**
Strong (>18)	4/2/**2**	6/3/**2**	8/3/**2**

Fuels < 10' tall / 10' < Fuel > 40 ' / Fuel > 40'

- Example 1: 3' tall sage brush, 20% slope, 10 mph wind
  Δ = 4 SSD = 8 x 3' x 4 = 96 ft or 0.6 acres
- Example 2: 20' tall juniper, 10% slope, 15 mph
  Δ = 1 – 2 SSD = 8 x 20' x 1 or 2 = 160 ft – 320 ft or 2 – 3 acres

Safe Separation Distance Based on Fuel Type from Heat Data

- Grasses SSD > 10-20' from approaching fire
- Shrubs SSD > 22-50' from approaching fire
- Tall Shrubs SSD > 150-200' from approaching fire
- Crown Fire SSD > 300' from approaching fire

Safe Separation Distance for Shelter Deployment Based on Entrapment Reports

Fire shelters increase chance of survival—the data proves it!
With use of fire shelter:

- flames < 30' tall SSD should be > 2-5 x Flm Ht
- flames > 30' tall SSD should be > 1-3 x Flm Ht

No fire shelter—**Double** the multipliers

- *Shrubs are most dangerous*
- For each % increase in slope, odds of injury increase 3%
- For each 3 ft. increase in flame ht., odds of injury increase 4%
- For each 3 ft increase in SSD, odds of injury drop by 11%

The *NWCG Guide to Fireline Fire Assessment* is developed and maintained by the Fire Behavior Subcommittee (FBS), under the direction of the Fire Environment Committee (FEC), an entity of the National Wildfire Coordinating Group (NWCG).

Previous editions (as Fireline Handbook Appendix B: Fire Behavior): 2006, 1993.

While they may still contain current or useful information, previous editions are obsolete. The user of this information is responsible for confirming that they have the most up-to-date version. NWCG is the sole source for the publication.

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