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NWCG Guide to Fire Behavior Assessment

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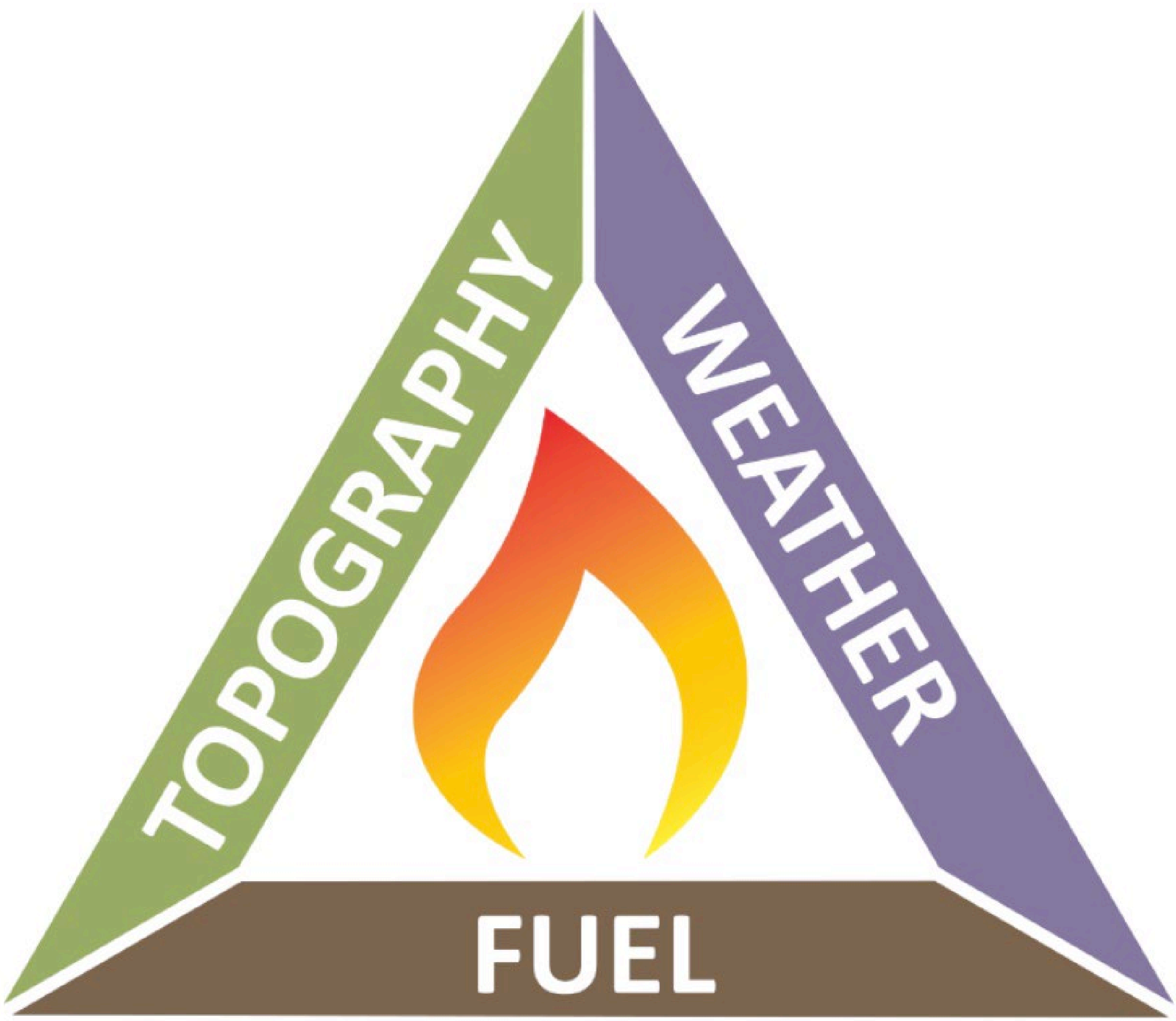

NWCG Guide to Fire Behavior Assessment

February 2023
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The NWCG Guide to Fire Behavior 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 (Fire Environment Assessment and Fire Behavior Estimation)

As a job aid, it supports:

- Fireline and offline assessment of 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 *NWCG 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 page 2, this guide is divided into three parts.

Part 1, Fire Environment Assessment Methods, begins on page 3. It includes practices that help inform decision-making on the fireline. Beginning firefighters may be exposed to these practices. Fireline leaders may assign them to their lookouts and field observers. 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.

Part 2 outlines methods used to Estimate Expected Fire Behavior and begins on page 48.

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

- Fuel Model Selection.
- Elevation/Slope/Aspect.
- Dead and 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 assessments provide the detail necessary for comparing expected changes in the fire environment and its effect on expected fire behavior.

Part 3, Other Resources, begins on page 105. It offers additional references for mapping and navigation, unit conversions, and safety considerations.

Together, they offer a range of descriptions and tools that can support the 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 to Follow.

Each Operational Period, Before Assigned.

- Review fire weather forecast, noting National Weather Service (NWS) Watches and Warnings and key discussion terminology.
- Review recent fire activity and notable fire behavior.
- Compare current fire danger levels to historic trends and thresholds on local Pocket Card to assess season severity.
- Consider critical fire weather patterns with fire weather forecast and predictive services seven-day outlook.

Once Assigned a Role and Enroute to the Fire.

- Acquire weather forecast and consider spot forecast needs.
- Recall weather from yesterday, overnight, and now.
- Utilize maps of the fire area to evaluate what has burned and what lies in advance of anticipated spread. Interpret sky and smoke conditions for stability, wind speed and direction, and signs of intense burning.

On Scene Fire Assessment.

- Validate forecast with current on-site weather conditions, especially windspeed and direction.
- Determine when, where, what, how, and why the fire is burning.
- Identify hazardous fuels and significant terrain ahead of the fire.
- Anticipate rapidly changing fire behavior.
- Continue to monitor the sky for cloud and smoke indicators.

Determine Decision Thresholds and Ensure LCES.

- Recognize how changes impact objectives, strategies, and tactics.
- Establish escape routes, time frames, and triggers for escape to safety zones.
- Identify best lookout locations to monitor for changes.
- Communicate weather and fire behavior observations.

Document Your Assessment.

- Record your observations and assumptions.
- Include assessments and decisions in personal logs.

Part One – Fire Environment Assessment Methods

Interpret Your Weather Forecast.

Make and Communicate Fireline Observations.

Anticipate and Interpret Expected Fire Behavior.

Interpret your Weather Forecast.

Fire Danger Rating System Components. (U.S. and Canada)

Element	United States National Fire Danger Rating System (NFDRS)	Canadian Forest Fire Danger Rating System (CFFDRS)
Weather Observations	Observations Required **Hourly** Temperature Relative Humidity Windspeed Rainfall Solar Radiation	Observations Required **Daily** Temperature Relative Humidity Windspeed Rainfall
Intermediate Weather Inputs	Max and Min Temperatures Maxand Min Relative Humidity Precipitation Duration Daylength Vapor Pressure Deficit (VPD) Growing Season Index (GSI)	None
Fuel Moisture Outputs	Max and Min Temperature Max and Min Relative Humidity Precipitation Duration Daylength Vapor Pressure Deficit (VPD) Growing Season Index (GSI)	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
Fire Behavior Outputs	Ignition Component (IC) Spread Component (SC) Energy Release Component (ERC) Burning Index (BI)	Initial Spread Index (ISI) Buildup Index (BUI) Fire Weather Index (FWI)
Current Conditions	Wildland Fire Assessment System (WFAS) https://wfas.net WildfireSAFE https://wfsafe.technosylva.com/	Mesowest Alaska https://akff.mesowest.org/ Mesowest Great Lakes https://glff.mesowest.org/

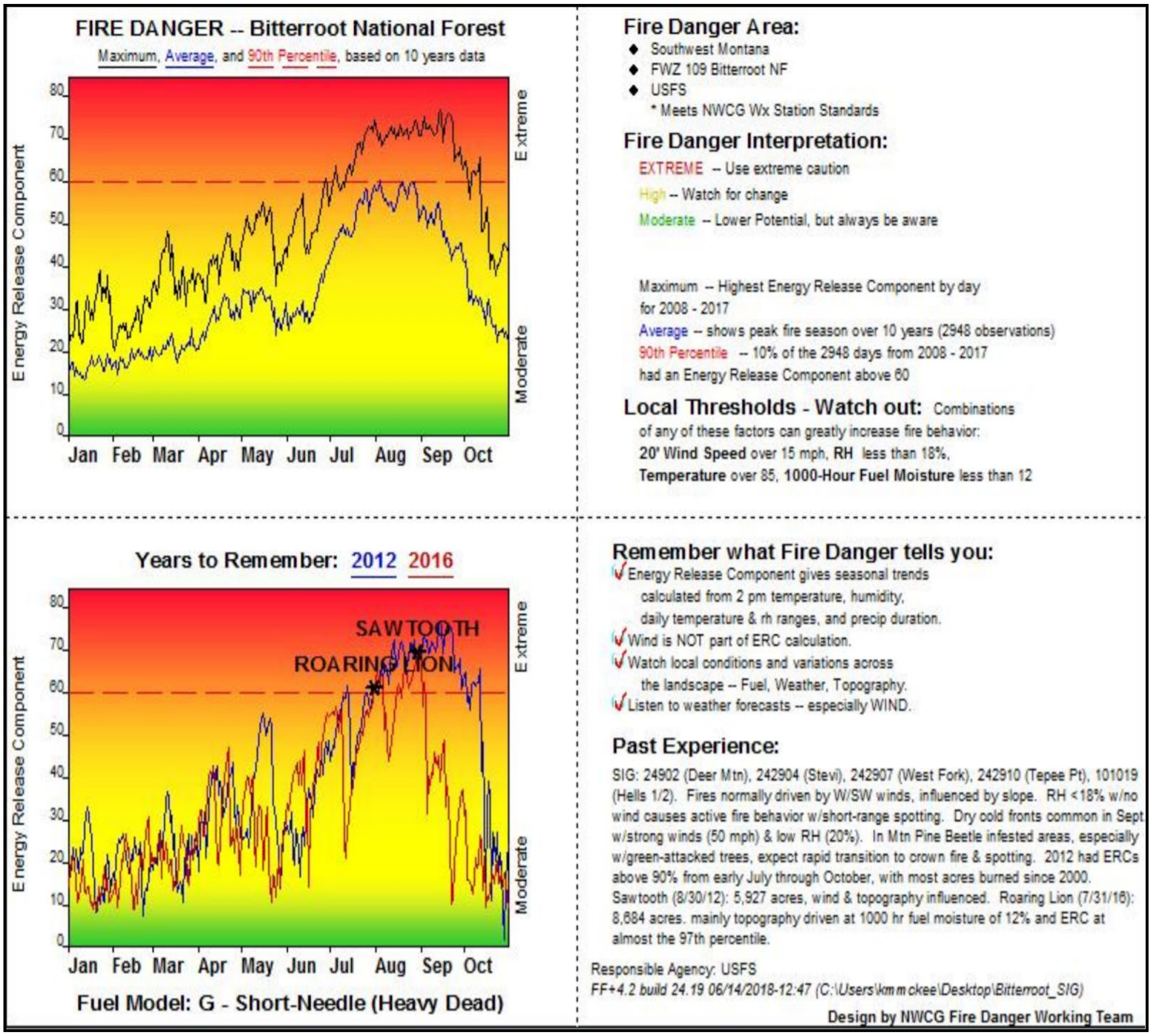
Visit the Fire Danger and CFFDRS chapters of the *NWCG Fire Behavior Field Reference Guide,* PMS 437, https://www.nwcg.gov/publications/pms437, for more information.

Be Mindful of Local Fire Season Climatology.

NWCG Pocket Cards.

https://famit.nwcg.gov/applications/WIMS/PocketCards/PocketCards

Figure 1. Example Pocket Card.



Upper left quadrant includes a graph of the fire season with the trend for 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.	**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 information can be found in the *NWCG Fire Behavior Field Reference Guide,* PMS 437. https://www.nwcg.gov/publications/pms437/weather/critical-fire-weather

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.

Geographic Area Critical Fire Weather Patterns.

The *italicized* words, below, are key terms that meteorologists typically use to describe critical fire weather patterns in the described region. These terms will often be used to explain weather patterns in narrative forecasts and in briefings. This terminology will be found in NWS Area Forecast Discussion (AFD) and fire weather planning forecast discussions as well as predictive service seven-day outlook assessments.

- **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 U.S.**, 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 U.S.**, 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 U.S.**, 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 relative humidity (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 like 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.

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 (WFAS), on its home page, https://www.wfas.net/, offers maps of both North American Fire Danger and the CONUS (continental United States) Severe Fire Weather Potential.

The National Interagency Coordination Center's **Predictive Services 7-Day Significant Fire Potential Outlook**, https://fsapps.nwcg.gov/psp/npsg, 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 National Weather Service **U.S. Climate Prediction Center Outlook** Products page, https://www.cpc.ncep.noaa.gov offers outlook trends for temperature and precipitation for days beyond the forecast period.

The **National Integrated Drought Information System** page, https://www.drought.gov, provides a drought assessment site with depictions of current conditions, outlook and forecast trends.

The Evaporative Demand Drought Index (EDDI), https://psl.noaa.gov/eddi/, is a product that can provide an early indicator of fire risk and 'flash drought' conditions, especially for areas that do not, typically, experience a lot of summer precipitation. The daily EDDI map can be found under the 'current conditions' tab.

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	Note, as the front passes, that winds can shift 45 to 90 degrees with a warm front and up to 180 degrees with a cold front.
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. and often toward values at risk.
Surfacing or Low-Level Jets	25 to 45 mph	Generally occurs hundreds of feet above the ground, and can impact fire plume.
Whirlwinds	50 (and higher) mph	Create dust devils and fire whirls. Inflow winds from around the whirl can be significant. Strong winds in the outer portion of the whirl can lift large embers.
Glacier Winds	30 to 50 mph	Downslope winds from glaciers that can extend well below areas with snow and ice cover.

Local Winds

Wind Type	Typical Windspeed Ranges	Interpretations
Upslope	3 to 8 mph	Follows sun on slopes.
Up valley	10 to 15 mph	Peaks in the afternoon with upslopes.
Downslope	2 to 5 mph	Follows evening end of upslope winds.
Down valley	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.

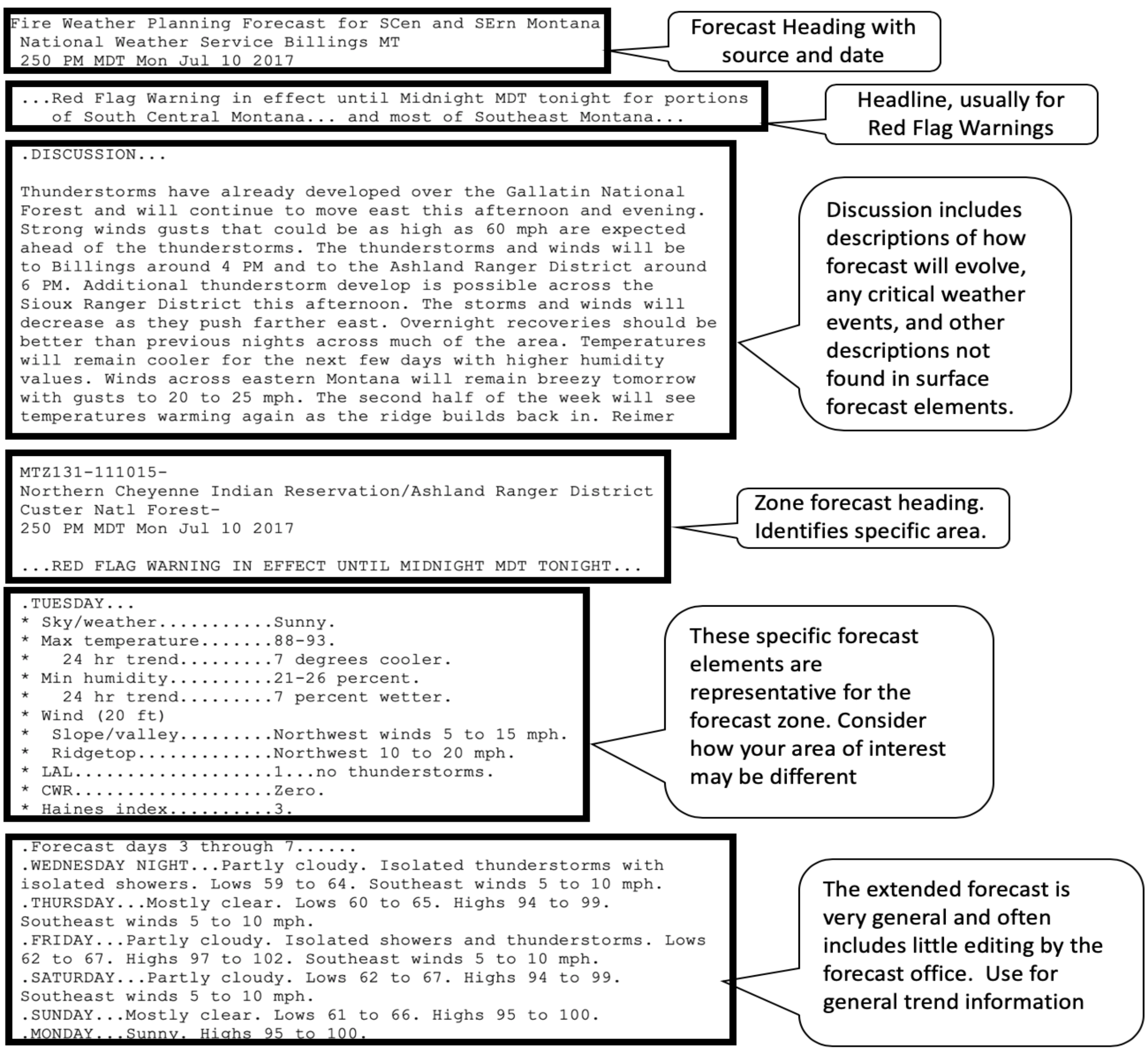
NWS Fire Weather Planning and Spot Weather Forecasts.

NWS local weather forecast office contacts can be found by clicking the map found at this link, https://www.weather.gov/stormready/contact.

The daily fire weather planning forecast and the spot weather forecasts have similar headings, headlines, discussion, and specific surface forecast elements, though there are important differences:

- 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.

Figure 2. Example narrative fire weather 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.
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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 buildups during stable conditions tend to be wider and flatter, sometimes covering much of the sky.

Note: strong general winds are still possible during stable conditions, depending upon the weather pattern.

<u>Smoke, Dust, and Fire.</u>

- A rising smoke column indicates neutral or unstable conditions. Flattening column indicates inversion at that point.
- A smoke column that changes direction as it rises indicates wind shear or local wind influence.
- A smoke column developing a Pyrocumulus cap cloud indicates strong instability and impending downdrafts.
- Haze and poor visibility are indicators of inversions. Is this localized (nighttime 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.
- Fire whirls 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. Fire whirls are difficult to predict.
    - Note: Be aware of the potential for gusty erratic winds and firebrand transport when dust devils and fire whirls are observed.

<u>Lightning and Wind.</u>

- 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.

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.

Monitoring Precipitation on the Fireline with Repurposed Water Bottles:

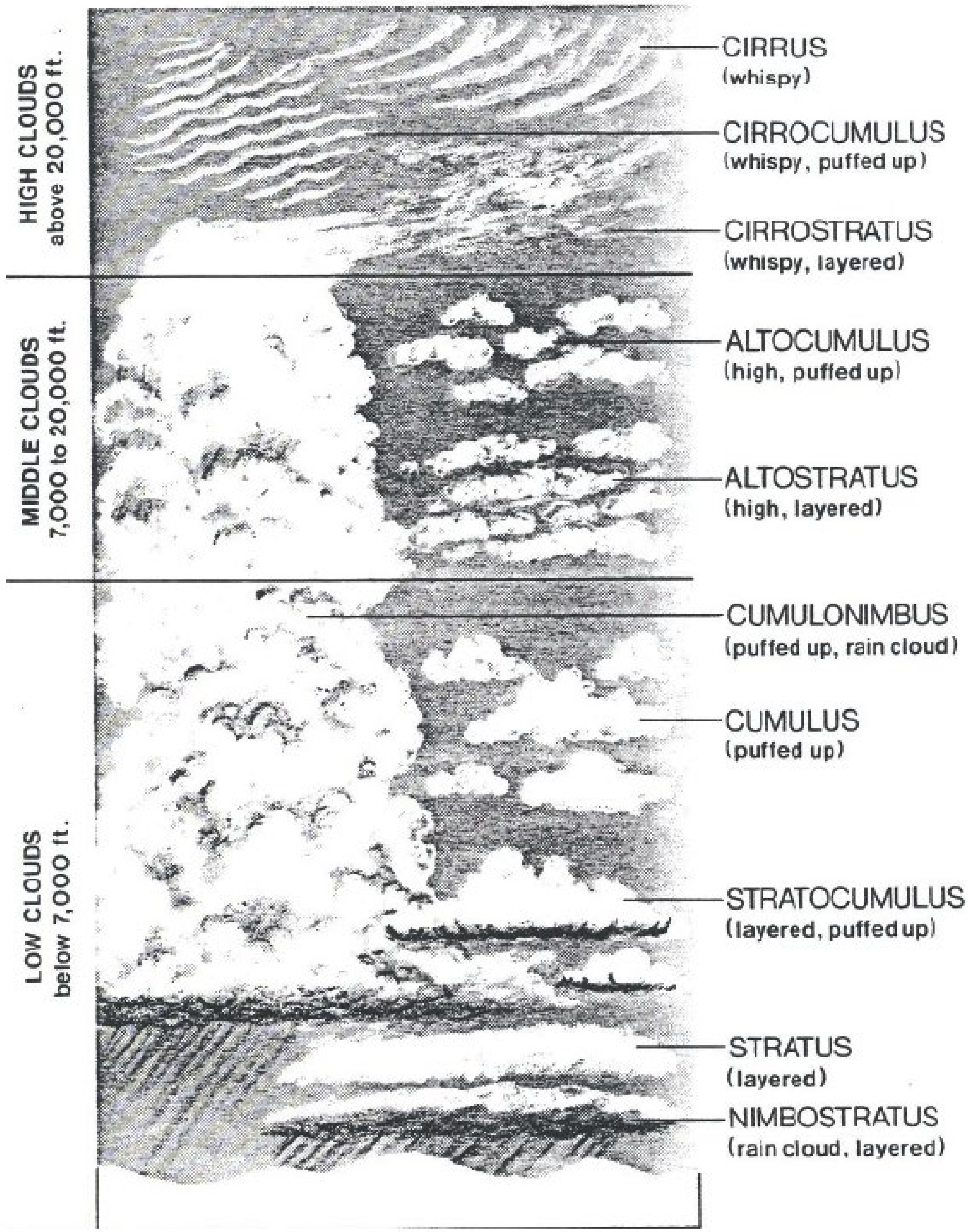
	Water bottles can be repurposed like this: • Cut the top off and connect, inverted, as a funnel. • Fill with water to a level that is full diameter and mark the zero line at that level. • If windy, reinforce with dirt, rocks and sticks around the base. • Measure from zero line upwards to determine inches of rain over observation period.

A network of these rain gauges on and near the fireline can provide valuable information that can be reported up the chain of command and included on the spot forecast request.

The Fire Weather Cloud Identification Chart.

The *NWCG Fire Weather Cloud Chart*, PMS 438 (https://www.nwcg.gov/publications/438) depicts sky signs of interest for wildland firefighters. These are valuable observations for 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 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 like 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.

Temperature and Humidity Observation.

Estimating temperature, RH, and dew point can provide insight into 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 Video Tutorial, in the WFSTAR Catalog, found at the following link, https://www.nwcg.gov/publications/training-courses/rt-130/fire-environment/fe401.

1. If your sling has been in your pack, you may need to hang it 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 to shade the psychrometer. If possible, take weather observations over a fuel bed that is representative of conditions the fire is burning in. Pick a site away from the fireline, roadways, or the 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 or distilled water at air temperature.
5. Ventilate thermometers by whirling at full arm's length, slowly, at about two revolutions per second. 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 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 or oily 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.
- Whirling the psychrometer too quickly can cause the wick to dry so rapidly that the wet bulb low point is not correctly captured.

Handheld Electronic Weather Instruments.

- Allow to acclimate out of pack or pocket for 3-5 minutes. Calibrate the 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 are included in the belt weather kit and provided with the *NWCG Fire Behavior Field Reference Guide*. The tables allow you to estimate RH and dew point from dry bulb (DB) and wet bulb (WB) temperatures.

The full set of tables can be found at this link, https://www.nwcg.gov/publications/pms437/weather/temp-rh-dp-tables#TOC-Full-Set-PDF-

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 (bottom value) and dew point (top value) in that cell.

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

DB temperature (black font) is located on the left axis and the WB temp (green) is located at the top of each column. Cells at their intersection include the resulting RH (red) and dew point (blue).

Figure 4. Example Psychrometric Table.

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		39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79
61	DP	-17	-3	6	12	18	22	26	29	33	35	38	40	43	45	47	49	51	53	55	56	58	59																			
61	RH	4	7	11	14	18	22	26	30	34	38	42	47	51	56	60	65	69	74	79	84	89	95																			
62	DP	-31	-9	2	9	15	20	24	28	31	34	37	39	42	44	46	48	50	52	54	56	57	59	60																		
62	RH	2	5	9	12	16	20	23	27	31	35	39	43	48	52	56	61	65	70	75	80	85	90	95																		
63	DP		-18	-3	6	12	18	22	26	30	33	36	38	41	43	45	47	49	51	53	55	57	58	60	61																	
63	RH		3	7	10	14	17	21	25	28	32	36	40	44	48	53	57	61	66	70	75	80	85	90	95																	
64	DP		-32	-9	2	9	15	20	24	28	31	34	37	40	42	45	47	49	51	53	54	56	58	59	61	63																
64	RH		1	5	8	11	15	18	22	26	29	33	37	41	45	49	53	57	62	66	71	75	80	85	90	95																
65	DP			-18	-3	6	13	18	23	27	30	33	36	39	41	44	46	48	50	52	54	55	57	59	60	62	64															
65	RH			3	6	9	13	16	20	23	27	30	34	38	42	46	50	54	58	62	67	71	76	80	85	90	95															
66	DP			-32	-9	2	10	16	21	25	29	32	35	38	40	43	45	47	49	51	53	55	57	58	60	61	63	65														
66	RH			1	4	8	11	14	17	21	24	28	31	35	39	43	47	51	55	59	63	67	72	76	81	85	90	95														
67	DP				-18	-3	6	13	18	23	27	30	34	37	39	42	44	46	48	50	52	54	56	58	59	61	63	64	66													
67	RH				3	6	9	12	15	19	22	25	29	32	36	40	43	47	51	55	59	63	68	72	76	81	86	90	95													
68	DP				-32	-9	2	10	16	21	25	29	32	35	38	41	43	45	48	50	52	54	55	57	59	60	62	64	65	67												
68	RH				1	4	7	10	13	17	20	23	26	30	33	37	41	44	48	52	56	60	64	68	72	77	81	86	90	95												
69	DP					-17	-3	7	13	19	23	27	31	34	37	40	42	45	47	49	51	53	55	56	58	60	62	63	65	66	68											
69	RH					3	6	9	12	15	18	21	24	27	31	34	38	41	45	49	53	56	60	64	69	73	77	81	86	91	95											
70	DP					-31	-9	3	10	16	21	26	29	33	36	39	41	44	46	48	50	52	54	56	58	59	61	63	64	66	67	69										
70	RH					1	4	7	10	13	16	19	22	25	28	32	35	39	42	46	49	53	57	61	65	69	73	77	82	86	91	95										
71	DP						-17	-2	7	14	19	24	28	31	35	38	40	43	45	47	49	51	53	55	57	59	60	62	64	65	67	68	70									
71	RH						3	5	8	11	14	17	20	23	26	29	33	36	39	43	46	50	54	58	61	65	69	73	78	82	86	91	95									
72	DP						-30	-8	3	11	17	22	26	30	33	36	39	42	44	46	49	51	53	55	56	58	60	62	63	65	66	68	69	71								
72	RH						1	4	7	9	12	15	18	21	24	27	30	34	37	40	44	47	51	54	58	62	66	70	74	78	82	86	91	95								
73	DP							-16	-1	8	15	20	24	28	32	35	38	41	43	46	48	50	52	54	56	58	59	61	63	64	66	67	69	70	72							
73	RH							3	5	8	11	13	16	19	22	25	28	31	34	38	41	44	48	51	55	59	62	66	70	74	78	82	87	91	95							
74	DP							-28	-7	4	12	18	23	27	31	34	37	40	42	45	47	49	51	53	55	57	59	61	62	64	65	67	68	70	71	73						
74	RH							1	4	6	9	12	14	17	20	23	26	29	32	35	38	42	45	48	52	55	59	63	67	70	74	78	83	87	91	95						
75	DP								-14	0	9	15	21	25	29	33	36	39	41	44	46	48	51	53	55	56	58	60	62	63	65	66	68	69	71	72	74					
75	RH								3	5	8	10	13	16	18	21	24	27	30	33	36	39	42	46	49	52	56	60	63	67	71	75	79	83	87	91	96					
76	DP								-26	-6	5	13	18	23	27	31	35	38	40	43	45	48	50	52	54	56	58	59	61	63	64	66	68	69	70	72	73	75				
76	RH								1	4	6	9	11	14	17	19	22	25	28	31	34	37	40	43	46	50	53	57	60	64	67	71	75	79	83	87	91	96				
77	DP								-54	-13	1	9	16	21	26	30	33	36	39	42	45	47	49	51	53	55	57	59*	61	62	64	66	67	69	70	71	73	74	76			
77	RH									3	5	7	10	12	15	18	20	23	26	29	32	34	37	41	44	47	50	54	57	61	64	68	71	75	79	83	87	91	96			
78	DP									-23	-4	6	13	19	24	28	32	35	38	41	44	46	48	51	53	55	56	58	60	62	63	65	67	68	70	71	73	74	75	77		
78	RH									1	4	6	9	11	13	16	19	21	24	27	29	32	35	38	41	44	48	51	54	57	61	64	68	72	76	79	83	87	91	96		
79	DP									-45	-11	2	10	17	22	27	30	34	37	40	43	45	48	50	52	54	56	58	60	61	63	65	66	68	69	71	72	74	75	76	78	
79	RH										3	5	7	10	12	14	17	20	22	25	27	30	33	36	39	42	45	46	51	55	58	61	65	68	72	76	80	84	88	92	96	
80	DP										-20	-3	7	14	20	25	29	33	36	39	42	44	47	49	51	53	55	57	59	61	62	64	66	67	69	70	72	73	75	76	77	79
80	RH										2	4	6	8	11	13	15	18	20	23	26	28	31	34	37	40	43	46	49	52	55	58	62	65	69	72	76	80	84	88	92	96

Vapor Pressure Deficit (VPD).

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 and incorporated as an input to Fire Danger Rating.

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

°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

Estimating Surface Wind Speed and Direction.

<u>Visual Estimate of Wind Speed – The Beaufort Scale.</u>

One of the first scales to estimate wind speeds and the effects was created by Britain's Admiral Sir Francis Beaufort. He developed a scale, in 1805, to help sailors estimate the winds using visual observations. This version is adapted for use on land. The Beaufort scale is still used today to estimate wind strengths without the aid of instruments.

Figure 6. Modified Beaufort Wind Scale for Land Application.

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.

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 height of 20-30 feet above the ground, in an area where the horizontal distance between the instrument and obstructions is at least ten times the height of the obstruction.

- Midflame wind speeds are derived from the 20- to 30-foot surface wind measurements for use in fire behavior assessments.
- 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.
- A **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 18 mph and the variation in wind speed between the peaks and lulls is at least 10 mph. The duration of a gust is usually less than 20 seconds.

Critical Winds as Surface Winds.

Critical winds are events that dominate the fire environment and easily override local wind influences.

Examples (frontal winds, Foehn winds etc.) are listed in the table on page 9 and are discussed, in more detail, below.

Breakdown of the Upper Ridge and Cold Frontal Passage.

Three main stages:

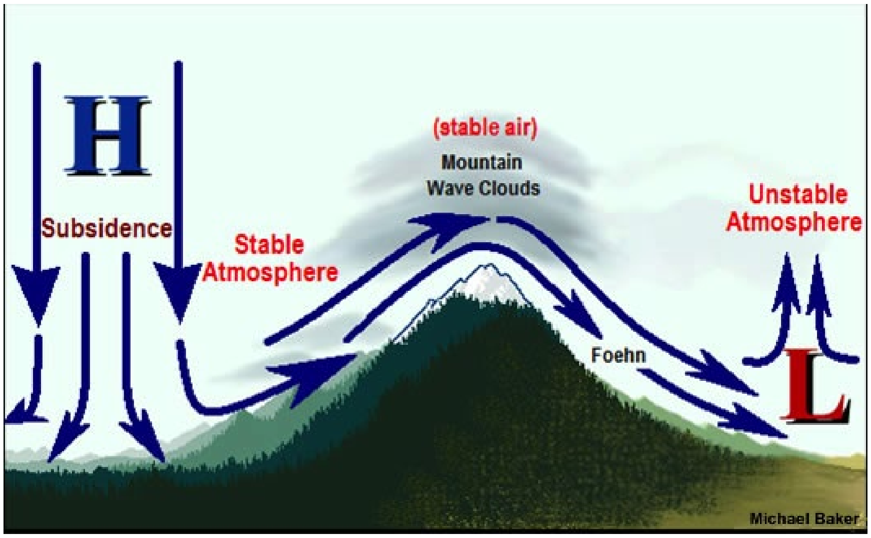
- First stage represents warmer-drier-breezy and unstable conditions.
- Second stage wind speeds will increase while conditions remain warm-dry and unstable.
- Third stage is defined by a cold frontal passage.

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

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 (California) and Chinook winds (Eastern Rockies).

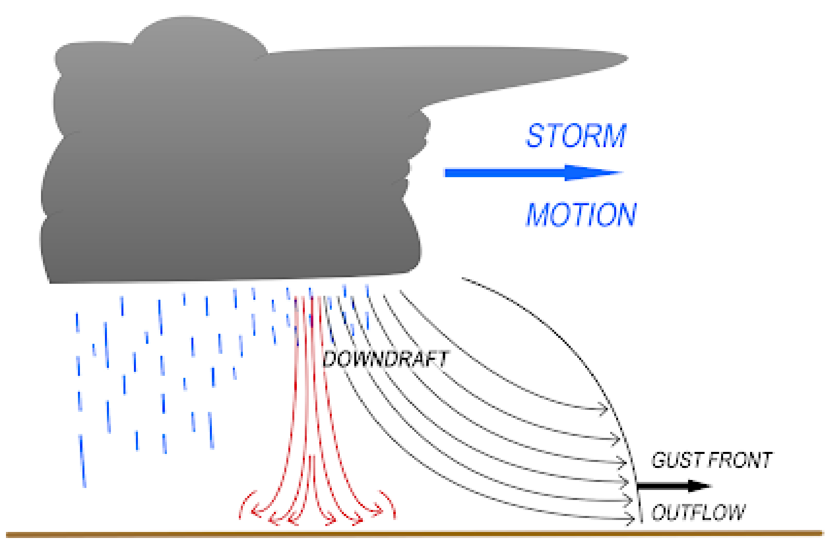
Figure 8. Atmospheric pressure and wind flows that produce Foehn Winds.



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 miles. 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 9. Thunderstorm downburst, outflow, and gust front.

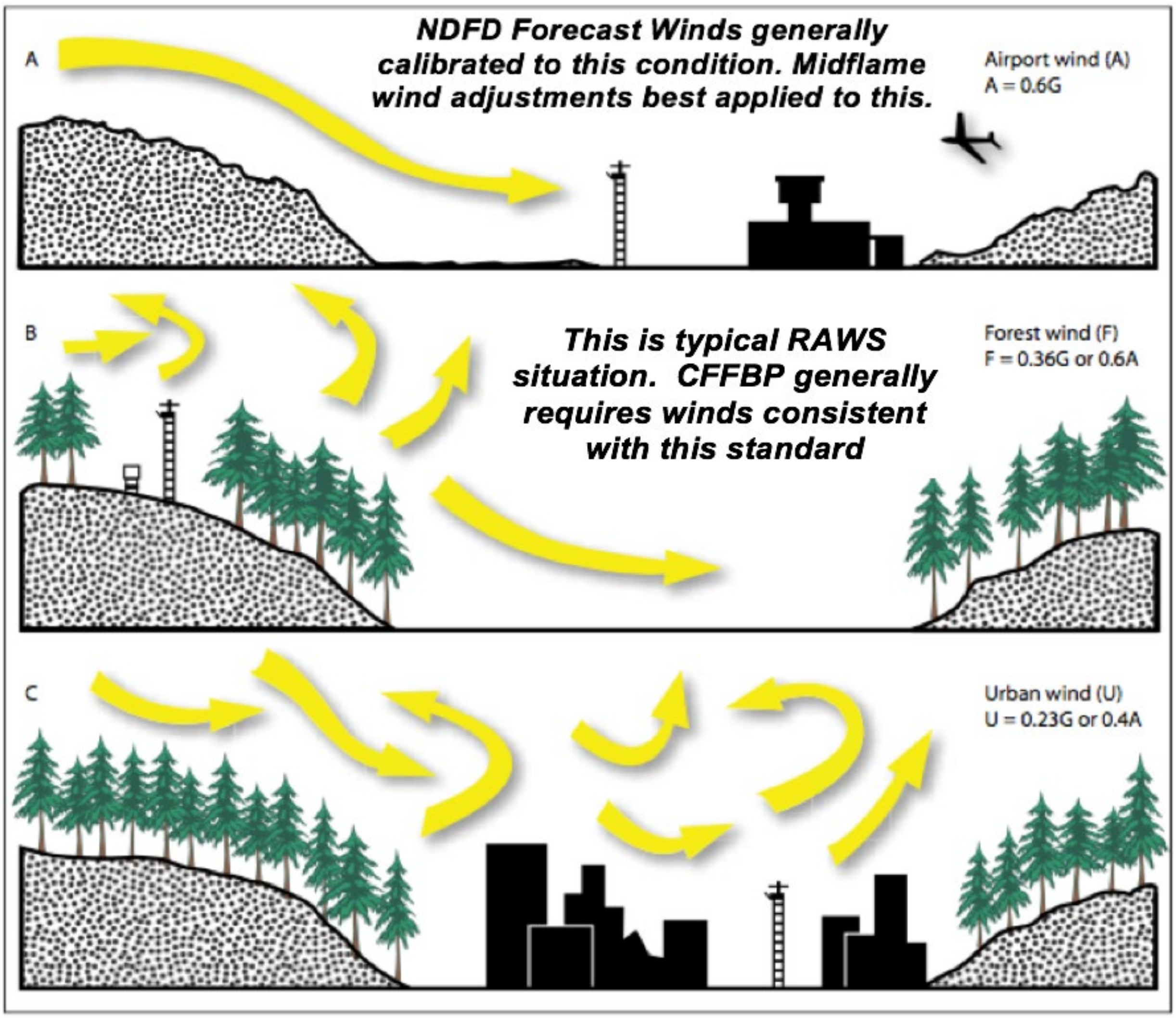


Observed Surface Windspeed.

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 versus 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. 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 the table below, "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 convert observations at the sensor location to the surface windspeed at the international standard 10m (33 feet) 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 Adjust. 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 most cases, the standard Fire Weather Planning Forecasts prepared and distributed by your local 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 20 ft) is provided and qualified based on influences like terrain (elevation, slope, and aspect) and mix of vegetation. Midflame wind speed 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 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 in a forested landscape, multiplying by 0.7 as a first try to improve CFFDRS FWI and FBP estimates.

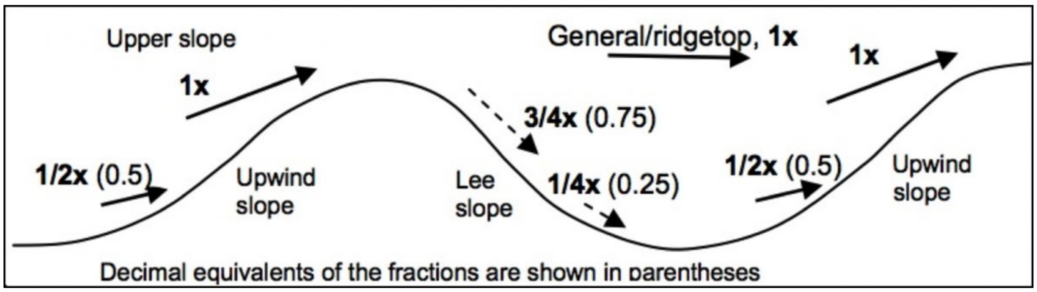
Adjusting Surface Wind Speed Forecasts for Your Situation.
Forecasted winds may relate to specific locations or broad general areas. The user needs to understand what wind forces (General, Local, Critical) are not integrated into the provided forecast and make adjustments as needed.

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, 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.

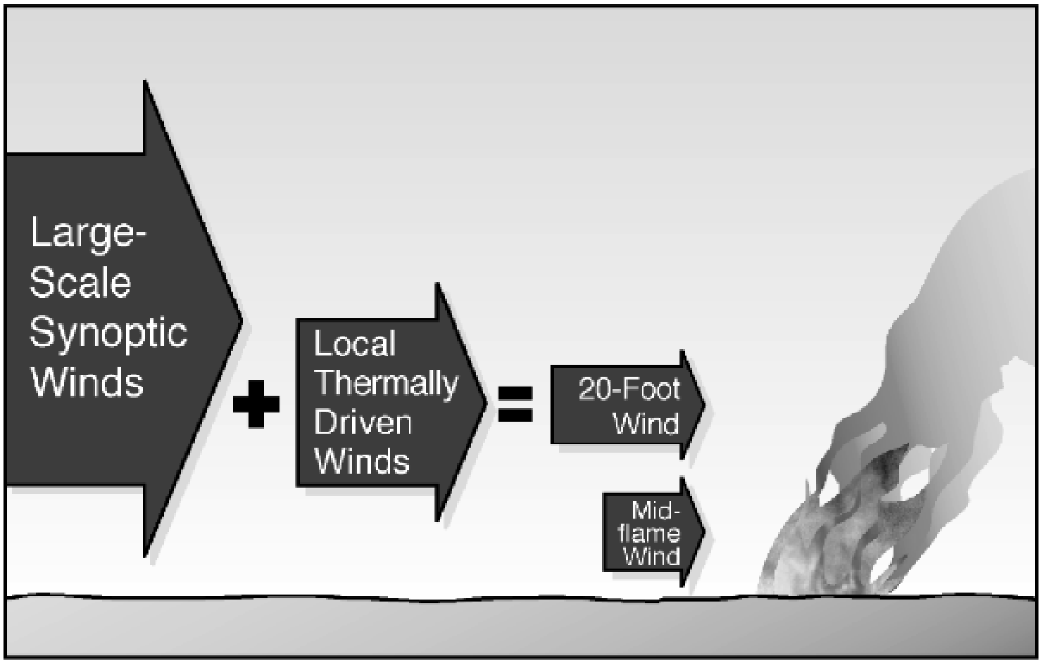
Thermal, convective, orographic, and gravity winds are all caused by local temperature differences generated over a comparatively small area by terrain and weather. They differ from general winds in that they are limited to near surface and are controlled by the strength of the daily solar cycle.

- **Slope Winds** are driven by heat exchange at the slope surface. They can react quickly to sun on a 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. Down valley 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 3-10 mph.

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.

The image, below, 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.



Combine Critical, General, Local Winds into Surface Wind Speed Forecast.

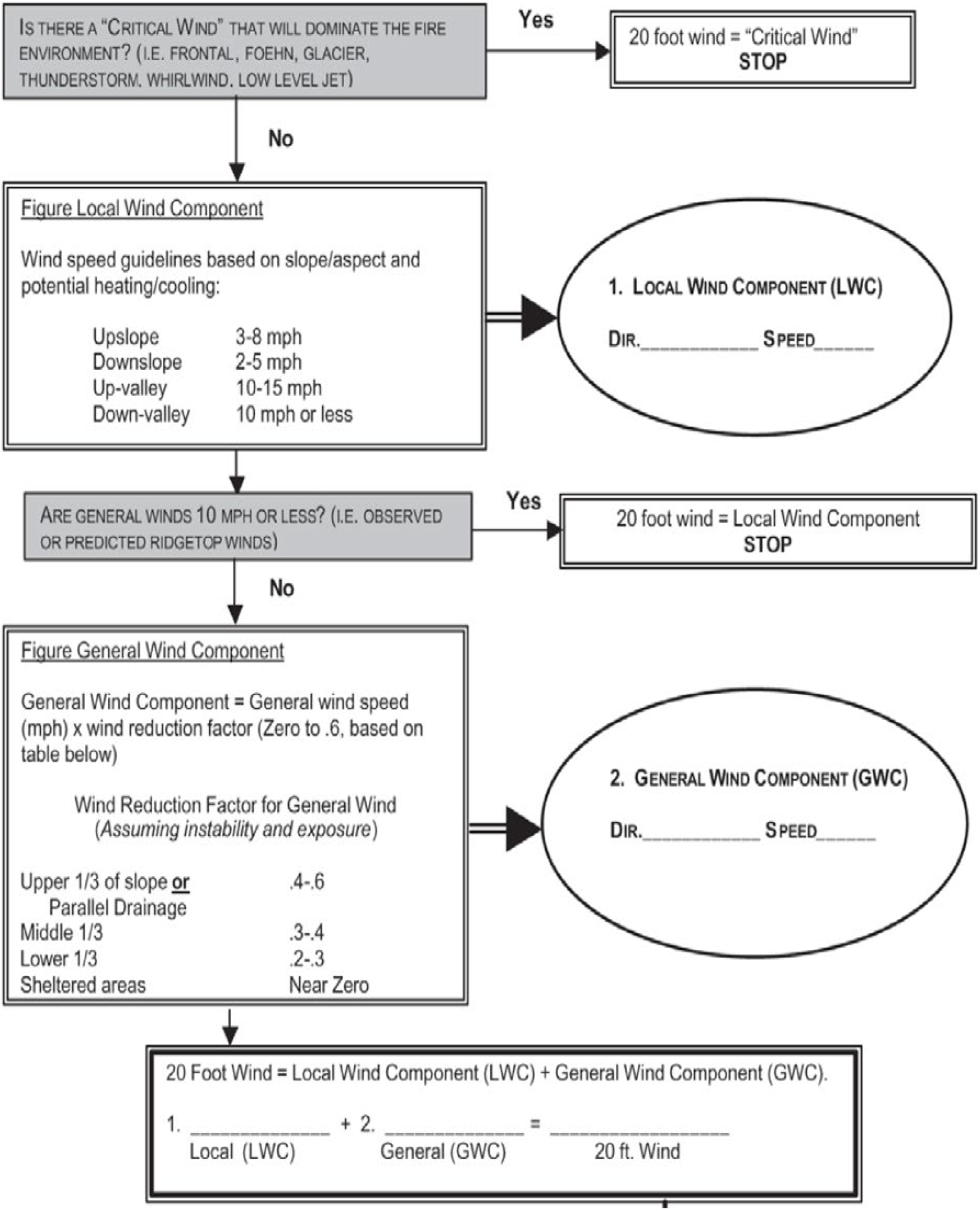
Both Planning and Spot Weather forecasts attempt to tailor windspeed forecasts to the submitted area of concern. Some represent winds for several situations (e.g., ridge, slope, valley locations) in the forecast. However, it is impossible to characterize every situation in mountainous terrain in a narrative. **Wind Ninja**, https://www.firelab.org/project/windninja, is an app for computers and mobile devices that uses a fluid dynamics model to help answer this question, spatially, and evaluate the influence of terrain on windspeed and direction.

The Surface Windspeed Worksheet.

Employ the worksheet**,** on the following page, to estimate forecast winds for your location if the 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 a 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, the forecast wind is the surface wind.
- Do general and local winds work together or oppose each other? Will that mean gustiness?

Figure 13. Surface Windspeed Worksheet.



Fuel Characteristics.

What surface fuels are burning at the fire's 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.

Fuel bed 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.

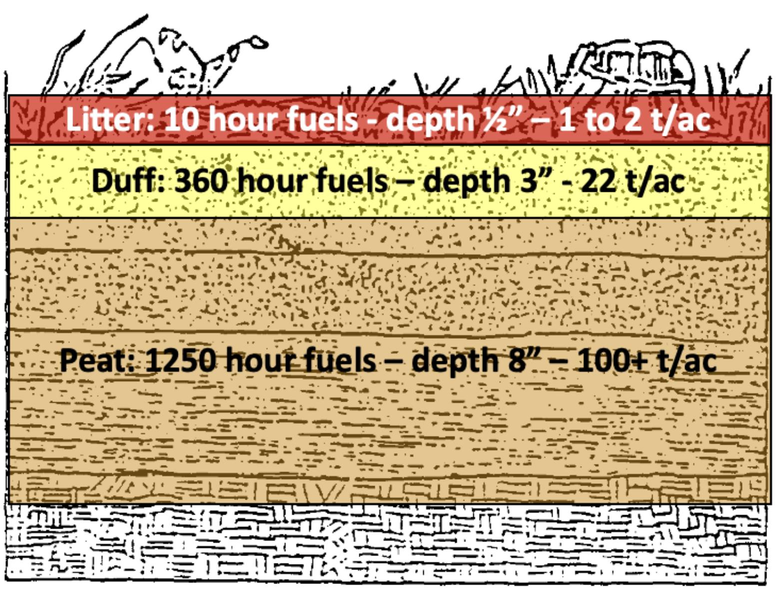
What surface fuels are, and will be, burning at the fire's leading edges? (continued)

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. Some live grasses (e.g., sawgrass) contain volatile oils that burn well, even when live.

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 of concern during the forecast period.

Duff fuels below the surface: In many situations, the surface fuel bed 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**, mop-up 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 are heavy loading and ladder fuels that connect to the crowns. Be aware of holdover fire and mop-up problems.

Are Trees and Shrubs Expected to Burn? (continued)

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.

Talk with local experts and take note of species and communities that burn readily. Make sure you can identify the vegetation of concern.

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 moderating effect of any 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.

Note: sun/safety glasses with orange lenses can make stressed vegetation much more apparent.

Is there damage to fuels ahead of the fire? (continued)

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. Frost nipped leaves take on a 'wilty' appearance.

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 previously burned areas.

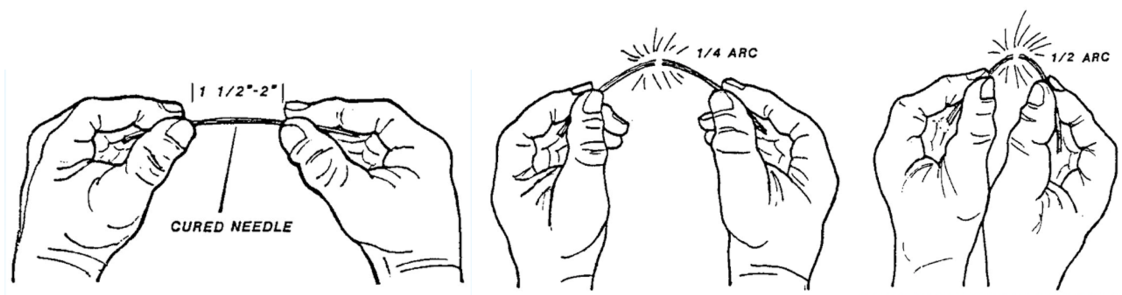
Fuel Moisture Observations; Field Estimation.

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 pine needles. Different fuel types and size classes 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; Shaded Long-Needle Pines (1-hour).

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

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



If the needle breaks before:

- ¼ arc: moisture content 4-7%. Burning conditions are very favorable.
- ½ arc: moisture contents 8-11%. Burning conditions are favorable.

If the needle does not break:

- 1-hr fuel moisture is high. Burning conditions are marginal.

If available, NFDRS 10-hour Fuel moisture sticks can be appropriately placed and weighed on scales to obtain acceptable fuel moistures. The 1-hour fuel moisture can be estimated by subtracting 1-2% from measured 10-hour moistures.

Duff Moisture.

The full depth of litter and duff layers should always be checked. If the lower layers are damp, this means that some litter or duff may remain after the fire and, even if charred, this can leave a protective covering over the soil.

If lower litter and duff layers are dry, fires will burn more intensely, especially in deep duff. The residual subsurface burning can force any remaining moisture out of the layers, and even the organic soil can begin to smolder. This phenomenon can impact an area for many weeks, despite control efforts, and cause 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 a heavy morning 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 the 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 sizes within the timelag class.
- Recently fallen material should be avoided.
- Remove all lichen, moss, and very loose bark from the 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 to between 60°C (140°F) – 100°C (212°F). Be sure to note the temperature used.
- Place un-taped 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 for 48 hours).
- Replace lids immediately after sample is removed from oven and weigh.
- Calculate fuel moisture using the worksheet in Figure 15 below:

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

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

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**

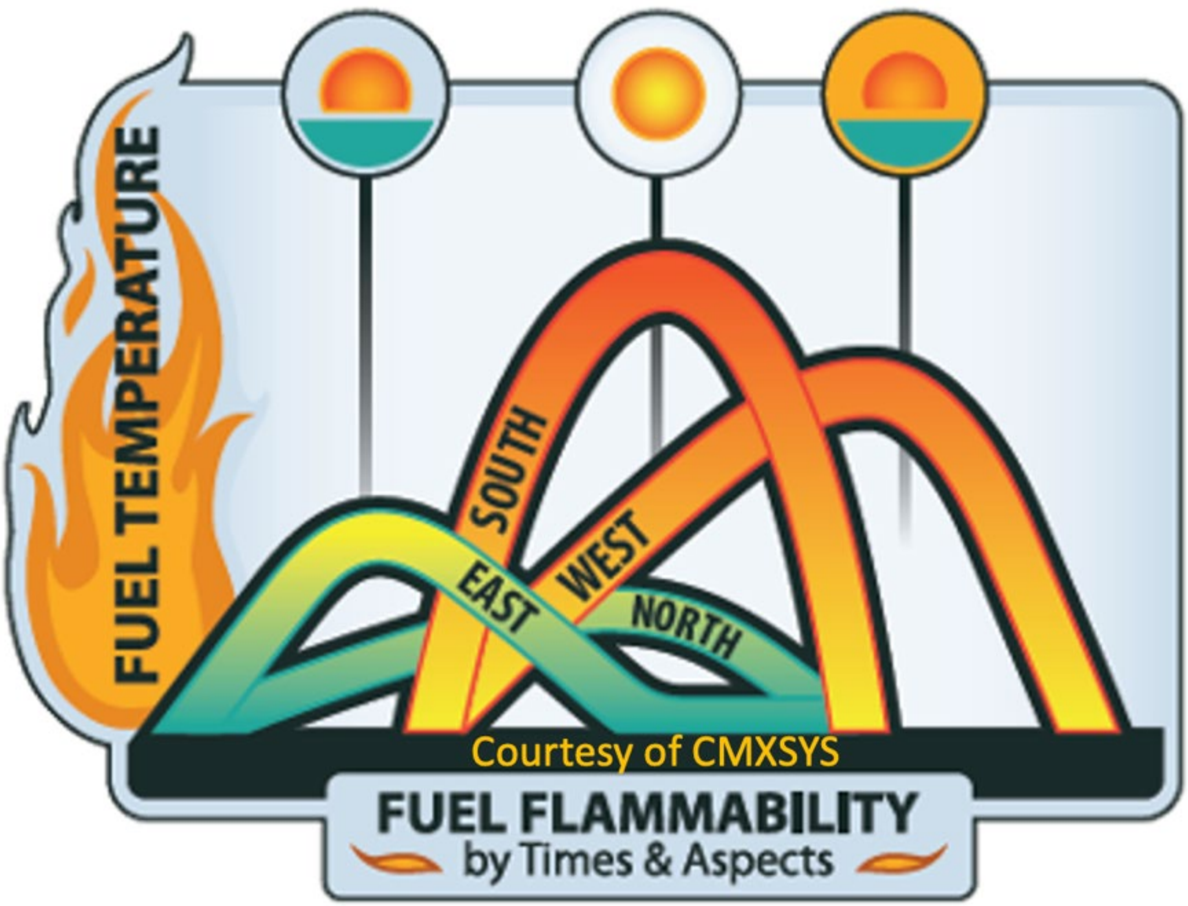
Terrain Features and Alignments.

Flammability Alignment Based on Aspect and Time of Day.

Use Figure 16, below, 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 are heated 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.

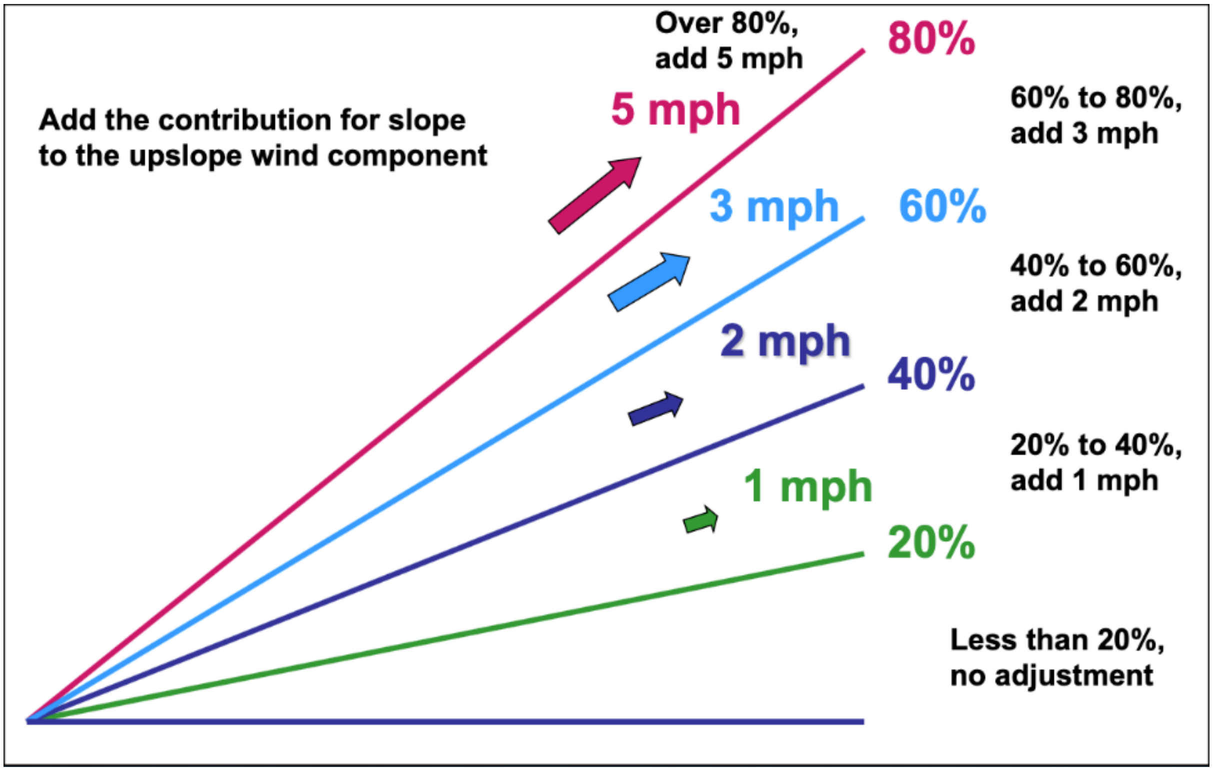


Steep Slopes.

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

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)



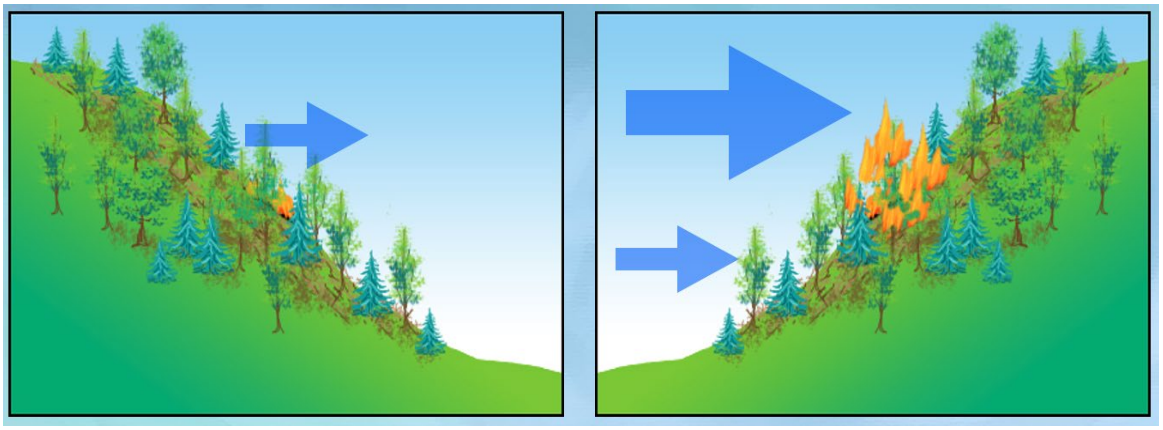
Be aware of fire below you on slopes and consider safety warnings about working above them.

- 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).



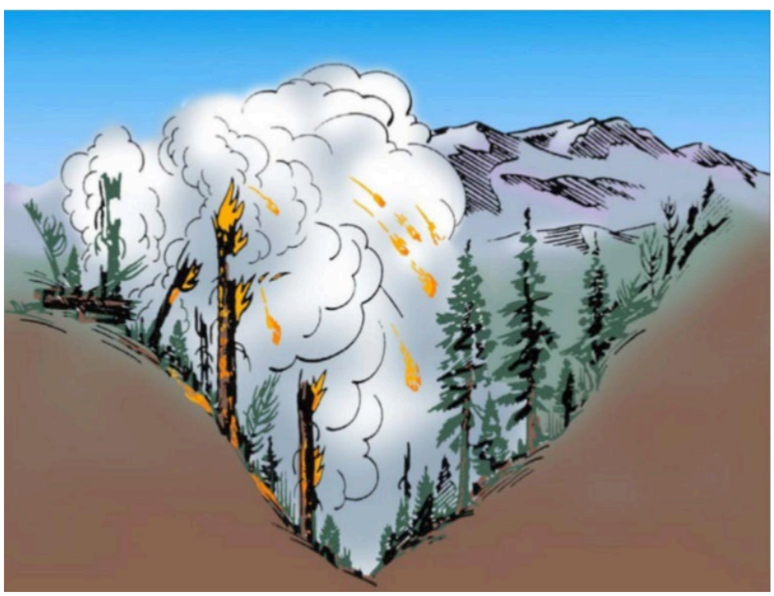
Narrow Canyons.

Narrow, steep canyons have produced many extreme fire events.

- Intensify heating on both sides when sunlight reaches the lower slopes.
- Channel winds, raising windspeed significantly.
- When under an inversion that breaks, fire behavior can increase very suddenly.

These narrow canyons can produce slope reversals from rollout, sending fires across at the bottom and/or through mid-slope spotting. 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.

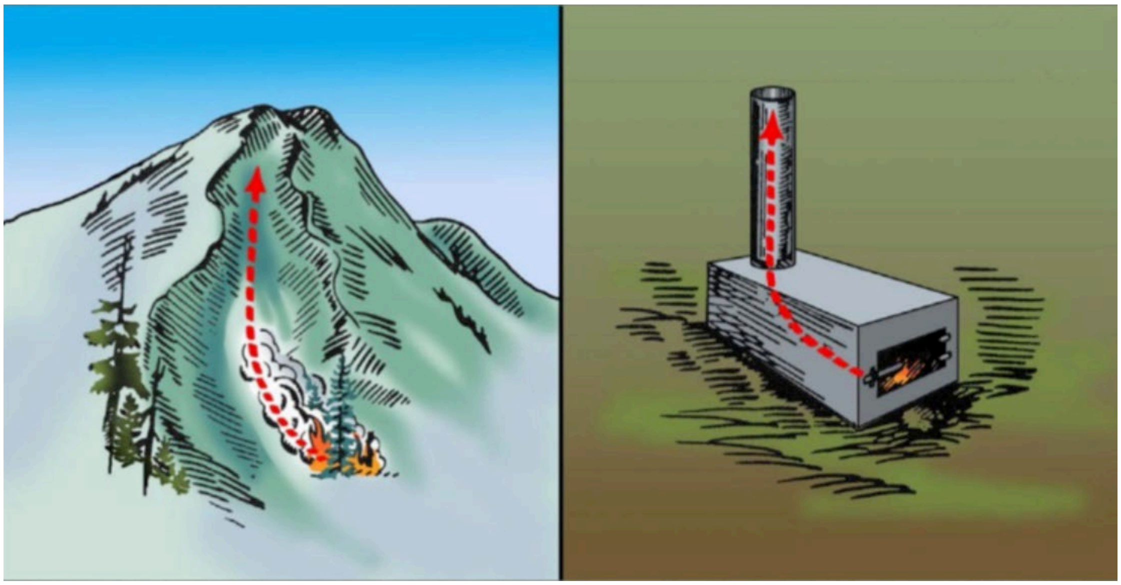


Box Canyons and Chutes as Chimneys.

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 any fire below you that can reach these chimneys. Consider the aspect of these features and what time of the day they will receive direct sunlight and become the most flammable.

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



Saddles, Passes and Gaps – Impacts on Windspeed and Direction.

These terms refer to different geographic features with similar topographic influences. Any of these breaks in blocking terrain will permit winds to be forced through at an increasing speed with greater turbulence, and eddying winds on the lee side. They differ, primarily, in the depth of the terrain break and how they are encountered in fire operations.

If you have experience with whitewater recreation, you can apply that knowledge to wind, which exhibits the same fluid **dynamic**s of water. Wind flows through eddies on the lee side of a saddle in the same way that water does behind two rocks in a river. The effects on the water/wind will differ based on the flow speed and the size, shape, and orientation of the feature(s).

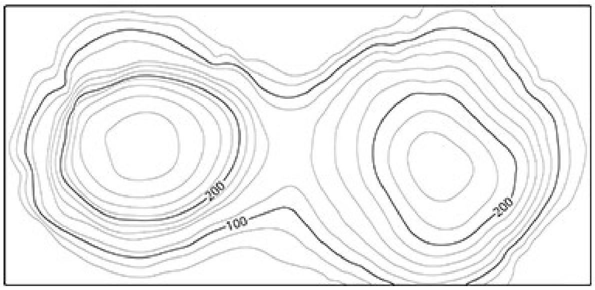
Tools like WindNinja, https://www.firelab.org/project/windninja, and experiential context, can assist in assessing terrain impacts on wind.

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.

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.

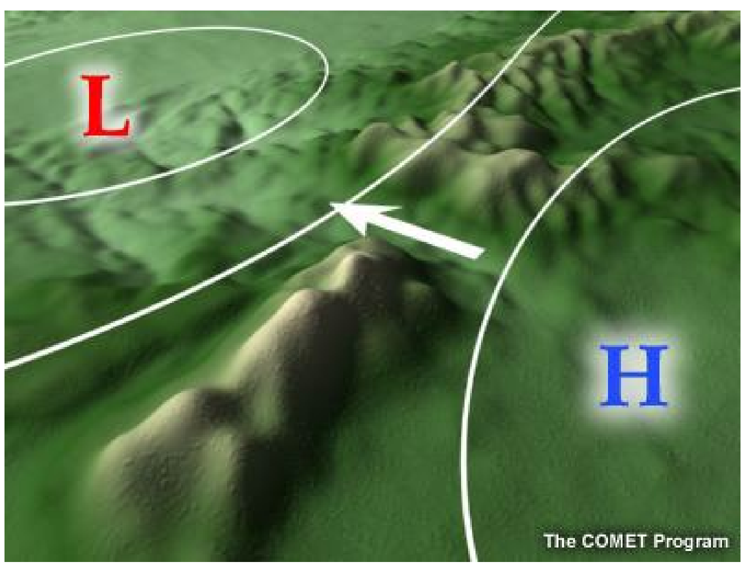
Passes are usually deeper than saddles and are named to represent locations where it is easiest to cross mountain ridges. When identified as named features, passes can be the locations of significant roads, trails, and traffic. Like saddles and gaps, passes permit wind to pass through blocking ridges 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.

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



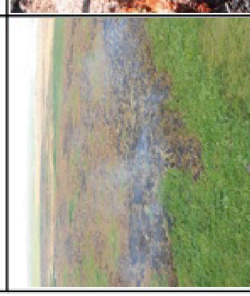
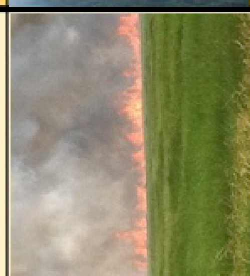
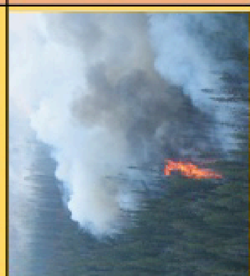
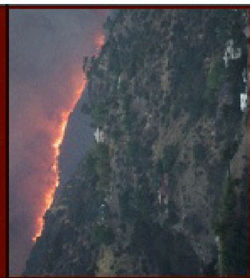
Gaps are the deepest of these depressions in mountain ridges. It is not uncommon for them to drop to the valley bottom with sharp steep sides. Associated with old geologic fault lines and deep river cuts. But, because these are frequently abrupt features in otherwise unbroken terrain, they are sites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

Figure 22. Gaps



Visual Fire Behavior Observation & Description.

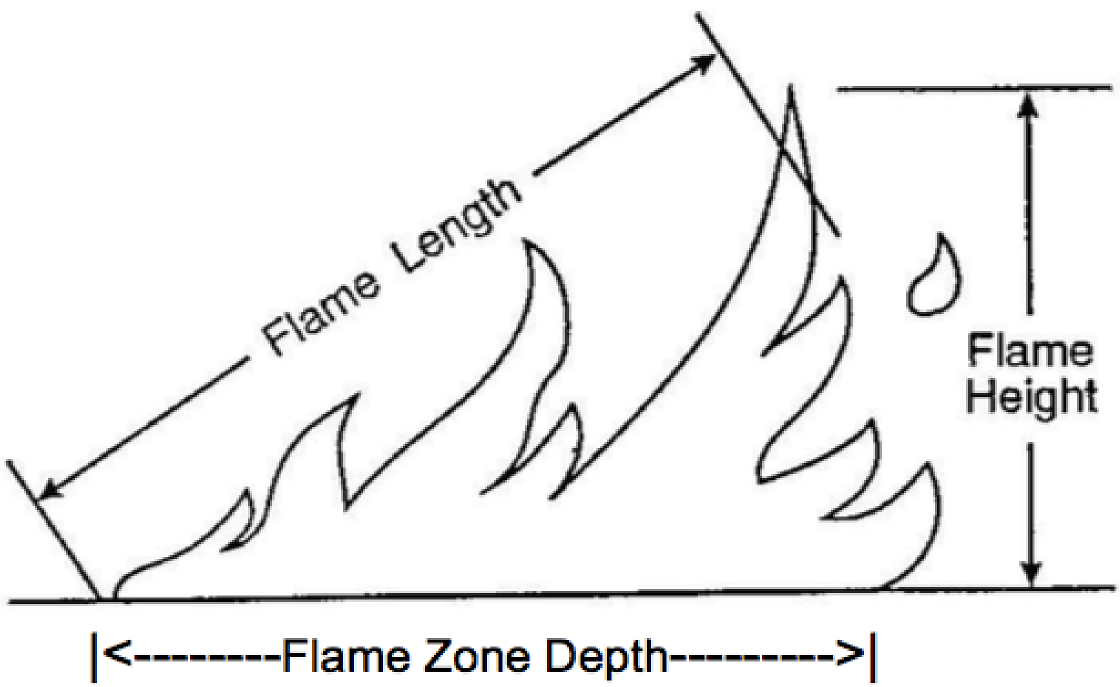
Figure 23. Fire Observation/Description Guide.

Surface Fire When fire is on the ground			***Crown Fire*** When trees and 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

Flame Length vs Flame Height.

Observing Flames, as proxy for fireline intensity and an indicator of tactical limitations, requires careful observation of flame length versus flame height. It is important to identify whether the observation is for the head, flank, or back of the fire as these differ greatly. Think of the following three measurements as forming a right triangle, as depicted in the image, below.

Figure 24. Flame length and flame height.



Flame Height: The average height of flames as measured from top to bottom. The vertical dimension of the triangle. It can be estimated by comparing the flame to a nearby object of known height.

Flame Length: The distance measured from the height of the average flame tip above the ground, down and back to the middle of the lower active flaming zone on the surface. It forms the hypotenuse of the triangle. It is measured on a slant when the flames are tilted due to effects of wind and slope. The greater the slope or wind effect, the more this measurement will exceed the Flame Height.

Flame Zone Depth: This measurement is not commonly used for operational needs. Flame Zone depth can provide an indication of 'residence time' and fire severity to surface layers. It is the horizontal (ground) measurement of the triangle, from the back to the front of the average active flame zone.

Rate of Spread Estimator Table.

Fireline observers can use this table to look up a timed spread rate to estimate how long a flaming front will take to move a given distance in one hour.

Spread Distance (ft)				
1	3	5	10	ROS
Time in Minutes (') and seconds (")				ch/hr (ft/min)
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.)

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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.

Use the thresholds and interpretations in this section, along with anticipation of spotting spread and active crown fire, to inform strategy and tactics and to inform LCES practices. 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.

Fire Behavior Classes, Interpretation.

These fire behavior classes correspond to those used in the Fire Observation and Description Guide (Figure 23) and with the six shades in the Fire Characteristics Chart (Figure 25).

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.**

Fine-Fuel Moisture and Fire Behavior.

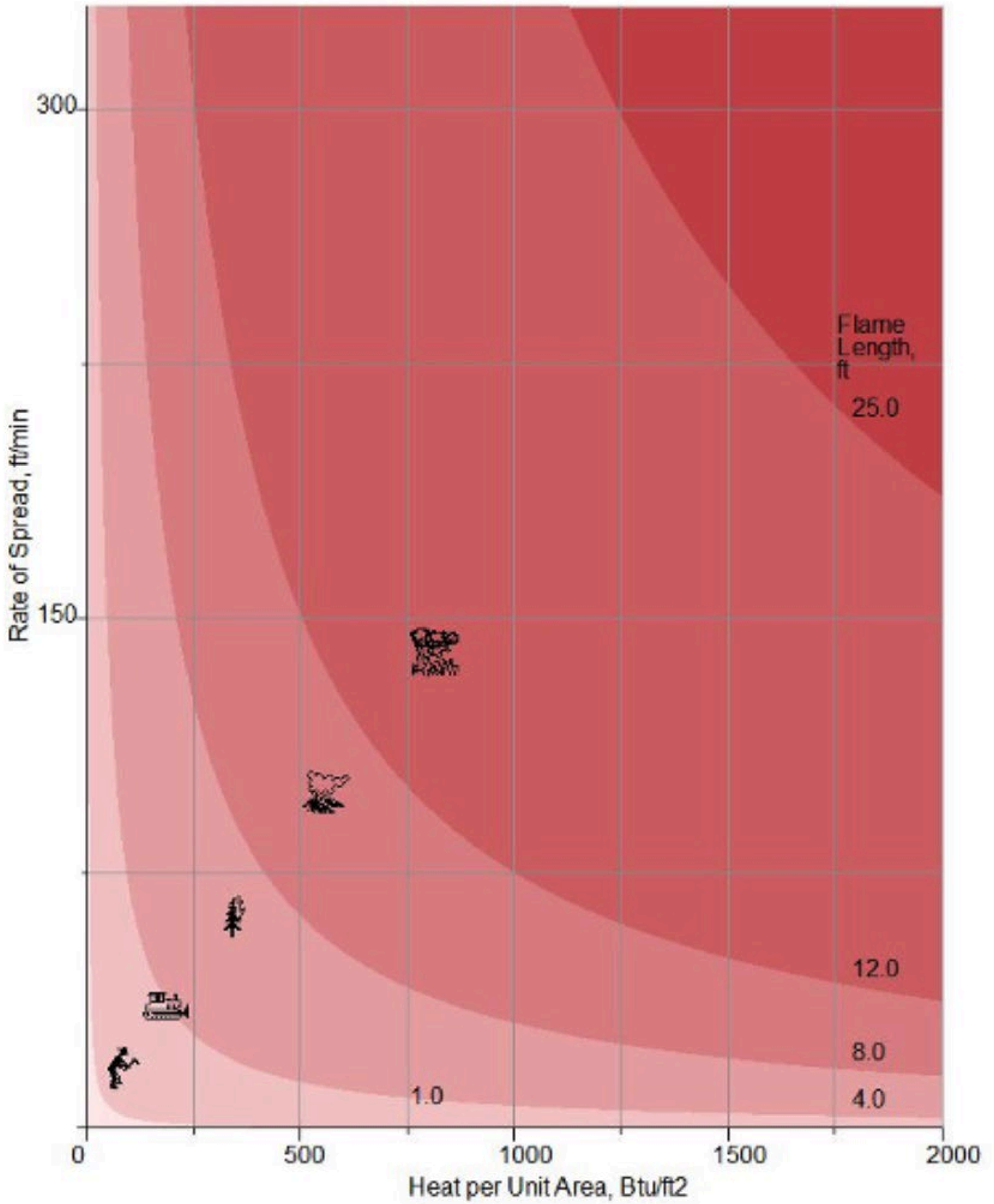
Table 2. Fire ignition Potential Factors.

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 Characteristics (Hauling) 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.



Fire Behavior Quick Tips.

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

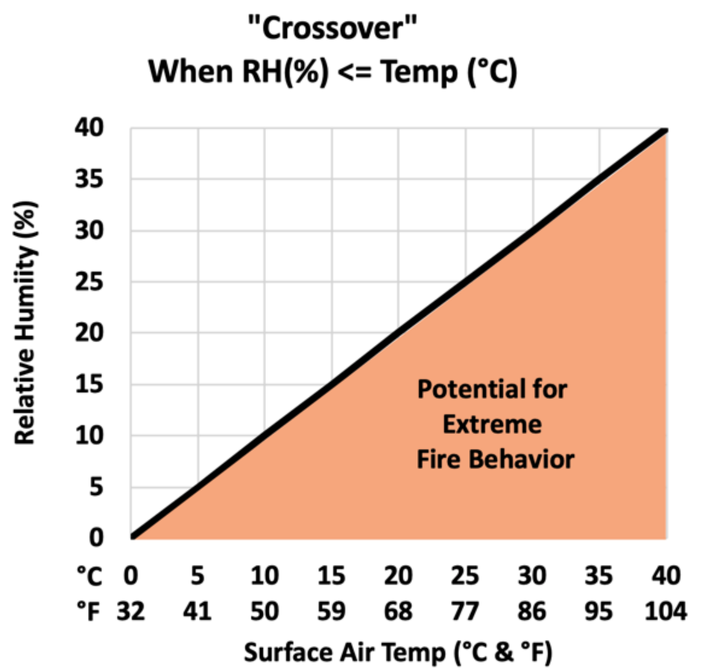
Figure 26. Crossover highlights potential for extreme fire behavior.

The combination of temperature and RH, falling in the orange area in graph, to the right, signals potentially severe fire behavior.

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

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

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



Estimating Rate of Spread from Surface Windspeed.

This calculation is for use on active wildfire during peak seasons. Use with grass fuels or with brush/crown fire. Note that slope effect is not included, so this estimation is best used for flat to gently rolling terrain. It is just an estimate. The error could be plus or minus 50% from actual spread.

In the table, below, find the **unsheltered surface windspeed** (20ft or eye level) and move downward to get a rate of spread for grass or brush/crown fires, respectively. The rate of spread result is in miles per hour. Multiply by 80 to get chains per hour. A result of '?' means that the grass spread is wind limited.

Table 3. Rate of Spread based on surface windspeed.

Input windspeed (mph)…

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

...corresponds to spread rate (mph).

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

Alexander and Cruz (2019), Bishop (2007), Lawson and Armitage (2008).

Part Two – Fire Environment Assessment Methods

Estimate Expected Fire Behavior.

You cannot use a single factor or 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** is often described using the Probability of Ignition (PIG) to evaluate the potential for spot fires. See the table on page 71.
- **Rate of Spread** is estimated and classified using the fire behavior classes, above.
- **Flame Length** is 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 (https://training.nwcg.gov/pre-courses/s290/S-290%20Student%20CD/FLAME%20in%20a%20Nutshell.pdf) (https://www.fs.usda.gov/research/treesearch/28551), he focused on the next big changes in the fire environment and identified these as:

- 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. Evaluation of the fire environment at the beginning, and throughout the operational period, can help anticipate and predict the "next big change" estimation of fire behavior.

Gather and Prepare the Inputs.

The Fire Behavior Worksheet, found on page 51, 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.
- 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.

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

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.

Fire Behavior Worksheet.

Use this worksheet to guide the process of collecting inputs and arriving at estimates. It can document your thinking about the fire environment as you are making your assessment.

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 U.S. 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. 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,* https://www.nwcg.gov/sites/default/files/training/docs/s-290-usfs-standard-fire-behavior-fuel-models.pdf, 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.

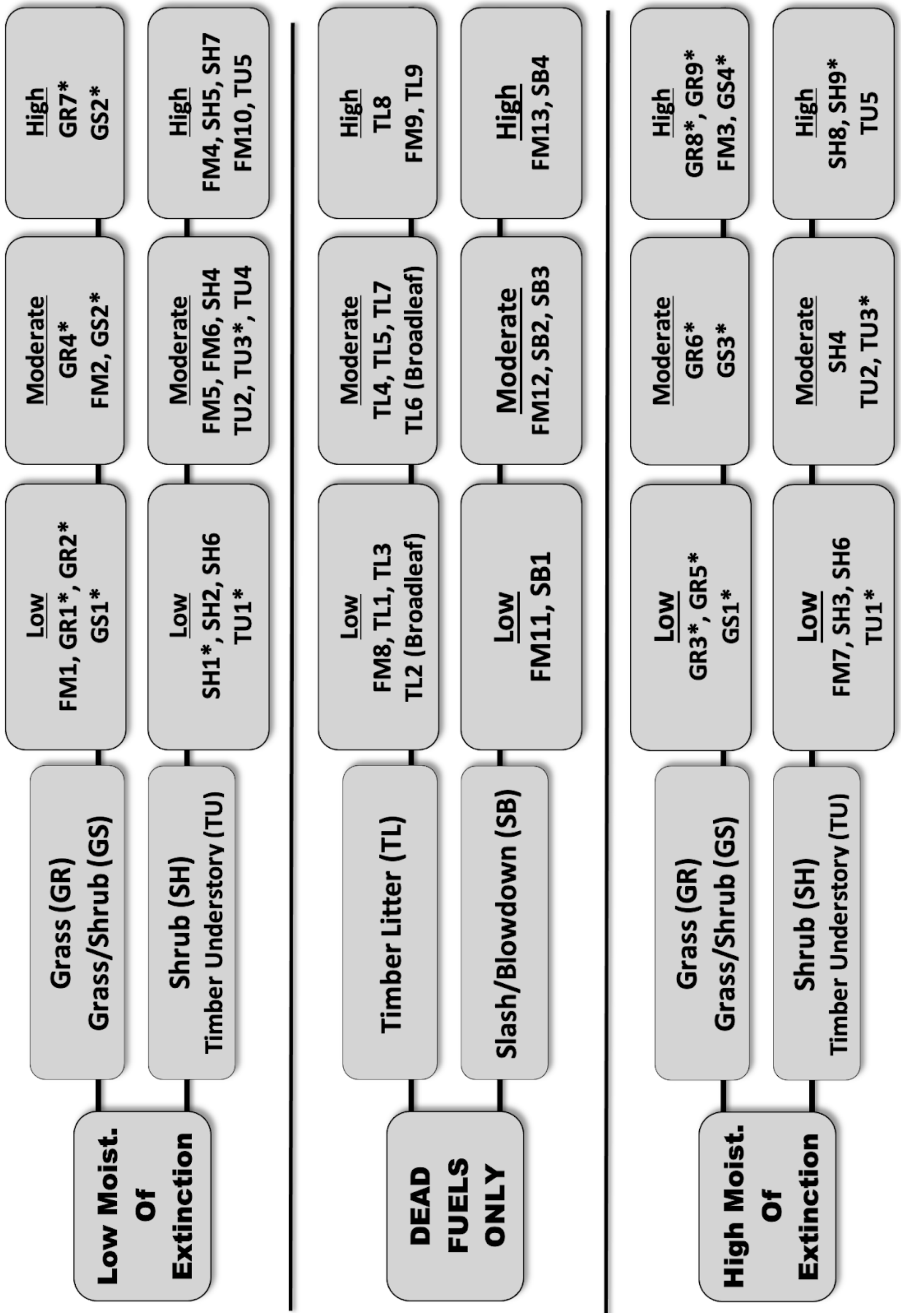
Start with the conventional locally suggested fuel model selections when available. Compare those to what the Fuel Model Selector Tool, Figure 28, on the following page, suggests.

1. Determine if live fuels are contributing to fire spread (asterisked in the tool).
2. 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.
3. Consider how much heat the fire might produce in low, moderate, or high conditions.

Try several alternatives, and both low and high moisture of extinction choices, when calibrating.

Note: Fuel models were developed based on the fire behavior observed from various fuel loadings and depths under different moisture and wind conditions in a controlled lab environment and then, were categorized in terms of fuel types to assist with selection. The vegetation descriptions and photos that follow are provided as a starting point, however, a timber model could burn more like a slash or a shrub model under certain conditions. Select a model based on observed fire behavior (rate of spread, flame length) for that model. A 'perfect fit' model selection will match real world fire behavior even when the weather, terrain and fuel moisture conditions change.

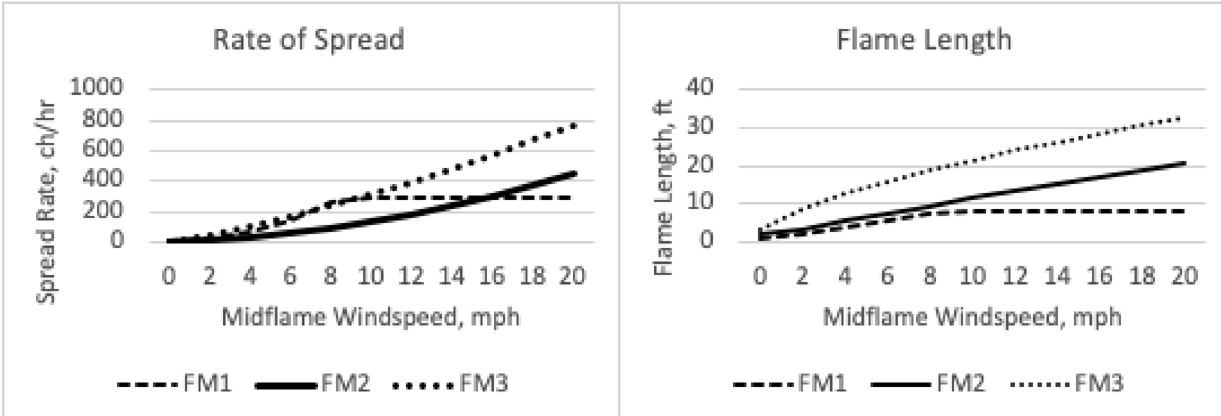
Figure 28. Quick Fuel Model Selector Tool. Uses moisture of extinction, primary carrier fuel category, and potential flammability to suggest fuel models. Asterisk (*) denotes a dynamic fuel model with live herbaceous load transfer potential.



Grass and Grass-Shrub Fuels.

Anderson (1982) Fuel Models.

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



	**<u>FM1 (01)</u>**: 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.
	**<u>FM2 (02)</u>**: 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.
	**<u>FM3 (03)</u>**: 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 like tall prairie and marshland grasses.

Scott and Burgan (2005) Fuel Models.

All these fuel models use dynamic transfer of herbaceous fuel load from live to dead as live fuel moisture falls below 120%. More info 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 fuel beds but may also be applied in high-extinction moisture fuel beds, 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. Fuel bed 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 fuel bed 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 herbaceous fuel load is relatively light; fuel bed 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.

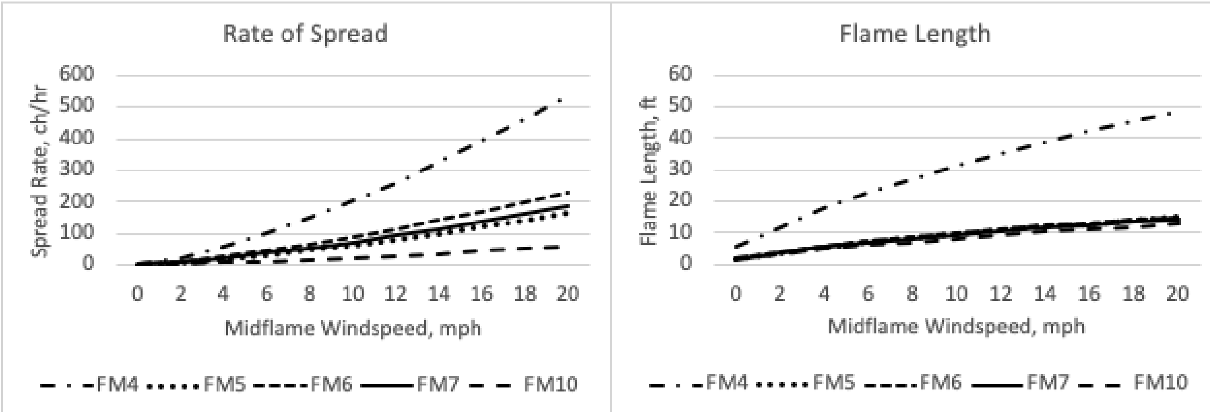
Figure 30. Grass and Grass-Shrub Fuel Model Parameter Table.

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

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 herbaceous fuel load from live to dead. The primary carrier of fire is woody shrubs and shrub litter. Low shrub fuel load, fuel bed depth about 1 foot; some grass may be present. Spread rate very low, flame length very low.
- **SH2 (142):** The primary carrier of fire is woody shrubs and shrub litter. Moderate fuel load (higher than SH1), depth about 1-ft, and no grass fuel present. Spread rate and flame length low.
- **SH5 (145):** The primary carrier of fire is woody shrubs and shrub litter. Heavy shrub load, depth 4-6 feet..
- **SH7 (147):** Primary carrier of fire is woody shrubs and shrub litter. Very heavy shrub load, depth 4-6 ft. Spread rate lower than SH5, flame length similar. Spread rate and flame length very high.
- **TU1 (161):** This model uses **dynamic** transfer of herbaceous 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 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 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 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 is woody shrubs and shrub litter. Dense shrubs, little or no herbaceous fuel, fuel bed depth about 2 feet. Spread rate high, flame length high.
- **SH8 (148):** The primary carrier of fire is woody shrubs and shrub litter. Dense shrubs, little or no herbaceous fuel, fuel bed depth about 3 feet. Spread rate high, flame length high.
- **SH9 (149):** This model uses **dynamic** transfer of herbaceous 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 is moderate litter load with shrub component. Spread rate moderate, flame length low.
- **TU3 (163):** This model uses **dynamic** transfer of herbaceous fuel load from live to dead. The primary carrier of fire in TU3 is moderate forest litter with grass and shrub components. Spread rate is high, flame length moderate.

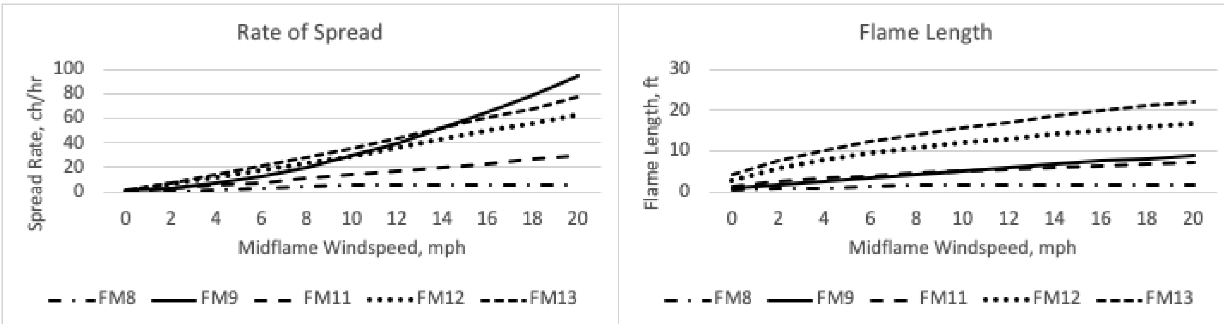
Figure 32. Shrub and Timber-Understory Fuel Model Parameter Table.

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

Timber Litter and Slash/Blowdown Fuels.

Anderson (1982) Fuel Models.

Figure 33. Timber Litter and Slash/Blowdown 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 ten pieces, 4 inches in diameter, along a 50-foot 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):** 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 tons/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 tons/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 tons/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, fuel bed not compacted, most foliage and fine fuel still attached to blowdown. Spread rate very high, flame length very high.

Figure 34. Timber Litter and Slash Blowdown Fuel Model Parameter Table.

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	--

Determine Elevation, Slope, and Aspect.

Elevation and Lapse Rate.

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

- It may be necessary to adjust RH up if the fire is burning at elevations more than 2000 feet above the weather observation location. Assume the same dew point and lower temperature based on lapse rate of 3-5 degrees per 1000 ft elevation change. 3 degrees lapse represents saturated air and is on the low side. For dry conditions, in peak fire season, 5 degrees is most appropriate.
- Conversely, it may be necessary to adjust RH down if the fire is burning at elevations more than 2000 feet below the weather observation location. Assume the 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.

Drying from solar heating impacts fuels the most dramatically on steeper terrain. South and southwest aspects are the 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. Changes in slope can cause dramatic changes in fire behavior, such as slope reversals. You will need to estimate the steepness of the slope. It can be estimated as:

- an eyeball estimate of terrain in the field, or, from contour spacing on a map,
- estimated angle from a leveling app on your smart phone, clinometer, compass, or,
- using the 'rise over run' formula to calculate (instructions, below).

For field analysis, slope estimation can be, coarsely, categorized into these categories and values. Note that slope is measured in percent where a 45 (not 90) degree slope is 100%.

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

<u>Calculate Slope Percent from a Map.</u>

1. **Determine Map Scale** from the Legend (verify if map is reproduced) or from known distance measurement (e.g., one side of a square mile section at 5280 feet/mile). Note: Feet and inches are used in this example, but other units of measure can be used to calculate percent slope, as long as they are used consistently, for both the rise and run values.
   - You will need a map measurement (in inches) for the known distance of 1 mile. Table Reference for several different map scales can be found in the Map Use section of this guide.
   - Divide 5,280 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.

<u>Slope Arc/Angle vs Percent.</u>

Slope (Degrees)	Slope (Percent)	Slope (Degrees)	Slope (Percent)
10°	17.6%	50°	119.2%
20°	36.4%	60°	173.2%
30°	57.7%	70°	274.7%
40°	83.9%	80°	567.1%
45°	100%	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-hour estimates, 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 tool is offered, here, for field use.

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)

1. Using **Figure 35 to get a Reference Fuel Moisture (RFM)** percentage from the intersection of observed temperature and RH. Record this RFM percentage.
2. Select **Figure 37, 38, or 39**, based on the month, to obtain the RFM correction to add.
3. **Determine shading**. Is the fine fuel more than 50% shaded by canopies and/or clouds (combined)? If yes, use the bottom (shaded) portion of the table. If no, use the top (exposed) portion of the table.
4. Select the appropriate row based on **aspect and slope**.
5. Select the appropriate column based on **time of day.**
6. **Choose the appropriate elevation.** Use "L" (level) if the area that you are calculating 1-hr fuel moistures is within 1000' in elevation of where the weather was collected. If you are projecting to a location above or below your weather observation, use "A" (above) if that location is 1000-2000' above your location, or, "B" (below) if it is 1000-2000' below you.
7. **Obtain the 1-hr Moisture Content Correction** (%) from the intersection of row and column.
8. **Add** the resulting 1-hr Moisture Content Correction (%) to the RFM (%) from Step 1.

Nighttime Estimates of 1-Hour Fuel Moisture.

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

1. Use Figure 35 to get an RFM value.
2. Add five to the value you get (this is based on the most common output for 0800, shaded, level in the three correction tables).

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 35. 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 36. Elevation of the fire compared to the position of the weather observation for applying the forecast.

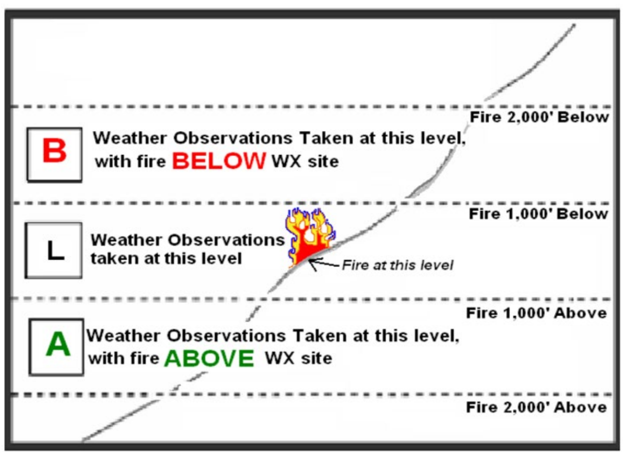


Figure 37. 1-hr Fuel Moisture Corrections (in %); **May-June-July**.

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 38. 1-hr Fuel Moisture Corrections (%); **Feb-Mar-Apr, 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 39. 1-hr Fuel Moisture Corrections (in %); **Nov-Dec-Jan**.

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	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.

Probability of Ignition (PIG).

The Probability of Ignition is the chance that a firebrand will cause an ignition when it lands on receptive fuels. This would, obviously, be difficult to measure quantitatively, in the fire environment. Figure 40, below, provides a method for estimating PIG using 1-hr fuel moisture, shading from cloud cover and tree/shrub shading (combined), and the ambient temperature.

Note that PIG assumes that all lofted embers will land on fuels that will support fire spread. A PIG of 100% assumes that every ember is hot, but this does not mean that every ember will start a spot fire. In reality, burning fuels may not be producing many firebrands and, of those that are lofted, many may get 'strained' by green foliage or land on unreceptive fuels (rock, water, soil, live fuels etc.). Conversely, a PIG of only 30% could result in activity that is very difficult control if the spotting is coming from volatile shrub fuels that are sending firebrand showers into very dry meadows.

Whether firebrands start spot fires or not depends, greatly, on the continuity and type of fuels that the fire is spotting into. PIG, when calculated every time weather is collected, provides a 0-100% scale that, regardless of actual observed spotting, incorporates fuel moistures, temperature and shading to provide a scaled indication of drying and spotting potential throughout the day.

Figure 40. Probability of Ignition Table.

	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

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 41 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 41. CFFDRS Cured Grass Fuel Equilibrium Moisture Content (%). Assumes that atmospheric moisture conditions have been relatively stable for the 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 the current status of live fuels in the field.

Figure 42. Live Fuel Moisture Content Levels

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**

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

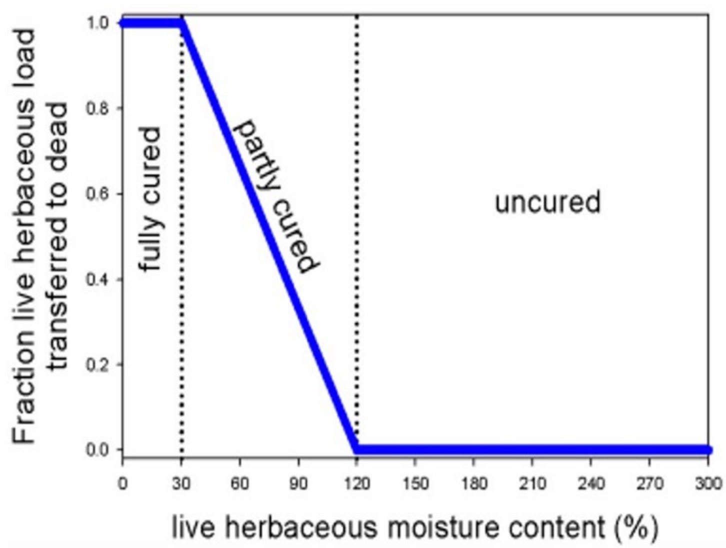
Herbaceous Fuel Moisture.

The 40 Standard Fuel Models (*Scott and Burgan, 2005*) include several grass (9), grass-shrub (4), shrub (2), and timber-understory (2) models that are influenced by herbaceous fuel moisture.

When live fuel moistures (LFM) in dynamic models are between 30% and 120%, a fractional portion of the live fuels are transferred into the dead category (Figure 43).

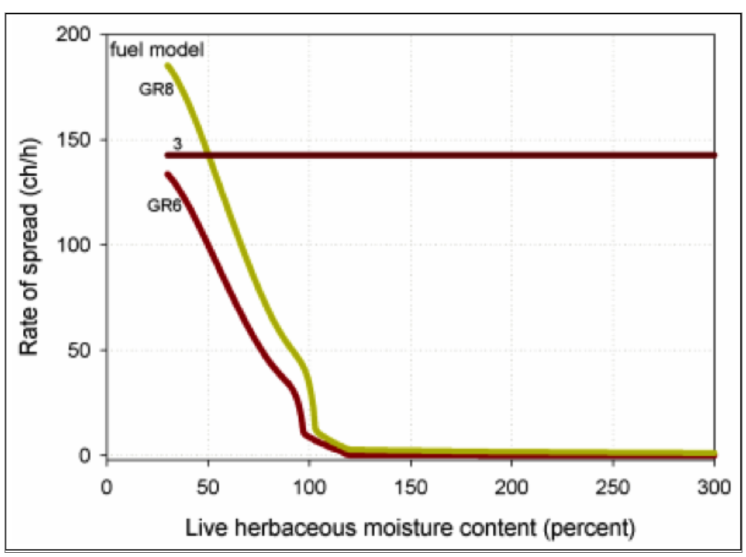
- At 30 percent LFM and below, all the live fuels will be considered dead (fully cured).
- At 75% LFM (midway between 30% and 120%), half of the live fuels are considered dead.
- At 53% LFM (a quarter of the way from 30% and 120%), 75% of the live fuels transfer to dead.
- LFM above 120% (100% uncured) usually limits fire spread in dynamic fuels.

Figure 43. Herbaceous fuel load transfer.



In some models, there is a dramatic drop in spread rate that is noted when herbaceous fuel moisture input is around 90% to a little over 100%. Small incremental changes in that range could result in a jump from no spread at all to 40 chains per hour.

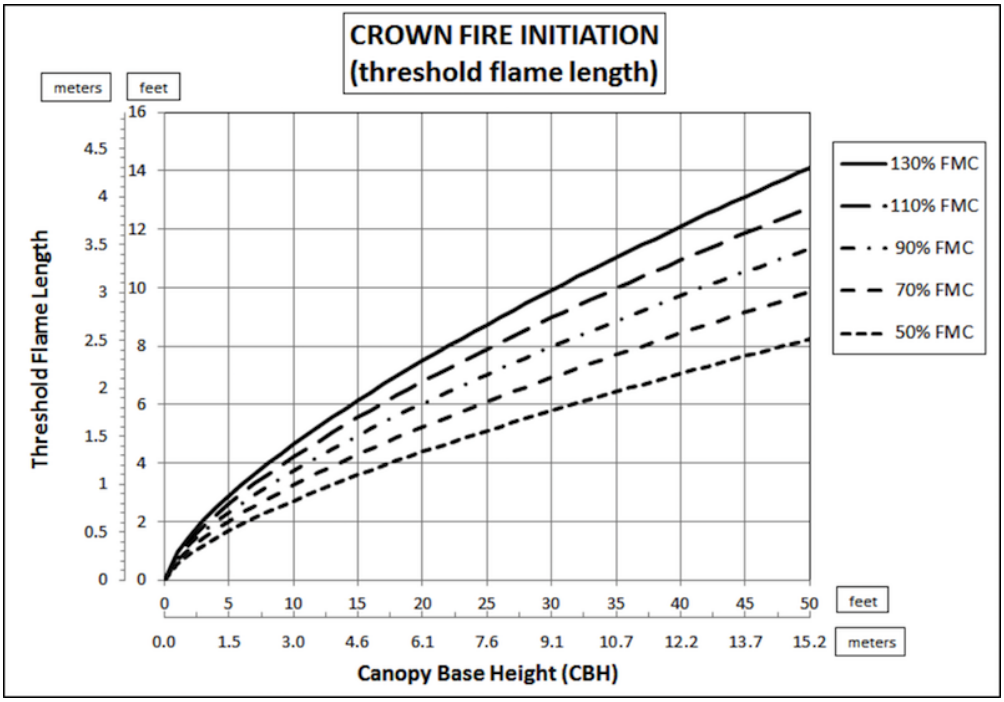
Figure 44. Effect of fuel load transfer.



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 45. 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.



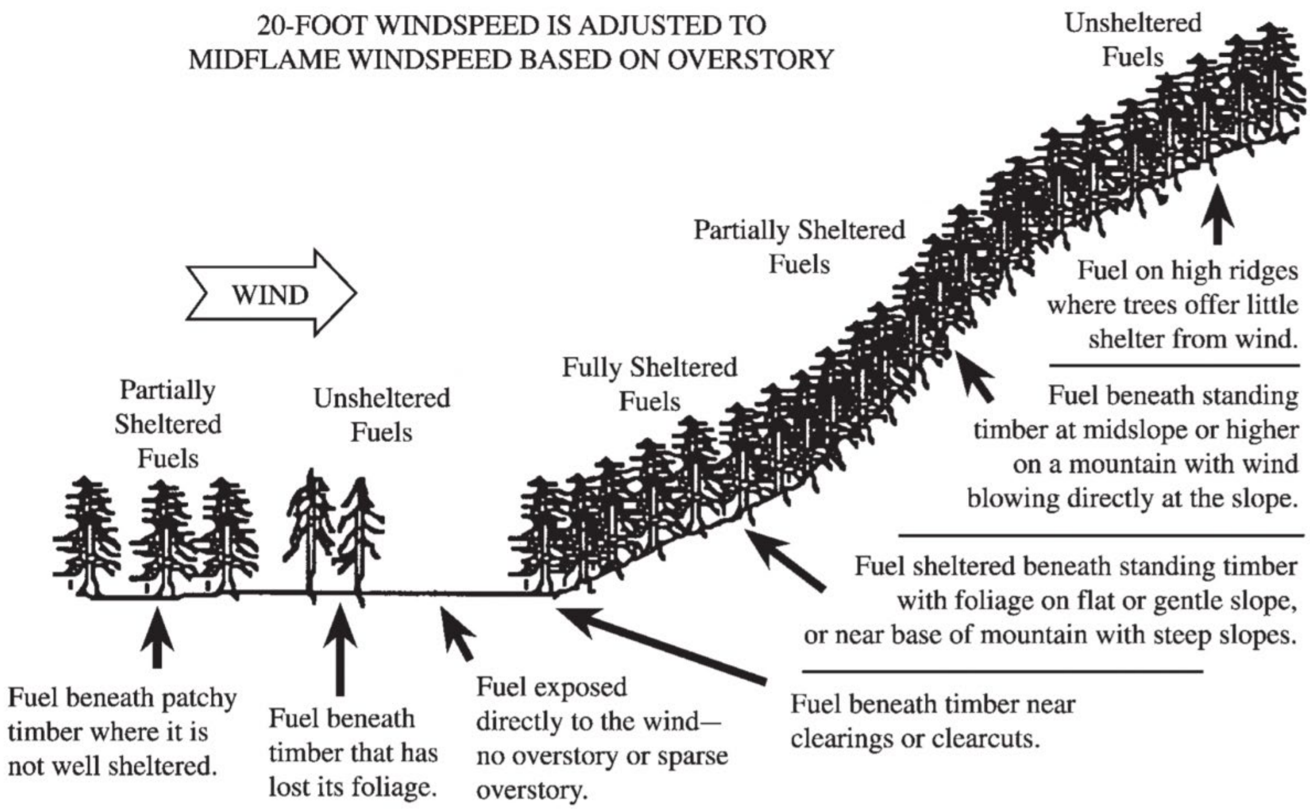
As with herbaceous fuel moisture, woody fuels with moistures above 120% reduce fire spread estimates where understory trees and shrubs are a significant part of the surface fuels. Mature needle moistures will rarely be much above that. Higher woody fuel moistures are generally only found in deciduous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

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, a Wind Adjustment Factor (WAF) must be applied to obtain midflame windspeed. This adjustment will depend on canopy sheltering and surface fuel bed depth. Note how the effect of sheltering varies based on the fire's position on a slope.

Figure 46. WAF criteria.



- 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.
- High ridges where trees offer little shelter from wind.
- Leafless canopy.
- Average Crown Ratio of less than 0.2 (crowns are less than 20% of tree height).
- Canopy Cover less than 20%.

Wind Adj. Factor	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 mid-slope or higher.
- Wind blowing directly at slope.

Wind Adj. Factor	Fuel Models	Bed Depth
0.3	All Fuel Models	Any

Fully Sheltered Fuels.

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

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

Fire Behavior Lookup Tables.

Follow this process for using 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.

When the ground is flat or gently rolling and the slope is near 0%, the 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 Windspeed (MFWS)** and **slope %** estimated earlier.
- Derive the **Effective Windspeed (EWS)** from the selected table.
- Use this **Effective Windspeed** to estimate fire spread rate and flame length, described below, and to estimate an emerging fire's potential fire size and shape (pages 100-104).

The EWS tables are color coded to provide an indication of when the MFWS and slope have the potential to produce crown fire, based on stand type. See legend, Figure 47, below.

Figure 47. Stand crown fire potential legend for EWS Tables 4, 5 and 6.

Closed Stands	Closed Stands **Open Stands**	Closed Stands **Open Stands** **Sparse Stands**

Estimate Rate of Spread and Flame Length.

- Select the appropriate fire behavior table (tables 7-19) for the **fuel model**(s) of interest.
- 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 by using the fire behavior classes described earlier in this document (Table 1, Figure 42, and Figure 23). Each Fire Behavior Table for the 13 Fuel Models (tables 7-19, below) contains a legend that matches the color coding used throughout this document for fire behavior classes.

Review the section on anticipating and interpreting expected fire behavior to aid in the assessment.

Effective Windspeed Tables.

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

Table 4

	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

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

Table 5

	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

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

Table 6

	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).

Table 7.

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*	**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	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).

Table 8.

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).

Table 9.

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	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		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	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).

Table 10.

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, %; (Woody moist. 120%-80%)													
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)												
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, %; (Woody moist. 120%-80%)													
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).

Table 11.

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).

Table 12.

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).

Table 13.

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).

Table 14.

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).

Table 15.

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				7	13	20	27	33	40	47	53	60	67
EWS	NWNS-0	Back - ½	Flank - 1	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				7	13	20	27	33	40	47	53	60	67
EWS	NWNS-0	Back - ½	Flank - 1	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).

Table 16.

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).

Table 17.

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).

Table 18.

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).

Table 19.

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*	<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 (0.5)												
*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 Behavior.

Crown Characteristics.

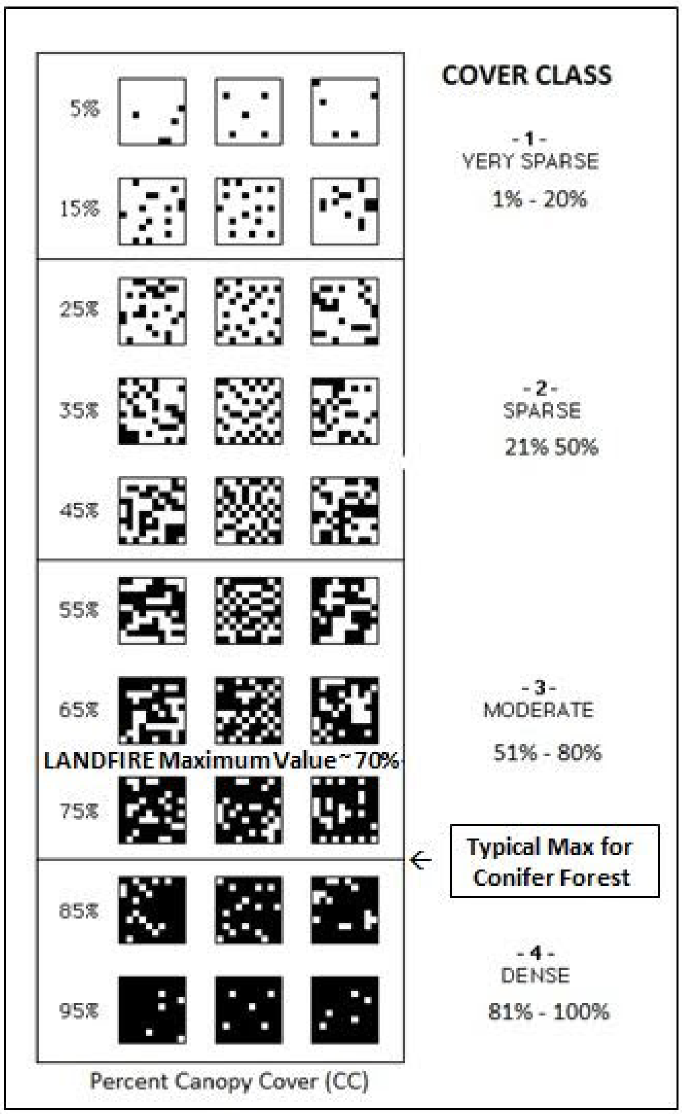
<u>Canopy Cover.</u>

The forest Canopy Cover (CC) describes the percent cover of the tree canopy in a stand. Specifically, CC describes the vertical projection of the tree shade onto the ground's surface. Estimate of CC is used to adjust the 20-foot winds to mid-flame and in 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 48) illustrates representative CC percentages and ranges within each cover class.

Figure 48. Canopy cover ocular estimation.



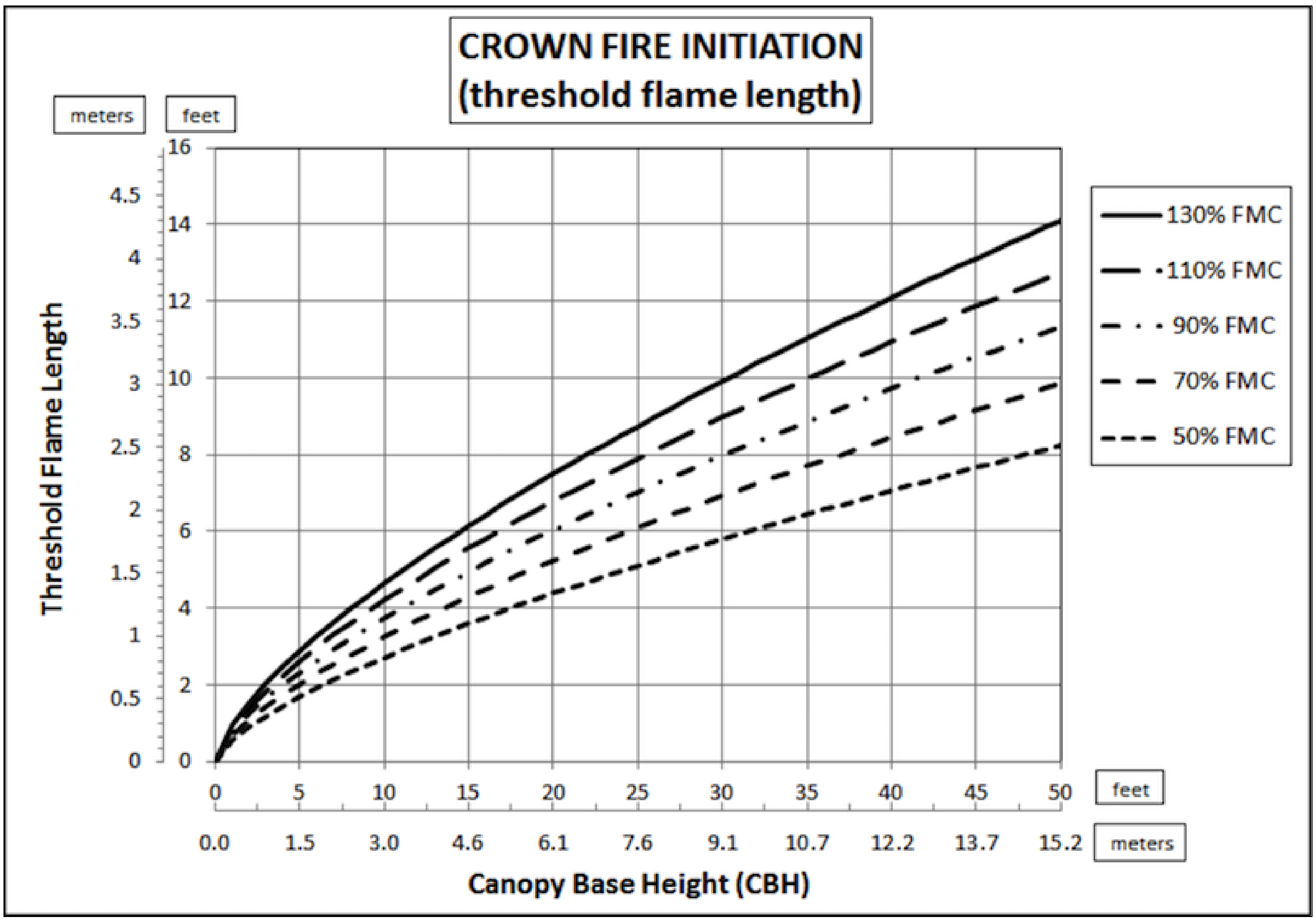
Stand (Canopy) Height.

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 enough 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 49).

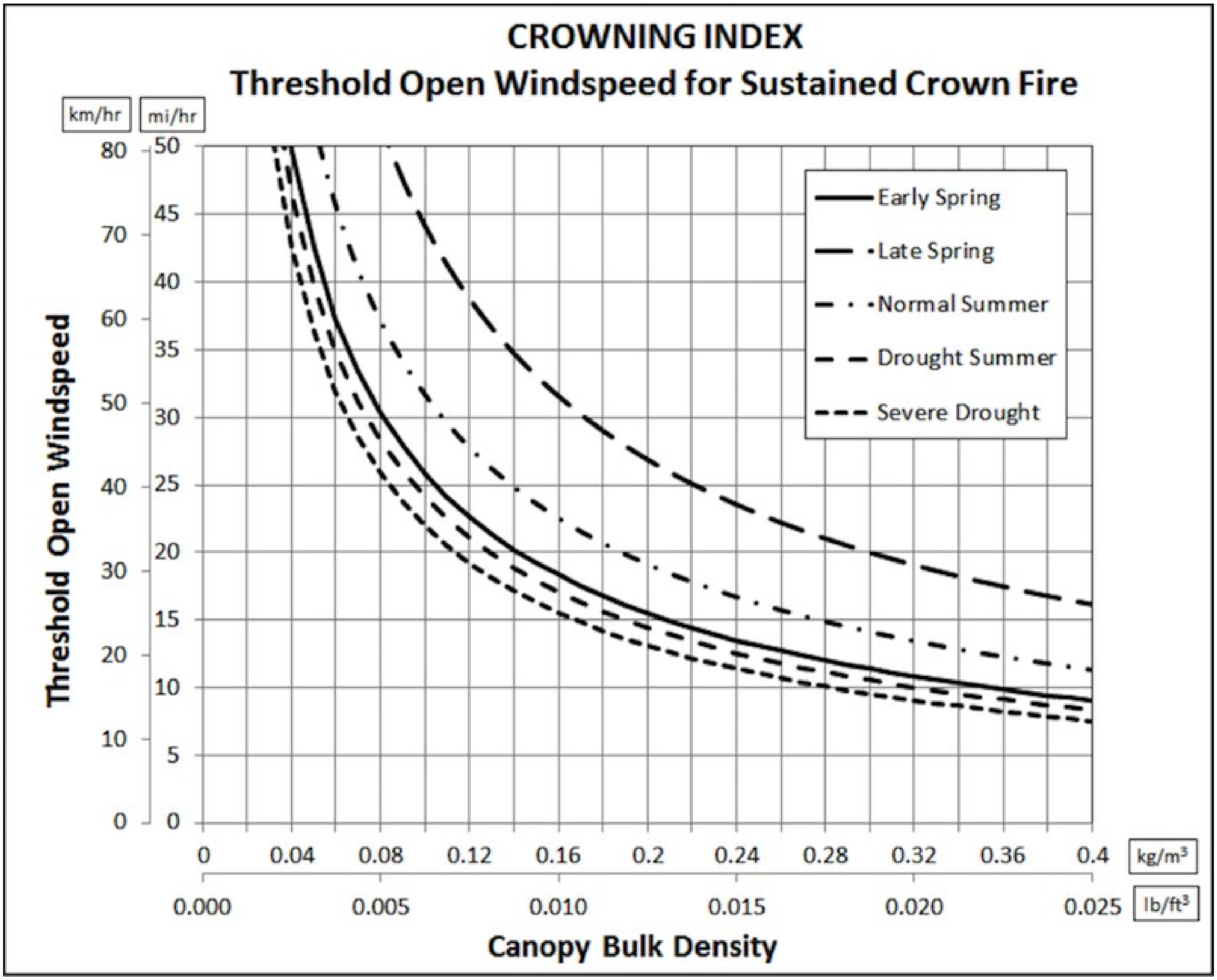
Figure 49. Crown Fire Initiation considers surface flame length, height to flammable canopy fuels, and foliar moisture content. Resulting intersection on the left axis represents minimum conditions for, at least, passive crown fire.



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 open wind speed (Figure 50), needed to sustain an active crown fire.

Figure 50. Crowning Index suggests windspeed needed to sustain an active crown fire based on how dense the flammable tree canopy is. The left axis represents minimum conditions for active crown fire activity.



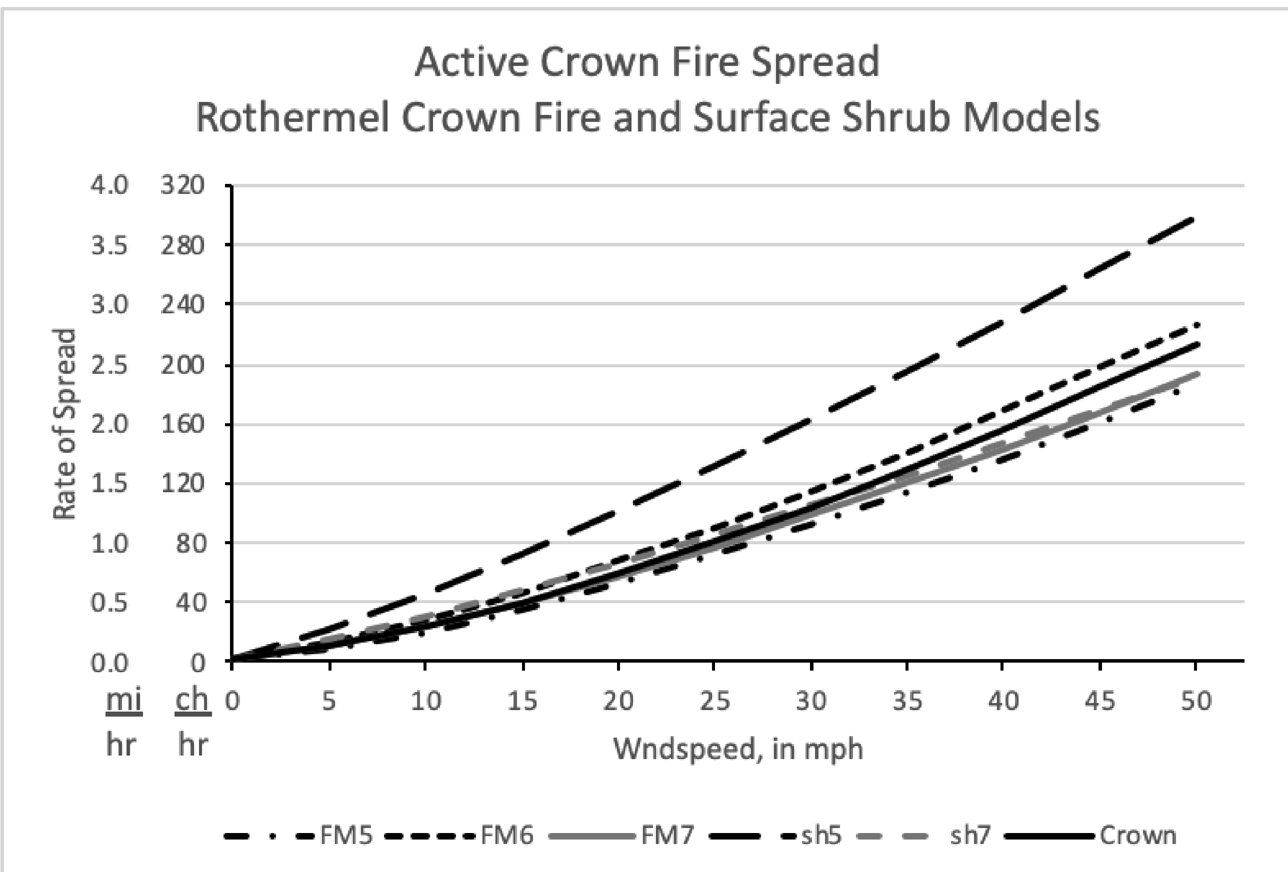
Estimating Active Crown Fire Spread.

In fireline assessments, it may be necessary to make quick estimates of crown fire spread based on simple inputs. 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 timber 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.
- Brush models in the *Scott and Burgan 40 Fuel Models* are, similarly, used to represent crowning timber. For example, using SH5 (145) in place of TU (timber-understory) models in Alaska Black Spruce.

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 crown fire rate of spread estimates, however, and the intensities, though low, are still extreme.

Figure 51. 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.

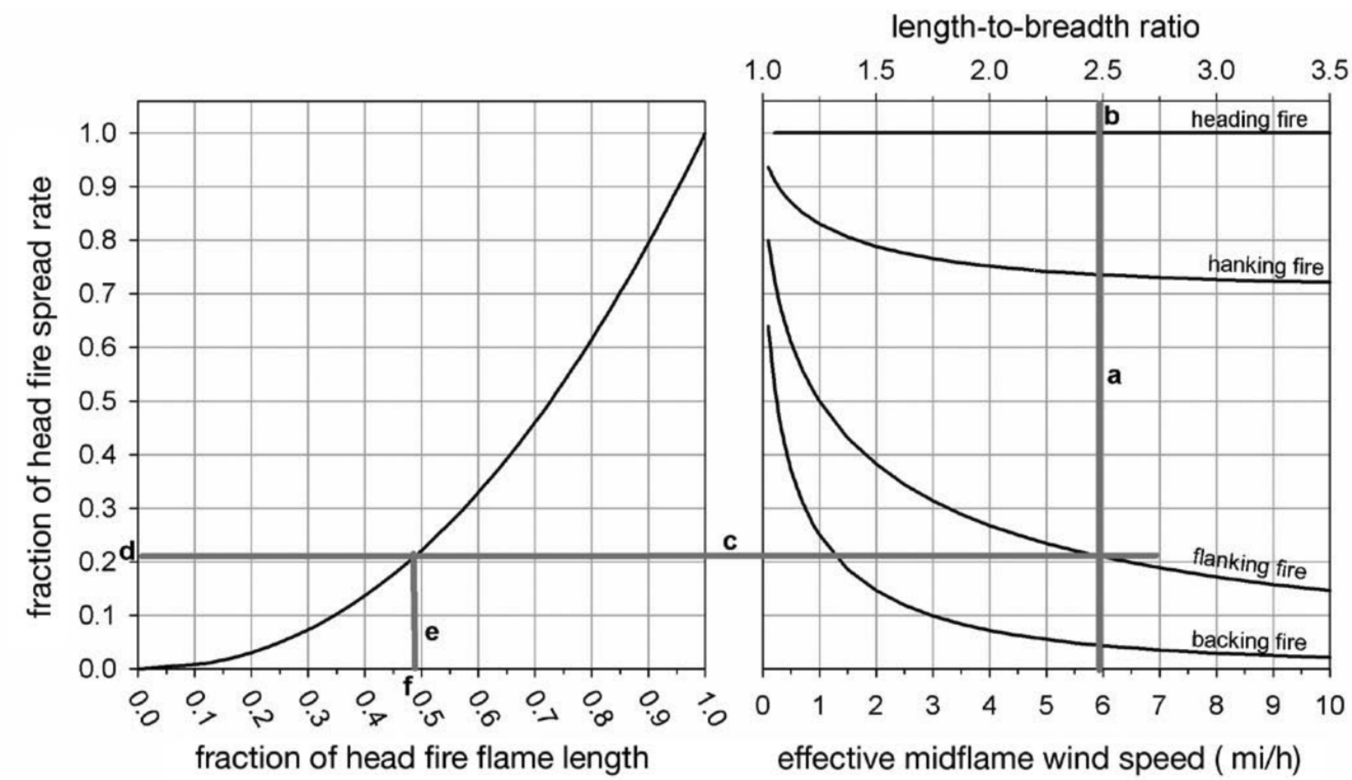
Estimating the spread rate and flame length for flanking and backing fire behavior can be important to tactical decisions on the fireline.

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 52 (*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" (fire spreading at, roughly, 45 degrees from the head and flank at the corners of the transition).

1. Estimate effective midflame windspeed from tables on page 79. (6 mph is used in this example)
2. Draw a vertical line to read the length-to-breadth ratio on the scale at the top. (a. 2.5 in example)
3. Draw a horizontal line from where the vertical line intersects either backing, flanking or hanking curves. (b. head) (c. flank)
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. 0.2 multiplier for backing ROS, 1.0 for head)
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. 0.5 multiplier for backing flame length, 1.0 for head.)

Figure 52. Nomogram for estimation of backing, flanking and hanking spread and intensity.



Spotting Distance.

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

Western Tree Species Quick Reference Lookup Table.

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.

20ft wind, mph→ Tree Species ↓	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.

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.

20ft wind, mph→ Tree Species ↓	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

Calibrating Fire Behavior Estimates.

It is important to calibrate your fire behavior predictions 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 **burn period** 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-hour fuel moisture	10-hour fuel moisture 100-hour fuel moisture
Burn Period Changes	Burn Period length Wind Speed & Direction Cloud Cover Precipitation 1-hour fuel moisture (when considered over 24 hours in ***primarily grass*** landscapes)	1-hour fuel moisture (when considered over 24 hours in ***mixed forest, shrub, and grass*** landscapes)	1-hour fuel moisture (if burn period only includes peak hours)

Fire Size and Shape.

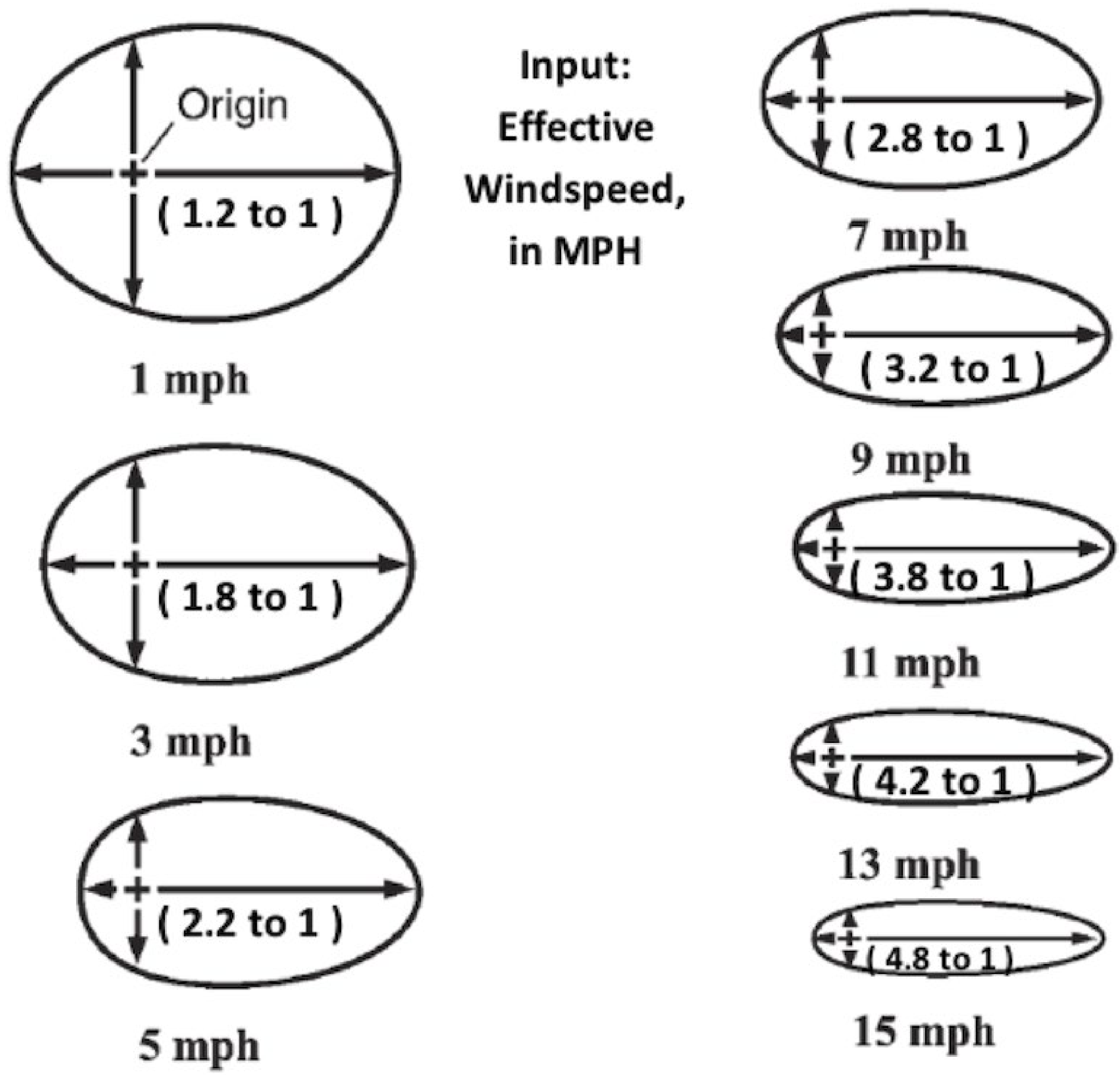
These tools are intended for use with initiating fires only. Multiply your estimated spread rate times the number of hours you think significant to determine a spread distance. Consider using:

- 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 53) in combination with your estimate of spread distance to overlay the expected fire perimeter on your map.

Figure 53. Elliptical Fire Shapes. Based solely on the estimated effective windspeed (midflame windspeed and slope factors combined). Ratio, in parentheses, provides representative comparisons between length and width (e.g., 1.2 to 1).



Surface Fire Area Estimation from Point Source Fire, in Acres.

Table 20. 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									
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 21. Fire Area (in acres) for spread distance 52-165 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

Fire Perimeter Estimation from Point Source Fire, in Chains.

Table 22. 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									
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 23. Fire Perimeter (in Chains for spread distances) 52-165 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

Part Three – Other Resources

[Map Use]

[Measurement Unit Conversions]

[Safety Considerations]

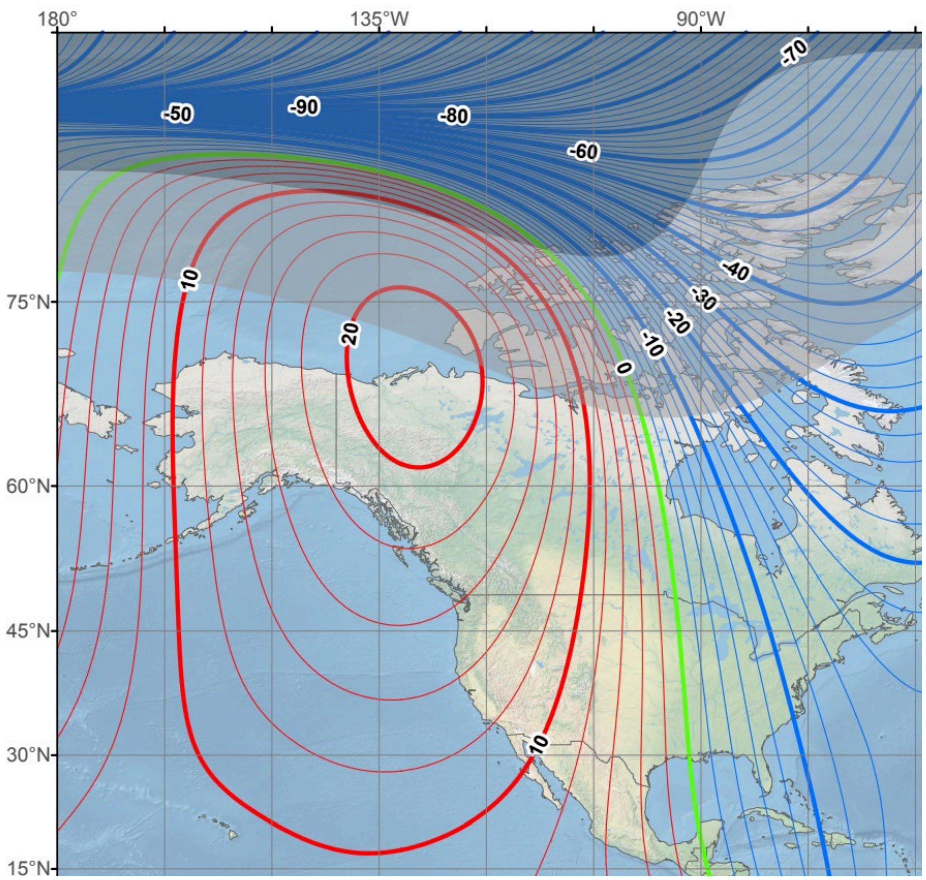
Map Use.

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 2020).

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



Source: https://www.ngdc.noaa.gov/geomag/WMM/

Measurement Unit Conversions.

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

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/m^2	4.460897	Tons/acre	0.22417	Kg/m^2
Kg/m^2	0.062	lb./ft^2	16.129	Kg/m^2
Tonnes/ha	0.44609	Tons/acre	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 be sure 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 fireline downhill with fire below.
10. Attempting frontal assault on fire.
11. Unburned fuel between you and fire.
12. Cannot see main fire; not in contact with someone who can.
13. On a hillside where rolling material can ignite fuel below.
14. Weather becoming 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. 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. During the 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)

- Experienced, competent, trusted.
- Enough lookouts at good vantage points.
- Knowledge of crew locations.
- Knowledge of escape and safety locations.
- Knowledge of trigger points.
- Map, weather kit, watch, Incident Action Plan (IAP).

Communication(s)

- Radio frequencies confirmed.
- Backup procedures and check-in times established.
- Provide updates on any situation change.
- Sound alarm early, not late.

Escape Route(s)

- More than one escape route.
- Avoid steep, uphill escape routes.
- Scouted for loose soils, rocks, vegetation.
- Timed considering slowest person, fatigue, and temperature factors.
- Marked for day or night.
- Evaluate escape time vs. rate of spread.
- Vehicles parked for escape.

Safety Zone(s)

- Survivable without a fire shelter.
- Back into clean burn.
- Natural features (rock areas, water, meadows).
- Constructed sites (clear-cuts, roads, helispots).
- Scouted for size and hazards.

Safety Zone Guidelines.

Previous safety zone rules of thumb were based on the height of the surrounding vegetation and/or anticipated flame lengths. Based on recent research, https://www.firelab.org/project/firefighter-safety, safety zones, to be adequate, must also account for convective heat transfer from windspeed and slope.

Safe Separation Distance Based on Forecast and Fire Environment.

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

SSD can be calculated by hand, with the formula and table, below, or through by using the Safe Separation Distance Evaluator (SSDE), an online mapping tool, at: https://firesafetygis.users.earthengine.app/view/ssde-en

Table 24. Slope-wind factors colored on a scale from blue (low Δ) to red (high Δ)

		Slope: Flat (0-7.5%)	Slope: Low (7.6-22.5%)	Slope: Moderate (22.6-40%)	Slope: Steep (>40%)	Burning Condition
Wind Speed	Light (<10 mph)	0.8	1	1	2	Low
Wind Speed	Light (<10 mph)	1	1	1.5	2	Moderate
Wind Speed	Light (<10 mph)	1	1.5	1.5	3	Extreme
Wind Speed	Moderate (10-20 mph)	1.5	2	3	4	Low
Wind Speed	Moderate (10-20 mph)	2	2	4	6	Moderate
Wind Speed	Moderate (10-20 mph)	2	2.5	5	6	Extreme
Wind Speed	High (>20 mph)	2.5	3	4	6	Low
Wind Speed	High (>20 mph)	3	3	5	7	Moderate
Wind Speed	High (>20 mph)	3	4	5	10	Extreme

<u>Calculating Safe Separation Distance.</u>

Calculating an SSD requires identifying a potential safety zone, noting the slope, and determining what the fuel, wind and fire behavior conditions would be at the time it would be used.

*Formula: SSD = 8 * Vegetation Height * Slope-Wind Factor (Δ)*

1. Multiply the height of the vegetation, in feet, adjacent to your proposed safety zone by 8.
2. Obtain the wind slope adjustment factor, or delta(Δ), from Table 11
   a. Select a windspeed range from the left-hand side of the table.
   b. Select a slope range from the top of the table.
   c. Determine if the expected fire behavior would be low, moderate, or extreme.
   d. Where the three values intersect on the table, record your delta(Δ) value.
3. Multiply the value from Step 1 by the value in Step 2. This is the minimum separation distance from the fuels you evaluated, on the slope you selected, for the fire conditions you expect.

SSD is a linear output, and safety zones are defined by an area. The SSD should be considered the minimum radius of a safety zone. To be secure in the center of a safety zone, its diameter would need to be twice the SSD. To get an estimate of the area of a circular safety zone, you can use the equation Pi*SSD^2. This result, in square feet, can be converted to acres using the area conversions on page 107. The SSDE, described above, and WiSE (Wildfire Safety Evaluator) tools quickly do all these calculations for you, and will display the results, spatially, on maps.

Below, are two example SSD calculation scenarios and their solutions:

Example 1: Fire is burning in three-foot sagebrush adjacent to the proposed open safety zone. Terrain is flat. A high wind of 22 mph is expected in the afternoon which will lead to moderate burning.

Solution 1:
Δ = 3
SSD = 8 x 3 feet x 3 Δ = 72 ft
(0.4-acre safety zone)

Example 2: Proposed safety zone is surrounded by 20-foot juniper. The slope is 18%. Winds are expected to get to 18 mph which will lead to moderate burning conditions.

Solution 2:
Δ = 2
SSD = 8 x 20 feet x 2 Δ = 320 ft
(7.4-acre safety zone)

Escape Routes.

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

Minimum Distance for Shelter Deployment (Entrapment Reports).

Fire shelters increase the chance of survival in an entrapment situation. SSD calculations are for Safety Zones, which, by definition, are survivable without using a fire shelter. These are some guidelines for distances from maximum flame heights that will increase the chances of survival with a shelter if entrapped.

With use of fire shelter:

- Flames < 30’ tall: deployment area should be, at least, 2-5 times the flame height.
- Flames > 30’ tall: deployment area should be, at least, 1-3 times the flame height.

No fire shelter:

- Double the above multipliers.

NOTES:

NOTES:

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NOTES:

The *NWCG Guide to Fire Behavior Assessment* is developed and maintained the Fire Behavior Subcommittee (FBSC), 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.

This publication is available electronically at https://www.nwcg.gov/publications.

Printed copies of this guide may be ordered from the Great Basin Cache at the National Interagency Fire Center in Boise, Idaho. Refer to the annual *NWCG NFES Catalog Part 2: Publications*, PMS 449-2, and find ordering procedures at https://www.nwcg.gov/catalogs-ordering-quicklinks.

Comments, questions, and recommendations shall be submitted to the appropriate agency program manager assigned to the FBSC. View the complete roster at https://www.nwcg.gov/committees/fire-behavior-subcommittee/roster.