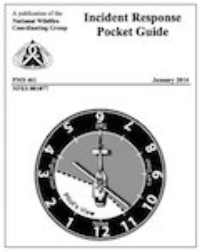
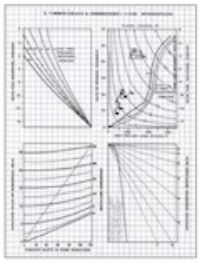
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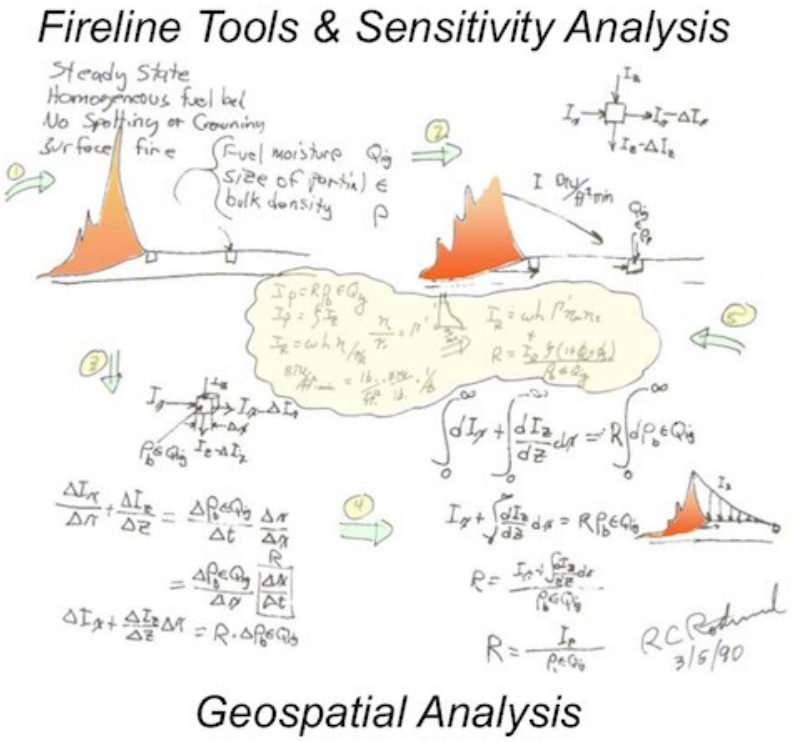
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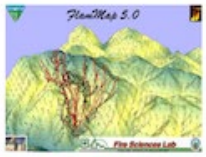
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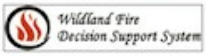


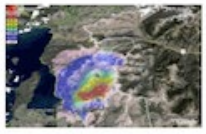














NWCG Fire Behavior Field Reference Guide

OCTOBER 2026
PMS 437

The *NWCG Fire Behavior Field Reference Guide* provides reference material to support decision-making for fire analysts using various tools and methodologies. It is updated to reflect the most recent science and technologies, helping improve decision support, firefighter safety, and fire behavior interpretation. This publication provides:

- Descriptions of weather forecast products and forecast confidence.
- Special tools to observe, characterize and track changes to the fire environment.
- Techniques to properly measure and document fire weather.
- References for understanding critical fire weather patterns.
- Best practices for utilizing fuels data and fuel moisture in modeling systems.
- An overview of topographic features that influence fire behavior.
- Resources for using and creating maps.
- Descriptions of fire behavior characteristics.
- Methods for documenting fire observations and analysis.
- An overview of fire danger and how it is used in characterizing the fire environment.
- Information about smoke management and safety.
- A comprehensive list of cited literature.

Moving forward, this publication combines PMS 437 and *NWCG Guide to Fire Behavior Assessment,* PMS 437-1, to provide a single source for all fire-environment guidance and reference materials. The revised document eliminates redundancies, enhances consistency across sections, and improves usability for both analysts and field personnel. This streamlined structure supports more effective and standardized application of fire-behavior tools throughout the wildland fire community. While previous editions may still contain current or useful information, they are now obsolete.

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 **1**
Weather **1**
Forecast Confidence 1
Best Practices for Determining Weather Confidence 2
Weather Outlook Forecast Products 3
Comprehensive Displays 3
Short-Term Forecast Products (1 to 7 Days) 3
Extended Forecast Products (1 Week to Several Months) 4
Forecast Models 4
Special Wildland Fire Guidance Tools 7
Global Tool 7
National Tool 7
CONUS Tools 8
Regional Tools 8
Long-Range Forecast Drivers 8
Observing Fire Weather 10
Fireline Observations 11
Wind Observations and Estimates 12
Temperature, Relative Humidity, and Vapor Pressure Deficit Observations 14
Sky Observations 17
Automated Weather Stations 21
Critical Fire Weather 23
Critical Fire Weather Patterns 24
Hot-Dry-Windy Index 26
Critical Wind Events 26
Hot, Dry, and Unstable Events 28
Fire-Slowing or Fire-Stopping Patterns 29
Estimating Winds for Fire Behavior 29
Definitions 29
Estimating Surface (20 foot) Wind Speed in Mountain Terrain 31
Adjusting Surface (20 foot) Wind to Midflame Wind Speed 36
Temperature, RH, and Dew Point Tables 39
Elevation 0 to 500 feet (0 to 300 feet in Alaska), 30 in. 40
Elevation 501 to 1,900 feet (301 to 1,700 feet in Alaska), 29 in. 44
Elevation 1,901 to 3,900 feet (1,701 to 3,600 feet in Alaska), 27 in. 48
Elevation 3,901 to 6,100 feet (3,601 to 5,700 feet in Alaska), 25 in. 52
Elevation 6,101 to 8,500 feet (5,701 to 7,900 feet in Alaska), 23 in. 56
Elevation 8,501 to 11,000 feet (above 7,900 feet in Alaska), 21 in. 60
Measures of Stability 63
Fire Season Climatology 63
Drought Assessments 63
Local Climatology and Current Season Trends 64
Regional Fire Seasonality 68
Weather Data Resources 83
Creating a FireFamilyPlus Database for Weather Analysis 83

Critique and Edit in FireFamilyPlus 83
Fuels 85
Surface Fuel Model Selection 85
Two Sets of Surface Fuel Models 85
Surface Fuel Model Evaluation 86
Moisture of Extinction 87
Fuel Model Parameters and Descriptions 88
Dynamic and Proportional Fuel Load Transfer 88
Surface Fuel Model Descriptions 90
Landscape Acquisition, Critique, and Editing 91
Landscape File Data Sources 91
Other Data Sources 91
Landscape File Fuel Themes 92
Nomenclature for Spatial Data Layers 93
LCP Critique 93
Image and Legend Pages for Each Theme 94
Editing and Updating the LCP File 95
Topography 96
Slope 96
Aspect 96
Elevation 96
Landforms 96
Fuel Moisture 97
Dead Fuel Moisture Content 97
Nelson Model 1- and 10-hour Fuel Moisture Estimation Methods 97
Fosberg Model 1-hour Fuel Moisture Estimation Methods 97
10-hour, 100-hour, and 1000-hour Fuel Moisture Content 100
Fuel Moisture: Probability of Ignition 100
Live Fuel Moisture Content 102
Concepts and Methods 102
Growing Season Index (GSI) 102
Foliar Moisture Content (FMC) 103
Vegetative Greenness 104
Fuel Moisture Sampling 105
Online Fuel Moisture Sampling History 105
Fuel Moisture Sampling Procedures 105
NASA Short-term Prediction Research and Transition (SPoRT) Land Information System 106
Mapping 108
Map and Field Measurements 108
Map Scale and Map Distance 108
Slope Estimation 108
Unit Conversions 109
Declination 110
Using Geographic Information Systems (GIS) 111
Map Datum 111
Map Projections and Coordinate Systems 112
Mapping Resources 113

Online Data Sources 113
Google Earth Pro 113
Field Maps Pocket Guide 113
Avenza Maps Pro 113
Other Products 114
Observing Current Fire Behavior 115
Visual Fire Behavior Descriptions 115
Observing Flame Length vs. Flame Height 116
Fire Behavior Observation Reports 117
Surface Fire 118
Surface Model Inputs and Outputs 118
Surface Model Inputs 118
Surface Model Outputs 118
Tools Available to Predict Surface Fire 119
Nomograms and Nomographs 119
Behave 120
Surface Fire Behavior Lookup Tables 120
Spatial Modeling (FlamMap, FARSITE) 121
Surface Fire Behavior Worksheet 121
Predicting Surface Fire Spread Using Lookup Tables 123
Using Surface Fire Lookup Tables 123
Effective Windspeed (EWS) 124
Grass Fuel Models 125
Grass/Shrub Fuel Models 126
Brush or Shrub Fuel Models 127
Timber Litter Fuel Models 131
Timber Understory Fuel Models 133
Slash/Blowdown Fuel Models 134
Predicting Flanking and Backing Fire Behavior 137
Estimating Rate of Spread from Observations 138
Interpreting Fire Behavior 139
Estimating Surface Fire Size and Shape 140
Surface Fire Area Estimation from Point Source Fire, in Acres 141
Surface Fire Perimeter Estimation from Point Source Fire, in Chains 143
Surface Fire Shape 145
Spotting and Crown Fire 146
Spotting 146
Estimating Maximum Spotting Distance 147
Reference Tables for Maximum Spotting Distance 148
Comparing Spotting Estimation Tools 150
Crown Fire 153
Definitions 153
Active Crown Fire Rate of Spread and Flame Length 153
Estimating Active Crown Fire Spread Rate using Surface Shrub Models 156
Crown Fire Initiation and Propagation 156
Linking Surface and Crown Fire Behavior 157
Crown Fire Initiation – Threshold Evaluation 157

Active Crown Fire Propagation and Crowning Index (CI) 159
Interpreting Expected Crown Fire Behavior 163
Crown Fire Size and Shape 164
Fire Modeling with Spatial Tools 167
Evaluating Expected Fire Behavior 167
Spatial Fire Behavior Models 167
FlamMap Basic 168
Minimum Travel Time (MTT) 168
FARSITE 168
FSPro 169
RANDIG 169
FSim 170
Modeling Applications 170
Spatial 170
Non-Spatial 171
Mobile Apps 172
Model Comparison 172
Key Spatial Analysis Factors 173
Landscape Characteristics 173
Datum, Projections, and Coordinate Systems 174
Crown Fire Method 174
Spotting 175
Fuel Moistures 175
Burn Period 177
Burn Day Frequency 178
Weather Observations and Forecasts 179
Wind Speed and Direction 179
Verification of Analysis Outputs 180
Other Considerations 181
Verification, Calibration, and Validation 182
Reference Fire History 182
Near Real-Time Remote Sensing Products 183
Evaluating, Finalizing and Sharing Analysis Results 183
Evaluating FSPro 184
Assessing FSPro Results 185
FSPro Daily Acres Pivot Table 185
Assessing Need for Reanalysis 186
Documenting Your Work 187
Briefing Guidelines and Products 187
Fireline Briefing Checklist 187
Fire Behavior Forecast Form and Instructions 187
Incident Briefing Outline Form and Instructions 187
Documentation Records 187
Incident Fire Behavior Narratives 187
Fire Behavior Documentation Package 188
Electronic Fire Behavior Documentation 189
Fire Danger 190

U.S. National Fire Danger Rating System (NFDRS) 190
NFDRS Structure 191
NFDRS Fuel Models 191
Annual versus Perennial Grass 192
Slope Class Setting 192
NFDRS System Inputs and Outputs 192
Observations and Forecasts 192
Primary System Components and Indices 192
Fire Danger PocketCard 193
Interagency Predictive Services 194
Canadian Forest Fire Danger Rating System (CFFDRS) 195
CFFDRS Components 195
Fire Weather Index (FWI) System 196
Fire Weather Index (FWI) System Process Flow Chart 196
Winds for CFFDRS 197
Fire Intensity Measures 198
Wildland Smoke and Air Quality 199
Quick Guide for Smoke and Roadway Safety 199
Nighttime Smoke Considerations 199
Probability Thresholds for Nighttime Smoke on Roads 199
Smoke Safety Resources 200
References 201

Introduction

The *NWCG Fire Behavior Field Reference Guide*, PMS 437 (FBFRG) contains helpful references to the factors from the fire triangle (fuels, weather, and topography), including features that are vital to field-going fire managers. It provides detail about fire behavior models and tools used to estimate probability of ignition, spread/size, fireline intensity, and crown fire potential. The reference material is intended to assist with decision support.

This guide will be reviewed annually and updated as needed to reflect the most recent science and technologies used to improve and assist with decision support, fireline safety, and fire behavior interpretation. As new and improved safety zone research is obtained and available for distribution, the FBFRG will be updated. Supporting documentation, including instructional videos, will be uploaded periodically to the official YouTube channel: www.youtube.com/user/FireBehaviorSC.

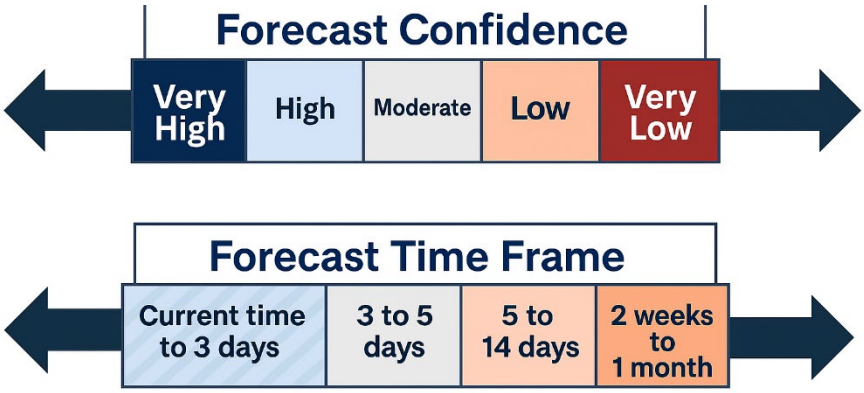
Weather

Forecast Confidence

Forecast confidence is the analyst's professional judgment about how reliable a given fire behavior forecast is based on the quality and consistency of the inputs used to produce it. It communicates to decision-makers how much trust they should place in the prediction, not just what the prediction says.

For applications requiring forecast information with very high confidence or accuracy, the typical Confidence Horizon is approximately three days. However, this horizon is not fixed; shifts in forecast skill routinely expand or contract the period during which very high confidence is achievable, thereby changing the Confidence Horizon.

Figure 1. Typical forecast Confidence Horizon.



Understanding these shifts is especially important when selecting an appropriate fire behavior modeling tool, applying forecast data within that tool, and documenting assumptions made during analysis.

The atmosphere is chaotic, but sometimes there is rhythm in the chaos. Climate outlook scientists study coupled oceanic and atmospheric forcing mechanisms—such as El Niño Southern Oscillation (ENSO) cycle and Madden Julian Oscillation (MJO)—that influence several teleconnection or long-range, long-term correlated weather patterns that determine meteorological impacts across North America.

Forecast skill typically increases (i.e., rhythm in the chaos) for mid- and long-range outlooks when certain forcing mechanisms and teleconnection patterns align. During these periods, the normal

Confidence Horizon may extend, allowing monthly or seasonal outlooks to carry medium—to occasionally high—confidence for general weather patterns such as warmer and drier conditions and sometimes frequent wind events. This represents a shift from the typically Low to Very Low confidence associated with longer-range forecasts. Other teleconnection alignments can produce mixed atmospheric forcing signals, thus leading to unusually Low confidence periods (e.g., no rhythm).

Best Practices for Determining Weather Confidence

Review routinely issued text discussions published by the National Weather Service (NWS), National Interagency Fire Center (NIFC) Predictive Services, Storm Prediction Center (SPC), and Climate Prediction Center (CPC).

- **NWS Area Forecast Discussion** – https://www.weather.gov/
  This NWS product provides a well-reasoned discussion of the meteorological analysis used to develop the gridded forecast. Forecasters highlight the key challenges influencing the forecast using plain language and wording that reflects their level of confidence. At the end of the discussion section the NWS lists all advisories, non-convective watches, and non-convective warnings. "Non-convective" refers to weather that is not caused by thunderstorms.

An intermediate Area Forecast Discussion is issued when significant forecast updates are being made or if interesting weather is expected to occur.

- **NIFC Predictive Services 7 Day Significant Fire Potential** – https://fsapps.nwcg.gov/psp/npsg/forecast#/outlooks?state=map
  This forecast, updated daily, identifies areas at risk for new large fires or significant growth on existing fires based on fuel dryness, weather, and ignition triggers. Expression of confidence may be written in the weather discussion portion of the product.
- **SPC Continental United States (CONUS) Discussions** – https://www.spc.noaa.gov/products/outlook/
  The SPC is tasked with forecasting the risk of severe thunderstorms and tornadoes in the contiguous United States. It issues convective outlooks, mesoscale discussions, and watches as a part of this process. Convective outlooks are issued for the following eight days. Discussions are provided twice daily for Day 1 and 2 outlooks during the early to late morning hours. The "Day 3-8" outlook and discussion is updated once per day during the afternoon.
- **CPC Official Forecast Outlooks for 6 to 10 Days, 8 to 14 Days, and 3 to 4 Weeks** – https://www.cpc.ncep.noaa.gov/products/forecasts/
  CPC forecast discussions for 6 to 10 day and 8 to 14 day outlooks are updated Monday through Friday, and 3 to 4 week outlooks are updated on Friday. Confidence is typically implied in these discussions.

When forecast information becomes uncertain and it is unclear where conditions fall on the Confidence Horizon, it is best to consult directly with Predictive Services forecasters, NWS forecasters, and Incident Meteorologists (IMETs). Engaging all three sources can help provide a clearer understanding of the Confidence Horizon. Contact information is in the Mobilization Guide, https://www.nifc.gov/nicc/logistics/reference-documents.

Several questions you might ask are:

- Does your office have access to a high resolution model, and is it used for grid editing?

- How often are forecast discussions updated? Is there a routine fire weather discussion during the fire season?
- Is there a long-range forecast specialist in the office?
- Does your office issue special email notices or produce routine webinars or webcasts during fire season or significant events?
- What does recent model variation or consistency look like?
- Are there any localized critical fire weather growth patterns for the area, and are they anticipated in the near term?

Weather Outlook Forecast Products

Comprehensive Displays

NWS National GIS Map Viewer – https://www.weather.gov/gis/
The NWS National GIS Map Viewer is a web-based system that provides a single access point for all NWS GIS-related resources. The pop-up on the website linked above provides experimental fire-related products.

Short-Term Forecast Products (1 to 7 Days)

NWS Routine Fire Weather Forecasts – https://www.weather.gov/fire/
Issued twice daily during a geographic area's primary fire season and updated as conditions warrant, these narrative forecasts include a discussion of expected weather events, general forecast weather parameters for the next 48 hours, and an outlook summary for days 3 to 5.

NWS Watches and Warnings – https://www.weather.gov/
This site provides access to a range of products, with a map emphasizing active watches and warnings. The issuance of a warning or watch indicates stronger forecast confidence level in conditions favorable for fire growth approximately 12 to 96 hours ahead of an event.

NWS Spot Weather Forecasts – https://spot.weather.gov/
This interface is used solely for submitting incident specific forecast requests to the National Weather Service. Submissions through this system are intended for internal agency use.

NWS Weather Prediction Center (WPC) – https://www.wpc.ncep.noaa.gov/#page=ovw
The WPC provides a variety of forecast products, including deterministic and probabilistic quantitative precipitation forecasts, forecast discussions, short-term and medium-range forecasts, and surface analysis.

NWS National Digital Forecast Database (NDFD) – https://www.ncei.noaa.gov/products/weather-climate-models/national-digital-forecast-database
NDFD graphic products are generated from the official NWS NDFD. These graphics are representations of the official NWS digital forecast. Forecast information for the Canadian portion of the Great Lakes is provided for informational purposes only and is not considered an official forecast.

NWS Storm Prediction Center – https://www.spc.noaa.gov/
The SPC provides convective and fire weather outlooks out to 8 days across the CONUS. They also offer specialized tools—including the High-Resolution Ensemble Forecast (HREF) and Short-Range Ensemble Forecast (SREF) viewers—for analyzing convective, fire weather, and precipitation patterns.

Predictive Services – https://www.nifc.gov/nicc/predictive-services
Predictive Services units provide decision support information to federal, tribal, state, and local wildland fire management agencies for operational management and strategic planning. Products include monthly and seasonal outlooks, 7 Day Fire Potential, and fire behavior advisories.

Predictive Services 7 Day Significant Fire Potential – https://fsapps.nwcg.gov/psp/npsg/forecast#/outlooks?state=map
This product identifies the likelihood that a wildland fire event will occur, which may require mobilization of additional resources from outside the affected area.

Analysts assess weather, fuel conditions, resource availability, and probabilities of ignition each day to determine significant fire potential for the next 7 days. Forecasts of Energy Release Component (ERC), Burning Index, 10–, 100–, and 1000-hour dead fuel moistures are also available on the main webpage.

Days are categorized as High-Risk fire potential when there is a 20% or greater probability for a significant fire.

Extended Forecast Products (1 Week to Several Months)

NWS CPC Extended Outlooks – https://www.cpc.ncep.noaa.gov/
The CPC produces seasonal climate outlook maps extending 1 to 13 months in the future. The CPC also issues extended range outlook maps for 6 to 10 and 8 to 14 days as well as several special outlooks, such as degree-day forecasts, drought and soil moisture products, and daily ultraviolet (UV) radiation index forecasts. Many of these outlooks are accompanied by technical discussions.

Predictive Services Seasonal Outlooks – https://www.nifc.gov/nicc/predictive-services/outlooks
Seasonal outlooks are released at the beginning of each month. These outlooks assess current and projected fuel conditions, weather patterns, and fire potential for the next four months.

NWS CPC Expert Assessments – https://www.cpc.ncep.noaa.gov/products/expert_assessment/
Expert assessments include Hazards Assessments, ENSO updates, and other climate related analysis. CPC meteorologists and oceanographers review observational climate and weather data and modeling results to evaluate climate drivers their significance, status, and likely future climate impacts. Findings are issued as assessments, advisories, special outlooks, and bulletins.

Drought Outlooks and Seasonal Climate Forecasts – https://www.cpc.ncep.noaa.gov/products/Drought/
These forecasts highlight expected drought trends for areas currently depicted in the U.S. Drought Monitor and identify areas where drought development is possible.

Forecast Models

Meteorologists produce weather forecasts primarily by interpreting and validating weather prediction models. Several models are available with varying update frequencies, output intervals, temporal ranges, and spatial resolutions. These models are periodically refined as new research, observing techniques, and increased computing capabilities emerge. No singular model is perfect.

Forecast models are classified into deterministic, ensemble and convective-allowing models (CAM). Models may be global, regional, or limited to small areas. High resolution models (≤ 5 km) generally fall into the CAM category. CAM operate on smaller areas with 15-minute to 1 hour time-steps and can account for data-intensive convection modeling. They can resolve terrain-induced and altered wind patterns, small-scale boundary passages and banded and cellular precipitation features.

Due to the differing scales, physics, and initial conditions, CAMs models can produce widely varying solutions, making it challenging for forecasters to determine which scenario is most likely.

Deterministic, or operational, models use the best estimate of the current atmospheric state (initial conditions) to provide a single forecast solution. These models typically provide higher spatial resolution compared to ensemble outputs.

Table 1. Comparison of deterministic model characteristics.

Deterministic Models	Updates per Day	Output Timestep (hours)	Range (hours)	Resolution (km)
Global Forecast Model (GFS)	4	6	384	13
European Computer Forecast Model (ECMWF)	2	12	240	9
North American Mesoscale Model (NAM)	4	1 to 3	60 to 84	3, 12, and 22
Global Environmental Multi-Scale Model Canada (GDPS/GEM/CMC)	2 to 4	1 to 6	54 to 240	Variable
Unified Model United Kingdom (UKMET)	4	6	144	10
Navy Global Environmental Model (NAVGEM)	4	3 to 6	144 to 180	13 to 31
High Resolution Rapid Refresh (HRRR)	24	15 minutes to 1 hour	18 to 36	3
Weather Research & Forecasting (WRF/different variants)	Variable	1	Variable but generally not beyond 72 hours	1.33 to 5

Probabilistic, or ensemble, models consist of multiple numerical model runs that display different possible outcomes. The variations occur because each ensemble member has been perturbed or initialized with slightly different starting atmospheric conditions, producing a range of plausible scenarios. Using ensemble systems can increase forecast skill during the first 1 to 2 weeks of a forecast period.

Table 2. Comparison of probabilistic model characteristics.

Probabilistic Models	Updates per Day	Output Timestep (hours)	Range (hours)	Resolution (km)	Members & Control
Global Ensemble Forecast System (GFES/GFS ensemble variant)	4	6	384	33	21
Ensemble Prediction System (EPS/ECMWF ensemble variant)	2	24	360	18	52
Global Ensemble Prediction System (GEPS/GEM ensemble variant)	2	6	384	66	21
North American Ensemble Forecast System (NAEFS/blend of GEPS & GFES)	2	6	336	111	42

Probabilistic Models	Updates per Day	Output Timestep (hours)	Range (hours)	Resolution (km)	Members & Control
Navy Global Environmental Model Ensemble (NAVGEM)	2	6	384	111	16
High Resolution Ensemble Forecast (HREFv2) https://www.spc.noaa.gov/exper/href/	4	1	48	Approx. 3	8
Short Range Ensemble Forecast (SREF) https://www.spc.noaa.gov/exper/sref/	4	1 to 3	87	16 to 40	22 to 26
North American Multi-Model Ensemble (NMME) https://www.cpc.ncep.noaa.gov/products/NMME/about.html	1	6 to 24	6 months	111	7

The amount of spread within an ensemble model should be directly related to forecast uncertainty because the observed weather should fall somewhere in between the individual members solutions. A tighter spread indicates higher forecast confidence, while a wider spread indicates lower confidence.

Figure 2. Diagram depicting the changes between the state of weather as time progresses for ensemble forecasts.

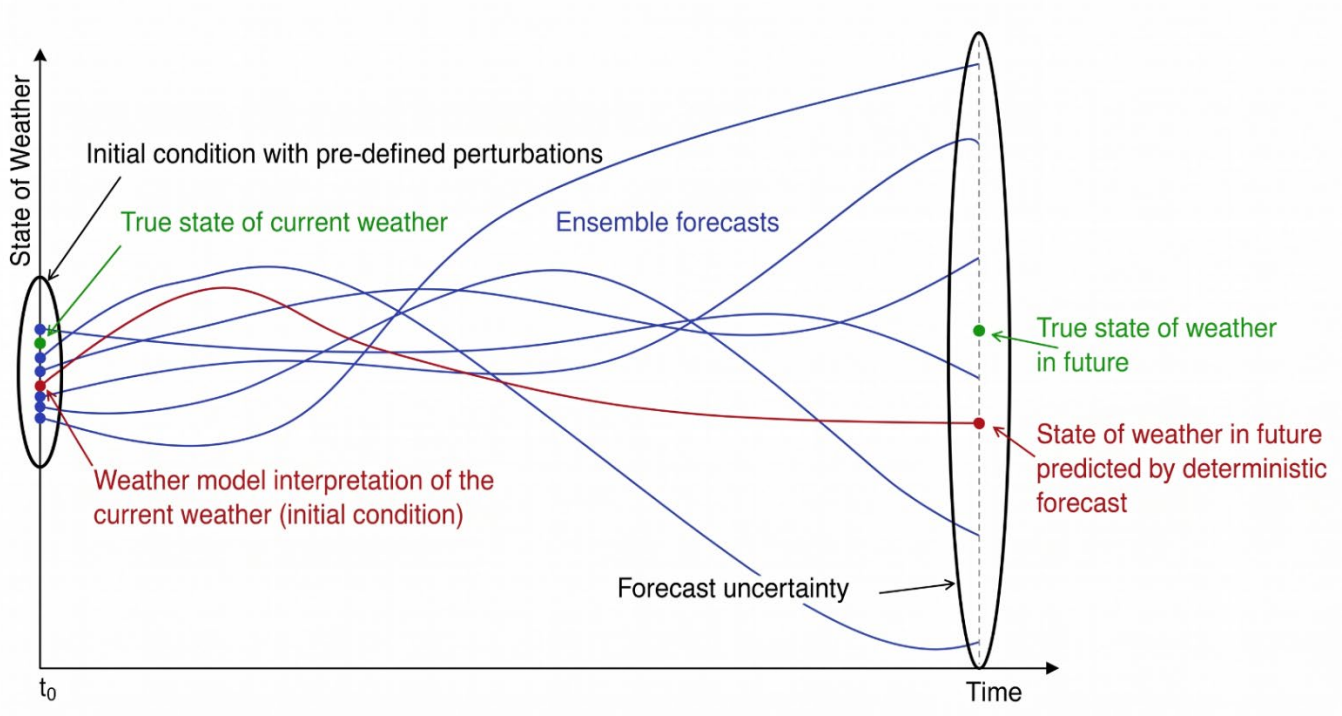


Table 3. Important terminology, definitions, and uses for ensemble systems.

Ensemble Terms to Know	Definition and Uses
Members	Individual models run in an ensemble suite perturbed by slightly different initial conditions. Forecasters look at spread of the members.
Mean	Average value of the individual ensemble model members. Smooths out "chaos."
Control	Mimics the operational model run because it uses the same initial conditions but with a courser spatial (vertical and horizontal) resolution. Forecasters compare it to the operational run, if output is different then differing spatial resolution has effect on the output.
Spread	Usually represented by standard deviation. Larger the deviation, more uncertainty in the forecast.
Normalized Spread	Put standard deviation in context with the general ensemble model behavior. For example, how does the current day 10 forecast standard deviation value compare to the past 30 days of day 10 model forecasts? Help determine proper confidence level.

Ensemble weather modeling can produce several useful outputs. For example, the NAEFS generates the following products by comparing the forecast to a 30-year climate record over a 3-week period centered on the valid day:

- Standard anomaly: Indicates how different the forecast is from the climatological mean.
- Percentile: Shows where the forecast falls relative to climatology. Maximum and minimum values indicate where the forecast falls out of the 30-year climate record and may signal a potentially significant event.
- Return interval: Indicates how often similar forecasts have occurred within the climatology.
- Probabilities: Show how many ensemble members support extreme values or conditions.

Special Wildland Fire Guidance Tools

These tools will help identify unusual or important fire weather and danger time periods and give higher confidence to a critical fire growth or slowing pattern. Publications explaining the tools or indexes are provided in the References section.

Global Tool

Global Wildfire Information System (GWIS), https://gwis.jrc.ec.europa.eu/apps/gwis_current_situation/index.html, provides 8 km ECMWF based Fire Weather Index (FWI) forecasts out to 10 days for locations worldwide.

National Tool

Hot-Dry-Windy Index (HDWI), https://hdwindex.fs2c.usda.gov/, is designed to help identify days with a higher likelihood of adverse weather conditions. It represents the product of maximum wind speed and maximum vapor pressure deficit (VPD).

CONUS Tools

Fire Potential Index (FPI), https://www.usgs.gov/ecosystems/lcsp/fire-danger-forecast/data-tools, is a linear index scaled from 0 to 100. An FPI value of 0 indicates vegetation that is green or nearly green and 100-hour dead fuels are too moist to burn. A value of 100 indicates fully cured vegetation and 10-hour dead fuel moisture is 2%.

Fosberg Fire Weather Index (FFWI), https://www.spc.noaa.gov/exper/href/?model=href&product=fosberg_mmm_series&sector=conus, is a numerical indicator used that combines temperature, relative humidity, and wind speed to estimate fire weather conditions. This tool helps assess the potential for wildfire ignition and spread, with higher values indicating more hazardous fire weather potential. The index is useful in dry, brush-dominated regions like the western United States.

Regional Tools

Alaska Fire & Fuels (AKFF), https://akff.mesowest.org/map, provides CFFDRS FWI forecasts for Alaska.

Great Lakes Fire & Fuels (GLFF), https://glff.mesowest.org/map, provides CFFDRS FWI forecasts for the Great Lakes region.

Southeast U.S. Fire Weather Intelligence Portal, http://climate.ncsu.edu/fwip/index.php, offers FWI maps, customizable layers, and downloadable data for the Southeast.

Southern California Santa Anna Wildfire Threat Index, https://fsapps.nwcg.gov/psp/sawti, provides tools and information tailored to wildfire threats in Southern California, including daily maps, an interactive map viewer, and downloadable data.

Long-Range Forecast Drivers

Meteorologists are responsible for understanding coupled atmospheric-oceanic teleconnections, but the fire analyst should be familiar with these teleconnections because these patterns are frequently referenced in longer-range forecast discussions. Table 4 introduces several key teleconnections and/or long-range outlook terms.

It is important to note that some teleconnection patterns can reinforce one another (constructive interference) while others work against each other (destructive interference). Research is ongoing regarding how climate change may be altering traditional teleconnection behavior and their associated impacts.

Table 4. Forecast impacts of Climate Teleconnections.

Coupled Oceanic-Atmospheric Forcing Mechanisms	Usefulness and Definition	Confidence Impact
Aleutian Low	Strength of the Aleutian low combined with Pacific Meridional Model (PMM) modes can accentuate or dampen MJO impacts on the jet stream position and storm track across western USA.	Confidence of an active storm track across western U.S. increases when the Aleutian low is stronger than average and combines with a positive PMM and a MJO is present.

Coupled Oceanic-Atmospheric Forcing Mechanisms	Usefulness and Definition	Confidence Impact
Arctic Oscillation (AO)	Represent a pattern of differences in air pressure between the Arctic and mid-latitudes. AOs influence winter weather in the northern hemisphere. Positive phase AOs are representative of strong pressure systems where low pressure is found over the Arctic and high pressure over mid-latitudes. Negative phase AOs represent a weaker pressure gradient due to less low pressure across Arctic and less high pressure in the mid-latitudes. AO phases can change in a matter of weeks.	During negative phase AOs there is higher confidence for cooler air, generally locked up in the Arctic, to eventually spill southward into CONUS while warmer air moves to the north.
Atlantic Multi-Decadal Oscillation (AMO)	Represents a coherent mode of natural variability occurring in the North Atlantic. Measurement is based upon average Sea Surface Temperature (SST) anomalies (0 to 80N). Cooler SSTs represent a negative phase. Warmer SSTs represent a positive phase.	It has been used to correlate temperature and precipitation anomalies across northern hemisphere. Positive AMOs have been linked to long-sustained droughts in Midwest and Southwest with increased Hurricane activity in North Atlantic.
El Niño Southern Oscillation (ENSO)	Irregular periodic variation in winds and SST over tropical eastern Pacific. Warming phase is El Niño and cooling phase is La Niña. There is also an ENSO neutral condition. Deep thunderstorm development over the eastern equatorial Pacific will help alter the jet stream and make more moisture available for Pacific storm systems that impact the USA.	Warm or cool phases combined with other climate drivers such as certain phases of the Pacific Decadal Oscillation (PDO) can lead to higher confidence long-term outlooks.
Madden Julian Oscillation (MJO)	MJO is a tropical disturbance that propagates eastward around the global tropics with a cycle on the order of 30 to 60 days. They typically are most active during late fall, winter, and early spring period. MJO can influence ENSO tendencies.	Active MJOs can increase forecast confidence for certain weather anomalies across USA.
Modoki	Alternation in normal La Niña and El Niño SST patterns across the tropical Pacific thus disrupting typical teleconnection patterns. “This isn’t your grandfather’s El Niño.”	Confidence becomes varied and can be less dependent on other coupled ocean-atmosphere phenomena.

Coupled Oceanic-Atmospheric Forcing Mechanisms	Usefulness and Definition	Confidence Impact
North Atlantic Oscillation (NAO)	Represents pressure difference between Iceland and the Azores. Azores typically have high pressure and Iceland low pressure. The magnitude of change dictates whether the NAO is in a positive phase or negative phase. Positive phases represent a large change in pressure, while negative phases are a small change. NAOs influence northern hemispheric weather by influencing the jet stream, especially during the winter months.	During positive phase, jet stream generally less undulating with muted, more progressive troughs, and ridges. During negative phase, jet stream is represented by high amplitude blocking troughs and ridges with a trough more over eastern portion of CONUS.
Pacific Decadal Oscillation (PDO)	A longer-lived northern Pacific climate variability has a negative and positive phase. The jet stream will tend to dip further south over the western United States under a positive phase and move further north under a negative phase.	Positive or negative phases to the PDO combined with other climate drivers such as ENSO conditions can lead to higher confidence long-term outlooks.
Pacific Meridional Model (PMM)	Describes the interaction between ENSO and PDO teleconnections and has a negative and positive phase.	Determining positive or negative phases of the PMM may help resolve the Spring Barrier issue and ENSO prediction. This should help lead to higher confidence outlooks originating during months of April through June.
Spring Predictability Barrier	Referring to the period when the statistical and dynamic climate models have less skill to predict ENSO trends. April-May-June represents this period for the northern hemisphere.	Lower confidence in long-range climate outputs when the models are initialized during the spring period.

Observing Fire Weather

Weather is the Most Variable Element when Anticipating Fire Behavior

Review weather forecasts and observe changing conditions. Fireline observations and data from automated weather stations supplement and validate forecast information. All Single Resources—whether a crew, squad, or individual—are responsible for staying informed about fire weather conditions and forecasts so they can base all actions on current and expected fire behavior.

This process includes obtaining and reviewing latest forecasts, taking observations throughout the assignment to validate those forecasts, communicating findings to those who need the information, and requesting forecast updates when conditions warrant.

Fireline Observations

Location and Timing of Fireline Weather Observations

There are four key observation times within a 24-hour period that are valuable for assessing forecasts and evaluating thresholds associated with fire behavior transitions:

- Early morning observations that capture minimum temperature and maximum humidity.
- Late afternoon observations that capture maximum temperature and minimum humidity occur.
- Times when active fire behavior increases or diminishes during the burn period.
- Hourly observations throughout the afternoon, or whenever conditions change, may be requested by fireline supervisors, or as needed to maintain situational awareness.

Selecting an Appropriate Observation Site

The weather observer should select observation sites that most accurately represent environmental conditions around the fire. Consider the following:

- Determine whether a ridgetop, midslope, or drainage bottom location is most representative.
- On slopes, account for aspect and slope steepness.
- Identify a fuel bed representative of fire conditions. Do not take observations in non-representative areas such as near bodies of water (with exceptions, as needed), on roads, in the burned area, or next to parked vehicles.
- Ideally, choose a safe site upwind or on the flank of the fire. Generally, ventilated areas in the shade are desirable locations for the observation.
- Minimize effects of the fire on your observation and avoid observations affected by gusty indraft flows and radiant heat from the fireline.

Note the Type of Instruments Used

Indicate whether observations were taken with an electronic weather sensor or traditional sling psychrometer. Electronic temperature and humidity sensors should be regularly calibrated against reliable instruments or by following calibration instructions from the manufacturer's website. Batteries should be checked frequently.

Communicate and Document the Weather Observation

Weather observations are only useful if communicated promptly and accurately to personnel who need it. Report current observations over the radio to maintain situational awareness.

- Follow established procedures for periodic radio reports to fireline supervisors or the incident communications unit.
- Report measurements with trends, such as "Temperature: 75 degrees, up 5 degrees from last hour."

Provide written documentation of weather observations to the fireline supervisor, situation unit, incident meteorologist, or local weather forecast office, and retain a copy for your records. Do not assume others are automatically receiving your weather observations. Observers may need to take the initiative to verify that information is being passed up the line. Standard forms are available for this purpose.

Wind Observations and Estimates

Obtain Forecast from Incident Meteorologist or Fire Weather Forecaster

Wind speed and direction are the most variable weather elements during an assignment. The observer must validate forecasted winds and measure current wind speeds. Producing localized wind forecasts can be difficult for meteorologists, particularly when terrain features influence the wind, but accurate field measurements help improve forecast interpretation.

Forecasted winds may require adjustment because they often represent winds at heights other than midflame—such as ridgetop or surface winds. Refer to the Estimating Winds for Fire Behavior section of this guide when making these adjustments. It is important to communicate with the meteorologist about the factors that influenced observed wind measurements. Use the Surface Wind Estimation worksheet.

Report wind observations by type and/or height. Identify aspect/slope position and sheltering conditions for the wind observation and note whether local winds are influencing the observation. Consider Possibility of Critical Wind: Estimate or Validate 20-foot Surface Wind Speed

If the weather forecast provides wind speed as free air or ridgetop, or if local winds influence winds in the fire area, it may be necessary to use the Estimating Winds for Fire Behavior worksheet (see Estimating Winds for Fire Behavior section) to determine 20-foot surface winds.

- Identify the forecasted critical wind speed and direction.
- Determine speed and direction of any local winds.
- Determine speed and direction of general winds and whether they will influence the 20-foot wind.
- Combine the factors above to estimate local surface (20-foot) wind speed.

Table 5. Visual Surface (20-foot) Wind Estimate - Modified Beaufort Scale.

Class	Wind Speed (mph)	Terminology	Visible Effect
0	Less than 1	Calm	Calm, smoke rises vertically.
1	1 to 3	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	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	Gentle Breeze	Leaves, small twigs in constant motion, tops of trees in dense stands sway, light flags extended.
4	13 to 18	Moderate Breeze	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	Fresh Breeze	Branchlets are broken from trees, inconvenience is felt in walking against wind.

Class	Wind Speed (mph)	Terminology	Visible Effect
6	25 to 31	Strong Breeze	Tree damage increases with occasional breaking of exposed tops and branches, progress impeded when walking against wind.
7	32 to 38	Moderate Gale	Severe damage to treetops, very difficult to walk into wind, significant structural damage occurs.
8	39 to 46	Fresh Gale	Surfaced strong Santa Ana, intense stress on all exposed objects, vegetation, buildings, canopy offers virtually no protection.
9	47 to 54	Strong Gale	Slight structural damage occurs, slate blown from roofs.
10	55 to 63	Whole Gale	Seldom experienced on land, trees broken, structural damage occurs.
11	64 to 72	Storm	Very rarely experienced on land, usually with widespread damage.
12	73 or more	Hurricane Force	Violence and destruction.

Estimate or Validate Midflame Wind Speed

Eye-level wind speed is generally assumed to be the same as midflame wind speed. It may be necessary to adjust forecasted 20-foot winds or observed midflame wind speed to allow for accurate comparisons and forecast validations.

Observing Eye-Level Wind Speed in the Field

The observer should face directly into the wind and monitor fluctuations on the wind speed indicator. Exposure to sunlight does not affect wind observation.

- Take at least one full minute of eye-level wind speed measurement sampling, longer is preferable.
- Note time and speed of transitions in diurnal winds.
- When using a Dwyer tube, mentally average the observed wind speed and record the peak gust during the sampling period.
- Electronic sensors simplify averaging wind speed and gust measurements and are preferred for eye-level wind speed observations because they are more accurate.
- Remember that wind direction is defined as the direction the wind is coming from.

Estimate Effective Wind Speed for Slope Influence

Slope effects on fire spread are incorporated through a slope-equivalent wind speed.

Where slope is significant (generally 20% or greater), fire behavior assessment tools in the Surface Fire section—including the Surface Fire Behavior Worksheet, nomograms and nomographs, and Behave—provide methods to estimate EWS.

Use the EWS, adjusted for slope, in place of midflame wind speed when making fire behavior predictions.

Temperature, Relative Humidity, and Vapor Pressure Deficit Observations

Estimating temperature, relative humidity (RH), and dewpoint can provide insight into critical fire behavior thresholds related to probability of ignition and crown fire potential.

Using Sling Psychrometers

The following steps outline how to obtain wet- and dry- bulb temperatures using a sling psychrometer:

- If the psychrometer has been in your pack, hang it in a tree or shaded area to let it adjust to the outside air temperature. This may be a good time to take the wind observation.
- Stand in a shaded, open area away with enough space to whirl the instrument without striking any objects. In open terrain, use your body shade to shade the psychrometer. Whenever possible, take observations over a fuel bed that is representative of the fuels involved in the fire. Avoid heat sinks such as black pavement, or extensive areas of rock.
- Face the wind to prevent body heat from influencing the thermometers.
- Saturate the wick of the wet bulb with clean, mineral free water (distilled, if available) at air temperature.
- Ventilate thermometers by whirling at full arm's length, arm parallel to the ground, for one minute.
- After one minute, read the wet bulb temperature. Whirl for another 40 to 50 times and read again. Continue this process until the wet-bulb temperature stops decreasing. Record the lowest value. If the wet bulb is not read at the lowest point, the calculated RH will be too high.
- Read the dry bulb temperature immediately after obtaining the lowest wet bulb temperature.
- Determine the RH using the psychrometric tables. Calculate dewpoint each time as significant variation may indicate an inaccurate observation.

Important Tips - Beginners may produce inaccurate psychrometer readings due to the following common mistakes:

- Switching psychrometers from one observation to the next. Use the same sling throughout.
- Not spinning/ventilating the psychrometer long enough to reach equilibrium.
- Not wetting the wick enough or allowing it dry.
- Holding the instrument too close to the body or taking too long to read the thermometers.
- Touching the bulb ends while reading.
- Not facing into the wind.

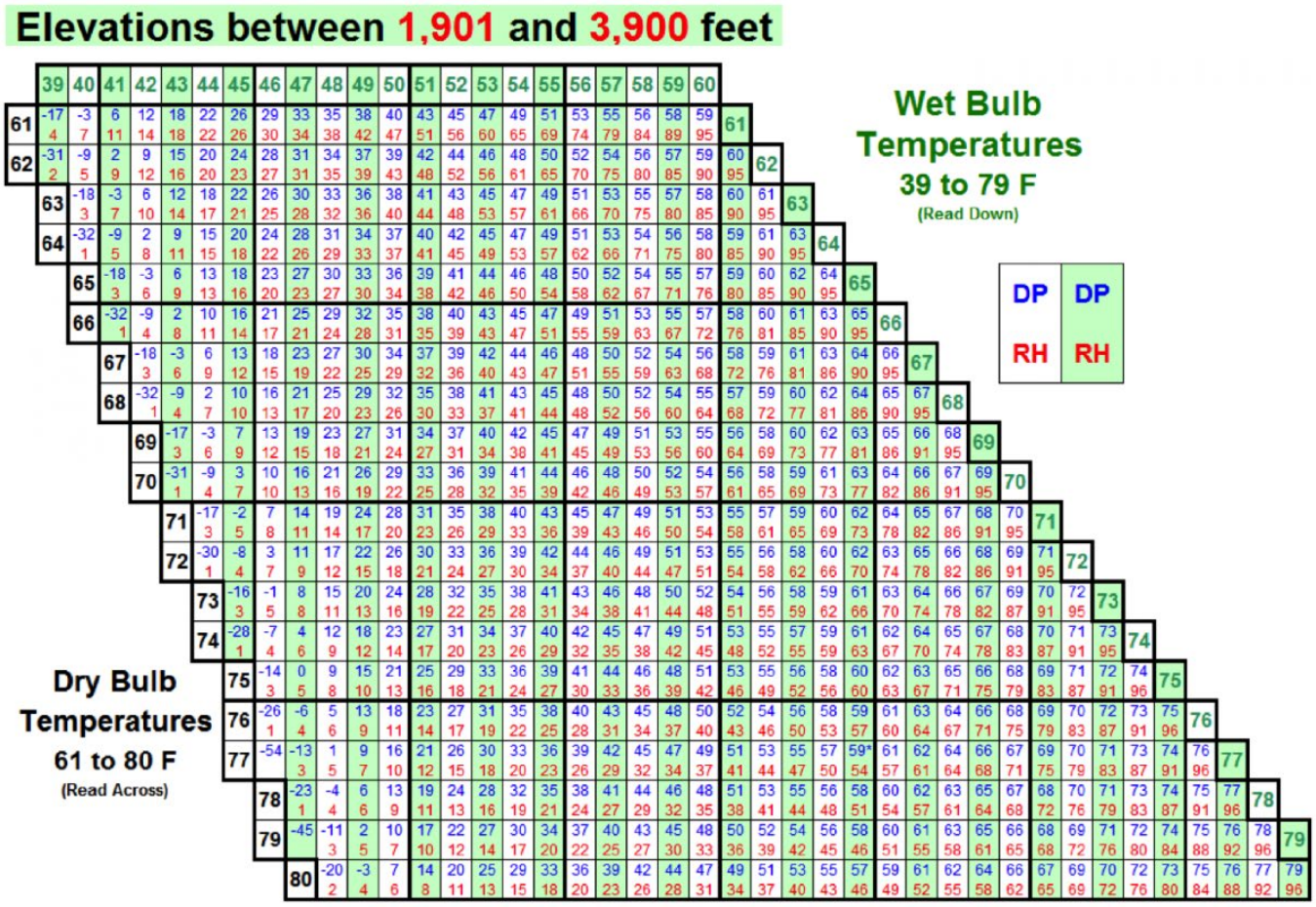
Estimating Relative Humidity and Dew Point from Psychometric Tables

Psychometric tables (included in the belt weather kit and in this guide). allow estimation of RH and dew point from dry bulb (DB) and wet bulb (WB) temperatures. Each table is labeled with an elevation range (including adjustments for Alaska). DB temperature is located on the left side, and the WB temperature is located at the top of each column (see Table 6). Read the cell at their intersection for the resulting RH and dew point.

Follow these steps to determine RH and dew point:

- Select the correct table for your observing location based on elevation.
- Use the DB temperature and WB temperature to locate the intersecting cell on the table.
- Read the resulting RH (lower number) and dew point (upper number) from the intersecting cell.

Table 6. Example table for determining RH.



Adjusting Relative Humidity for Changes in Temperature and Elevation

Under certain circumstances, estimating RH for a particular elevation may not be possible using standard forecasts. It may be necessary to make a field adjustment to the forecasted RH for a later time in the burn period. In both situations, if the air mass is stable and neutral, field adjustments can be made using the current estimates of dew point and temperature:

Case 1: **Estimating RH for an elevation above or below the point of observation:**
Assume an average lapse rate of approximately 4° Fahrenheit (F).

- For each 1,000 feet **decrease** in elevation, **increase** the temperature by 4°F.
- For each 1,000 feet **increase** in elevation, **decrease** the temperature by 4°F.

Using this adjusted temperature and the observed dew point, determine the new RH from the appropriate psychrometric table.

Case 2: **Validating a Forecasted RH:**
Use the observed dew point and the forecasted temperature to determine the expected RH using the appropriate psychometric table.

Calculating Vapor Pressure Deficit

Used extensively in greenhouse and agricultural applications, VPD is a strong indicator of green vegetation moisture stress. The Growing Season Index (GSI) incorporates VPD as a key criterion to green-up and curing phenology, with values around 9 mb (millibars) considered optimal for plant growth.

While RH expresses the amount of water vapor (moisture) in the air as a percentage of saturation, VPD measures the absolute difference between the actual moisture and the amount it could hold at saturation. Potentially counter-intuitive to RH, VPD increases as the moisture deficit increases and generally follows a seasonal trend, low in winter and higher in warm summer months, driven by variation in temperature and atmospheric humidity.

VPD provides important insight about the role of ambient temperature and atmospheric humidity.

- At low temperatures, even low RH does not produce a high VPD.
- At high temperatures, the same low RH can result in a much higher VPD, indicating a stronger drying potential.

Figure 3 provides an example of interpreting VPD. Colors depict potential for extreme fire behavior: green indicates optimal plant growth conditions, but as the temperature increases, higher VPD indicates drier air, increased moisture loss from vegetation, and greater potential for extreme fire behavior. Crossover Concept thresholds, where extreme fire behavior exists, are indicated by black boxes on VPD tables.

The Crossover Concept

The Crossover concept, introduced by the Alberta Forest Service (1985), is a fire weather indicator used to identify potentially critical burning conditions. A “Crossover” occurs when the temperature (in degrees Celsius[C]) exceeds the RH (in %). For example, a temperature of 25°C and a RH of 20% indicates a Crossover situation.

Crossover conditions indicate a high potential for fire ignition and rapid spread, especially when combined with wind. The Crossover point is significant because it reflects very dry air and fuels, making it a valuable tool for fire managers in anticipating elevated, dangerous fire behavior.

An RH 15% at 60°F has a different effect on the fire environment than at 80°F.

Figure 3. VPD and the potential for extreme fire behavior table.

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

Sky Observations

Local terrain and other site-specific factors can modify general atmospheric conditions, creating more localized effects. Weather observers provide important information to meteorologists by reporting the visual cues and the timing of changes throughout the day. Visual cues should be recorded in the remarks section of the weather observation to provide a time-stamped reference. Firefighters should pay attention to both the fire weather forecast and the sky for signs of changing or severe conditions that can influence the fire environment. When visual cues are significant, photographs—paired with a photo log noting location, date, time, and other identifiers—can provide valuable supporting documentation.

Airport webcams, available at http://airportwebcams.net/airport-webcams-by-time-zone/, can provide useful real-time information.

Synoptic (large-scale) forecasts current-condition reports reference the relative stability of the atmosphere. Several indicators of stability are outlined below.

In general, a stable atmosphere suppresses strong vertical motion. Cloud build-ups during stable conditions tend to be broad and flat, sometimes spreading across much of the sky. Additionally, stable conditions favor smoke accumulation near the surface, which can moderate fire behavior due to limited

winds, lack of solar radiation to heat fuels, reduced temperatures, and higher relative humidities. However, strong general winds can still occur during stable conditions depending upon the overall weather pattern.

In contrast, unstable conditions enhance vertical motion and typically increase ventilation around active fires.

Lightning and Wind

- Report **lightning** immediately so fireline supervisors can take appropriate safety precautions and meteorologists can review lightning-detection tools.
- **Sudden wind shifts** may indicate a breaking inversion or frontal passage.

Indicators of Stability: Smoke, Dust, and Fire

- A **rising smoke column** signals neutral or unstable conditions, while a **flattening smoke column** indicates an inversion at that level.
- A **smoke column** that **changes direction as it rises** indicates wind shear or influence from local winds.
- A **smoke column** that **develops a pyrocumulus cap cloud** indicates strong instability and the potential for downdrafts.
- **Haze and reduced visibility** often indicator inversions. Determine whether the inversion is local (e.g., nighttime) or more general and persistent throughout the day.

If haze or poor visibility lifts during the burn period, expect increased fire behavior.

Dust clouds radiating away from thunderstorms indicate potentially dangerous downdrafts.
Dust devils indicate surface instability.
Firewhirls occur when fire-generated convection interacts with winds, adjacent terrain-generated eddies, instability from cold fronts, and/or multiple interacting fire plumes. Firewhirls are difficult to predict.

The presence of dust devils and firewhirls indicates the potential for gusty, erratic winds and firebrand transport.

Clouds, Fog, and Precipitation

Clouds form when moisture condenses into visible droplets or ice crystals, typically as moist air cools while rising. Cloud shape and texture can reveal whether lifting has been gradual and gentle or rapid and potentially violent. Paying attention to the sky can help firefighters stay aware of the current fire environment and anticipate potential changes.

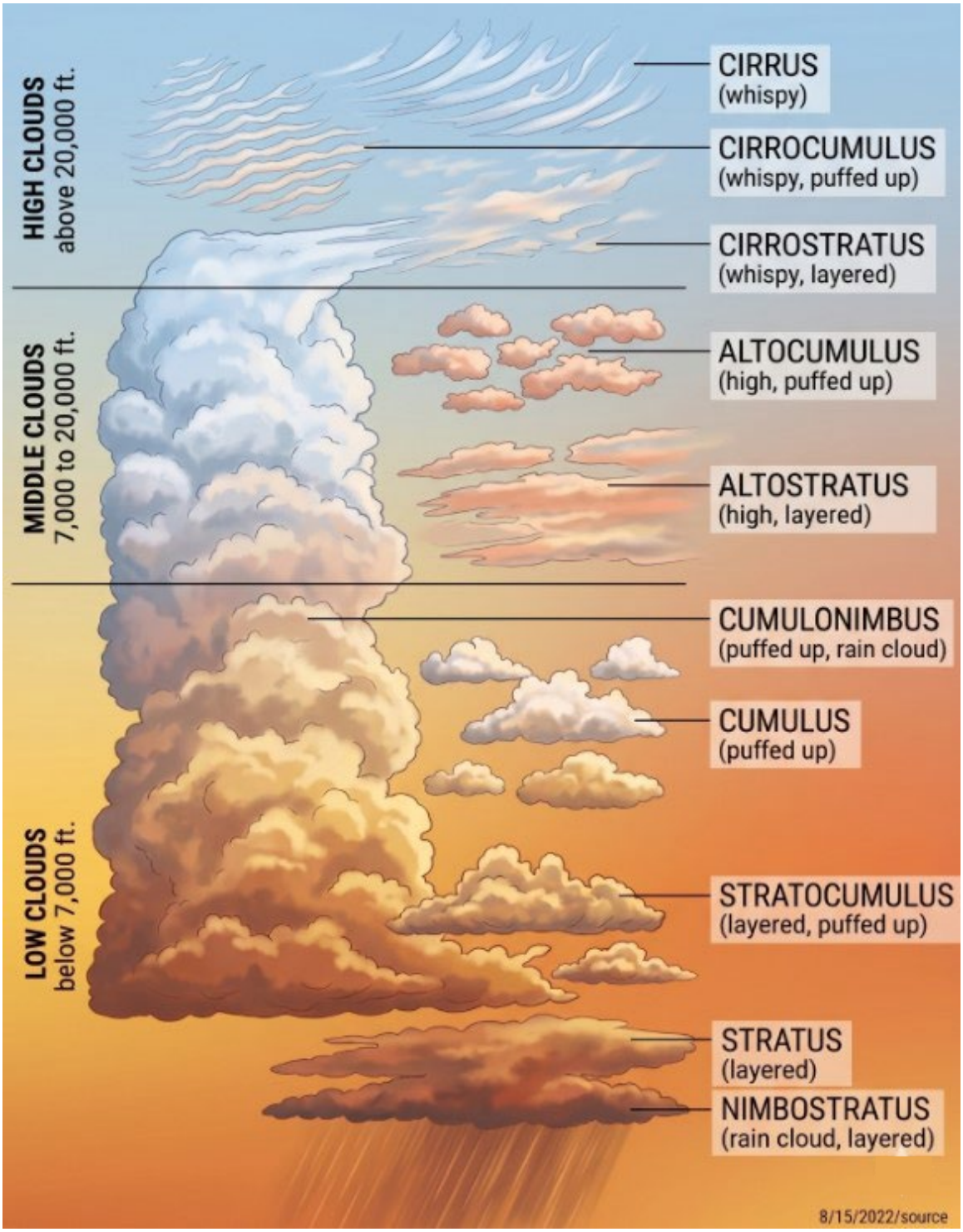
- **Cloud cover** (in percent) is a key factor in fuel moisture shading.
- **Building cumulus, towering cumulus, and thunderstorms** signal significant instability likely already influencing surface winds.
- **Showers or virga** may also indicate instability.
- Monitoring conditions conducive to fog formation—such as cloud cover, temperature, RH, and wind speed—during periods of overnight smoke production helps identify reduced visibility and potentially hazardous driving conditions early.

The *NWCG Fire Weather Cloud Chart*, PMS 438, https://www.nwcg.gov/publications/438, provides examples of sky features important for wildland firefighters. Cloud types and formations are valuable indicators of atmospheric stability and potential changes.

Clouds That Indicate Instability in the Atmosphere

- **Cumulus** (various types) – Signal weak instability. They are usually not a concern for firefighters, but continued vertical growth should be monitored. Developing cumulus can precede sudden downdrafts and gusty winds.
- **Altocumulus** (various types, including castellanus) – Indicate increasing moisture and instability in the upper atmosphere and a possible upcoming weather change. Altocumulus castellanus in particular indicate increasing moisture and instability with the potential for thunderstorms.
- **Cumulonimbus** – Reflect very unstable conditions. Fully developed, mature thunderstorms contain extreme vertical motion and can produce sudden gusty, erratic winds—sometimes miles away from the cloud buildup. Severe thunderstorms can generate localized wind gusts over 100 mph along with lightning, virga, hail, shelf clouds or even tornadoes. Clearly, cumulonimbus clouds pose many hazards to the firefighter exposed on the fireline.
- **Pyrocumulus** – Very unstable. Pyrocumulus clouds form above ongoing wildfires, drawing energy from the heat of combustion and moisture from condensation 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 precipitation, and occasionally lightning are possible.

Figure 4. Image of cloud types that may be present at different altitudes.

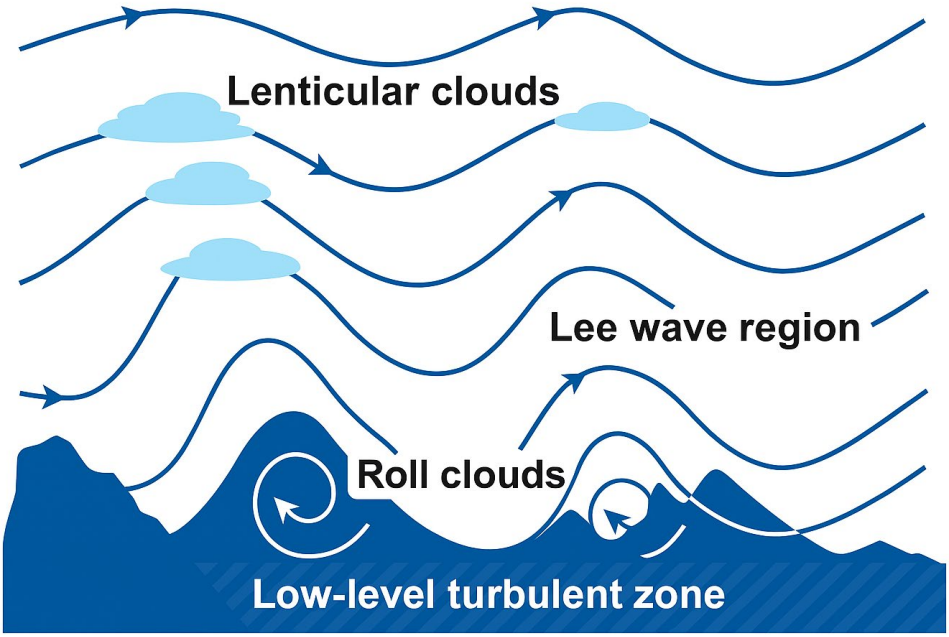


Clouds That Indicate Stability in the Atmosphere

- **Stratus** (various types) – Stable and moist. Stratus clouds can cover much of the sky, blotting out sunlight or sometimes producing rain. Stratus cloud presence generally corresponds with higher humidity and reduced fire behavior and are typically not a concern for firefighters.

- **Cirrostratus** (various types) – High-level stratus clouds formed of ice crystals are not usually a concern for firefighters. However, increasing cirrostratus from the west or northwest may indicate an approaching front with strengthening general winds. Check the fire weather forecast.
- **Altostratus** (various types) – Mid- to high-level stratus clouds are a good indicator of an approaching front with strengthening general winds. Check the fire weather forecast.
- **Wave clouds or Lenticular clouds** – Smooth, almond-shaped clouds that sometimes form over mountainous terrain, appearing to be stacked dishes. These clouds tend to remain fixed over one peak and indicate 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.

Figure 5. Depiction of lenticular cloud formation.



Automated Weather Stations

A range of weather observing networks are available to support fire weather assessment:

- **Mesowest at the University of Utah**, https://mesowest.utah.edu/, provides access to current and archived weather observations through a website allowing visualizations and tables of current weather, and interactive weather maps. This site will be sunset on December 31, 2026. Its features will move to Synoptic Data, https://synopticdata.com, which will enhance Mesowest's capabilities.
- **NWS Weather and Hazards**, https://www.weather.gov/wrh/hazards, provides weather observations in context with radar, forecasts, and wildfire information.
- **Weather Underground**, https://www.wunderground.com/wundermap, provides observations collected by websites and web applications.
- **Iowa Environmental Mesonet**, https://mesonet.agron.iastate.edu/, provides access to current and historic data.

Networks of Interest

- **Remote Automated Weather Stations (RAWS)** support land management agencies by tracking air quality, fire weather, and research needs. Fire weather RAWS follow National Fire Danger Rating System (NFDRS) standards, though other standards exist.
- **Incident Remote Automatic Weather Stations (iRAWS)** are intended for rapid deployment on or near the fireline and can be relocated by Fire Behavior Analysts (FBANs) or IMETs to capture real-time, incident specific weather data. iRAWS data helps to predict fire behavior, prescription burning times, fire weather forecasting, and canyon and ridge top winds. As with RAWS equipment, mast heights may vary.
- **Automated Surface Observing System (ASOS) and Automated Weather Observing System (AWOS)** stations are typically located near airports to serve aviation operations. ASOS stations also serve as a primary climatological observing network and follow international standards for weather observations.

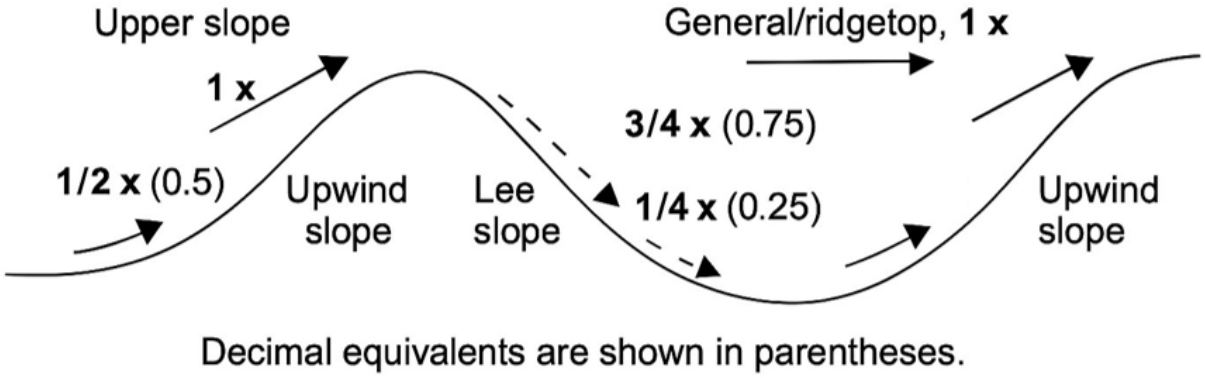
Other Networks are available and may be appropriate for local, project-specific, or ad hoc uses.

Wind Observations from Automated Sensors

Surface wind estimates from automated sensors are influenced by four main factors:

1. **Local terrain influences the general winds.** Terrian affects general winds through exposure and differential surface heating related to slope, water and ice factors, and channeled air flow. Figure 6 demonstrates the effect of terrain on wind measurements in different locations (Bishop, 2010).

Figure 6. Depiction of how local terrain influences general winds.



2. **Sensor standards for timing and duration of observation.** Fire weather standards use a 10-minutes average for wind speed, while international standards use a 2-minute average.
3. **Surface characteristics produce differing friction factors.** For example, friction in areas surrounded by large, smooth surfaces (airports and agricultural areas) is less than that experienced in forest openings and in cities (Lawson & Armitage, 2008). Generally, gradient winds are reduced by friction from the Earth's surface. See Figure 7.
4. **Sensor height above surrounding vegetation or structures.** A 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). See Table 7.

Figure 7. Depiction of how surface characteristics impacts wind observations.

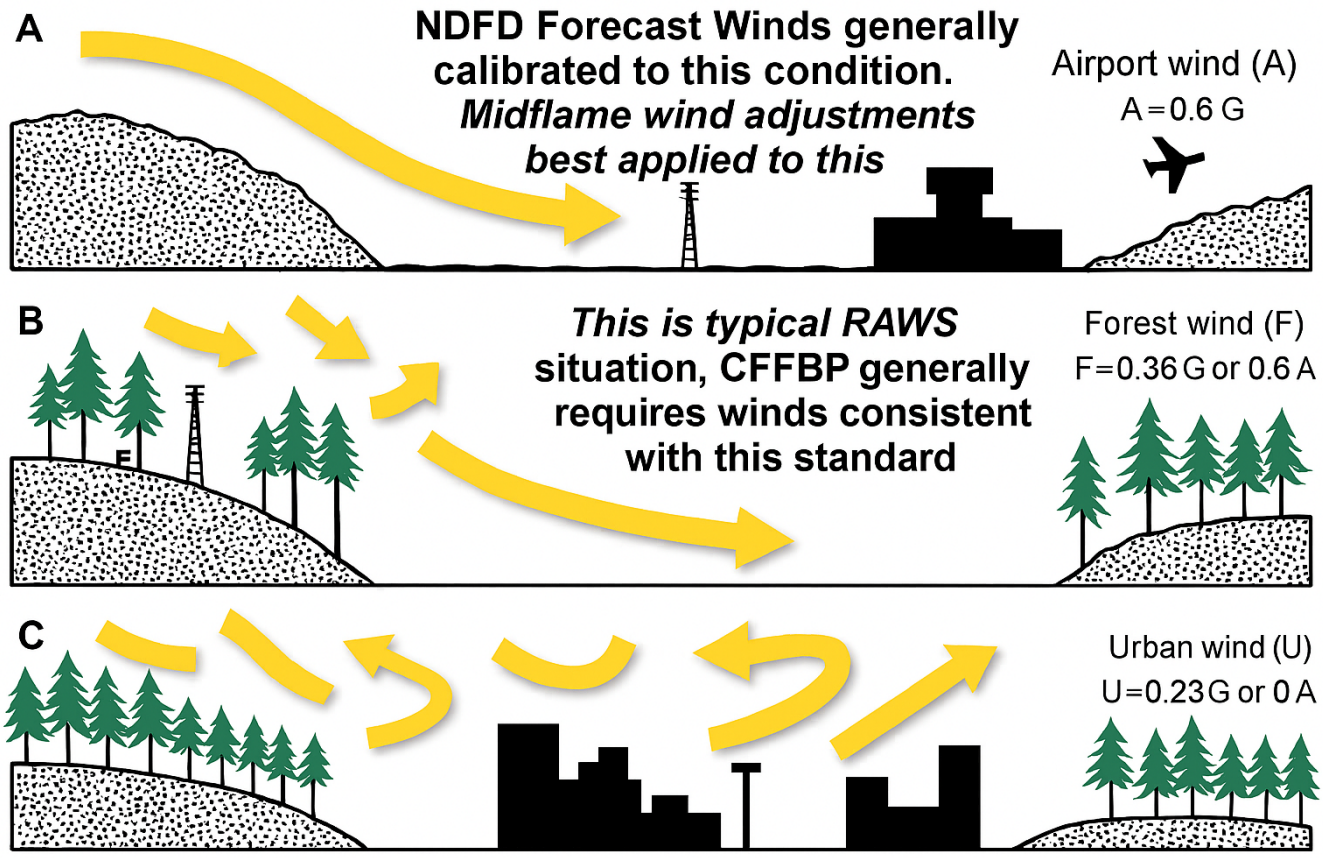


Table 7. Wind adjustment factors for different observation heights and surfaces.

Mast Height (meters)	Rough Surface Adjustment Factor	Smooth Surface Adjustment Factor
1.5	1.94	1.48
2.0 to 2.9	1.54	1.31
3.0 to 3.9	1.37	1.22
4.0 to 4.9	1.26	1.16
5.0 to 6.9	1.18	1.11
7.0 to 8.9	1.06	1.03
9.0 to 11.9	1.00	1.00

Critical Fire Weather

Two references for critical fire weather are:

Synthesis of Knowledge of Extreme Fire Behavior: Volume 1 for Fire Managers, Chapter 3 – https://research.fs.usda.gov/treesearch/39553

Critical Fire Weather Patterns; Program for Climate, Ecosystem, and Fire Application (CEFA) – https://cefa.dri.edu/CriticalFire/home.php

The four critical weather elements that may produce extreme fire behavior are **low RH, strong surface wind, unstable air,** and **drought**. Critical fire weather patterns that support these conditions can be separated into two primary categories: (1) patterns that produce strong surface winds, and (2) patterns that produce atmospheric instability. In both cases, an unusually dry airmass for the region and season must also occur. In brush and timber fuels, drought becomes an important precursor by increasing fuel availability and receptiveness.

Most periods of critical fire weather occur in transition zones between high- and low-pressure systems, at both the surface and upper levels. Surface-pressure patterns of most concern are those associated with cold fronts and terrain-driven 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, warm, and dry, sometimes abruptly so. The region between the upper ridge and upper trough has the most critical upper-air pattern because of unstable air and strong winds that can mix to the surface.

Critical Fire Weather Patterns

These descriptions include common terminology used by meteorologists to describe critical fire weather patterns. While you will often encounter these terms in NWS Area Forecast Discussion (AFD), https://forecast.weather.gov/product_sites.php?site=CRH&product=AFD), fire weather planning forecasts, and Predictive Service seven-day outlook assessments, other terminology may be used.

East of the Rocky Mountains:

Critical fire weather patterns are associated with the periphery of high pressure systems, particularly in the pre-frontal and post-frontal areas. In the Northern Plains, Great Lakes, and the Northeastern U.S., pre-frontal high pressure from the Pacific, Northwestern Canada, and Hudson Bay can produce very dry conditions. Cold fronts can produce relatively short-lived but intense periods of strong winds and instability capable of driving extreme fire behavior.

Southeastern U.S.:

Drought is frequently associated with La Niña state of the southern oscillation pattern or a blocking ridge aloft near the Atlantic coast. Often critical fire weather patterns follow the frontal passage that brings extremely dry air due to a strong westerly or northwesterly flow. Watch for strong winds that accompany the flow. Beware of advancing tropical storms that can produce significant wind shifts as well.

Southwestern U.S.:

Before monsoons develop, the breakdown of the upper ridge produces breezy, dry, unstable surface conditions that often intensify as the ridge collapses. During transition to the monsoon pattern, shallow monsoons can produce gusty wind, low RH, and lightning without much precipitation.

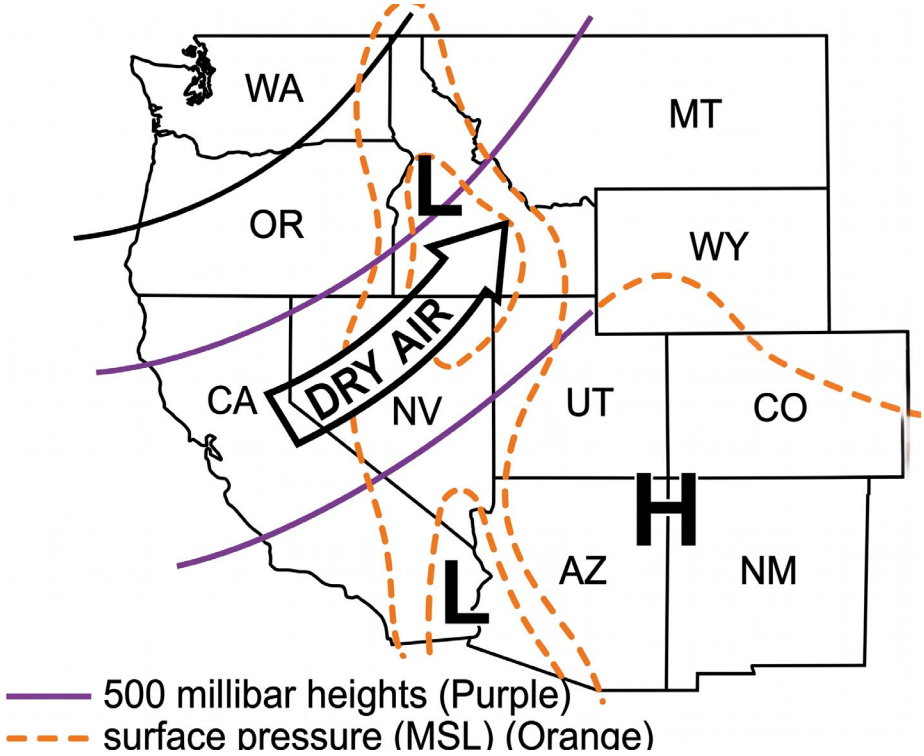
Rocky Mountain and Intermountain Regions:

The primary pattern is the upper ridge combined with a 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.

Across the Intermountain West, critical fire weather is associated with upper troughs, overhead jet streams, or surface-dry cold front passages.

Figure 8. Western U.S. critical fire weather pattern.



Pacific Coast (Washington to California):

Offshore flow or foehn wind patterns are the dominant concern.

In the Pacific Northwest, east winds bring strong winds and dry air west of the Cascades. Upper-ridge breakdown is like that described in the Rocky Mountain and Intermountain regions.

In California, critical patterns include the north and mono winds in the north and central regions and the Santa Ana and sundowner winds of southern California. The subtropical high aloft brings heat waves.

Alaska:

Critical fire weather often develops when the upper ridge breaks down and southeast flow brings gusty winds and dry lightning to the interior of Alaska after a period of hot, dry weather.

Hawaii:

The dry season is May through September, and the wet season is October through April.

Critical fire growth events can occur any time of the year when live fuels are drought stricken and/or when herbaceous green-up has senesced. Critical fire weather patterns align with strong trade wind periods when high pressure builds north or when a significant tropical cyclone passes to the south of the main Hawaiian Islands. Strong southwest winds from frontal systems have led to critical fire weather by creating down-sloping winds across typically windward slopes.

Hot-Dry-Windy Index

The Hot-Dry-Windy Index (HDWI) product suite (https://hdwindex.fs2c.usda.gov/) is designed to help identify days that are more likely to have adverse atmospheric conditions that could make wildland fire management more difficult. HDWI combines surface and low-level atmospheric data into a simple first-look tool. HDWI is calculated by multiplying the maximum wind speed by the maximum VPD in the lowest approximately 50 millibars of the atmosphere. Because HDWI is affected by heat, moisture, and wind, HDWI values may vary seasonally and regionally when comparing values from different locations and times.

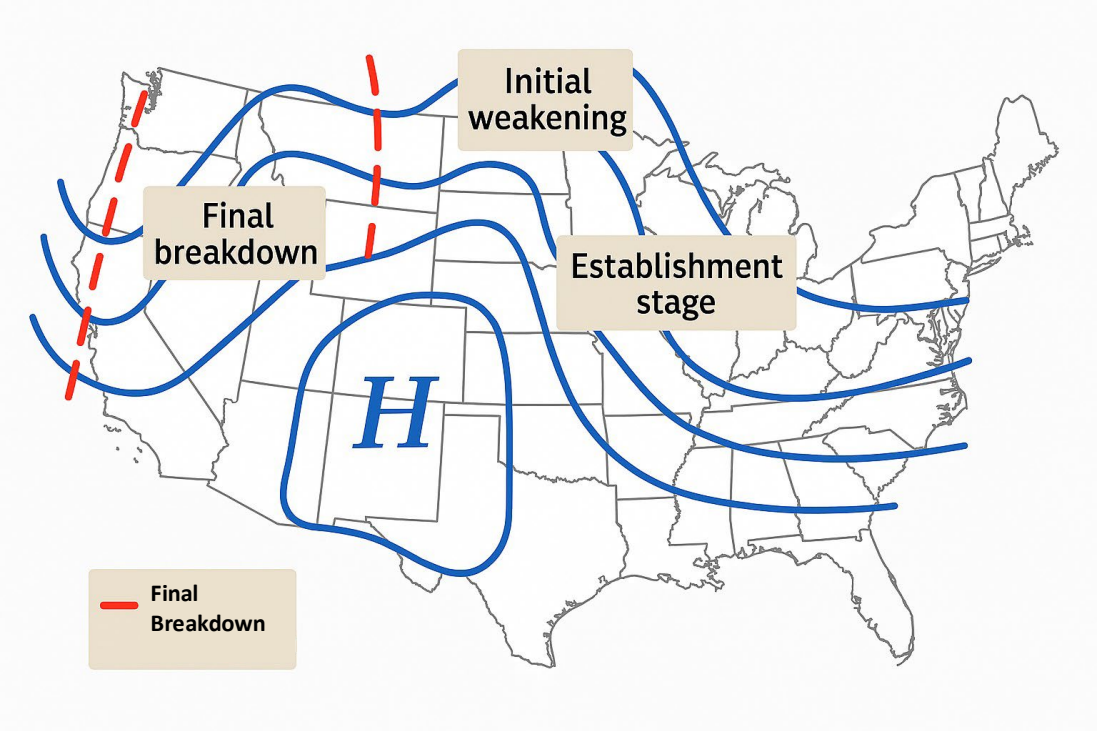
Critical Wind Events

Breakdown of the Upper Ridge and Cold Frontal Passage

Breakdown of an upper ridge generally occurs in three stages (Figure 9):

- Stage 1: Warm, dry, breezy, and unstable conditions.
- Stage 2: Increasing wind speeds with continued warm, dry, unstable conditions.
- Stage 3: Passage of a cold front.

Figure 9. Three stages of the breakdown of an upper ridge.

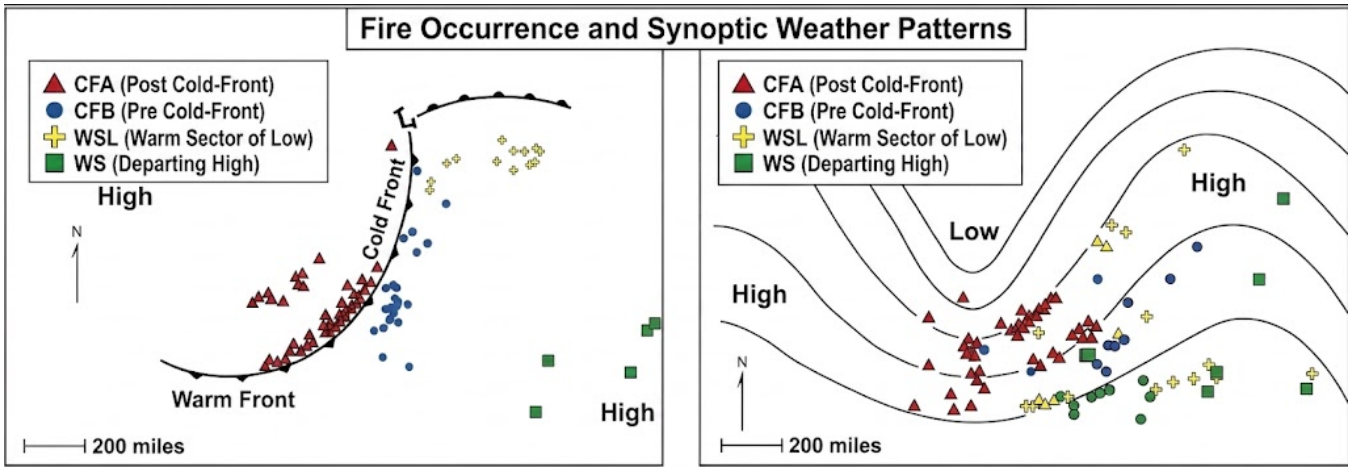


In the western U.S. and Alaska, significant fire growth can occur during all three stages but is most common during stage 2. In the eastern U.S., significant fire growth is most frequently associated with post cold frontal conditions (stage 3) but can occur during the stage 2.

Figure 10 illustrates locations for fire growth relative to cold frontal passage and general breakdown of a high pressure ridge.

- CFA is after the cold front passage.
- Crown fraction burned (CFB) is before cold front passage.
- WSL is warm sector of Low.
- WS is warm sector of departing High.

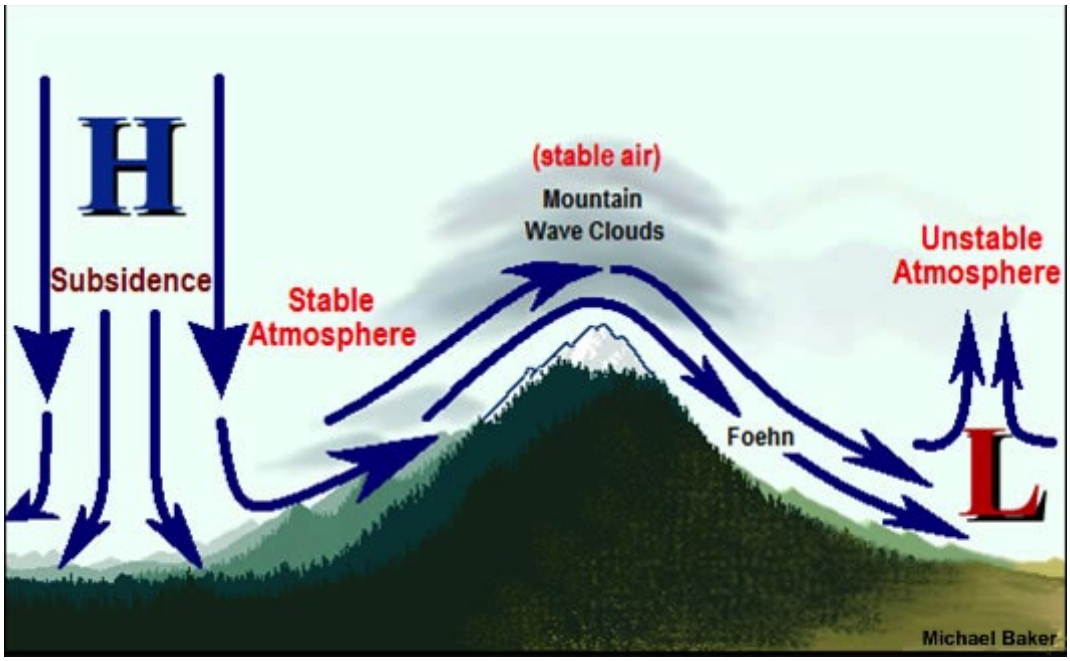
Figure 10. Relationship of fire growth to cold frontal passages.



Foehn or Downslope Winds

Foehn or downslope winds—known by various regional names—occur when stable air is forced over mountain ranges and through mountain passes. These winds are typically warm, dry, and strong. Examples include Santa Ana winds in southern California and Chinook winds along the eastern Rockies.

Figure 11. Foehn or downslope wind patterns.

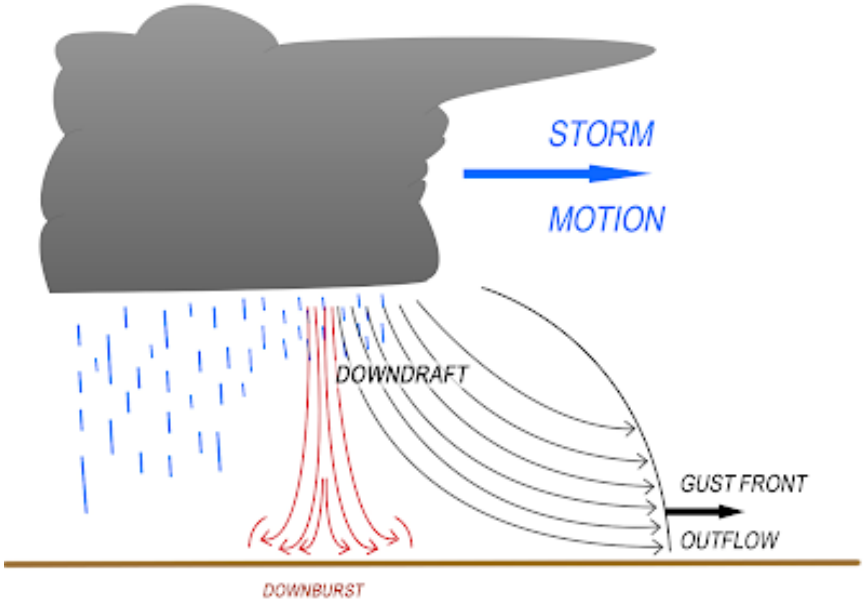


Thunderstorm Dynamics: Outflows, and Downbursts

Thunderstorms near a fire have the potential to generate outflow gust fronts or downbursts, regardless of whether the storm is influenced by the fire. Any sign of precipitation—rain at the surface or virga aloft—indicates the storm has developed enough to produce these types of winds, along with lightning.

Outflow gust fronts spread outward from the base of the storm, usually in the direction of storm motion. They occur with all well-developed convection, can last tens of minutes to an hour or more, and can travel tens to hundreds of kilometers. Downbursts are much less common, shorter lived, and affect a much smaller area but can also produce abrupt changes in wind speed and direction. Either type of wind can abruptly change the speed and direction of fire spread.

Figure 12. Thunderstorm dynamics.



Sea Breeze Fronts

Along coastal regions, sea breeze or sea breeze fronts can bring gusty, shifting winds and changes in humidity and stability that can drive fire behavior. The few hours preceding sea breeze are typically the warmest and driest and coincide with increasing wind speeds and unstable conditions. After the sea breeze front passes, temperatures become cooler while humidity and stability increase. Sea breezes are more critical than land breezes because they occur during the daytime burn period.

Tropical Systems

Tropical systems, including tropical storms and hurricanes, can create areas of relatively warm, dry, and windy conditions along their northern and western flanks as they move ashore. This may support rapid fire growth.

Hot, Dry, and Unstable Events

Critical fire growth periods are also tied to hot, dry, and unstable weather patterns. These patterns are typically associated with an upper ridge and a strong mid-level dry intrusion—two ingredients that often precede the breakdown of the upper ridge pattern. A strong “heat bubble,” combined with unusual vertical mixing, can produce above normal temperatures (sometimes a heat wave) and very low day and nighttime humidity. The unusual mixing is caused by an unstable atmosphere related to the heat bubble.

Near the surface, thermal lows may develop and help concentrate this instability. These hot, dry, and unstable weather patterns are normally linked to the subtropical high in the western U.S. and the Bermuda high in the eastern U.S. On rare occasions, the high pressure centers coalesce into a "super high" which can impact large portions of the country.

Fire-Slowing or Fire-Stopping Patterns

Geographic areas experience **fire-slowing** and/or **fire-stopping** periods for three primary reasons:

- A partial or widespread change in the weather and fuel regime.
- Partial green-up or increased fuel moisture promoted by periods of precipitation.
- Temporary changes—such as a cool, moist, stable weather regime replacing hot, dry, and unstable conditions during a multi-day period.

Understand that the fire-slowing and/or fire-stopping period is a temporary change. Across the U.S., four main patterns commonly produce fire-slowing or stopping conditions:

- Closed low, deep-trough frontal passages
- Monsoon bursts
- Tropical storms
- Smoke events

The season-ending period is similar to a fire-slowing period, but the magnitude and duration of change are greater. During a season-ending transition, fuels undergo significant changes—such as long-lasting green-up or a significant rise in larger-sized fuel moisture values. Most regions do not reach season's end through a single event; instead, it is a cumulative effect of a series of weather events. For example, the Southwest monsoon evolves over several days to weeks, creating a mosaic of wetting rains and moisture recovery across live and dead fuels.

Estimating Winds for Fire Behavior

Definitions

Critical Winds dominate the fire environment and can easily override local wind influences. Examples include frontal winds, Foehn winds, thunderstorm outflows, whirlwinds, surfacing or low-level jets (reverse wind profiles), and glacier winds.

General (Synoptic-Scale) Winds—such as synoptic scale, gradient, free air, and ridgetop—are large-scale winds produced by broad pressure gradients between high- and low-pressure systems. They may be influenced and modified considerably in the lower atmosphere by terrain and vegetative structure.

Local (Mesoscale) Winds—such as thermal, convective, drainage, and slope winds—develop from local temperature differences generated over comparatively small areas by local terrain and weather. They differ from synoptic winds because they are confined to near surface and are controlled by the strength of the daily solar cycle.

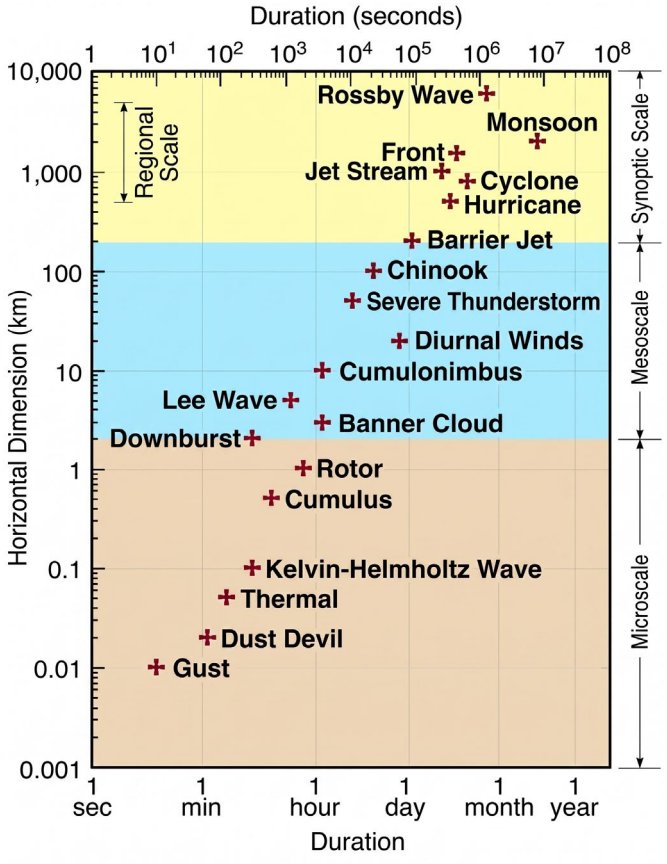
- **Slope Winds** are driven by heat exchange at the slope surface. Upslope winds can begin within minutes of solar heating and are influenced by slope length, steepness, and aspect. Typical speeds range from 3 to 8 mph.

The transition from upslope to downslope wind begins when slopes enter afternoon shadow and cooling of the surface begins. The transition includes: (1) weakening upslope flow, (2) a period of relative calm, and (3) gentle, laminar downslope flow. Downslope winds are very **shallow** and at a **slower** speed than upslope winds, generally 2 to 5 mph. The cooled denser air is stable and the downslope flow, therefore, tends to be laminar.

- **Valley Winds** are linked to slope winds but development lags behind slope winds by 1 to 3 hours. Peak speeds can double those of slope winds, reaching 10 to 15 mph.

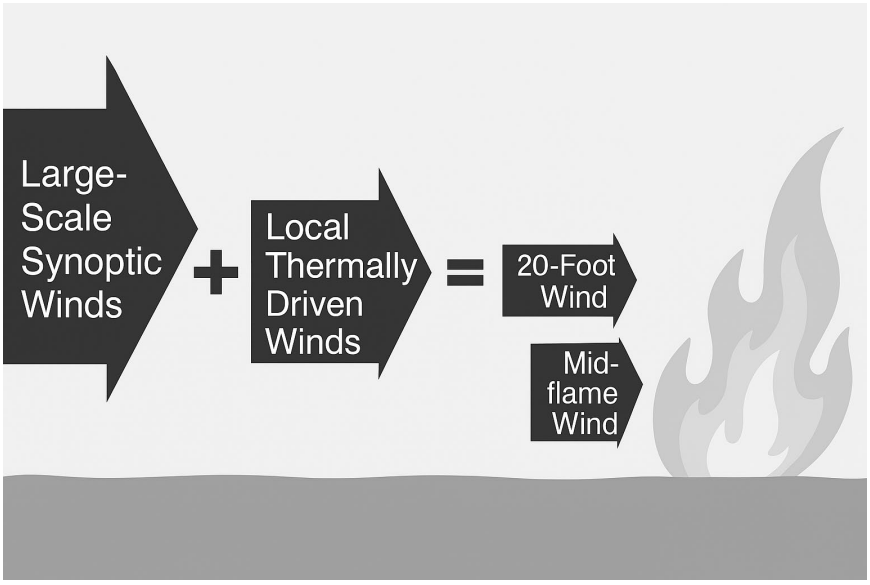
Land and Sea Breeze Circulations form during the day and can reach 10 to 15 mph during peak solar heating in the afternoon. The nighttime land breeze is lighter, generally 5 to 10 mph. Figure 13 illustrates the source elevation and duration of various wind types, including general (synoptic), local (mesoscale), and gust (microscale) winds.

Figure 13. Height and duration of atmospheric winds.



Surface Winds are measured near the ground at an observing station, typically at a height of 20 feet (10 meters) above the average vegetative surface and a distance equal to at least 10 times the height of any obstruction to limit distortion from obstacles or terrain.

Figure 14. Large-scale wind impact on surface wind.



- **Wind Gust** is a brief, sudden increase in wind speed. According to U.S. weather observing practice, a gust is reported when the peak speed reaches at least 16 knots (18 mph) and the variation in wind speed between peaks and lulls is at least 9 knots (10 mph). Gusts usually last less than 20 seconds.
- **Midflame Wind Speed** is the estimated wind speed at midflame height. This is the wind input used in the Rothermel surface fire model to estimate fire spread. If not directly observed or measured, it is derived from the Surface Wind (20 foot) and adjusted based on canopy sheltering and fuel bed depth.
- **Eye-Level Winds** are frequently used to represent midflame wind speeds, though they may overestimate wind for shallow or sparse fuel beds that have lower flame heights or underestimate wind for shrub and crown fuels with deep fuel beds.
- **Effective Wind Speed** is the combined effect of Midflame Wind Speed and the slope-equivalent wind in the direction of maximum spread (head fire). Effective Wind Speed replaces midflame wind speed when winds blow upslope and is needed to determine fire shape and length-to-width ratio. See Effective Wind Speed section.

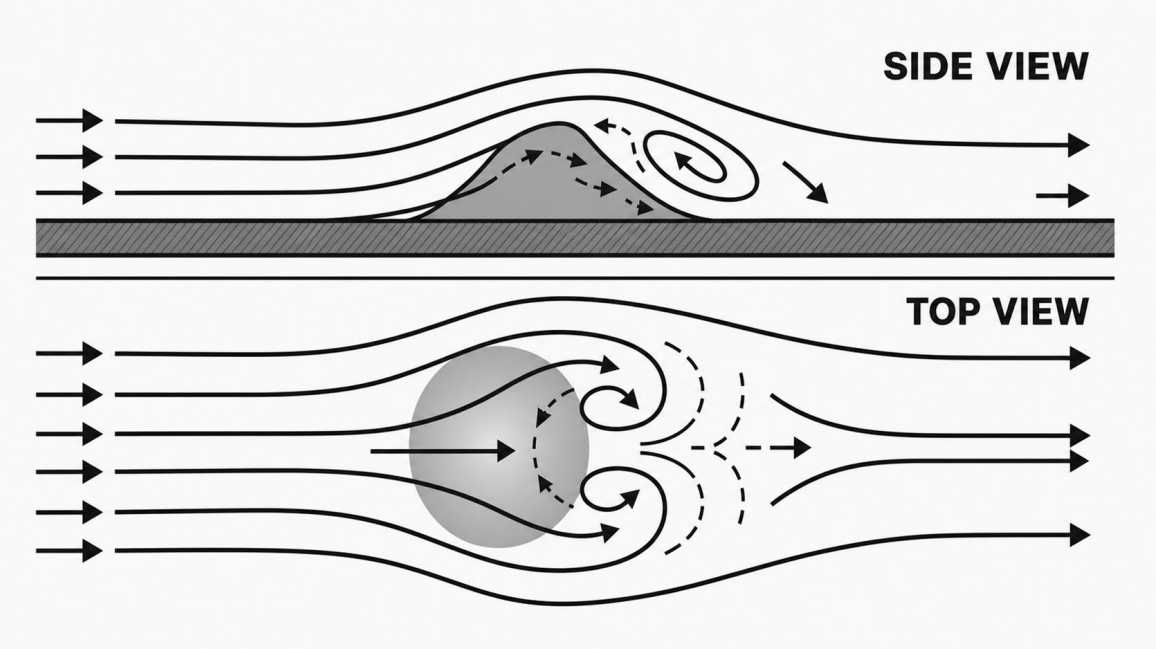
Estimating Surface (20 foot) Wind Speed in Mountain Terrain

Slopes and Ridges of Mountains

Isolated peaks tend to divert general winds both horizontally and vertically. Some acceleration of general winds is likely around the flanks and over the tops of isolated mountains peaks with gently inclined slopes. On the lee side of the peak, turbulent flow reversals or wind eddies may form.

Mesas tend to **slow** general winds because energy is required to form separation eddies on the upwind and downwind sides of their steep faces. Near these eddies—and on top of the mesa—20-foot winds may be weaker than expected, with frequent gusts and shifting wind directions.

Figure 15. Wind speed in mountain terrain depiction.

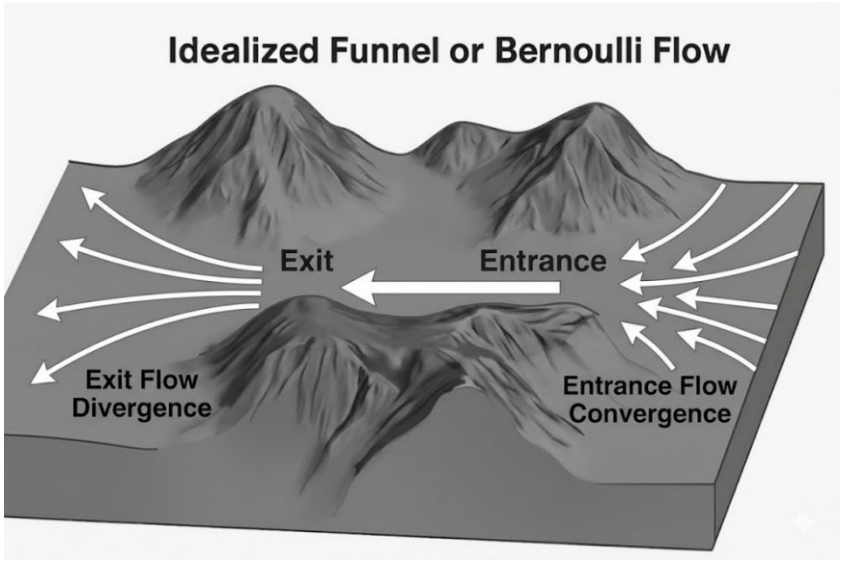


Continuous Ridges may block weak winds under stable conditions, forming a stagnant zone below the ridgeline. However, if the airmass is unstable, general winds can flow over the ridge. The atmospheric stability, the strength of the general wind, angle of the wind compared to the ridgeline, and diurnal winds (which may be opposing) will influence winds on the downwind side of the ridge.

Gaps in Terrain can create a venturi effect, where winds accelerate downwind of the constriction—especially in the exit region. These gap winds are part of the general wind because they are based on general winds.

- **Low Level Gorges** frequently facilitate gap flow when the upwind airmass is stable. This discourages winds from rising over higher terrain, causing them to flow through lower-elevation gorges. These gap winds are shallow, often less than a few thousand feet in depth.
- **Mountain Passes and Saddles** form upper-level winds that impact high terrain and tend to flow through the lowest available gap in a mountain chain rather than crossing higher ridges.

Figure 16. Wind flow through saddles and passes.



Valley Influences

Local drainage winds shift throughout the day from upslope as sunlight reaches upper slopes, to up-valley as heating becomes widespread, to downslope as the sun sets, and finally down valley overnight (Figure 17).

The effect of general winds on valley surface winds depends on wind strength, alignment with the valley axis, valley depth, aspect alignment, and time of day.

Figure 17. Valley influences on diurnal winds.

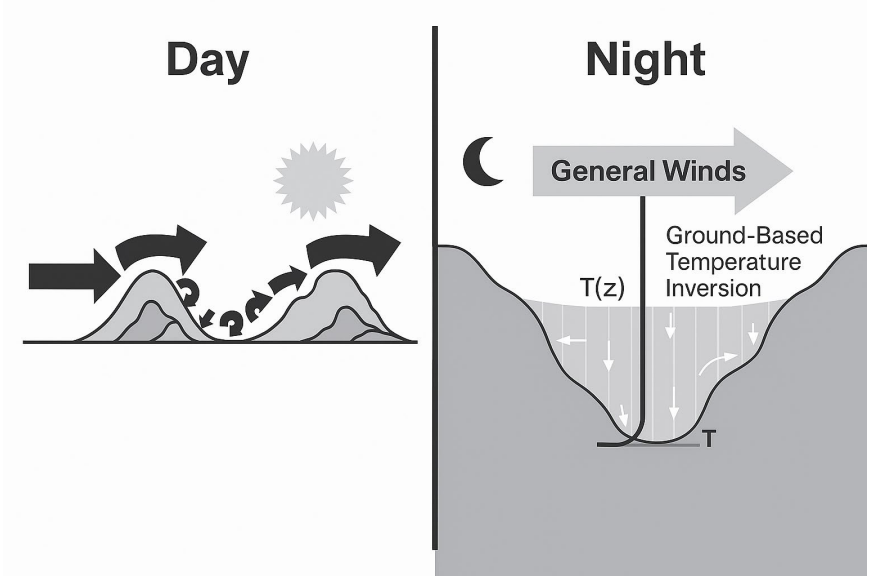
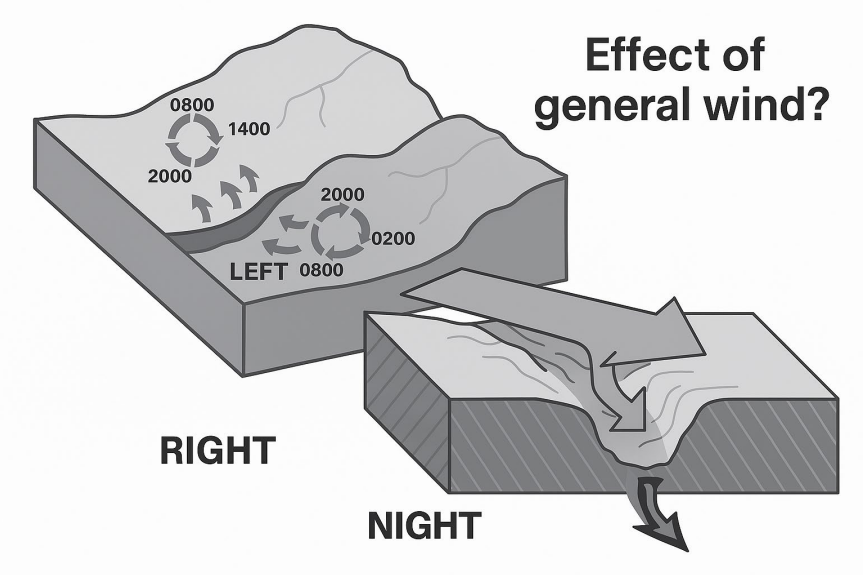


Figure 18. Valley influence on wind strength and alignment.



During the day, general winds aligned with up-valley wind will increase surface wind speeds. Opposing winds result in reduced surface winds, while perpendicular general winds have little effect on the local winds.

During the night, general winds are most likely to surface when they are strong and aligned parallel to the valley axis.

Additional valley considerations are:

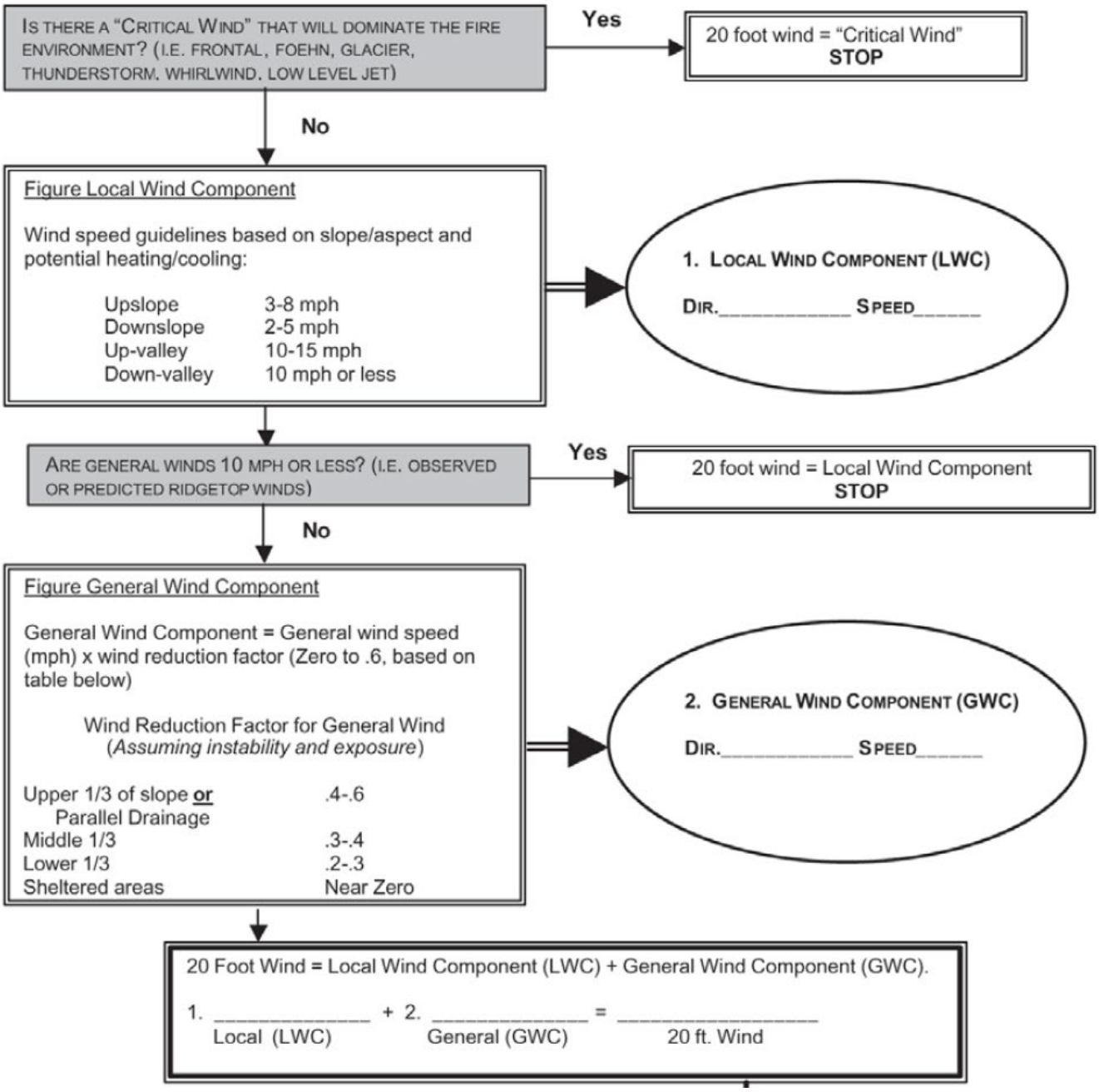
- **Enclosed or Isolated Basins**, which typically have reduced surface winds, especially low on the slopes and valley bottoms. Inversions may limit even occasional gusts.
- **Elongated Valley Winds** tend to channel and organize wind flow more effectively than enclosed basins, but they still exhibit distinct day–night patterns driven by terrain-induced circulations. During the daytime, differential heating often promotes up-valley and upslope winds, yet the extent to which general winds surface depends heavily on how well they align with the valley's axis. When the larger-scale flow runs parallel to the valley, general winds can penetrate more readily, producing stronger and more continuous surface winds. Where the alignment is poor, local thermal winds typically dominate, especially in narrower or more sheltered segments. At night, elongated valleys behave more uniformly. Cooling of the terrain leads to downslope and down-valley drainage flows that generally override weak synoptic winds. However, strong general winds that align closely with the valley axis may still surface, especially in more exposed stretches, potentially enhancing nighttime wind speeds beyond typical drainage expectations.
- **Forked or Bent River Drainages** amplify local wind dominance, though the relationships are even more complex. During the day, general winds may surface primarily in exposed segments, creating a mosaic of stronger and weaker surface winds depending on alignment. At night, this simplifies with predominately local downslope and down valley flows. Beware of strong general winds that are aligned with certain sections.
- **Valley Inversions** are very effective at preventing general winds from mixing to the surface on the midslope or the valley floor. Light local slope and valley flow will likely be the dominant winds. Expect to adjust 20-foot wind speeds downward when inversions are present. Although they usually form at night, inversions may persist through daylight hours if sunlight is

diminished by smoke, fog, or cloud cover. Beware that strong general winds at night can erode an inversion through turbulent mixing.

Critical Winds

Foehn winds, barrier jets, downslope windstorms, and cold-air avalanches may interact with mountain terrain to produce even stronger localized flows.

Figure 19. Worksheet for Estimating 20-foot Surface Winds. Use Table 8, Table 9, Table 10 to determine the Wind Adjustment Factor (WAF).



Adjusting Surface (20 foot) Wind to Midflame Wind Speed

Once general winds have been adjusted to represent 20-foot surface winds based on terrain and other local factors, the next step is to convert 20-foot wind to midflame wind speed (MFWS). MFWS is the velocity of wind at the mid-height of the flames and is always less than the 20-foot wind speed due to the friction of vegetation closer to the surface. This is why adjustment factors are always less than 1. The adjustment depends on canopy sheltering and surface fuel bed depth. The process involves understanding how the wind is oriented with the terrain, whether the terrain is flat or sloped, and a characterization of the canopy characteristics.

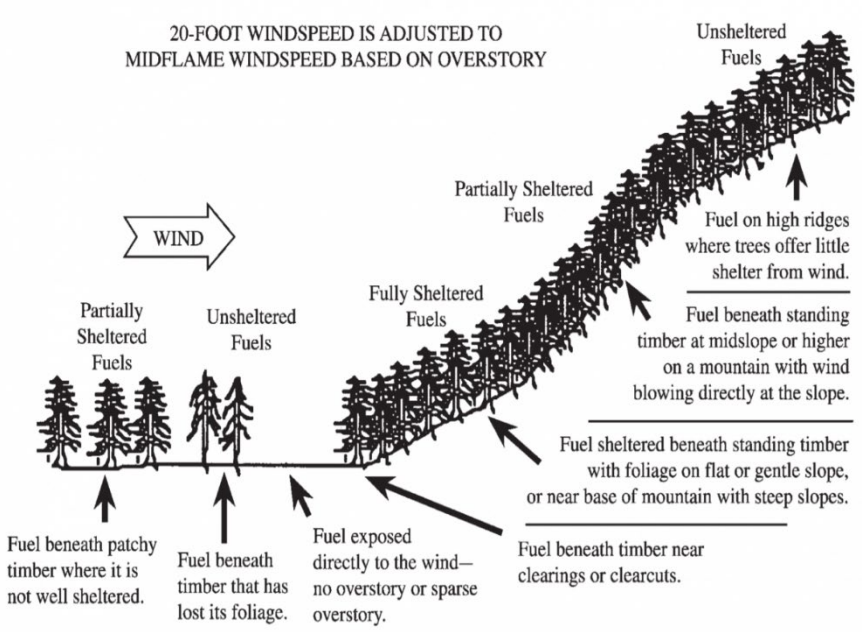
For additional information and examples with student solutions, see the Firefighter Math page about midflame windspeed, found here: https://www.nwcg.gov/course/ffm/fire-behavior/firefighter-math-82-midflame-windspeed.

Note that the degree of sheltering also varies depending on fire position within terrain features. Adjustment criteria include:

For unsheltered fuels, all canopy covers less than 20%, and all crown ratios are less than 0.2. WAF for unsheltered fuel is a function of fuel bed depth only (typically estimated by identifying the fuel model).

For sheltered fuels, WAF depends on a combination of canopy cover, canopy height, and average crown ratio for the site. As combinations of these factors increase, WAF transitions from partially sheltered to fully sheltered.

Figure 20. Adjusting surface wind for sheltered fuels.



Unsheltered Fuels

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

Table 8. Wind Adjustment Factors for different fuel models.

WAF	Fuel Models	Bed Depth
0.5	Grass (GR7, GR8, GR9) Shrub (4, SH4, SH5, SH7, SH8, SH9) Slash (13, SB4)	More than 2.7 feet
0.4	Grass & Grass-Shrub (1, 2, 3, GR2, GR3, GR4, GR5, GR6, GS1, GS2, GS3, GS4) Shrub (5, 6, 7, SH1, SH2, SH3, SH6) Timber Understory (10, TU2, TU3) Slash (11, 12, SB1, SB2, SB3)	0.9 to 2.7 feet
0.3	All Timber Litter Fuels (8, 9, TL1 through TL9) GR1, TU1, TU4, TU5	Less than 0.9 foot

Partially Sheltered Fuels

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

Table 9. WAF for Partially Sheltered Fuels.

WAF	Fuel Models	Bed Depth
0.3	All Fuel Models	Any

Fully Sheltered Fuels

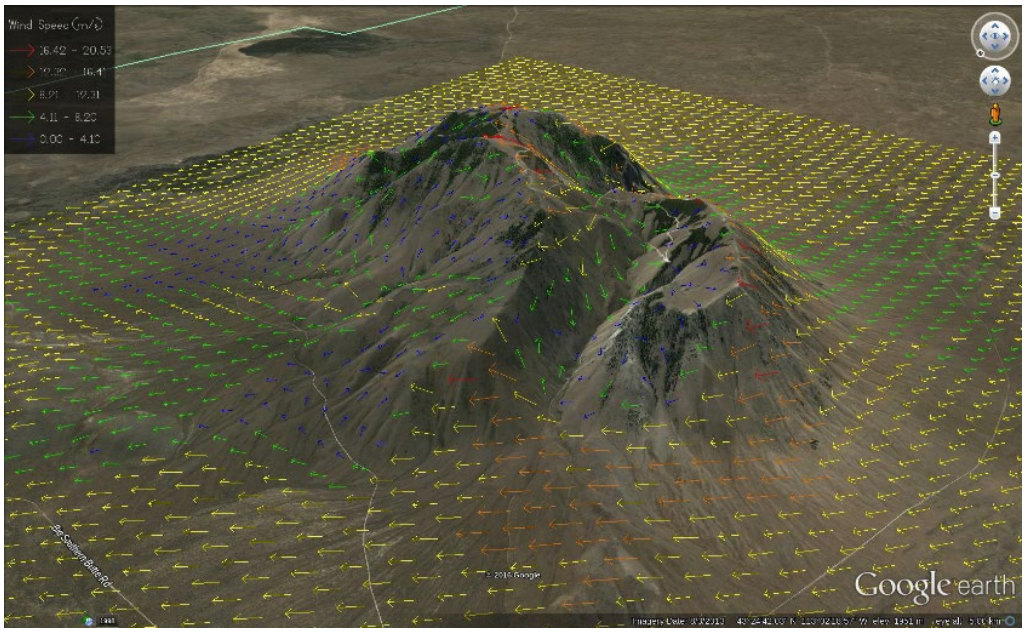
- Dense timber on flat or gentle slope.
- Dense timber near base of mountain with steep slopes above.

Table 10. WAF for Fully Sheltered Fuels.

WAF	Fuel Models	Bed Depth
0.2	Open Canopy	Any
0.1	Dense Canopy	Any

WindNinja is a computer program that generates spatially varying wind fields for wildland fire and other applications that require high resolution wind prediction in complex terrain.

Figure 21. WindNinja spatial output.



WindNinja can be run in three modes, depending on the application and available inputs:

- Forecast Mode: Uses coarse-resolution mesoscale weather model data from the NWS to forecast winds at future times.
- Surface Observation Mode: Uses one or more surface wind measurements to produce a wind field across the area.
- User-Defined Mode: Uses a user-specified average surface wind speed and direction.

WindNinja outputs include:

- Direct map display.
- Google Earth KMZ files.
- ArcGIS shapefiles and ASCII rasters.

WindNinja can be downloaded on laptops and mobile devices from:
https://research.fs.usda.gov/firelab/products/dataandtools/windninja.

Temperature, RH, and Dew Point Tables

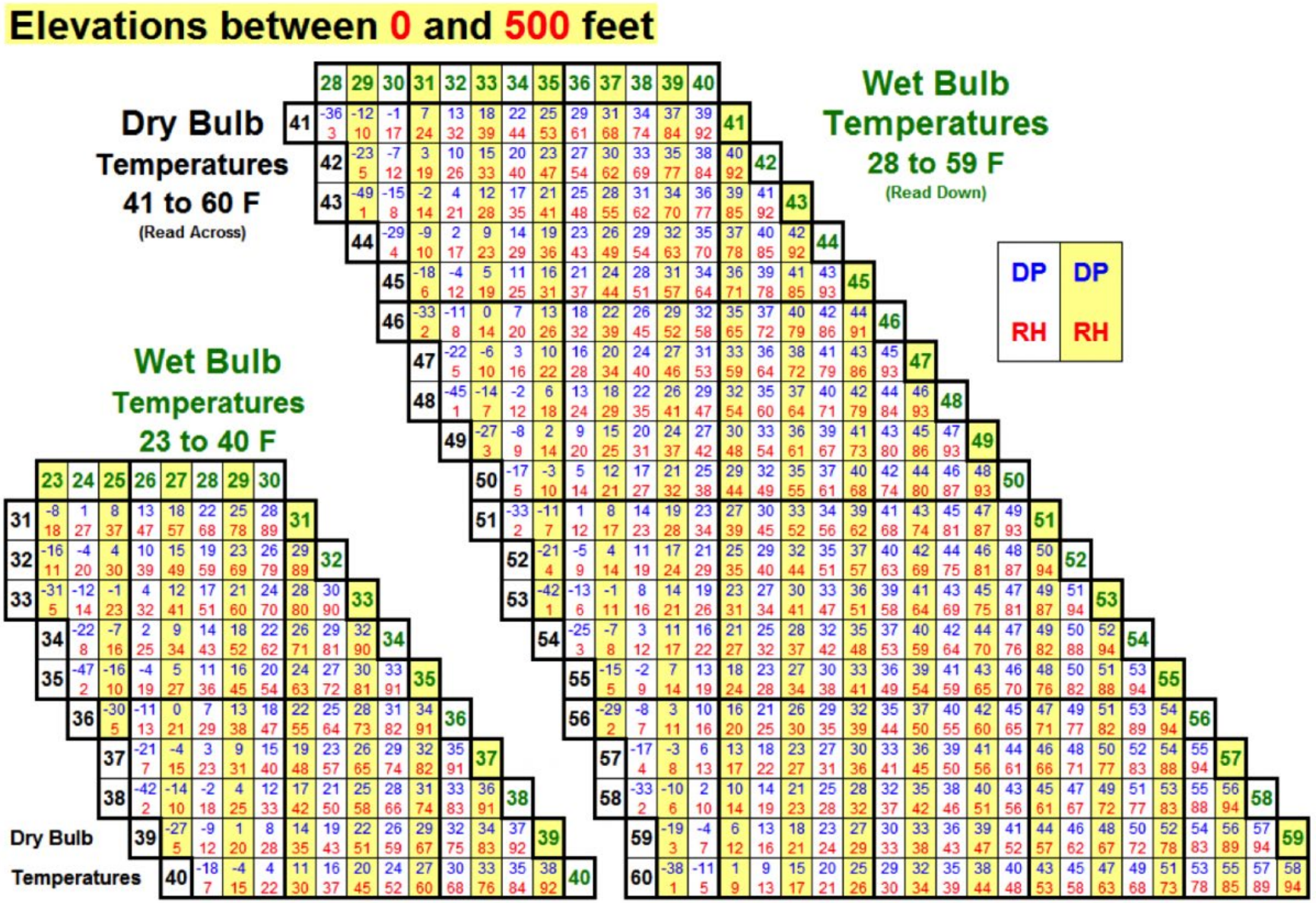
The following tables provide dew point and RH based on observed WB and DB temperatures, along with the elevation at the site of the observation. These calculations can be performed automatically using free Wildland Fire RH Calculator Apps for iOS and Android.

The full set of tables is available in PDF for here:
https://www.frames.gov/documents/nwcg/fbfrg/us_2012_temp-rh-dewpoint-lookup-tables_fbfc.pdf.

An online dew point calculator tool is available here: http://johnrinier.com/Humidity.htm.

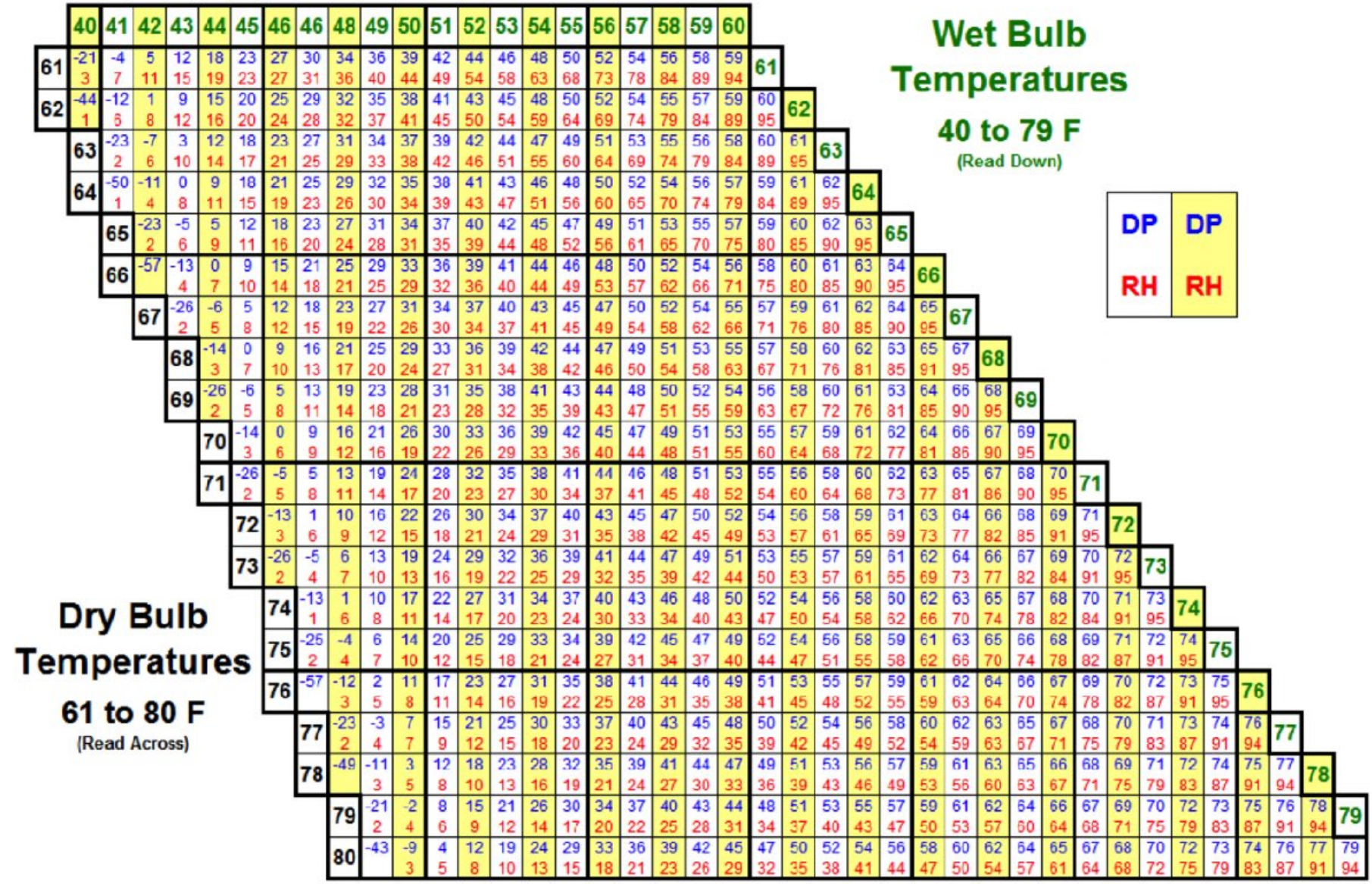
Elevation 0 to 500 feet (0 to 300 feet in Alaska), 30 in.

Dry Bulb Temperature 41 to 60°F



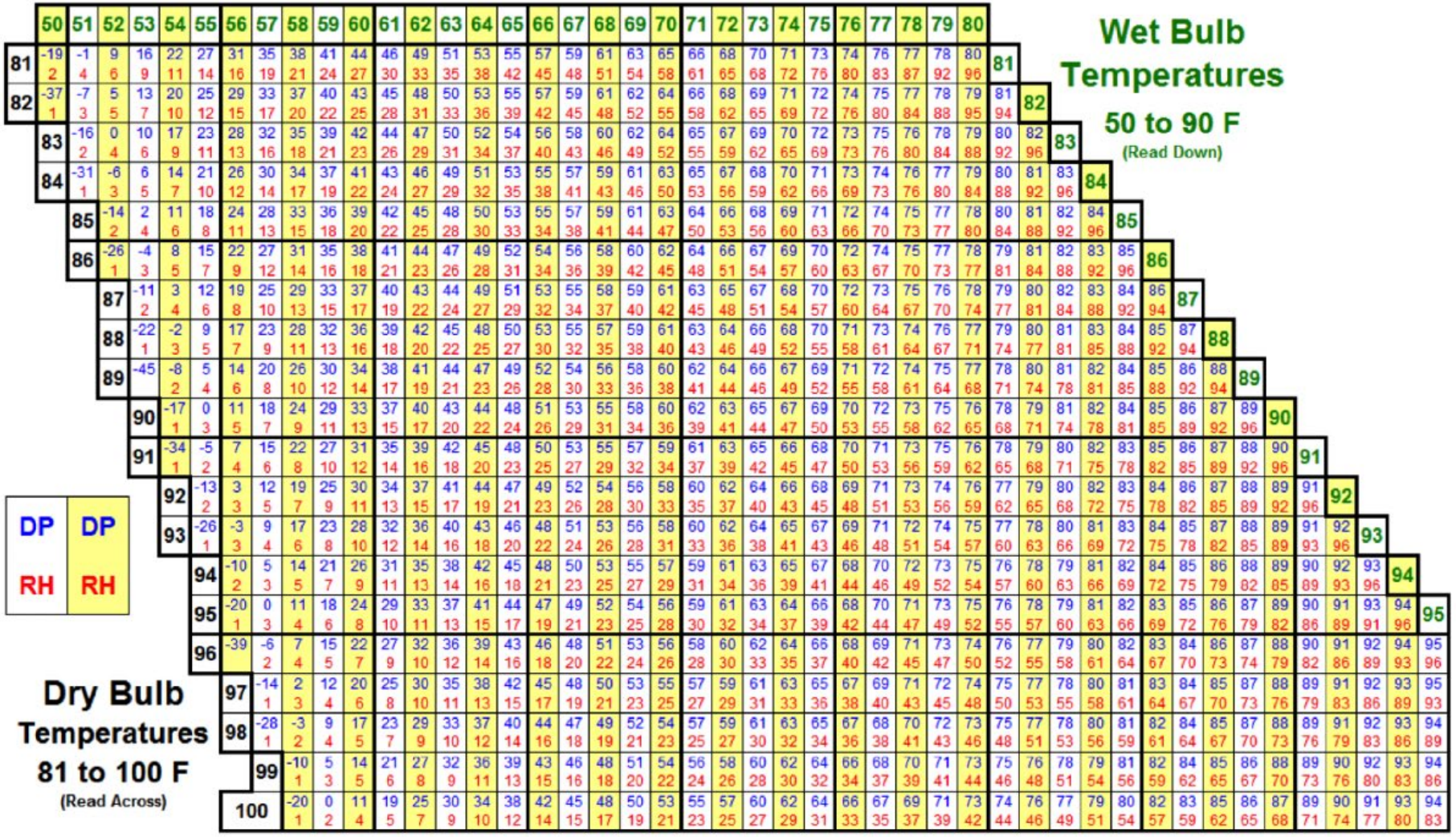
Dry Bulb Temperature 61 to 80°F

Elevations between 0 and 500 feet



Dry Bulb Temperature 81 to 100°F

Elevations between 0 and 500 feet



Dry Bulb Temperature 101 to 119°F

Elevations between 0 and 500 feet

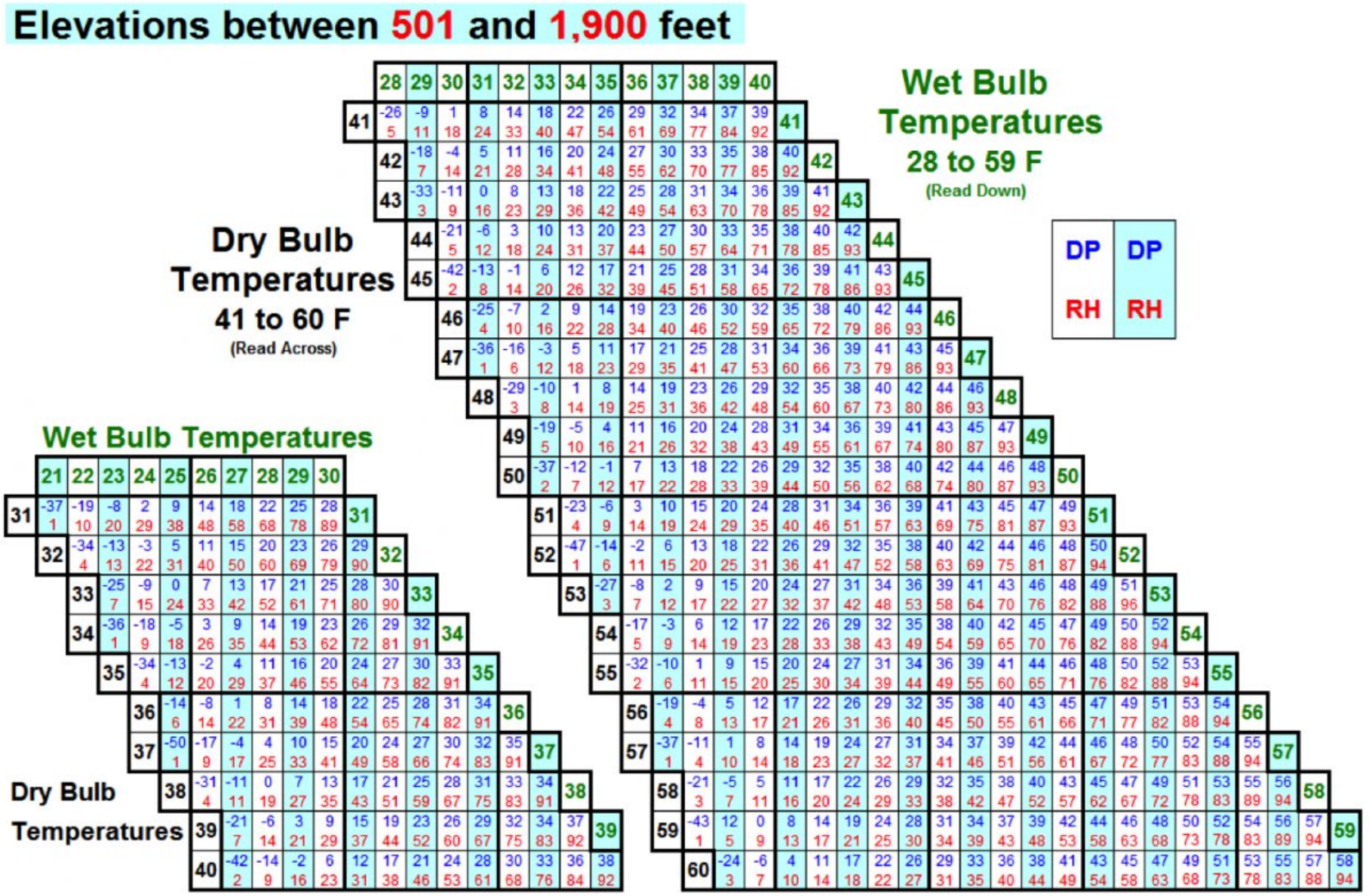
Wet Bulb Temperatures, 58 to 95 F

(Read Down)

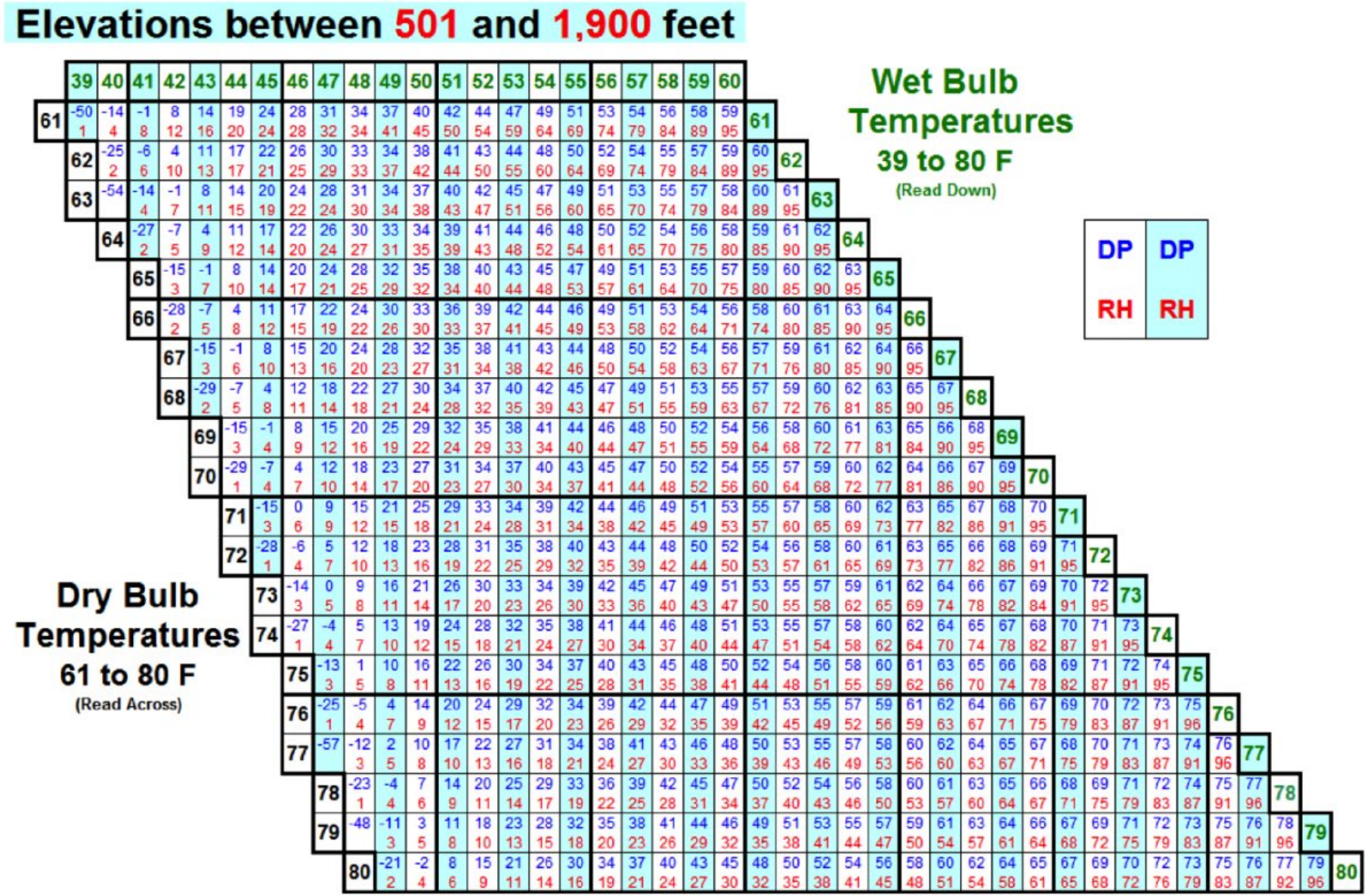
Dry Bulb Temperatures 101 to 119 F (Read Across)	DP RH	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95
101	DP	-40	-6	8	16	23	28	33	37	40	44	47	49	52	54	57	59	61	63	65	67	69	70	72	74	75	77	79	80	81	83	84	86	87	88	90	91	92	94
	RH		2	3	5	6	8	9	11	13	14	16	18	20	21	23	25	27	29	31	33	36	38	40	42	45	47	49	52	54	57	60	62	65	68	71	74	77	80
102	DP	-14	3		13	21	26	31	36	39	43	46	49	51	54	56	58	61	63	65	66	68	70	72	73	75	77	78	80	81	83	84	86	87	88	90	91	92	93
	RH	1	3		4	5	7	9	10	12	13	15	17	18	20	22	24	26	28	30	32	34	36	38	40	43	45	47	50	52	55	57	60	63	65	68	71	74	77
103	DP	-26	-2		10	18	24	30	34	38	42	45	48	50	53	55	58	60	62	64	66	68	70	71	73	75	76	78	79	81	82	84	85	87	88	89	91	92	93
	RH	1	2		3	5	6	8	9	11	12	14	16	17	19	21	23	25	26	28	30	32	34	37	39	41	43	45	48	50	53	55	58	60	63	66	68	71	74
104	DP		-8		6	15	22	26	33	37	40	44	47	50	52	55	57	59	61	63	65	67	69	71	73	74	76	77	79	80	82	83	85	86	88	89	90	92	93
	RH		1		3	4	6	7	9	10	12	13	15	16	18	20	22	23	25	27	29	31	33	35	37	39	41	44	46	48	51	53	55	58	61	63	66	69	72
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	RH	1	2	4	5	6	8	9	11	12	14	15	17	18	20	22	23	25	27	29	31	32	34	36	38	41	43	45	47	49	52	54	56	59	61	64			
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	RH	1	2	3	4	6	7	8	10	11	13	14	16	17	19	21	22	24	26	27	29	31	33	35	37	39	41	43	45	47	50	52	54	57	59	62			
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	RH		1	3	4	5	6	7	8	10	11	12	14	15	16	18	19	21	22	24	25	27	29	30	32	34	36	38	39	41	43	45	47	50					
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	RH	1	1	2	4	5	6	7	8	9	10	11	13	14	15	16	18	19	20	22	23	25	26	28	29	31	33	34	36	38	40	41							

Elevation 501 to 1,900 feet (301 to 1,700 feet in Alaska), 29 in.

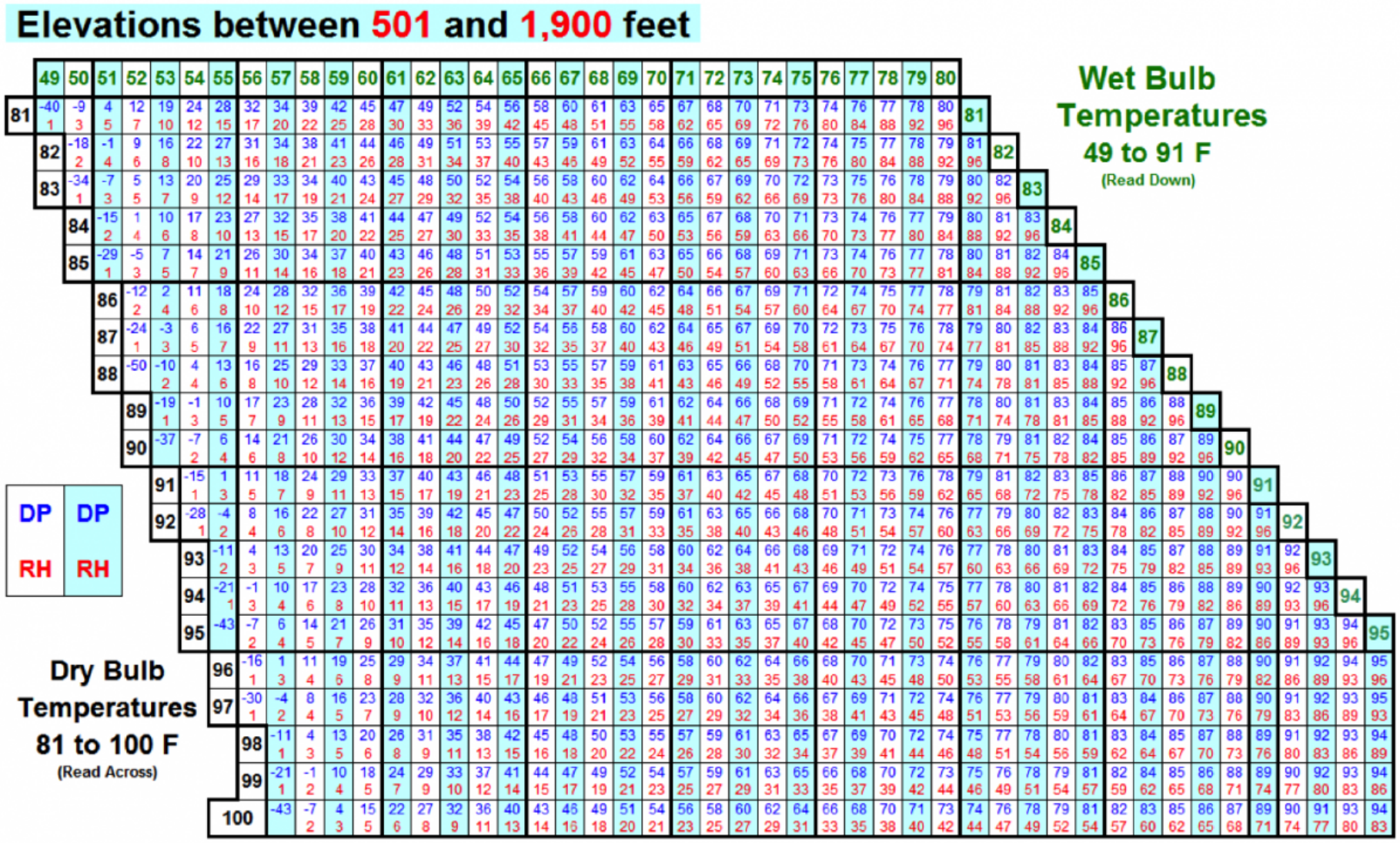
Dry Bulb Temperature 41 to 60°F



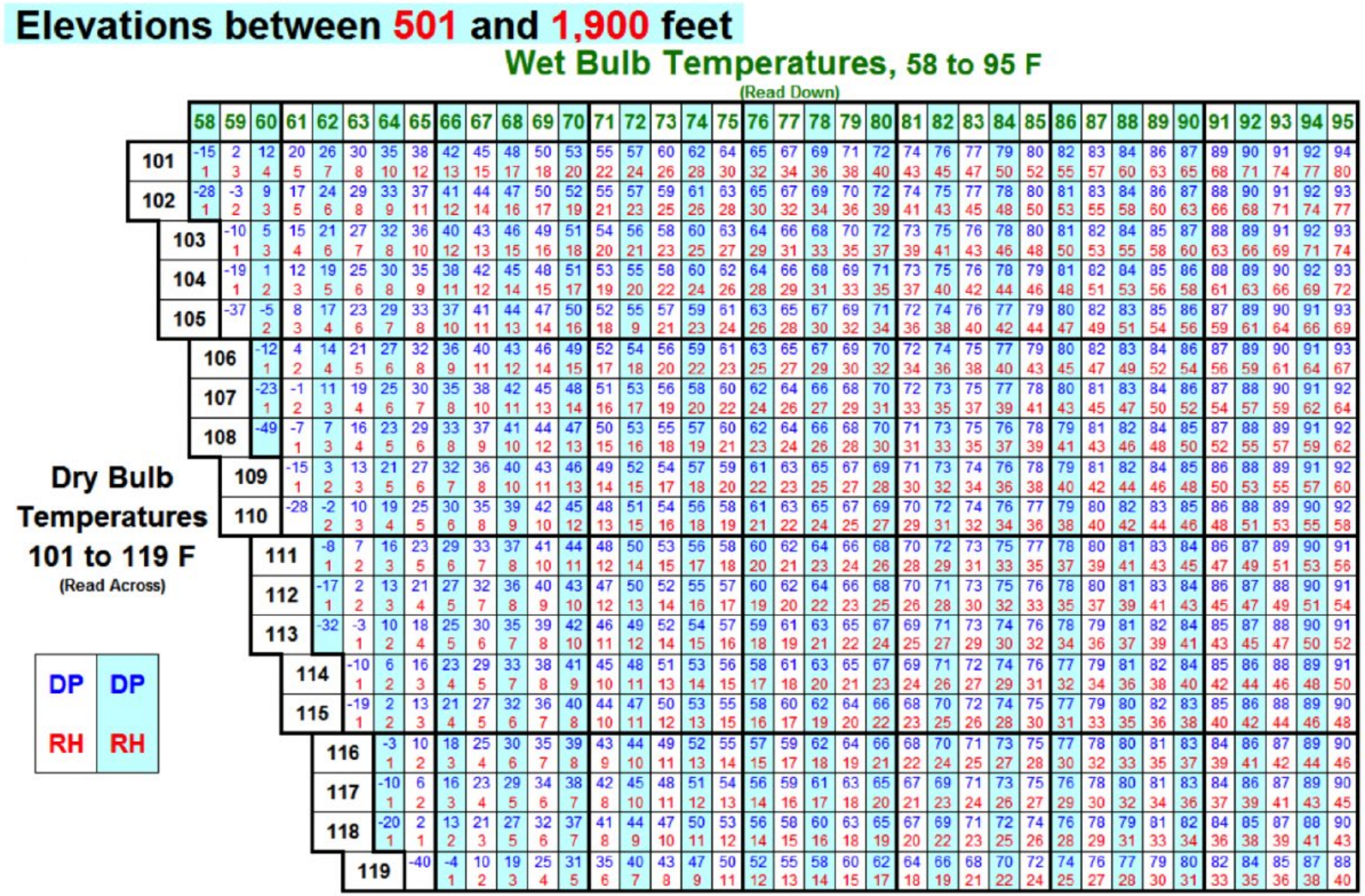
Dry Bulb Temperature 61 to 80°F



Dry Bulb Temperature 81 to 100°F



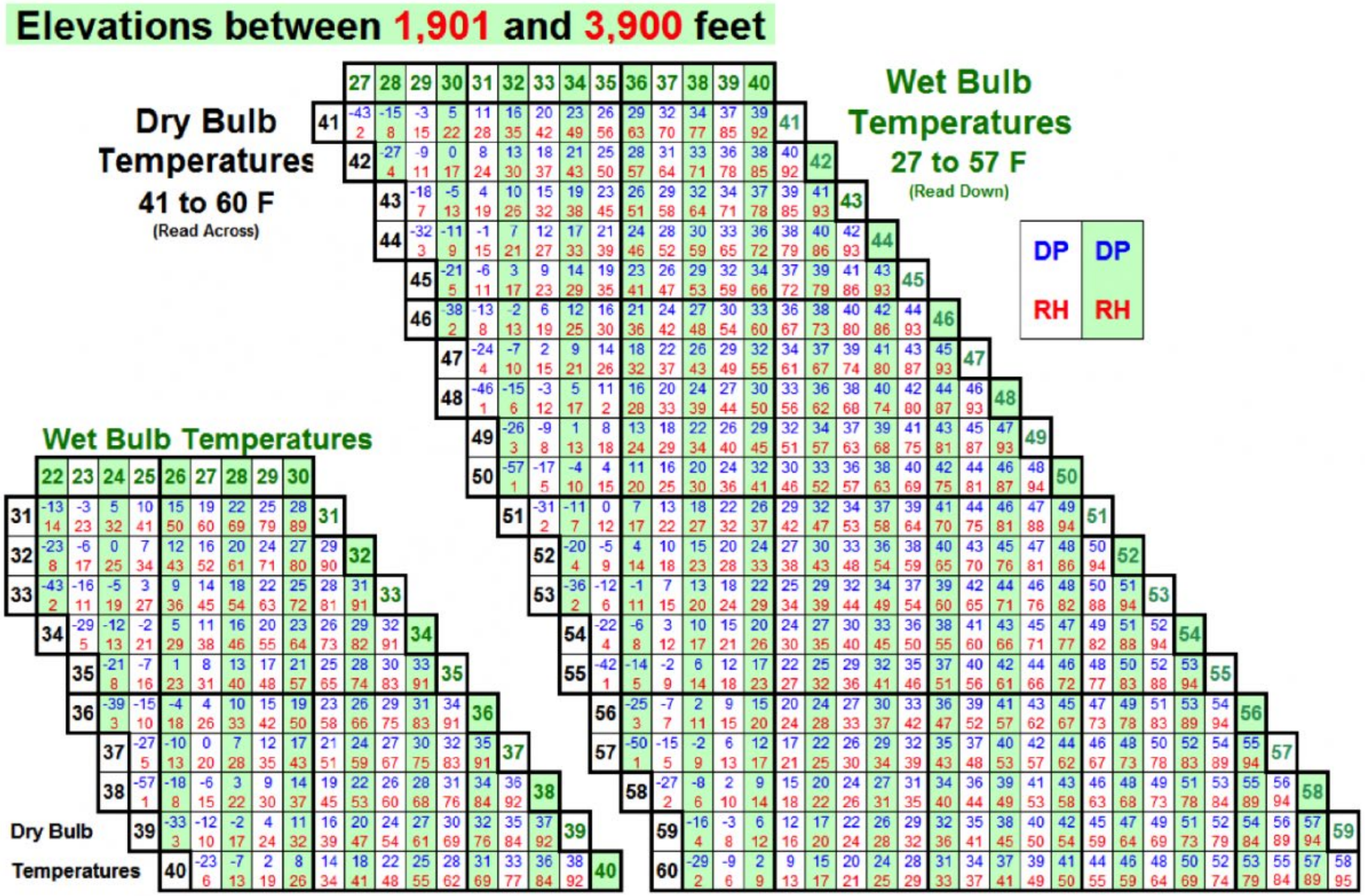
Dry Bulb Temperature 101 to 119°F



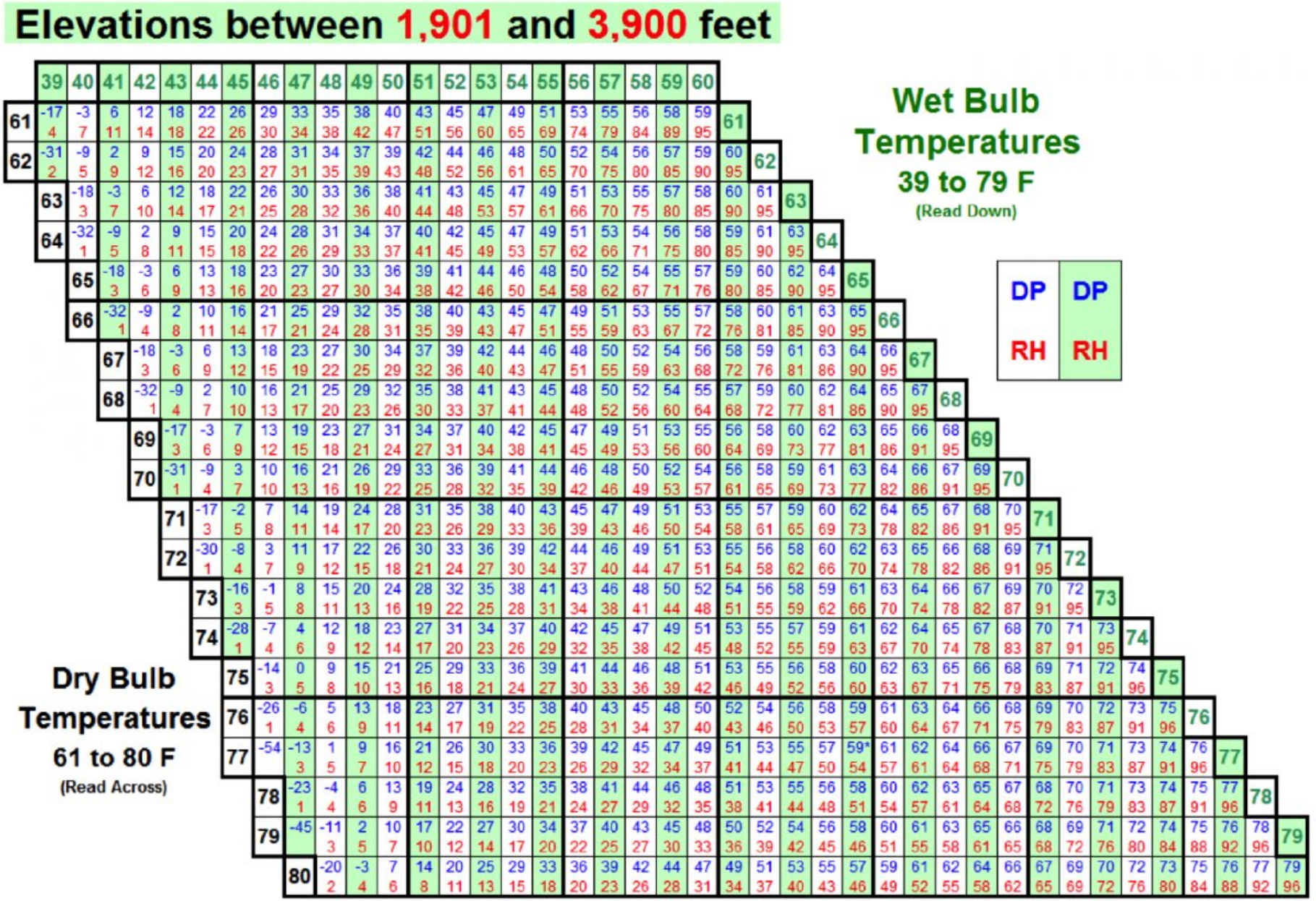
Dry Bulb	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95
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		1	2	3	4	5	6	7	8	9	11	12	13	14	15	17	18	19	21	22	24	25	27	28	30	31	33	35	36	38	40							

Elevation 1,901 to 3,900 feet (1,701 to 3,600 feet in Alaska), 27 in.

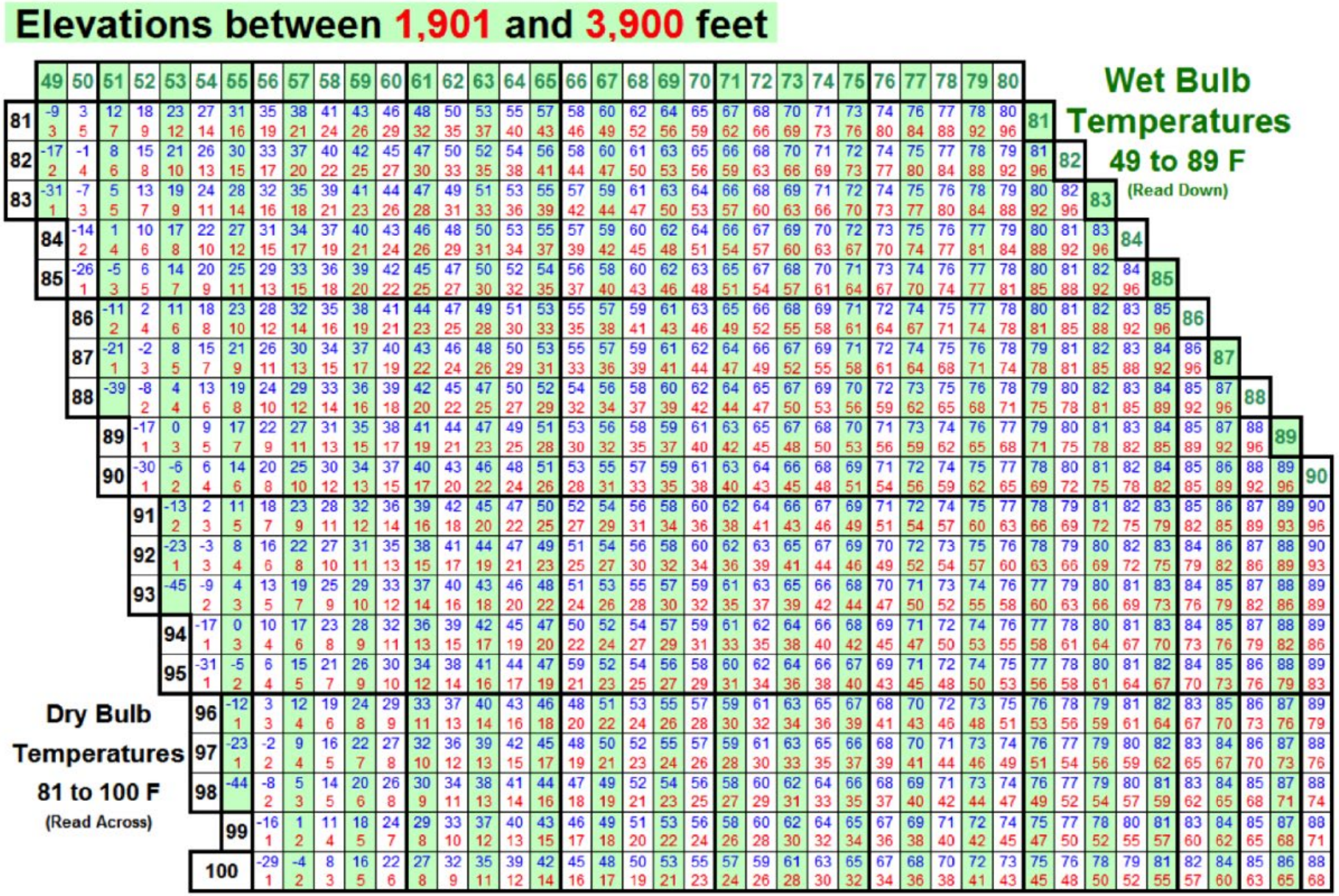
Dry Bulb Temperature 41 to 60°F



Dry Bulb Temperature 61 to 80°F



Dry Bulb Temperature 81 to 100°F



Dry Bulb Temperature 101 to 119°F

Elevations between 1,901 and 3,900 feet

Wet Bulb Temperatures, 57 to 90 F

(Read Down)

DP DP
RH RH

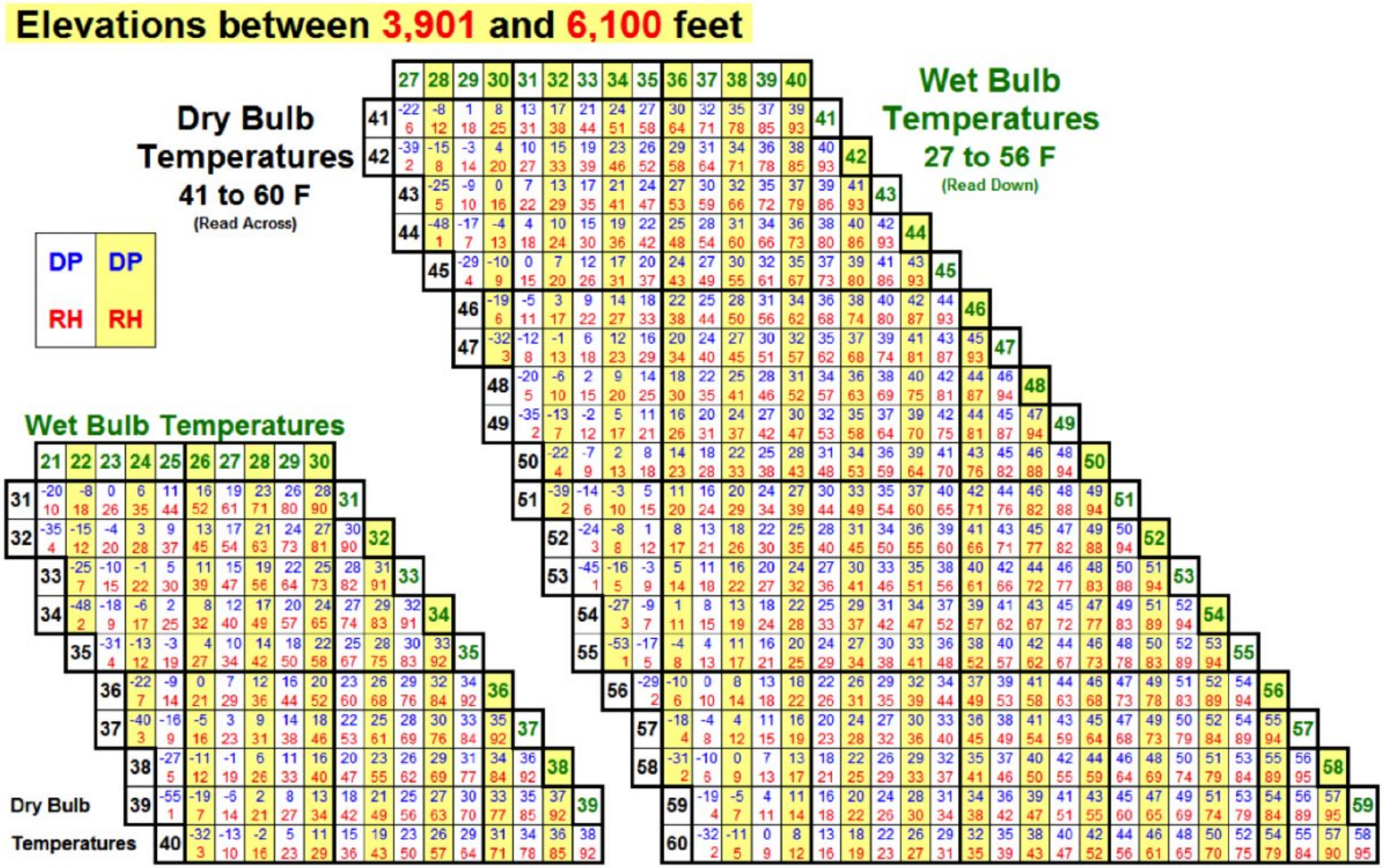
Dry Bulb Temperatures 101 to 119 F

(Read Across)

Dry Bulb	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90
101	-11	4	13	20	25	30	34	38	41	44	47	50	52	54	57	59	61	63	65	66	68	70	71	73	75	76	78	79	81	82	83	85	86	87
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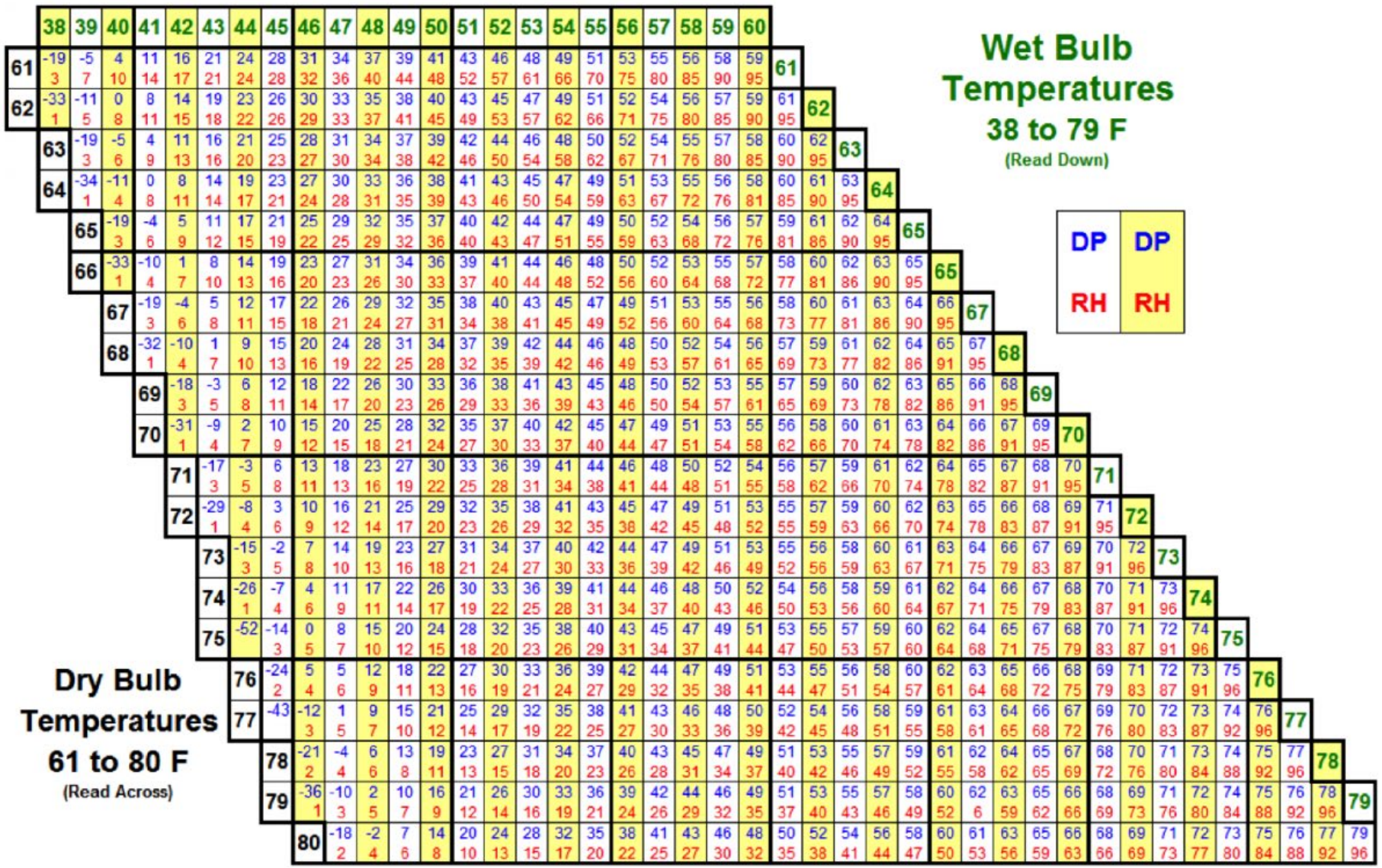
Elevation 3,901 to 6,100 feet (3,601 to 5,700 feet in Alaska), 25 in.

Dry Bulb Temperature 41 to 60°F



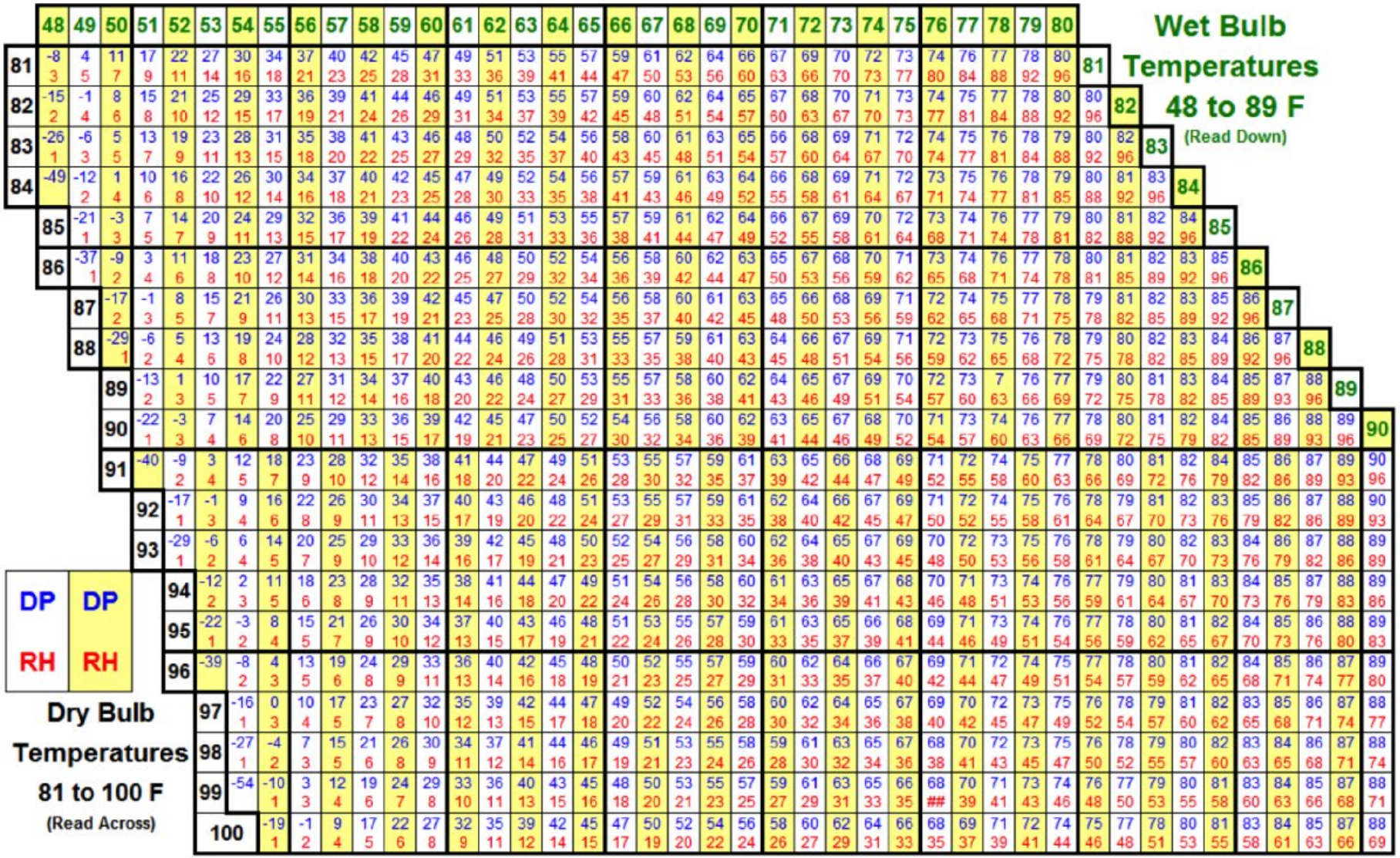
Dry Bulb Temperature 61 to 80°F

Elevations between 3,901 and 6,100 feet

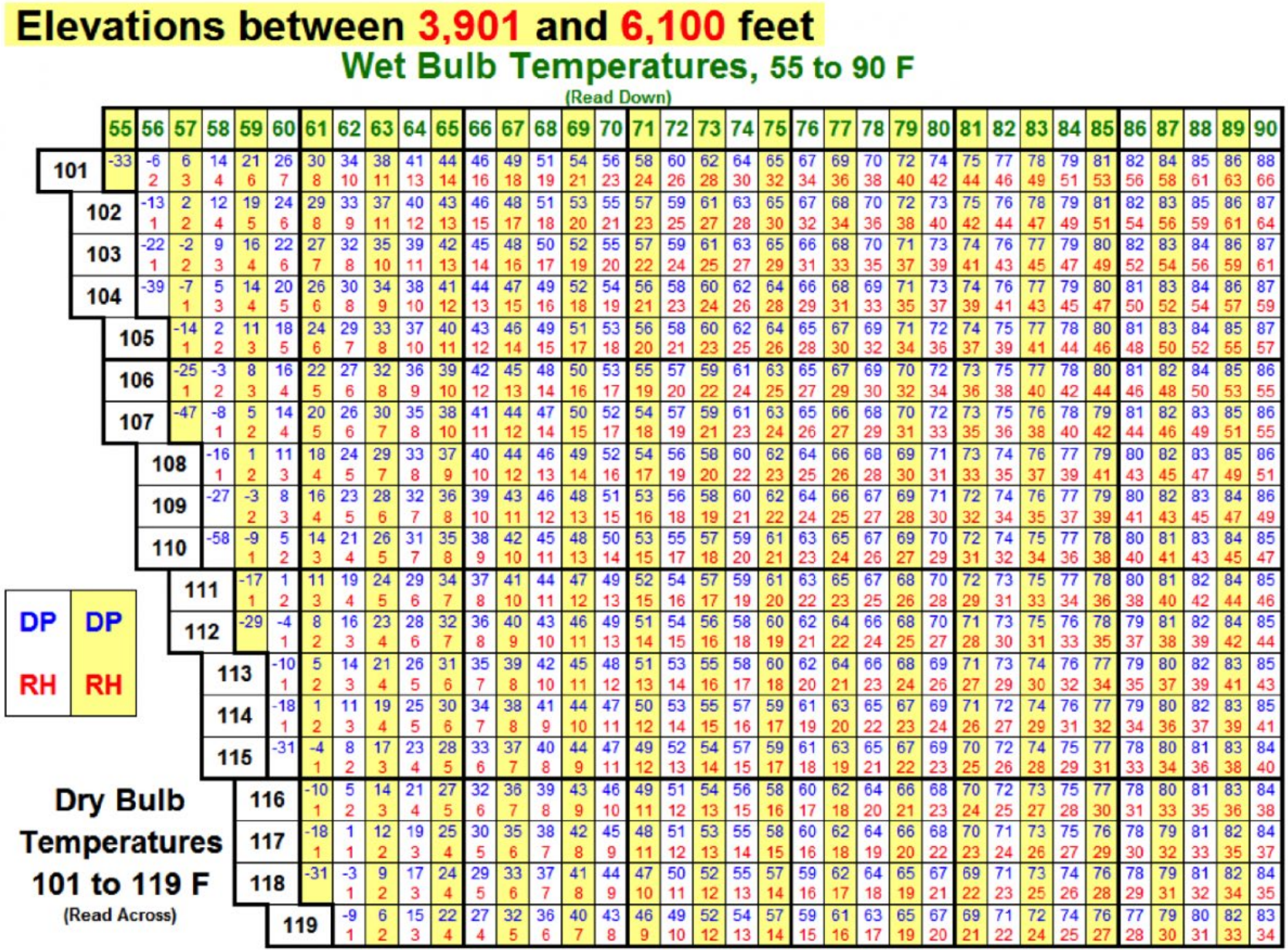


Dry Bulb Temperature 81 to 100°F

Elevations between 3,901 and 6,100 feet



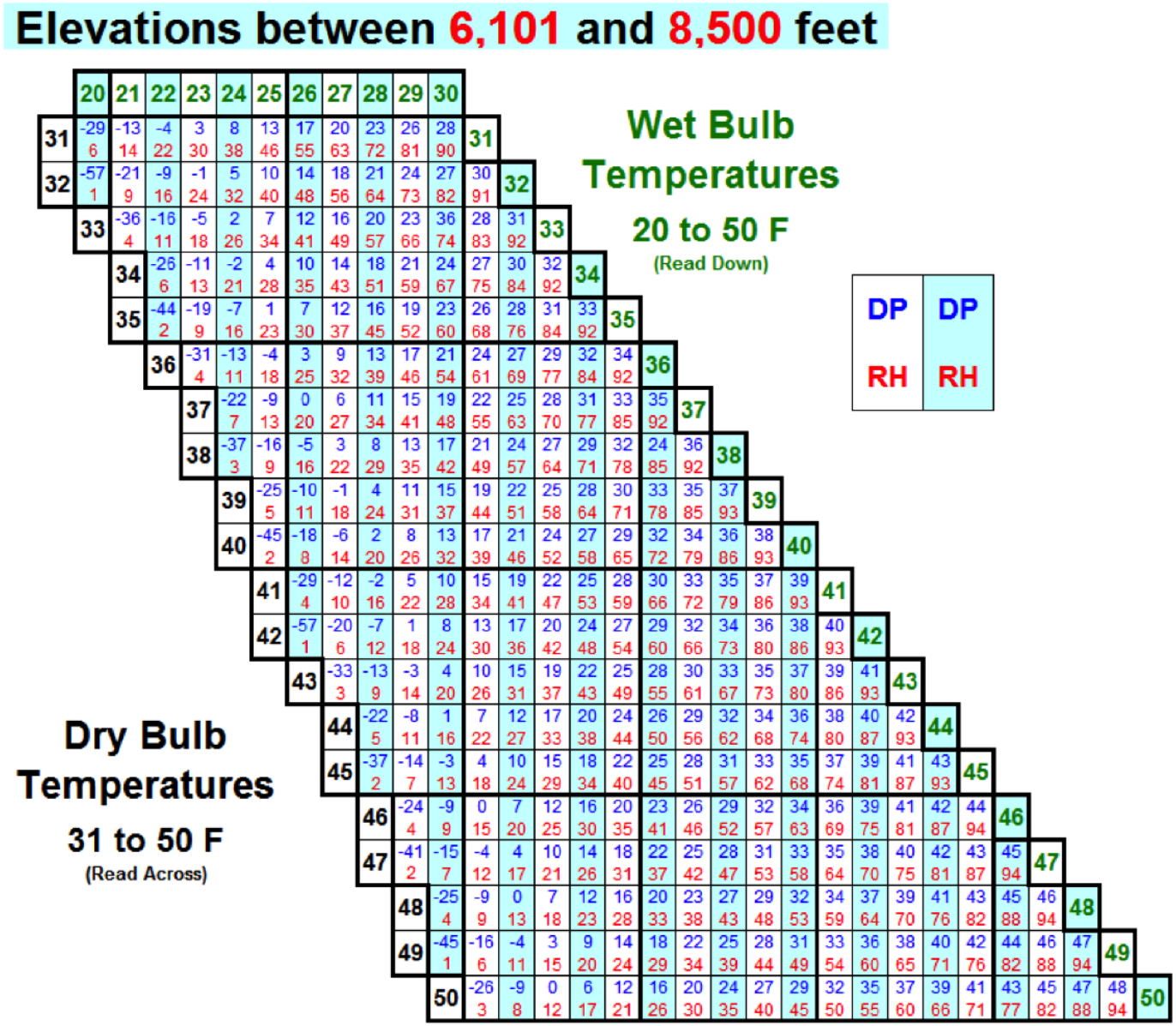
Dry Bulb Temperature 101 to 119°F



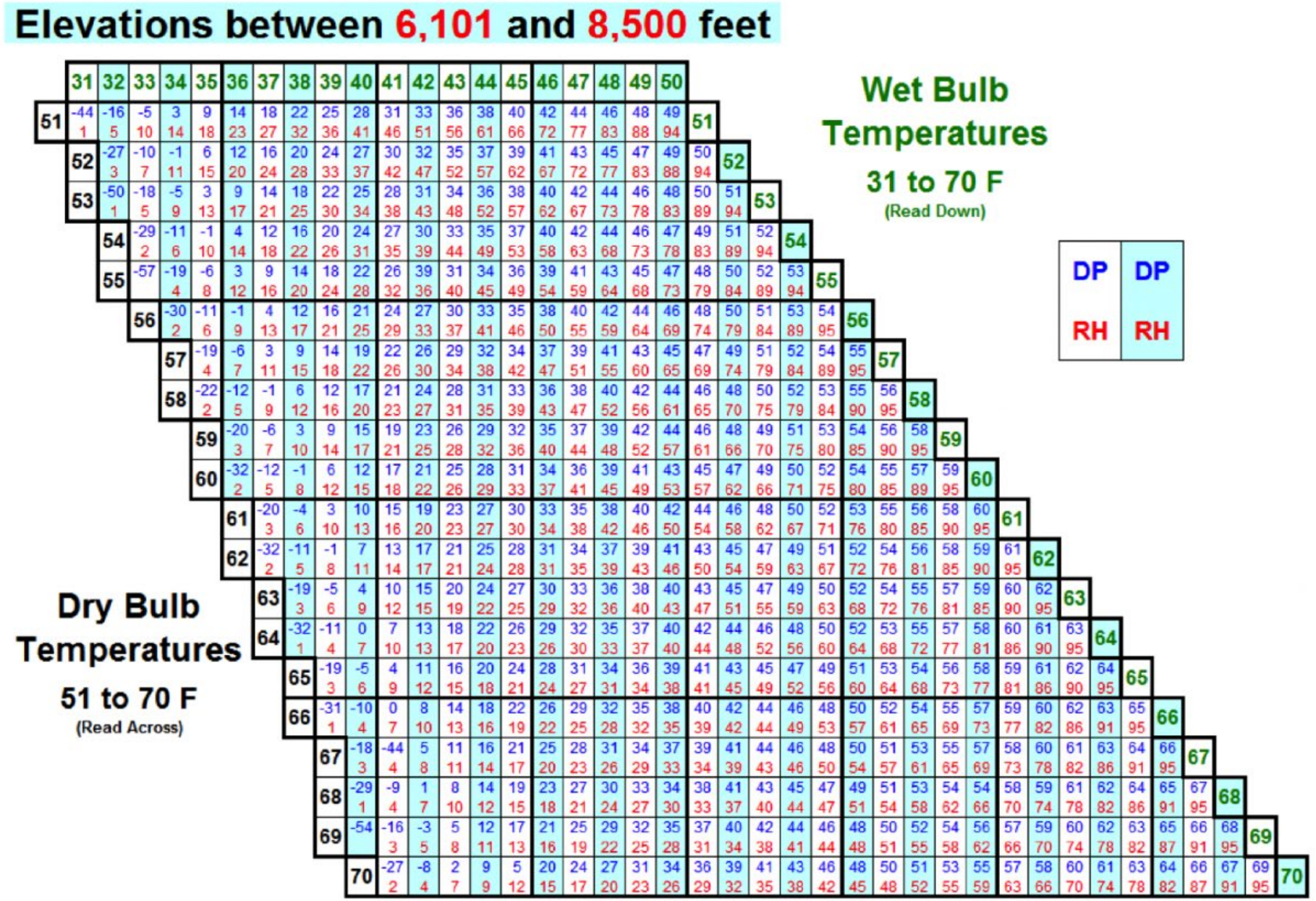
Dry Bulb	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90
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103		-22	-2	9	16	22	27	32	35	39	42	45	48	50	52	55	57	59	61	63	65	66	68	70	71	73	74	76	77	79	80	82	83	84	86	87
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105			-14	2	11	18	24	29	33	37	40	43	46	49	51	53	56	58	60	62	64	65	67	69	71	72	74	75	77	78	80	81	83	84	85	87
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106			-25	-3	8	16	22	27	32	36	39	42	45	48	50	53	55	57	59	61	63	65	67	69	70	72	73	75	77	78	80	81	82	84	85	86
			1	2	3	4	5	6	8	9	10	12	13	14	16	17	19	20	22	24	25	27	29	30	32	34	36	38	40	42	44	46	48	50	53	55
107			-47	-8	5	14	20	26	30	35	38	41	44	47	50	52	54	57	59	61	63	65	66	68	70	72	73	75	76	78	79	81	82	83	85	86
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108				-16	1	11	18	24	29	33	37	40	44	46	49	52	54	56	58	60	62	64	66	68	69	71	73	74	76	77	79	80	82	83	85	86
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109				-27	-3	8	16	23	28	32	36	39	43	46	48	51	53	56	58	60	62	64	66	67	69	71	72	74	76	77	79	80	82	83	84	86
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112					-29	-4	8	16	23	28	32	36	40	43	46	49	51	54	56	58	60	62	64	66	68	70	71	73	75	76	78	79	81	82	84	85
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114						-18	1	11	19	25	30	34	38	41	44	47	50	53	55	57	59	61	63	65	67	69	71	72	74	76	77	79	80	82	83	85
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115						-31	-4	8	17	23	28	33	37	40	44	47	49	52	54	57	59	61	63	65	67	69	70	72	74	75	77	78	80	81	83	84
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116							-10	5	14	21	27	32	36	39	43	46	49	51	54	56	58	60	62	64	66	68	70	72	73	75	77	78	80	81	83	84
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119								-9	6	15	22	27	32	36	40	43	46	49	52	54	57	59	61	63	65	67	69	71	72	74	76	77	79	80	82	83
								1	2	3	4	4	5	6	7	8	9	10	12	13	14	15	16	17	19	20	21	22	24	25	27	28	30	31	33	34

Elevation 6,101 to 8,500 feet (5,701 to 7,900 feet in Alaska), 23 in.

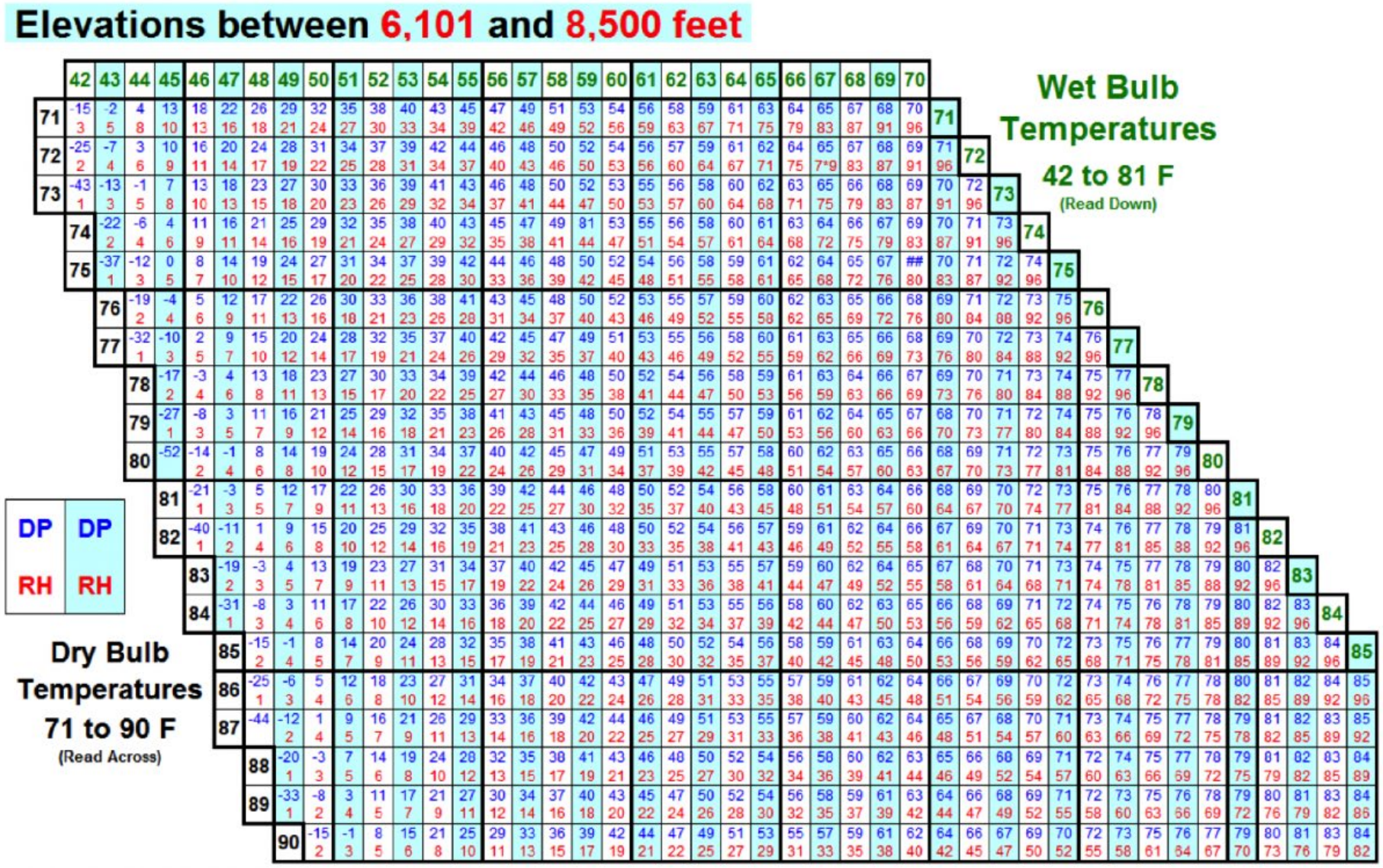
Dry Bulb Temperature 31 to 50°F



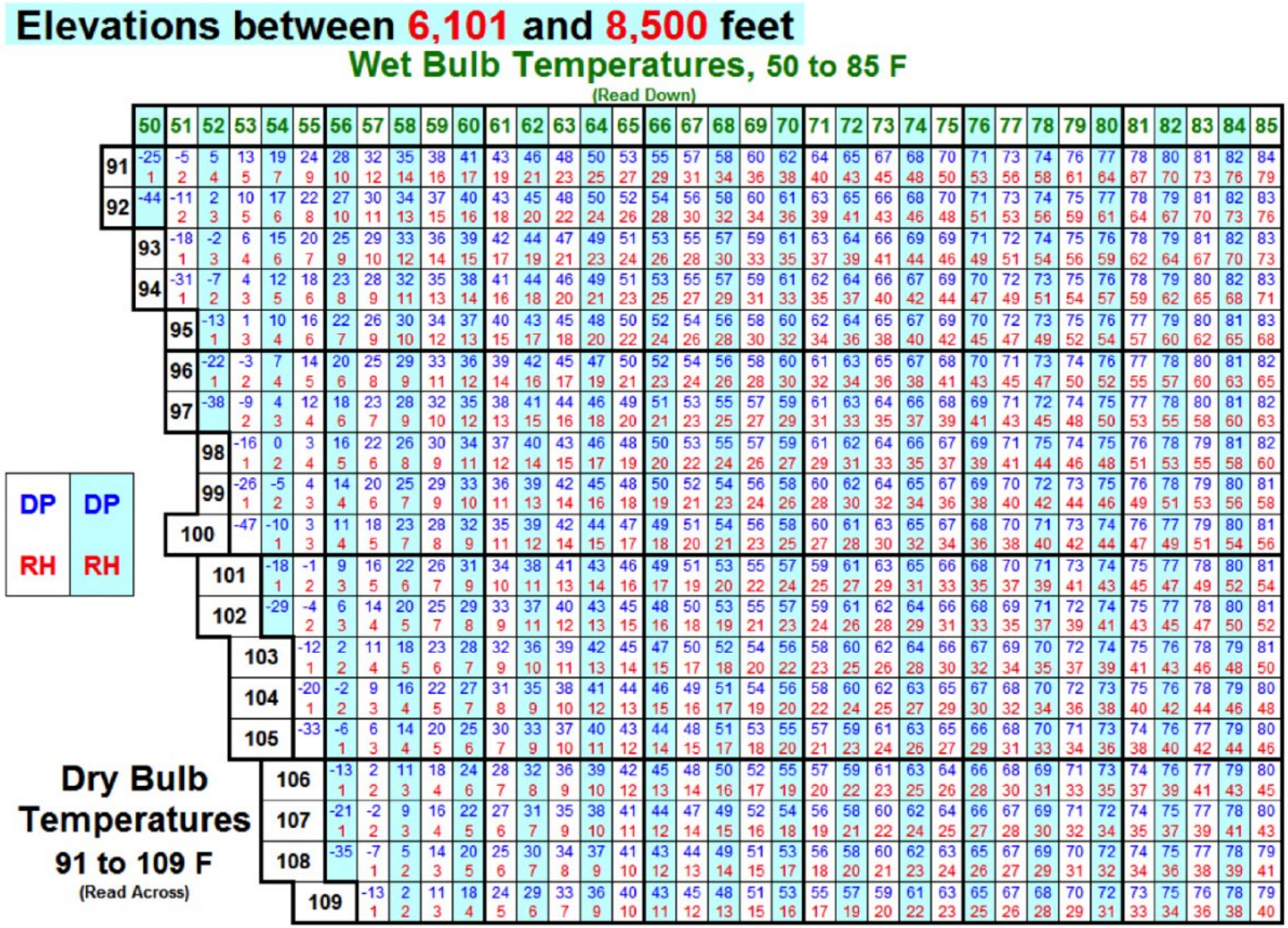
Dry Bulb Temperature 51 to 70°F



Dry Bulb Temperature 71 to 90°F



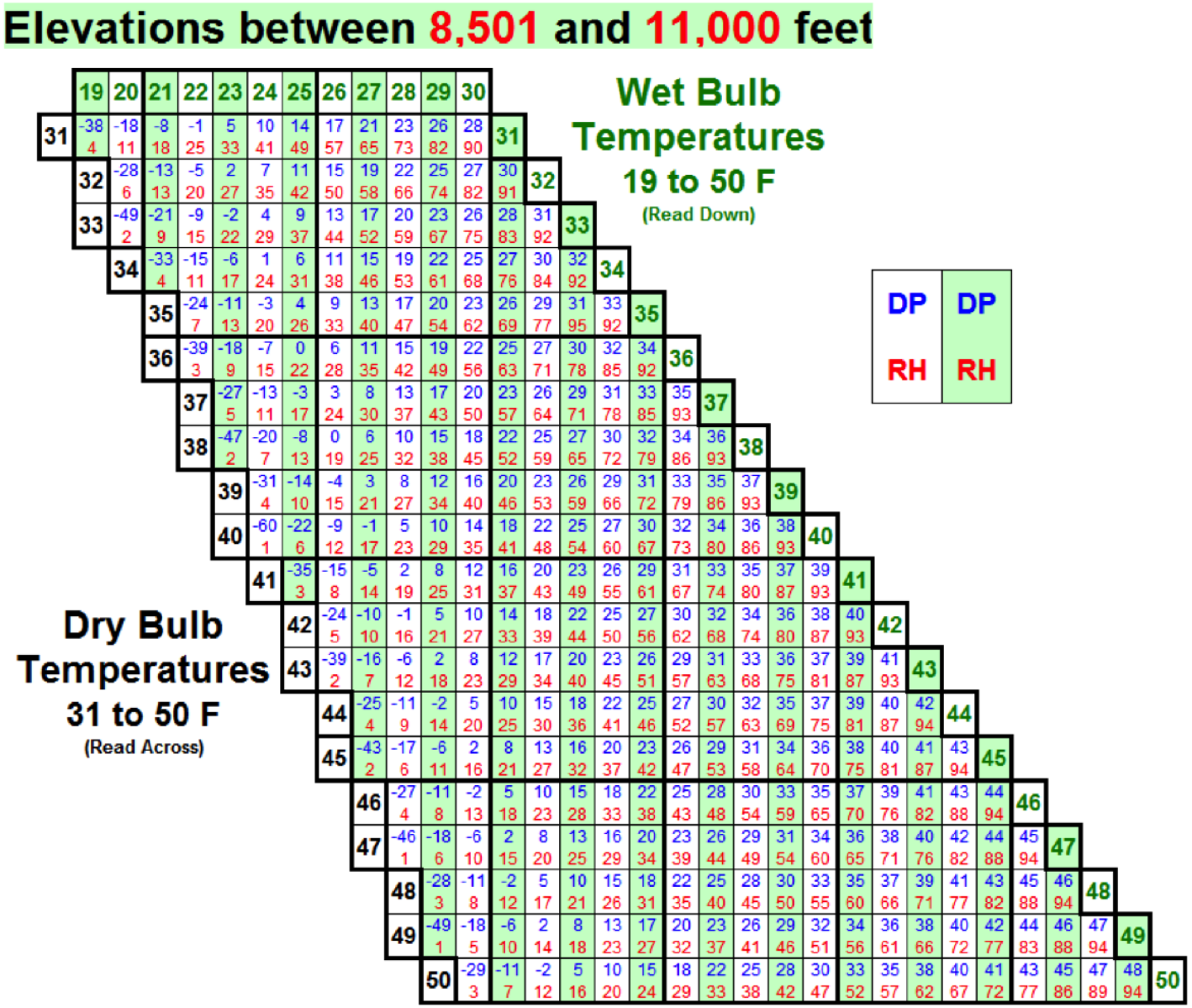
Dry Bulb Temperature 91 to 110°F



Dry Bulb	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	80	81	82	83	84	85
91	-25	-5	5	13	19	24	28	32	35	38	41	43	46	48	50	53	55	57	58	60	62	64	65	67	68	70	71	73	74	76	77	78	80	81	82	84
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92	-44	-11	2	10	17	22	27	30	34	37	40	43	45	48	50	52	54	56	58	60	61	63	65	66	68	70	71	73	74	75	77	78	79	81	82	83
		2	3	5	6	8	10	11	13	15	16	18	20	22	24	26	28	30	32	34	36	39	41	43	46	48	51	53	56	59	61	64	67	70	73	76
93	-18	-2	6	15	20	25	29	33	36	39	42	44	47	49	51	53	55	57	59	61	63	64	66	69	69	71	72	74	75	76	78	79	81	82	83	
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94	-31	-7	4	12	18	23	28	32	35	38	41	44	46	49	51	53	55	57	59	61	62	64	66	67	69	70	72	73	75	76	78	79	80	82	83	
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97	-38	-9	4	12	18	23	28	32	35	38	41	44	46	49	51	53	55	57	59	61	63	64	66	68	69	71	72	74	75	77	78	80	81	82		
		2	3	4	6	7	9	10	12	13	15	16	18	20	21	23	25	27	29	31	33	35	37	39	41	43	45	48	50	53	55	58	60	63		
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		1	3	4	5	7	8	9	11	12	14	15	17	18	20	21	23	25	27	28	30	32	34	36	38	40	42	44	47	49	51	54	56			
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103	-12	2	11	18	23	28	32	36	39	42	45	47	50	52	54	56	58	60	62	64	66	67	69	70	72	74	75	76	78	79	81					
	1	2	4	5	6	7	9	10	11	13	14	15	17	18	20	22	23	25	26	28	30	32	34	35	37	39	41	43	46	48	50					
104	-20	-2	9	16	22	27	31	35	38	41	44	46	49	51	54	56	58	60	62	63	65	67	68	70	72	73	75	76	78	79	80					
	1	2	3	4	5	7	8	9	10	12	13	15	16	17	19	20	22	24	25	27	29	30	32	34	36	38	40	42	44	46	48					
105	-33	-6	6	14	20	25	30	33	37	40	43	44	48	51	53	55	57	59	61	63	65	66	68	70	71	73	74	76	77	79	80					
		1	3	4	5	6	7	9	10	11	12	14	15	17	18	20	21	23	24	26	27	29	31	33	34	36	38	40	42	44	46					
106	-13	2	11	18	24	28	32	36	39	42	45	48	50	52	55	57	59	61	63	64	66	68	69	71	73	74	76	77	79	80						
	1	2	3	4	6	7	8	9	10	12	13	14	16	17	19	20	22	23	25	26	28	30	31	33	35	37	39	41	43	45						
107	-21	-2	9	16	22	27	31	35	38	41	44	47	49	52	54	56	58	60	62	64	66	67	69	71	72	74	75	77	78	80						
	1	2	3	4	5	6	7	9	10	11	12	14	15	16	18	19	21	22	24	25	27	28	30	32	34	35	37	39	41	43						
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		1	2	3	5	6	7	8	9	10	12	13	14	15	17	18	20	21	23	24	26	27	29	31	32	34	36	38	39	41						
109	-13	2	11	18	24	29	33	36	40	43	45	48	51	53	55	57	59	61	63	65	67	68	70	72	73	75	76	78	79							
	1	2	3	4	5	6	7	9	10	11	12	13	15	16	17	19	20	22	23	25	26	28	29	31	33	34	36	38	40							

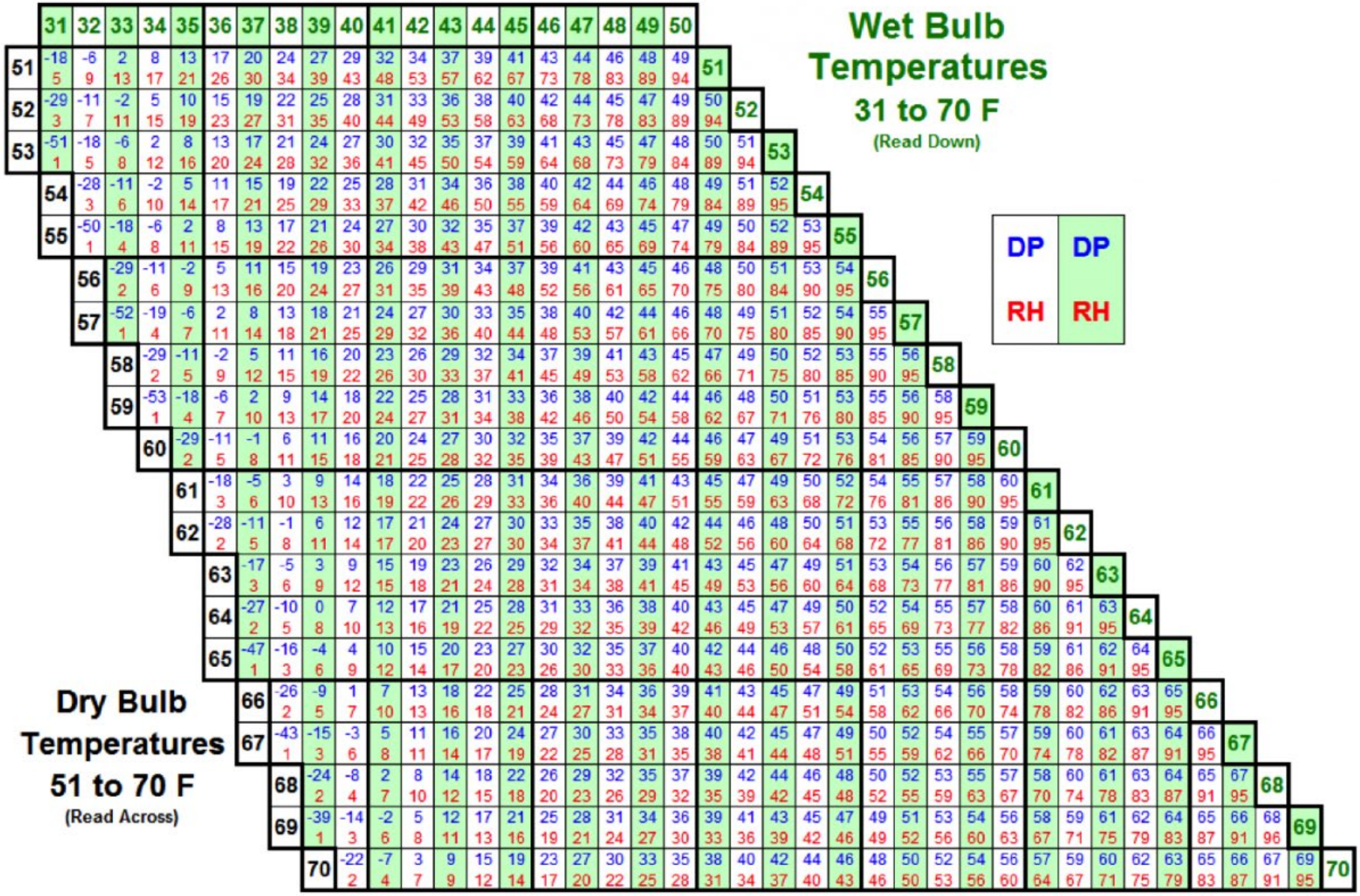
Elevation 8,501 to 11,000 feet (above 7,900 feet in Alaska), 21 in.

Dry Bulb Temperature 31 to 50°F

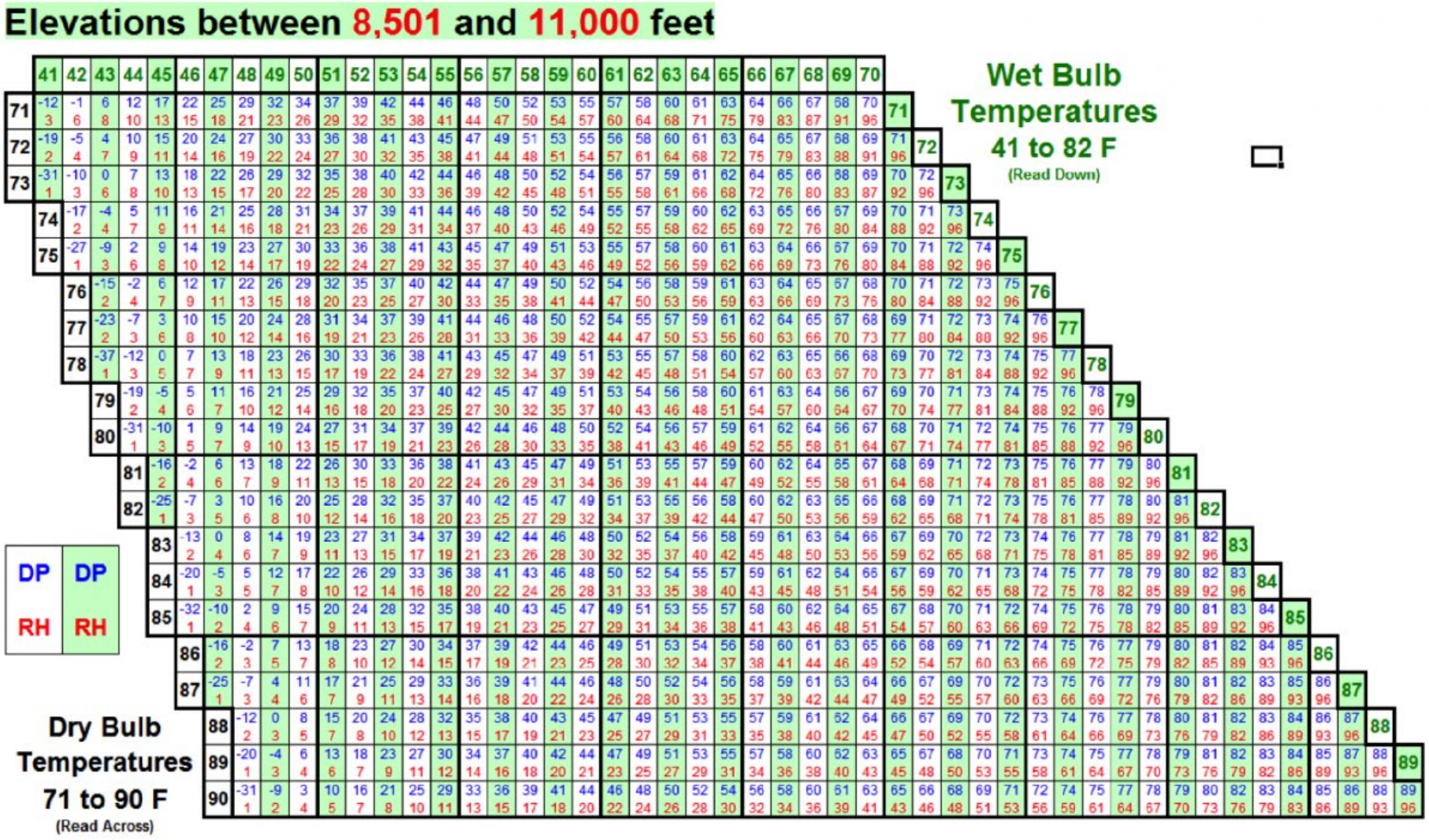


Dry Bulb Temperature 51 to 70°F

Elevations between 8,501 and 11,000 feet



Dry Bulb Temperature 71 to 90°F



Measures of Stability

Table 11. Comparison of stability indices.

Index	Major Factors	Primary Utility	Application
Davis Stability Index	Lapse rate	Basic measure of stability	Southeast U.S.
Ventilation Index	Mixing height and transport wind	Smoke dispersion	United States
Pasquill Stability Index	Solar radiation, cloud cover, and surface wind speed (surface-based stability)	Smoke dispersion	Simple Approach Smoke Estimation Model (SASEM)
Lavdas Atmospheric Dispersion Index	Pasquill, mixing height, transport wind	Smoke dispersion and fire growth potential	Florida

Fire Season Climatology

Drought Assessments

Meteorological Indicators

A wide range of weather-based indices are available to assess drought, including those based solely on accumulated precipitation and others that incorporate modeled evaporation and/or transpiration rates with precipitation. These tools include spatial representations of soil moisture, vegetative stress, agricultural impacts, and water supply. Many are available through the assessment resources listed below.

- **NFDRS** include 1000-hour timelapse fuel moisture, ERC.
- **Canadian Forest Fire Danger Rating System (CFFDRS)** includes the Duff Moisture Code (DMC), Drought Code (DC), and Buildup Index (BUI).
- **Evaporative Demand Drought Index (EDDI)**, https://psl.noaa.gov/eddi/, is an experimental drought monitoring and early-warning tool that evaluates anomalies in atmospheric evaporative demand (E0) (also known as "the thirst of the atmosphere") for a given period of time and location.
- **Standardized Precipitation Evapotranspiration Index (SPEI)**, https://spei.csic.es/map/maps.html#months=1#month=4#year=2025, measures drought severity based on intensity and duration. SPEI can identify drought onset and recovery and allows comparison of drought severity through time and space, since it can be calculated over a wide range of climates.
- **Evaporative Stress Index (ESI)**, https://www.drought.gov/data-maps-tools/evaporative-stress-index-esi, highlights temporal anomalies in evapotranspiration (ET), highlighting areas with anomalously high or low rates of water use across the land surface.
- **Standardized Precipitation Index (SPI)**, https://climatedataguide.ucar.edu/climate-data/standardized-precipitation-index-spi expresses precipitation anomalies in terms of standard deviations relative to the long-term mean, using a transformation to normalize precipitation data.

- **Quantitative Precipitation Estimate (QPE)**, https://www.ncei.noaa.gov/products/climate-data-records/precipitation-nexrad-qpe, provides multi-sensor estimates and spatial distribution of precipitation. This is one of the best sources of timely, high resolution precipitation information available.

Assessments Resources

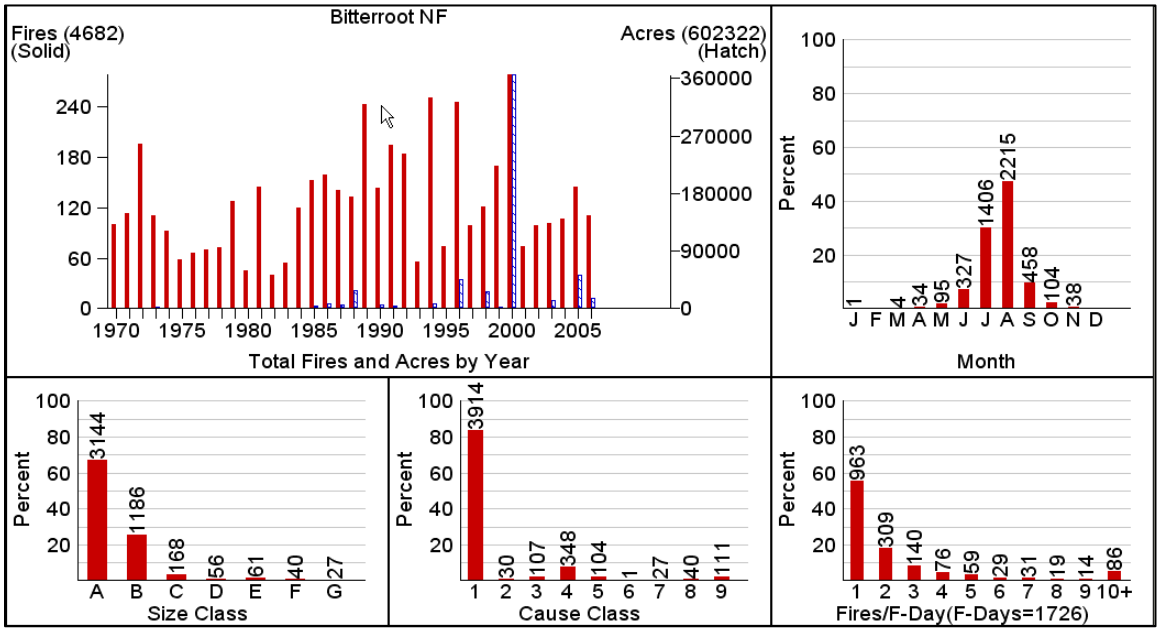
- **U.S. Global Climate Change Research Program (USGCRP)**, https://www.congress.gov/crs-product/R48478, mandated by the 1990 Congress in the Global Change Research Act (GCRA), supports national and global efforts to understand, assess, predict, and respond to natural and human-driven climate processes.
- **National Oceanic and Atmospheric Administration (NOAA) Climate.gov**, https://www.noaa.gov/climate, offers timely and authoritative climate data, maps, news, and educational resources.
- **Western Water Assessment**, https://wwa.colorado.edu/, a NOAA Integrated Sciences and Assessments partnership, provides societal vulnerabilities to extreme weather and natural hazards, particularly those related to water resources.
- **U.S. Drought Monitor**, https://droughtmonitor.unl.edu/, shows where and how severe drought is across the U.S. and its territories. This map is released weekly on Thursday by the National Drought Mitigation Center (NDMC), NOAA, and USDA.
- **National Integrated Drought Information System (NIDIS),** https://www.drought.gov/, is a multi-agency platform providing drought monitoring, forecasting, planning, and information at national, state, and local levels, including resources about fire. It is part of the National Centers for Environmental Information, https://www.ncei.noaa.gov/, which offers additional sector-specific resources.
- **National Drought Mitigation Center**, https://drought.unl.edu/Climographs.aspx, produced by University of Nebraska – Lincoln, provides average monthly temperature and precipitation over a year in graph form for various locations' climates.
- **River Forecast Centers**, https://water.noaa.gov/about/rfc, part of the NWS Advanced Hydrological Prediction Services, provide graphic and digital depictions of river flows, flooding, and rain and snowfall.

Local Climatology and Current Season Trends

Evaluate Fire Occurrence Patterns

FireFamilyPlus (FFP) provides useful depictions of fire occurrence patterns and ignition patterns. However, in areas where fires commonly experience multiple growth episodes during extended periods of active fire behavior, these depictions may offer limited insight into climatology or typical fire dynamics.

Figure 22. FireFamilyPlus charts show different fire season metrics.



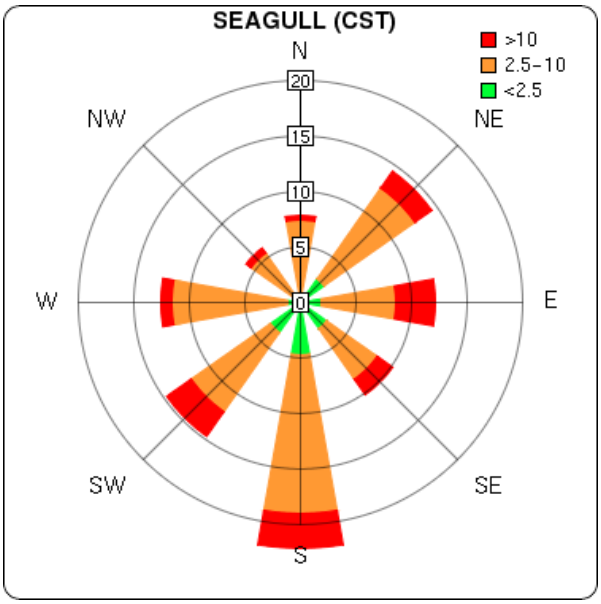
Identify Normal Seasonal Trends

Use FFP graphs to determine when most fires occur throughout the year.

Local Winds Climatology

Wind roses are available in FFP, the Western Regional Climate Center (https://wrcc.dri.edu/), and other tools. Ensure analyses include only relevant winds, (e.g., exclude other seasons, nighttime winds).

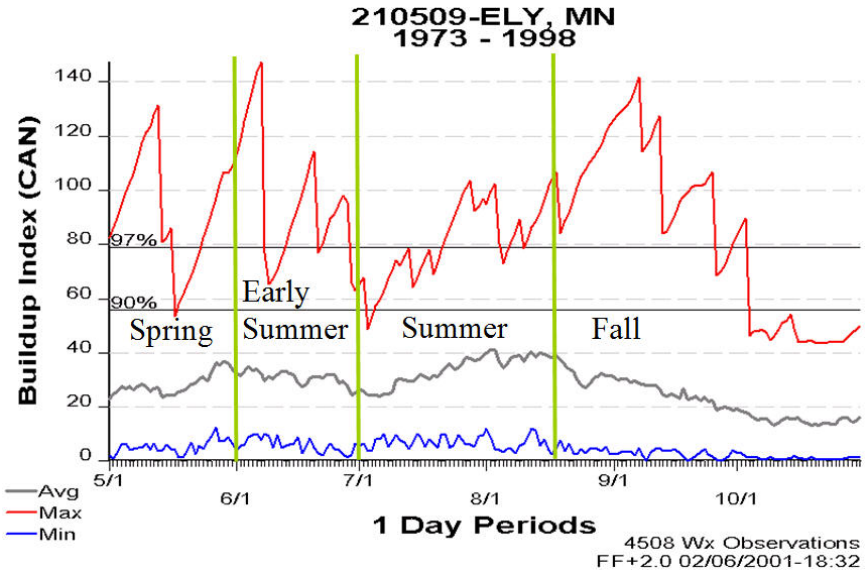
Figure 23. Wind rose for Seagull RAWS.



Understanding Fire Seasonality

Use appropriate **Fire Potential Indicators**—such as ERC and BUI—to determine season start, peak season, shoulder seasons, and season end.

Figure 24. Seasonal trend analysis for BUI.

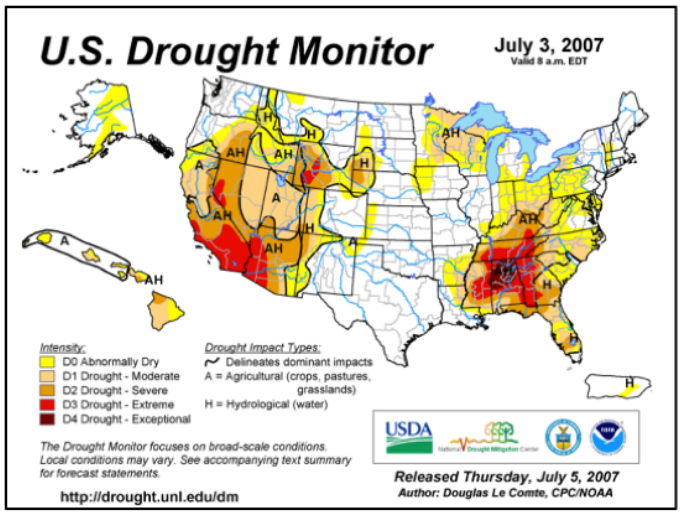


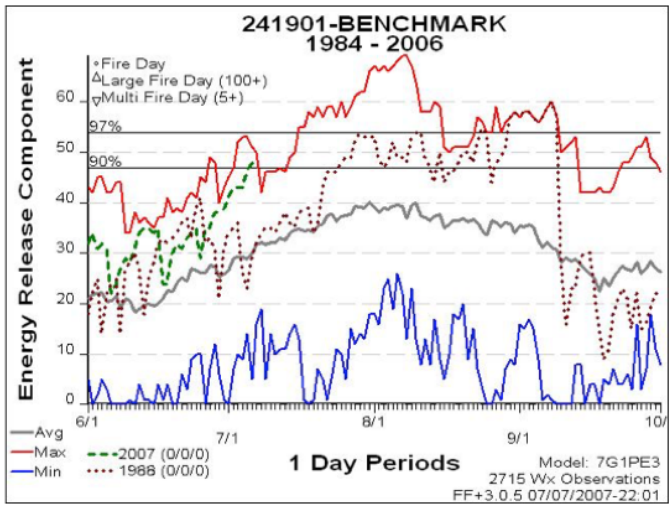
Current Trends and Historic Norms/Extremes

General Trends

Evaluate and spatially depict current conditions using a combination of drought-assessment resources appropriate for the area of interest.

Figure 25. Evaluating current trends and historic conditions.





Current Local Conditions

Graphical Time Series can highlight seasonal departures from normal conditions and help identify exceptional seasons. FireFamilyPlus climatology graphics typically include historic range (average, maximum, minimum), current year, and an analog year for comparison. Tracking the current year compared to the historic range is a helpful way to characterize the current fire season as higher or lower

than usual. The analogous years, or years that tracked similarly to the current year, can lend context to the current year when fire managers recall the past similar season.

Consult with Local Managers and Experts.

Local fire managers can help interpret objective analyses and identify any local nuances or anomalies that may not be apparent.

Evaluate Historic Trends for Weather That Slows or Stops Fire Growth

Fire-Stopping Events

Latham and Rothermel (1993) documented criteria based on expert opinion from people familiar with fire and fire weather in the Northern Rockies—for example 0.5 inches of rainfall accumulated over 5 days or fewer. Other indicators, such as cloud cover and RH, can also signal periods of continuous low- or no-spread days during a fire season in a locality. These discrete events may not signal the end of the fire or the season, so understanding their frequency and duration is as important as estimating when the next event may occur. It is very important to view any potential for a fire-stopping event in the context of the whole fire season (Figure 24) and understand if conditions for future fire spread may still exist.

Fire Season-Ending Date

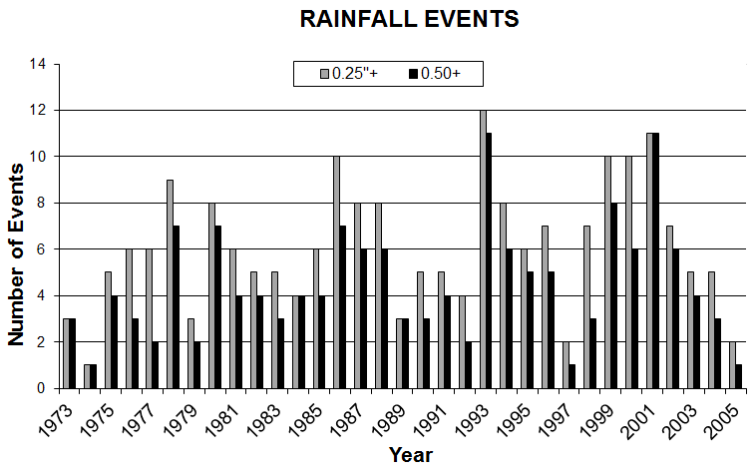
It is possible to identify the date in a fire season when fire growth is no longer likely or possible, an indicator of the end of fire season. When threats to values are imminent, or early in the fire season, it may be more relevant to predict when a specific weather event will slow fire growth rather than predicting the end of fire season.

In regions with bimodal seasons (such as the spring seasons in the Southwest and the Lake States) weather criteria can suggest an early-season fire ending date even though fire potential is expected to rise again in subsequent periods. Anticipating this date may be critical to strategic decisions as the season end approaches.

Event Frequency and Duration

As suggested in Figure 26, identifying the frequency—and typical duration—of fire-slowing or stopping events is valuable, especially where these events are more common, such as in the eastern US. The FireFamilyPlus Event Locator can be used to evaluate data from a local RAWS.

Figure 26. Climatological rainfall graph.

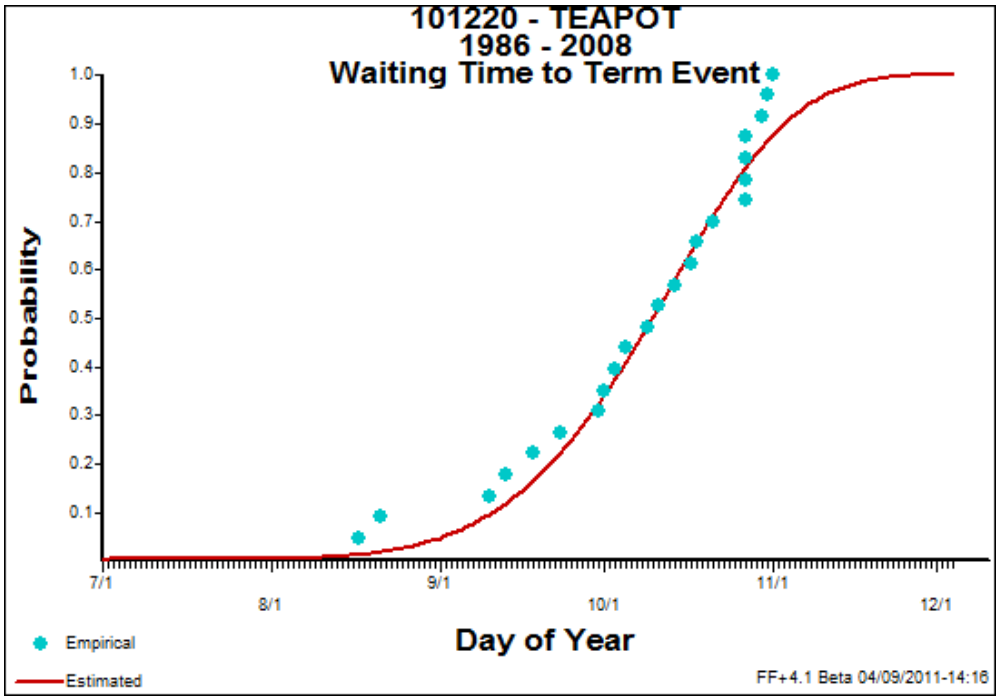


TERM Waiting Time Distribution

FireFamilyPlus includes a TERM tool (found in the Weather menu) to produce waiting time distributions for historic fire- or season-ending dates. Each year is assigned a single ending date based on established criteria—often developed with input from local fire managers (e.g., a specified amount of rainfall over a defined period). These dates are determined through data analysis and recorded, and the distribution is plotted to estimate the probability that the fire or season will end by a specific date (Figure 27).

TERM graphs may also be generated through the Risk Management Assistance (RMA) Dashboard by uploading a fire perimeter file. Using only gridded ERC criteria in the fire area, the tool calculates the waiting time distribution curve to estimate when the ERC will drop and fail to rebound. Results are scale-dependent, reflecting the aggregate behavior of all modeled ERC values across the uploaded area.

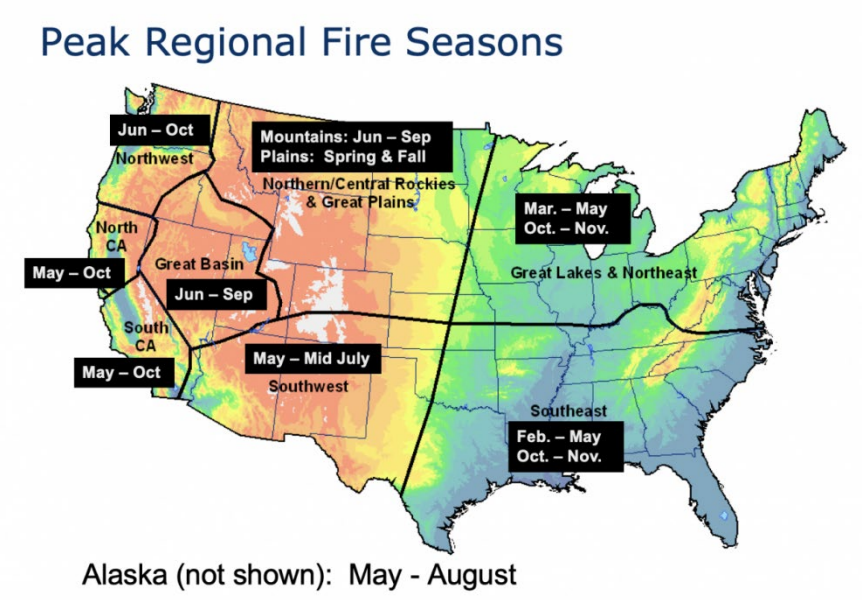
Figure 27. Term file from FireFamilyPlus.



Regional Fire Seasonality

Temperature, atmospheric moisture, and wind patterns are the fundamental climate and weather factors that affect fuel conditions and influence the likelihood of fire start and spread. The characteristics of a region's fire season are driven by seasonal and continental-scale weather patterns, their movement, and variation. Changes in seasonal air masses and the position of the jet stream affect each region differently and at different times of the year.

Figure 28. Map of peak regional fire seasons for CONUS.



The terms below represent common keywords and phrases meteorologists typically use to describe critical fire weather growing and slowing patterns. These descriptors often appear in NWS Area Forecast Discussions, fire weather planning forecasts, and Predictive Service 7-day outlook assessments, though they are not the only terms used.

<u>Alaska</u>

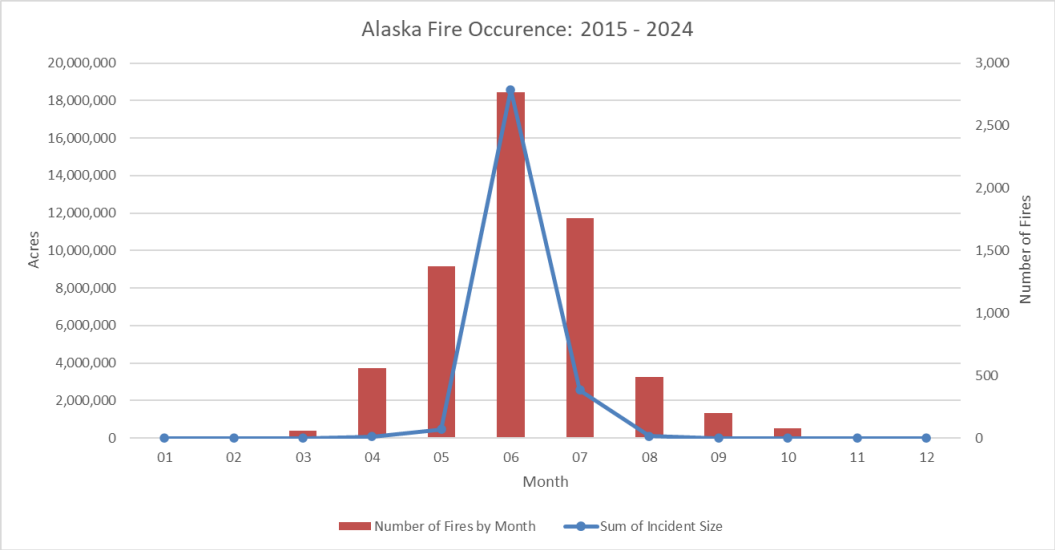
Climatology

- Winter – Generally very cold and dry.
- Spring – Cold and dry early, then warming with increasing downslope wind event potential.
- Summer – Warm and dry with lightning in June, then gradually moistening. Occasional wind events.
- Fall – Moist initially, then back towards winter conditions.

Fire Activity

- Peak fire activity in late spring and summer coincides with warmest/driest conditions, wind events, and dry lightning potential.
- Great majority of activity in interior between Alaska and Brooks ranges.
- Season ramps up quickly after snow melt and strongly relates to length of day.
- Season ends quickly with late summer/early fall moisture increase.

Figure 29. Fire occurrence in Alaska from 2015 to 2024.



Critical Weather Events

- Foehn and Downslope Wind – Glacial Katabatic downstream from glaciers, e.g. Juneau fjords, Alaska Range Chinook in the western Tanana Valley, Hillside Katabatic Winds, e.g. Anchorage Bowl, and Yukon Chinook winds in the eastern interior and through the Brooks Range.
- Breakdown of the Upper Ridge – Boreal interior area from Galena to Fort Yukon, warming-drying ahead of the low-pressure system originating from the Sea of Okhotsk with gusty W-SW winds, and Low Pressure moving inland and loses wetting characteristics but keeps enough moisture for drier storms.

Fire-Slowing or Stopping Events

- Closed low/occluded low is a low-pressure system that originates from the Sea of Okhotsk and Bering Sea moves inland and stays for a multi-day period or a persistent moist southwest flow impacting the coastal areas.
- Marine Inversion: coastal areas of Alaska especially during night.

Fire Growth Potential Indicators

- Fine Fuel Moisture Code (FFMC) and BUI
- ISI
- FWI

<u>Northwest</u>

Climatology

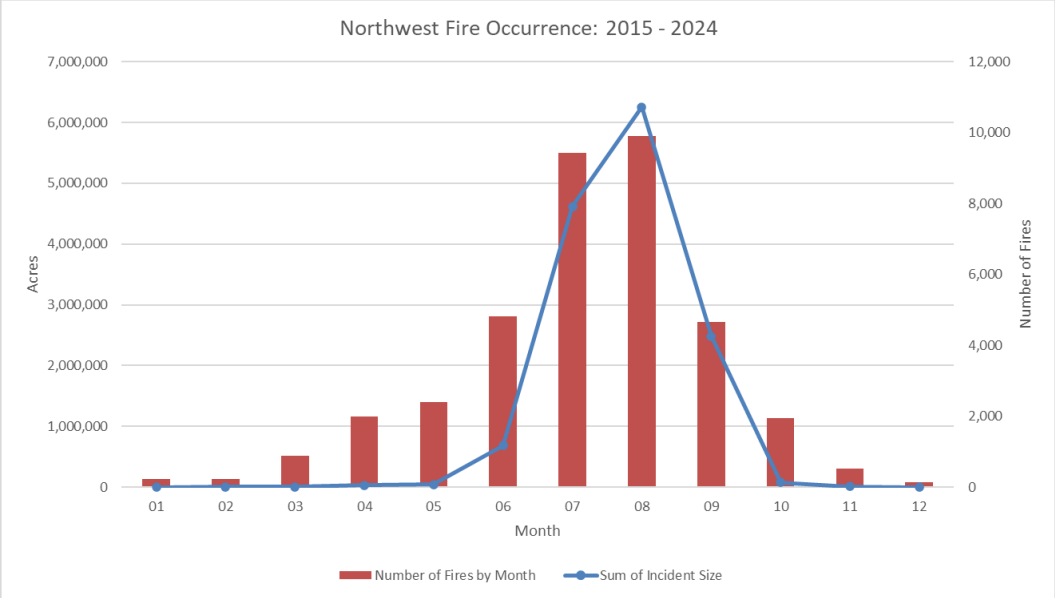
- Winter/Spring – Cool and moist with frequent and abundant precipitation, especially western portion of area. Relatively dry east.
- Summer – Some windy and dry potential early, then becoming generally warm and dry with infrequent wind events due to dry cold fronts.

- Fall – Return of cooler, more moist conditions ushered in by a period of windy, dry conditions with cold frontal passages. Potential for dry onshore wind events behind storm systems.

Fire Activity

- Fire activity peaks in summer due to increasingly warm and dry conditions and potential for wind and lightning with dry cold frontal passages.
- Rapid decrease in activity in fall with Pacific moisture on the increase, though this the peak period for dry onshore wind events and a few dry cold front passages are still possible.
- Little to no activity late fall through spring.

Figure 30. Fire occurrence in the northwestern U.S. from 2015 to 2024.



Critical Weather Events

- Thermal Low/Subtropical Ridge
- Breakdown of the Upper Ridge and Passage of a dry cold front
- Foehn or Downslope Wind (East Wind west slopes of Cascades and Chinook Wind east slopes of the Cascades)

Fire-Slowing or Stopping Events

- Closed Lows/Wet Cold Front
- Marine Layer/Onshore Flow
- Smoke Events

Fire Growth Potential Indicators

- ERC
- 100-hr fuel moisture
- AVHRR satellite NDVI DA and Relative Greenness (RG)

- NWS QPE (30 to 60 days)
- Drought Monitor

Northern California

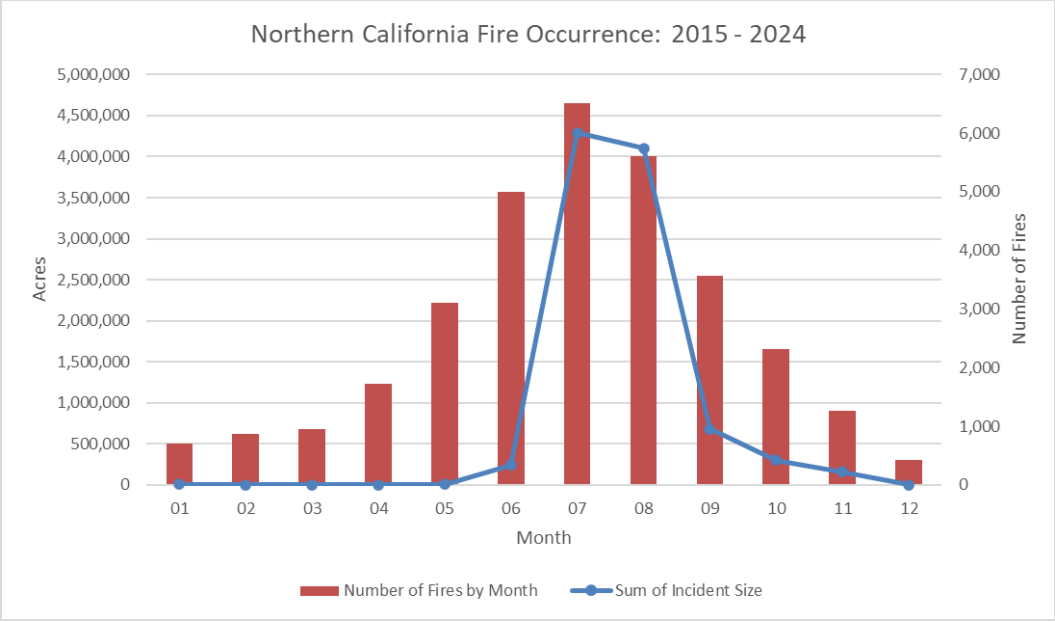
Climatology

- Winter/Early Spring – Cool and moist with regular precipitation events, especially in the mountains.
- Late Spring/Summer – Some windy/dry potential early, then generally warm and dry with infrequent wind events due to dry cold front influences.
- Fall – Return of cooler, more moist conditions ushered in by a period of windy, dry conditions with cold frontal passages. Potential for dry, north through east wind events behind storm systems.

Fire Activity

- Fire activity peaks in summer due to increasingly warm and dry conditions and potential for wind and lightning with infrequent dry cold frontal passages.
- Rapid decrease in activity by late fall with Pacific moisture on the increase, though peak period for dry northeast wind events.
- Little to no activity late fall through early spring.

Figure 31. Fire occurrence in northern California from 2015 to 2024.



Critical Weather Events

- Foehn or Downslope Wind (Mono, North Winds)
- Breakdown of the Upper Ridge in the Interior
- Subtropical Ridge/Thermal low

Fire-Slowing or Stopping Events

- Closed Low/Pacific Trough
- Marine Layer/Onshore flow
- Smoke Events

Fire Growth Potential Indicators

- Spread Component (SC)
- Burning Index (BI)
- ERC
- Live Fuel Index (LFI)/GSI
- AVHRR satellite NDVI DA and RG
- NASA Short-term Prediction Research and Transition (SPoRT) GVF
- NWS QPE (30 to 60 days)
- Drought Monitor

Southern California

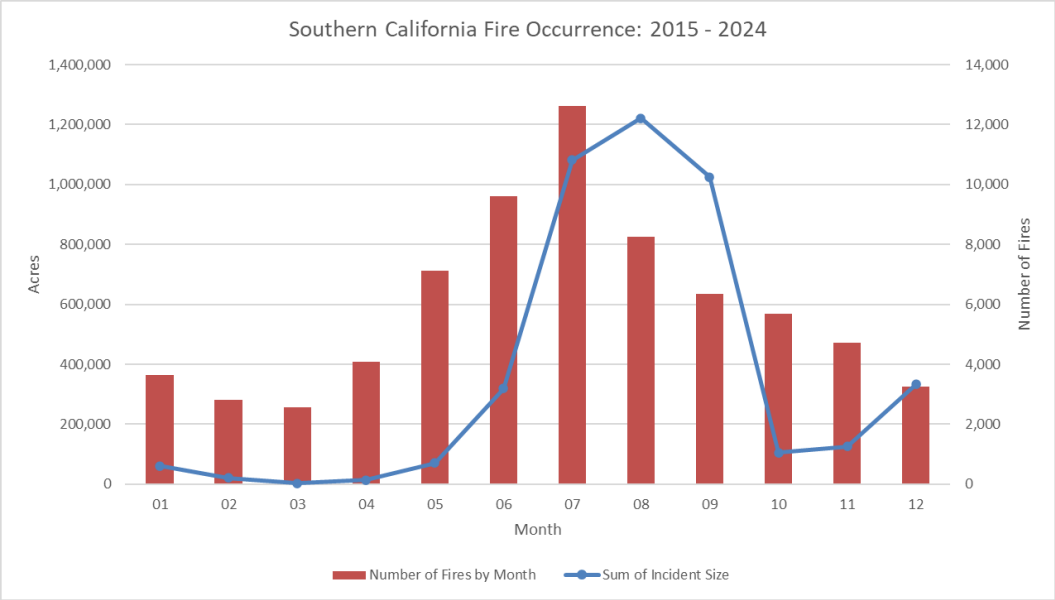
Climatology

- Winter – Occasional storm systems with mainly mountain precipitation. Inland intrusions of cool, moist Pacific air. Relatively dry inland lower elevations.
- Spring – Less frequent precipitation events and substantial inland intrusions of marine air.
- Summer – Hot and dry inland and maritime influence along coast. Occasional influx of monsoon moisture from southeast.
- Fall – End of any monsoon moisture influence and begin of gradual inland shift in marine air mass. Period of greatest potential for dry offshore wind events.

Fire Activity

- Fire activity peaks late spring through fall, when influence of maritime air is diminished.
- Greatest potential for offshore wind events in the fall, when fuels are often driest.
- Little activity winter and early spring due to maritime influence.
- Fires are possible at any time with offshore wind events.

Figure 32. Fire occurrence in southern California from 2015 to 2024.



Critical Weather Events

- Foehn or Downslope Wind (Santa Ana and Sundowners)
- Breakdown of the Upper Ridge away from the coast
- Subtropical Ridge

Fire-Slowing or Stopping Events

- Marine Layer/Onshore Flow
- Closed Low/Pacific Trough

Fire Growth Potential Indicators

- SC
- BI
- ERC
- National Fuel Moisture Database
- Live Fuel Index (LFI)/GSI
- AVHRR satellite NDVI DA and RG
- NASA SPoRT GVF
- NWS QPE (30 to 60 days)
- Drought Monitor

Southwest

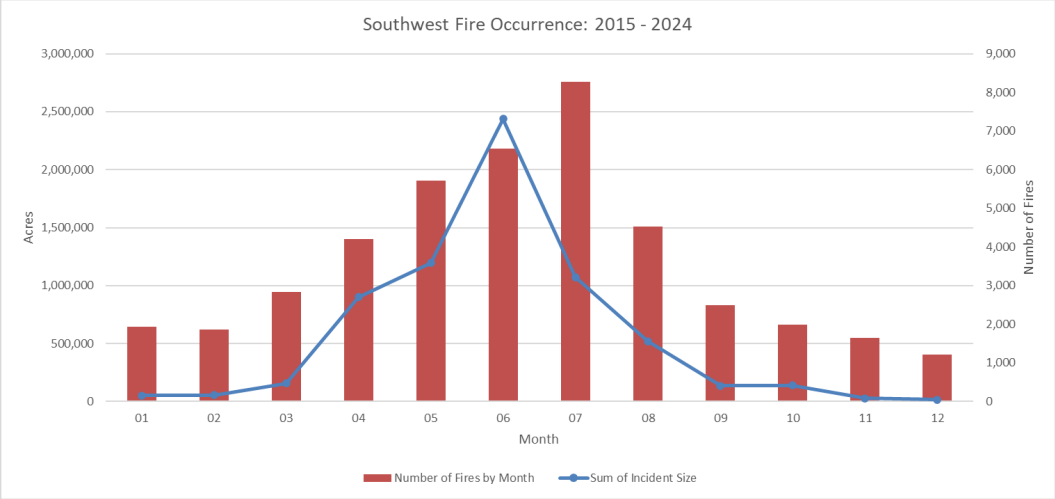
Climatology

- Winter – Cool to cold with occasional precipitation. Dry, downslope winds possible in lee of Rockies.
- Spring – Warming, windy and dry transitioning to hot and dry.
- Summer – Hot and dry gives way to warm and moist abruptly with monsoon.
- Fall – Turning much drier and mild. Potential for few wind events followed by dropping temperatures.

Fire Activity

- Fire activity increases in spring as it transitions from windy and dry to hot and dry.
- Peak from May to mid-July, with monsoon thereafter.
- Rare secondary fall season as moisture exits and jet drops south and wind event potential returns.
- Little activity late fall to early winter.

Figure 33. Fire occurrence in the southern U.S. from 2015 to 2024.



Critical Weather Events

- Breakdown of the Upper Ridge
- Subtropical Ridge
- Monsoon Transition (Edge of a Monsoon Burst and Edge of Back Door Cold Front)
- Foehn or Downslope Wind
- Low Level Jet on Rangeland of the Front Range
- Surface Dryline Passage on Rangeland of the Front Range

Fire-Slowing or Stopping Events

- Closed Low-Cold Frontal Passage
- Back Door Cold Front
- Monsoon Burst

Fire Growth Potential Indicators

- ERC and BI
- NFMD
- LFI/GSI
- AVHRR satellite NDVI RG and DA
- NASA SPoRT GVF
- NASA SPoRT RSM (0 to 10 cm)
- NWS QPE (30 day)
- Drought Monitor

Great Basin

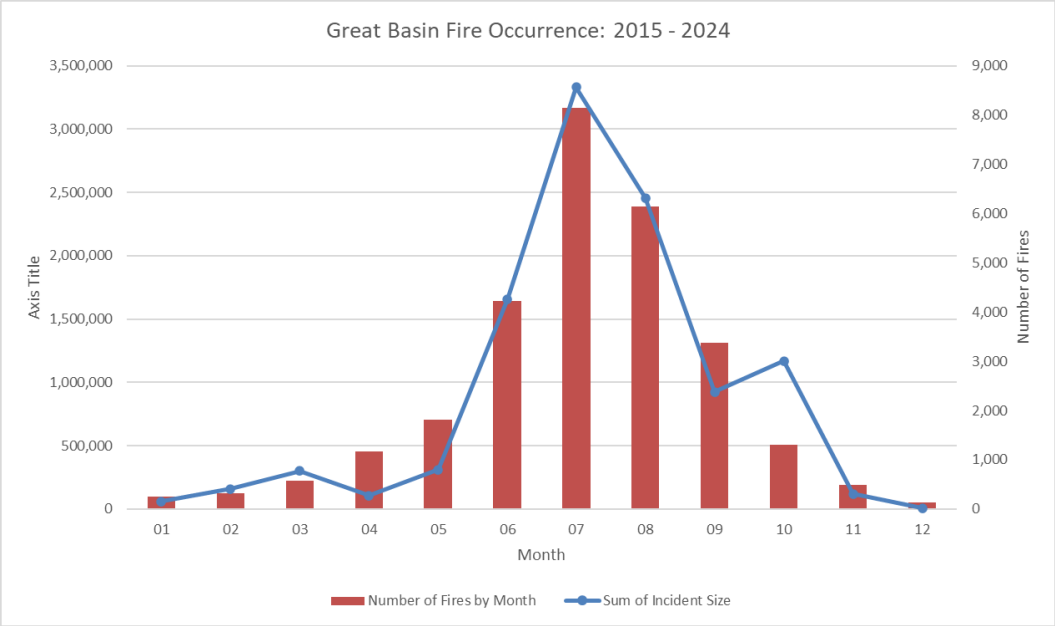
Climatology

- Winter – Periodic precipitation, mainly over mountains.
- Spring – Becoming windy, dry, and warmer.
- Summer – Hot and dry. Periodic wind events north and moisture surges south.
- Fall – Period of windy and dry conditions often followed by period of fair and dry weather before cooler temperatures and increased precipitation potential.

Fire Activity

- Generally fine fuel types, fire season dependent on cured fuels and windy/dry conditions.
- These conditions occur almost exclusively in the summer.
- Little to no activity outside of summer.

Figure 34. Fire occurrence in the Great Basin of the U.S. from 2015 to 2024.



Critical Weather Events

- Breakdown of the Upper Ridge
- Subtropical Ridge
- Edge of a Monsoon Burst (Hybrid)
- Foehn or Downslope Wind (Chinooks down east slopes of the Sierras and west slopes of the Wasatch Mountains)

Fire-Slowing or Stopping Events

- Closed Low/Pacific Trough
- Monsoon Burst duration of three days or more

Fire Growth Potential Indicators

- ERC and BI
- National Fuel Moisture Database
- LFI/GSI
- AVHRR satellite NDVI DA and RG
- NWS QPE (30 to 60 days)
- NASA SPoRT RSM 0 to 10 cm/GVF
- Drought Monitor

Northern/Central Rockies and Great Plains

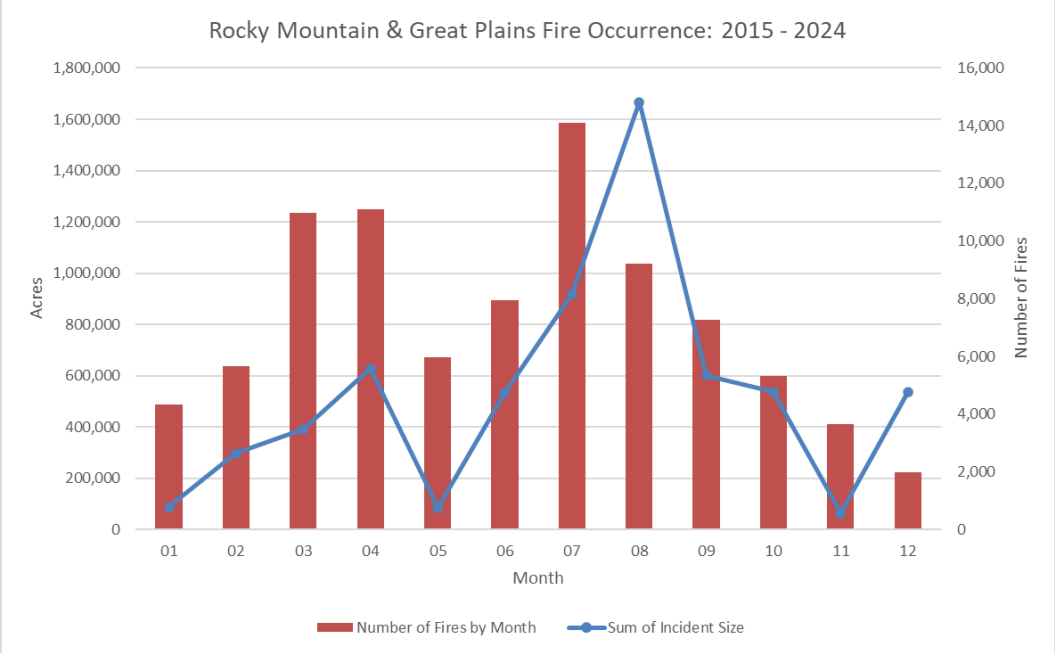
Climatology

- Winter – Regular storm systems and precipitation, especially over mountains. Cold overall with potential for arctic air intrusions.
- Spring – Period of heaviest precipitation in the mountains, but greatest Chinook wind potential in lee of Rockies and adjacent plains.
- Summer – Warm and dry over most mountain areas with occasional wind events north. It is increasingly moist across the plains and far south.
- Fall – Period of windy/dry potential, then fairly dry and mild until temperatures drop and moisture increases.

Fire Activity

- Fire activity on the plains peaks in spring and fall when windy/dry periods coincide with dormant or cured fine fuels.
- Fire activity in the mountain's peaks in the summer when it's warmest and driest and some dry cold frontal passages are possible.
- Little to no activity late fall through early spring.

Figure 35. Fire occurrence in the Rocky Mountain and Great Plains region from 2015 to 2024.



Critical Weather Events

- Breakdown of the Upper Ridge (Dynamic dry slot and Dry Cold Front)
- Subtropical Ridge (Mid-level dry intrusion)
- Edge of a Monsoon Burst (Hybrid)
- Foehn or Downslope Wind (Chinook)

- Low-Level Jet and Surface Dryline on the Great Plains

Fire-Slowing or Stopping Events

- Closed Low-Pacific Trough-Cold Frontal Passage
- Monsoon Burst
- Smoke Event

Fire Growth Potential Indicators

- ERC and BI
- National Fuel Moisture Database
- Live Fuel Index (LFI)/GSI
- AVHRR satellite NDVI DA and RG
- NASA SPoRT GVF
- NWS QPE (30 to 60 days)
- Drought Monitor

<u>Great Lakes and Northeast</u>

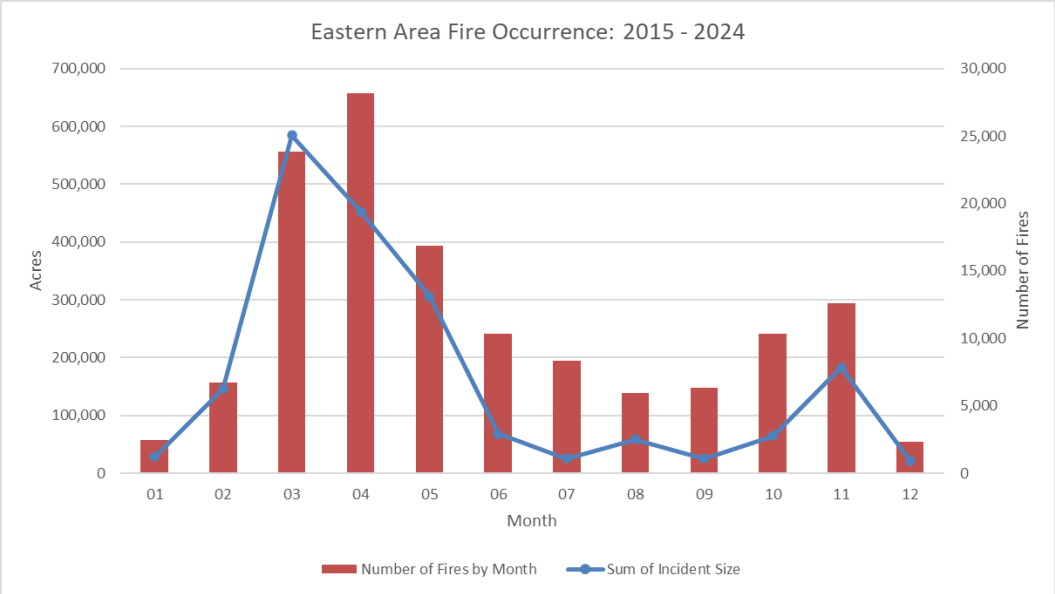
Climatology

- Winter – Generally cold with dry periods between widespread periodic precipitation.
- Spring – Warmer, windier, and drier. Driest immediately behind storm systems.
- Summer – Generally warm and humid under Bermuda High influence. Occasional windy/dry events far north.
- Fall – Turning much drier, then generally mild and dry with potential for windy and dry periods before temperatures drop.

Fire Activity

- Fire activity is maximum in spring and fall, coincident with windy periods near jet stream.
- Building warmth and dormant fine fuels in spring, leaf-off in fall.
- Season can extend well into summer far north if jet remains active and brings windy/dry events that are preceded by dry conditions of two weeks or more.
- Little or no activity during winter months.

Figure 36. Fire occurrence in the eastern U.S. from 2015 to 2024.



Critical Weather Events

- Post Cold Frontal
- Pre-Cold Frontal Southwest Wind cases
- Bermuda High

Fire-Slowing or Stopping Events

- Cold Frontal Passage
- Stationary Front
- Closed Low

Fire Growth Potential Indicators

- CFFDRS
- Buildup Index (BUI)
- FWI
- Initial Spread Index (ISI)
- National Fire Danger Rating System
- Ignition Component (IC)
- SC
- ERC
- AVHRR NDVI RG and DA

Southeast

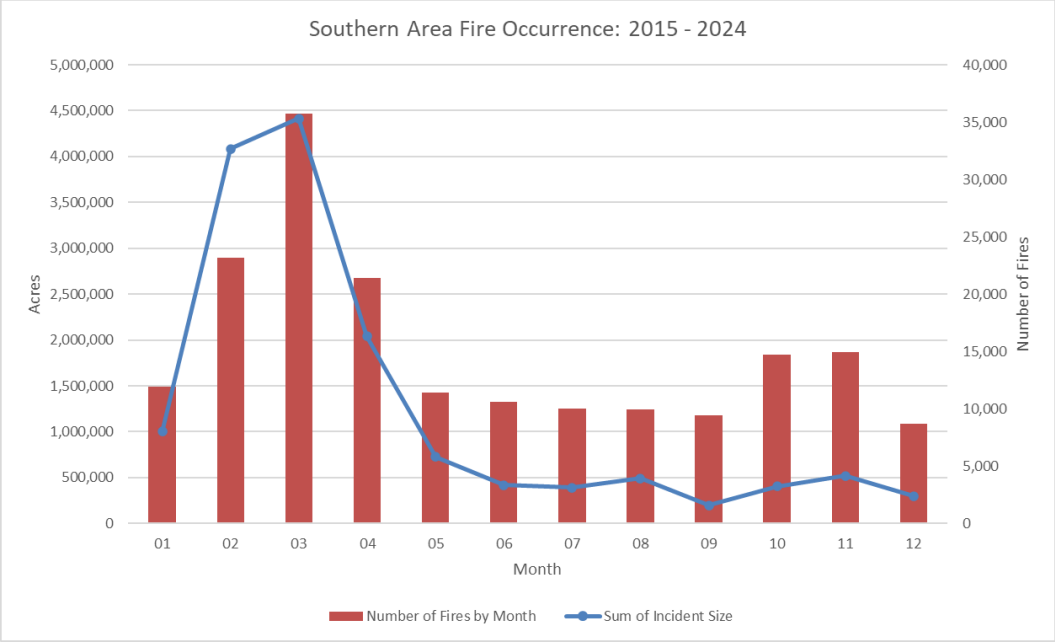
Climatology

- Winter – Generally driest time of year with greatest wind event potential behind passing storms, though widespread precipitation can also occur.
- Spring – Windy/dry potential retreats north, and warm, moist conditions become increasingly dominant.
- Summer – Warm to hot and humid with light winds. Occasional dry spells. Tropical cyclone activity increases late in the season.
- Fall – Very moist initially, then gradual infiltration of dry air. Moist conditions often persist along Gulf Coast.

Fire Activity

- Fire activity maxima in late winter or early spring and fall, coincident with greatest potential for windy/dry conditions behind passing storm systems.
- Dormant fine fuels with low live fuel moisture in winter and spring, leaf-off in fall in northern portion of region.
- Season can extend year-round anytime warm/moist air becomes suppressed south and east.
- Usually there is little activity in summer months, though significant fire activity has historically occurred during unusual dry spells.

Figure 37. Fire occurrence in the southern U.S. region from 2015 to 2024.



Critical Weather Events

- Post Cold Frontal
- Westerly Downslope Wind in the Appalachians and Ozarks

- Sea Breeze
- Tropical Storms
- Bermuda High

Fire-Slowing or Stopping Events

- Closed Low/Cold Frontal Passage
- Stationary Front
- Tropical Storm
- Sea Breeze

Fire Growth Potential Indicators

- ERC
- 100-hour Fuel Moisture
- Keetch-Byram Drought Index (KBDI) is sometimes misused
- SPI
- Crop Moisture Stress Index
- NWS QPE (30 to 60 days)

Hawaii

Climatology

- May occur every year.
- Winter – Windward (NE) and mountain areas. Hurricanes and tropical storms can bring very strong winds and dry air just prior to arrival or as they pass to the south.
- Fall – Transition from dry-to-wet season for most of the state.

Fire Activity

- Fires of significance can and have occurred on every calendar day of the year.
- Lightning ignitions are relatively rare, primarily occurring in dry woodlands on the lee side of the islands.
- Lava ignitions may occur during eruption events on Hawaii Island.

Critical Weather Events

- Foehn or Downslope Wind on Lee Sides of the Islands
- Approaching or Passing Hurricane or Tropical Storm
- Subsidence Inversion

Fire-Slowing or Stopping Events

- Large-scale weather systems such as Kona Lows, cold fronts, strong upper tropospheric lows/troughs, and direct hit or near miss tropical cyclones.

Fire Growth Potential Indicators

- BI
- Live Herbaceous Fuel Moisture
- Drought Monitor

Weather Data Resources

Sources of Digital Weather and Fire Records

Fire Environment Mapping System (FEMS) (https://fems.fs2c.usda.gov/ui?Weather/hourly/temperature/3/topo/0/12120/false/false) provides access to archived hourly and daily fire weather records for NFDRS stations back to 2005 or to the station's installation date. Gaps in historic data had been filled by DRI.

FAMWEB Fire/Weather Data Warehouse (https://www.wildfire.gov/application/famweb-data-warehouse) integrates fire and data from the Fire Statistics (FIRESTAT) system, National Interagency Situation Report (SIT/209), and Annual Wildfire Summary Report (AWSR).

Local Online Resources

These and other locally relevant resources should be considered. Many can be found by asking local fire managers and subject-matter experts. Examples include:

- **Alaska Fire and Fuels** – https://akff.mesowest.org/download/
- **Great Lakes Fire andFuels** – https://glff.mesowest.org/download/
- **OK-FIRE** – https://www.mesonet.org/index.php/okfire/home
- **Southeast Fire Weather Intelligence Portal** – https://products.climate.ncsu.edu/fire///

Creating a FireFamilyPlus Database for Weather Analysis

Consider the following steps when building a FireFamilyPlus database for your analysis area.

- FEMS is the authoritative source for weather and NFDRS information.
- Standardized station catalogs and gap-filled weather data can be downloaded for all RAWS in the U.S.
- Check the FEMS website for current suggested workflows.

Critique and Edit in FireFamilyPlus

FireFamilyPlus, available through the Fire, Fuel, Smoke Science Program (https://www.frames.gov/firelab), is an effective tool to review and edit archived weather records obtained from the resources listed above. After importing data, the following steps can help evaluate the weather record for time span, accuracy, and completeness:

- Evaluate the Active Working Set for the archive to determine if the record covers a sufficient time span (15 or more years) for climatological analysis.
- Evaluate record completeness of the record by evaluating the data count for the archive. Determine whether the station collects year-round data, and if not, identify which portions of the year have the most complete record.
- Evaluate individual data elements for accuracy. Examine basic observations (temperature, RH, wind speed, precipitation, maximum and minimum values) for outliers by sorting records in ascending and descending order to locate erroneous values. Download the historic hourly data in CSV format and review data-element flags to understand the quality of the station. Reference the FEMS QC'd gap-filled period-of-record weather description at https://www.wildfire.gov/node/3473.
- Evaluate data elements and calculated indices by reviewing climatology graphs (e.g., maximum and minimum values) and individual years to identify erroneous trends and outliers.
- Review the wind rose to determine whether wind speed and direction are representative of the fire environment being analyzed.

If edits are necessary, they can be made in the View Observations table. Before modifying any archived observation, compare it to data from surrounding stations. Any changes should be documented by the local fire management agency.

FEMS has many graphical tools that make viewing climatological graphs easy. However, as an analyst, creating graphs for analogous years and understanding the fire history currently requires using FFP.

Fuels

Surface Fuel Model Selection

Each surface fuel model is a selection of numerical inputs used in the Rothermel (1972) surface fire spread equation. Fuel model selection guides are useful, but the final choice must be made by the analyst based on experience with fire behavior in the fuel bed being evaluated.

Two Sets of Surface Fuel Models

This guide integrates the original 13 models with the 40 standard models introduced in 2005. Although the 40 standard models were designed to stand alone, all 53 models are available in current fire modeling systems. While the original 13 models were grouped into only four carrier types, they can be effectively redistributed across the six types defined with the newer models. Consider the objectives that guided the development of these two sets. Even though the newer fuel models have been around for 20 years, some operational people are still more comfortable with the original 13 fuel models.

The original 13 fire behavior fuel models (Anderson, 1982), https://www.fs.usda.gov/rm/pubs_int/int_gtr122.pdf:

- Represent wildfire behavior under peak fire conditions with cured herbaceous fuels.
- Are sensitive to live fuel moisture in only five of the models, with substantial response predominately in fuel models 4 and 5; none are dynamic.
- Were created before crown fire modeling existed, requiring several models (fuel models 4, 6, and 7) to approximate crown fire behavior. See Active Crown Fire Behavior for more information.

On the other hand, the 40 standard fuel models (Scott and Burgan, 2005), https://www.fs.usda.gov/rm/pubs/rmrs_gtr153.pdf:

- Support analyses for fire use and fuel modification treatments.
- Represent green, growing season conditions and cured, peak season conditions.
- Incorporate dynamic fuel load transfer in some of the models, allowing behavior to shift with changing conditions.
- Handle live herbaceous fuel moisture much differently.

The most important benefit of integrating both fuel model sets is that users familiar with the original 13 can transition to the expanded model set, effectively providing a “dual language” guide.

Considerations for choosing a fuel model:

- Identify the primary carriers of surface fire (**Grass/Grass-Shrub, Shrub/Timber Understory, Timber Litter, or Slash/Blowdown**) and consider alternatives.
- Determine whether diurnal changes in fuel moisture conditions bind the burn period each day, excluding much of the evening, overnight, and morning hours? If so, prioritize **Low Moisture of Extinction** fuel models rather than High Moisture of Extinction models. Low Moisture of Extinction is associated with drier climates where fuels do not combust at a relatively low moisture content compared to those in humid environments where fire is supported at higher fuel moistures.
- If a specific fuel bed shows little seasonal influence from green-up or summer conditions,

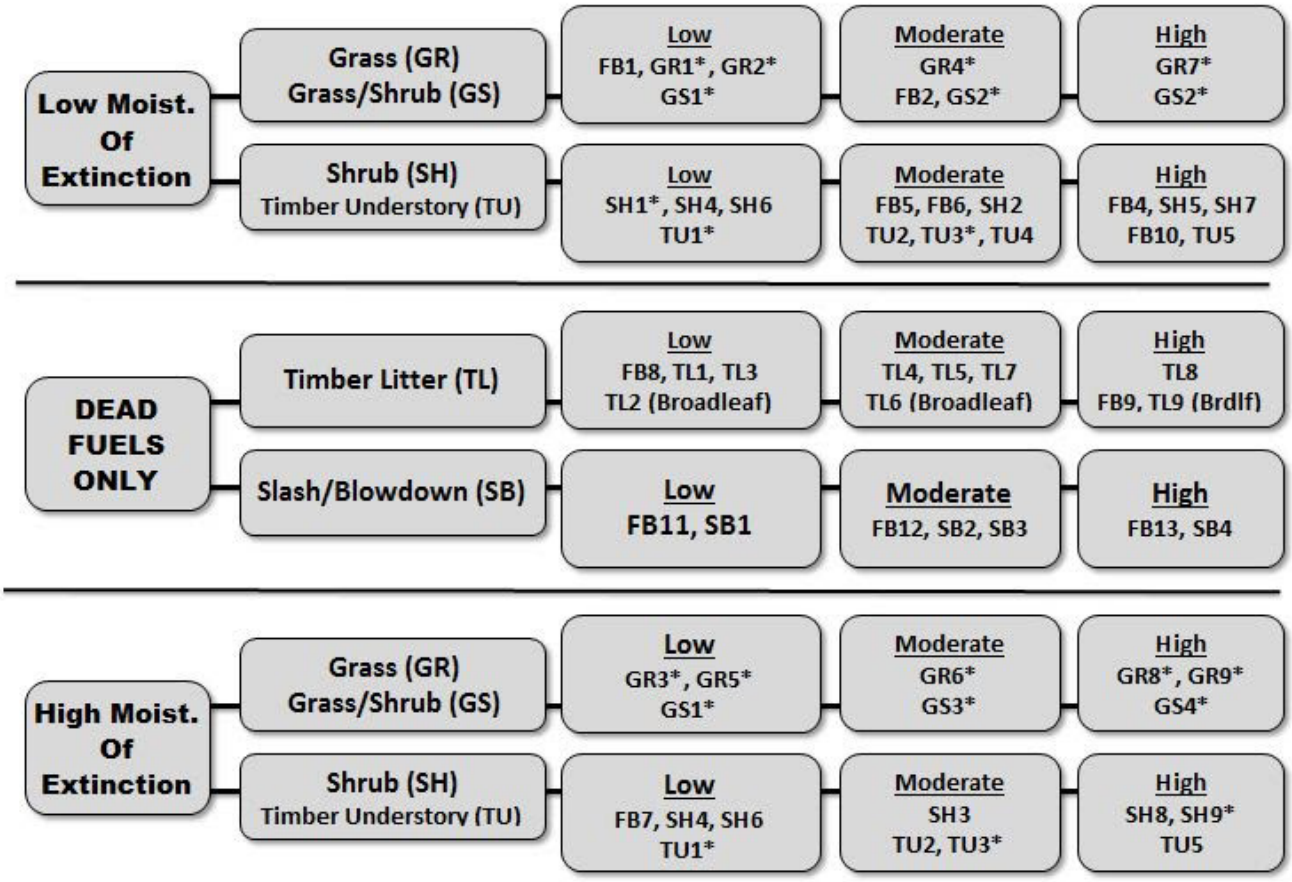
consider **dead fuels only** models during those periods.

- **Dynamic Fuel Models** (marked with an asterisk) allow greater variability due to seasonal transitions in live fuels. They are primarily concentrated among the grass and grass-shrub models due to annual green-up and curing.

Note that SH1, SH9, TU1, and TU3 also include herbaceous fuel loads and are dynamic.

- **Low, Moderate, and High** classifications within each fuel group reflect relative Heat per Unit Area. Use these categories to narrow the range of appropriate fuel models.

Figure 38. Fuel model selection guide. An asterisk * denotes dynamic fuel model with herbaceous fuel load transfer.



Surface Fuel Model Evaluation

After selecting several candidate fuel models, evaluate their fire behavior outputs (rate of spread and flame length) using representative environmental inputs. This is only the initial step in calibration.

Table 12. Fire behavior class table.

Fire Behavior Class	Rate of Spread (chains per hour)	Flame Length (foot)
Very Low	0 to 2	0 to 1
Low	2 to 5	1 to 4
Moderate	5 to 20	4 to 8

Fire Behavior Class	Rate of Spread (chains per hour)	Flame Length (foot)
High	20 to 50	8 to 12
Very High	50 to 150	12 to 25
Extreme	150 or more	25 or more

It may be helpful to compare modeled and observed fire behavior in terms of Fire Behavior Classes, or ranges of flame length and spread rates. If fireline personnel can effectively report observed fire behavior in these terms, differentiating what they see through the burn period and as environmental inputs change, the analysis will be improved dramatically.

Testing the range of a fuel model's characteristic fire behavior requires analysis of several environmental inputs. Behave, a sensitivity tool, can assess only two variables at a time, but daily variation is typically driven by at least three—wind, slope, and fuel moisture. Fortunately, the Rothermel fire spread model incorporates slope as an equivalent wind speed, so representing wind as a range of effective wind speeds generally accounts for slope effects. In some cases, it may still be necessary to analyze slope effect separately. Key inputs for evaluation:

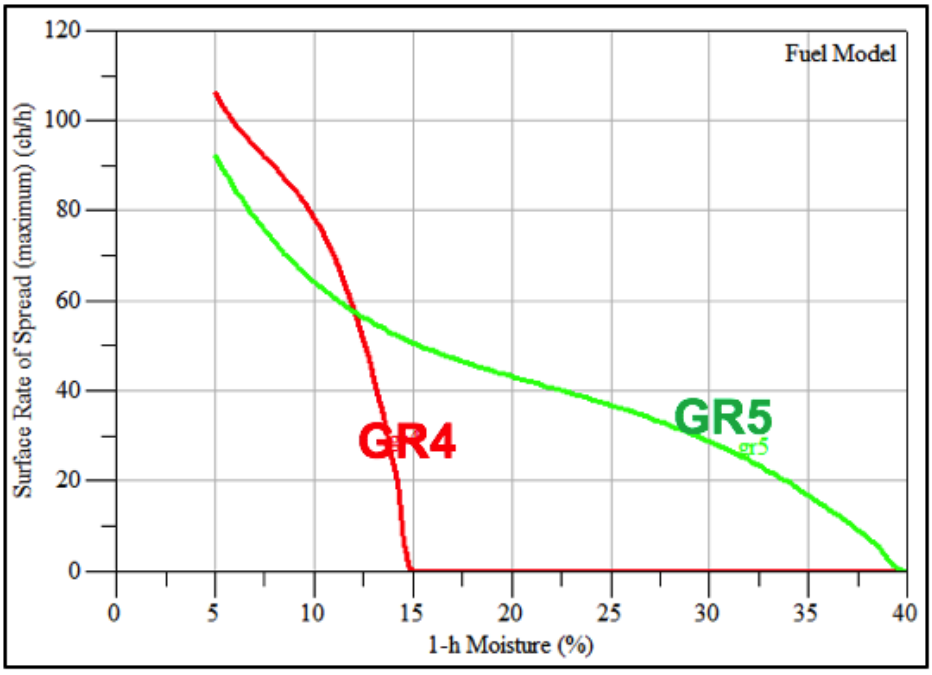
- **1-hour Fine Dead Fuel Moisture & Effective Wind Speed:** Establish a realistic range of midflame wind speeds, then account for slope using slope-equivalent wind speed to create a range of effective wind speeds for calibration. The dominant factors are wind, slope, and fuel moisture.
- **Live Herbaceous Moisture:** For dynamic fuel models, test fire behavior across a range of 30 to 120% live herbaceous moisture while holding other variables at representative levels.
- **Live Woody Moisture:** Critical for grass/shrub, shrub, and timber understory fuel models. Because there is no fuel load transfer in the live woody component, default ranges are characteristic of the current season. Set other environmental inputs at representative levels. Keep in mind that live woody moisture levels change rather slowly in most cases. Depending on the time of year and the drought situation, it may not be necessary to consider a wide range of moistures. However, it is critical that appropriate levels are identified for the analysis.
- **Slope and Spread Direction:** While often a secondary factor, backing and flanking fire behavior related to slope reversals—especially during prescribed fire ignitions—may be important. A slope reversal is when the fire direction and rate of spread (ROS) changes as fire crosses a drainage bottom and is now on a different aspect with potentially different fuels, winds, and moisture.

Moisture of Extinction

One of the first considerations when selecting a fuel model should be whether fuels are expected to burn under high fuel moisture conditions. Though many modeling tools allow the user to limit the burn period regardless of the Moisture of Extinction being reached, humid climate fuel models (with high moisture of extinction) may still produce significant fire behavior at moisture levels where dry climate fuels estimate no fire spread. Truncating the burn period can result in under-projecting fire spread when modeling with humid climate fuel models.

For example, Figure 39 GR4 shows no fire spread at 15% fuel moisture, while GR5 can project spread rates up to 50 chains per hour. Ensure the fuel model selected accurately represents potential fire spread and intensity across the expected range of fuel moistures.

Figure 39. Effect of 1-hour fuel moisture on ROS.



Fuel Model Parameters and Descriptions

Accurate modeling requires a disciplined fuel model selection process. With the addition of 40 fuel models representing six carrier fuel types, users can more easily identify the appropriate fuel model whose parameters reflect the expected range of fire behavior over the range of anticipated environmental conditions.

Key considerations:

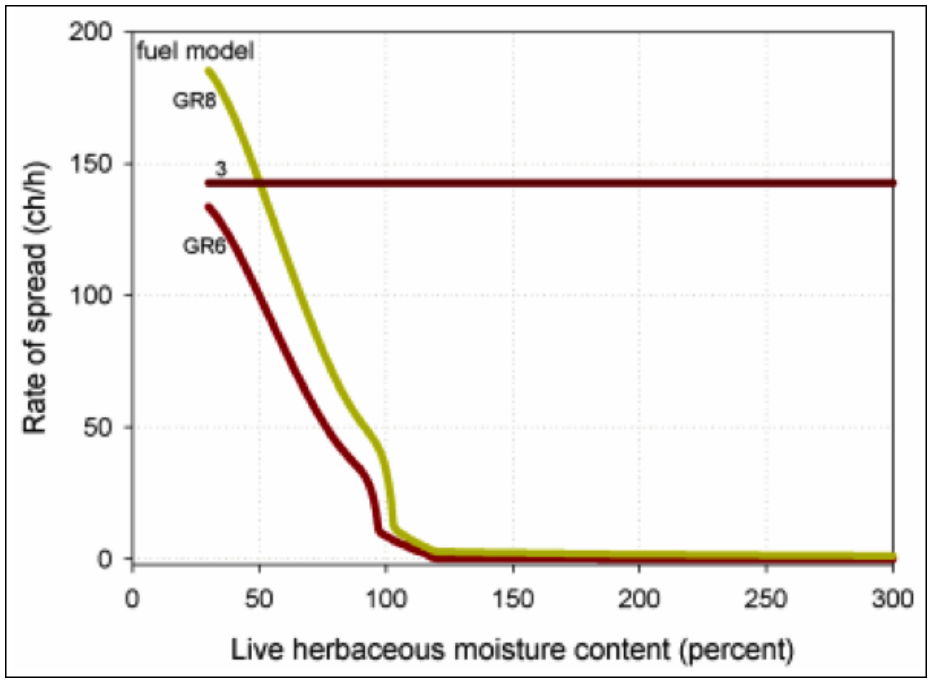
- Identify the primary fuel type (GR, GS, SH, TU, TL, or SB) that is expected to carry fire. Keep in mind there are analogous characteristics that can cross these fuel types. However, if your fuel bed includes a significant canopy layer, a TU or TL model may be more appropriate.
- Determine which fuel categories (1-hour, 10-hour, 100-hour, herbaceous, woody) are likely to burn in the flaming front under anticipated range of environmental conditions. Do one or more of these categories represent the distribution of fuel loads better than another?
- Assess whether the fuel bed is shallow or deep and whether any shrub layers will burn as part of the surface or canopy layer.
- Confirm that the descriptive text of the fuel model matches field observations.

Dynamic and Proportional Fuel Load Transfer

The NFDRS introduced the concept that most herbaceous fuels transition from green to cured conditions over the course of a fire season. As live herbaceous fuel cures, its load transfers into the dead category, redefining the fuel complex with each proportion transferred, making it a critical fuel model characteristic—particularly compared with the static fuel models in the original 13.

Figure 40 shows spread rate for dynamic fuels GR6 and GR8 with the corresponding static FB3 from the original set of 13.

Figure 40. Effect of live herbaceous moisture content on ROS.



In the development of the new set of fuel models, dynamic or proportional fuel load transfer is implemented in all fuel models that include herbaceous loads. This includes all grass, grass/shrub, two shrub (SH1 & SH9), and two-timber understory (TU1 & TU3) models.

Figure 41 and Table 13 depict that the fuel load transfer (implemented in FlamMap, Interagency Fuel Treatment Decision Support System [IFTDSS] and Wildland Fire Decision Support System [WFDSS] Fire Behavior analysis tools) depends on the input Live Herbaceous Moisture Content (LHMC).

- At 120% or greater LHMC, no load transfers.
- At 30% or lower LHMC, the entire herbaceous load transfers to the dead herbaceous fuel category and is assigned 1-hour moisture content.
- Between 30% and 120% curing, a proportional amount of herbaceous live fuel transitions into dead fuel and is assigned the 1-hour moisture content.
- The input LHMC that represents a particular portion of the load transferred from live to dead is shown in the table. It can be calculated using this equation and an assumed curing percentage: Input LHMC = 120 - (90 x fraction cured).

Figure 41. Concept of fuel load transfer.

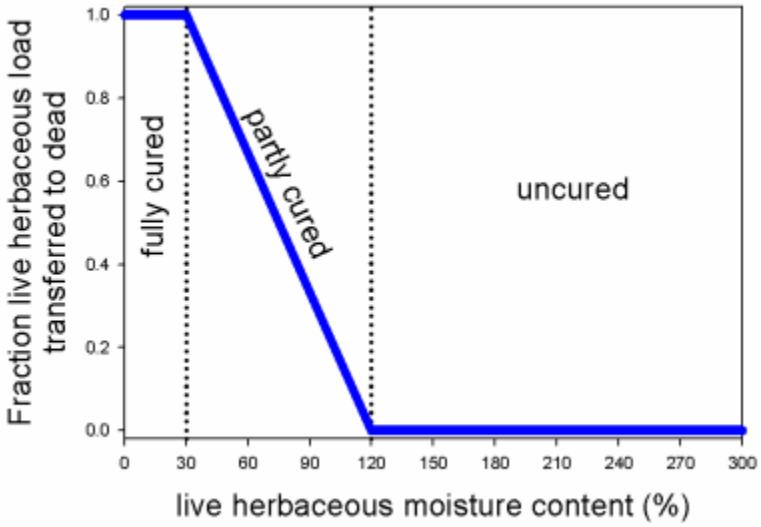


Table 13. Live fuel moisture estimates.

LHMC Value (to input into fire model) (%)	Observed Level of Curing (fuel load transferred)	Curing Classification
120 or more	0/1 cured	Uncured
98	1/4 cured	One-quarter cured
90	1/3 cured	One-third cured
75	1/2 cured	One-half cured
60	2/3 cured	Two-thirds cured
53	3/4 cured	Three-quarters cured
30 or less	1/1 cured	Fully cured

Important cautions:

Between 90% and 100% input LHMC, very rapid changes in fire behavior outputs can occur. Be sure to test the sensitivity to this input.

Though it is agreed that live fuels can provide a critical influence on fire behavior, serving as both the heat sink and heat source in varying combinations, the mechanisms are not well modeled or understood.

Because curing and LHMC are not necessarily correlated, Behave allows users to input curing percentage separate from LHMC.

Surface Fuel Model Descriptions

For a complete list of fuel model characteristics, reference https://www.fs.usda.gov/rm/pubs_series/rmrs/gtr/rmrs_gtr153.pdf.

Landscape Acquisition, Critique, and Editing

A Landscape file (LCP) is a file that represents surface fuel, canopy, and topographic characteristics and is used as an input in fire modeling applications.

Landscape File Data Sources

- **LANDFIRE Data Distribution Site –** https://www.landfire.gov/viewer/
  Several versions of LANDFIRE data are available, including LCP files (2001, 2016, 2020, 2022, 2023, and 2024, older versions have been archived). The Version Comparison Table (https://www.landfire.gov/data/comparison-table) outlines what is included in each release. LANDFIRE does not provide an online tool for editing files before download. Files can be downloaded in either the U.S. Albers projection or the local Universal Transverse Mercator (UTM) zone.
- **FlamMap** – https://research.fs.usda.gov/firelab/products/dataandtools/flammap
  FlamMap includes a "Get Landscape" tool to retrieve LCP files from LANDFIRE. Users can also edit LANDFIRE landscapes with FlamMap and save them as new files.
- **WFDSS** – https://wfdss.firenet.gov/help/Content/Home.htm
  WFDSS analysis tools include downloadable LCP files obtained from LANDFIRE. Users may edit the LCP files before download. Downloaded files come with a custom Albers projection that may require some reprojection before combining with shapefiles in FlamMap analysis.
- **IFTDSS** – https://iftdss.firenet.gov/iftdss2/#/landing
  IFTDSS allows users to generate LCPs from LANDFIRE data, edit them, and download them for use in other applications. Like WFDSS, downloaded LCPs use a custom Albers projection that may require some reprojection before combining with FlamMap shapefiles. IFTDSS also allows users to upload LCPs generated in other applications for use in modeling.

Other Data Sources

- Wildland Fire/Treatment History
  - Burn severity layers
  - Fire progression layers
  - Fuel treatments
  - Prescribed fire perimeters
  - Wildfire perimeters
- Ecological Considerations
  - Areas of critical environmental concern
  - Sensitive or critical wildlife habitat
  - Threatened, endangered, and sensitive (TES) flora and fauna habitat
  - Rivers and streams
  - Water bodies
  - Vegetation or cover-type classification

- Socio-Economic Considerations
  - Ownership and jurisdiction layer
  - Historical and recreational sites
  - Primary and secondary residences
  - RAWS
  - Roads and Trails
  - Urban development
- Other Base Layers
  - Aerial photos
  - Digital orthophoto quad (DOQ) or quarter quad (DOQQ)
  - Digital Raster Graph (DRG)

Landscape File Fuel Themes

Values in LCPs must be in integers to work in fire modeling programs. This is why many of these units must be converted to obtain the actual value. Canopy themes all relate to a forest canopy that affects midflame wind speed, spotting, and crown fire potential. Additional themes are needed to complete an LCP (slope, aspect, elevation).

Values in LCPs must be stored as integers for use in fire modeling programs. As a result, many units are scaled and must be converted to obtain their actual values. Canopy-related themes represent forest canopy characteristics that influence mid-flame wind speed, spotting potential, and crown fire behavior. Additional themes—such as slope, aspect, and elevation—are required to complete an LCP.

- **Surface Fuel Model** – Selected from 13 original Fuel Models (Anderson, 1982) or 40 Standard Fuel Models (Scott and Burgan, 2005).
- **Canopy Cover (CC)** – Expressed as a percentage, 0 to 100. In most conifer fuel types, practical Maximum canopy cover is about 70%.
- **Canopy Height (CH or SH)** – Stored in units of meters multiplied by 10. To calculate actual height in meters, divide by 10.
- **Canopy Base Height (CBH)** – Stored in units of meters multiplied by 10. To calculate actual height in meters, divide by 10.
- **Canopy Bulk Density** – Stored in units of kilograms per cubic meter multiplied by 100. To calculate, actual canopy bulk density, divide by 100.

Nomenclature for Spatial Data Layers

Fuel Model Numbers

Table 14. Fuel model numbering outline.

Fuel Type	Fuel Model Bloc	Pre-Defined	Reserved for Future Pre-defined Models	Available for Custom Fuel Models
FB	01 to 13	01 to 13	N/A	N/A
Custom	14 to 89	N/A	N/A	14 to 89
NB	90 to 99	91 to 93, 98, 99	94, 95	90, 96, 97
GR	100 to 119	101 to 109	110 to 112	100, 113 to 119
GS	120 to 139	121 to 124	125 to 130	120, 131 to 139
SH	140 to 159	141 to 149	150 to 152	140, 153 to 159
TU	160 to 179	161 to 165	166 to 170	160, 171 to 179
TL	180 to 199	181 to 189	190 to 192	180, 193 to 199
SB	200 to 219	201 to 204	205 to 210	200, 211 to 219
Custom	220 to 256	N/A	N/A	220 to 256

LCP Critique

The LCP Critique report is an essential element in the calibration process. LCPs can be critiqued in several different applications. FlamMap desktop can critique an LCP and generate a PDF or HTML report. IFTDSS can run a landscape report for review within the application, with options to save tables, images, or PDFs. A stand-alone **LCP Critique** tool is also available at https://www.frames.gov/catalog/11606.

On the first page of the LCP Critique:

- View the filename, latitude, cell resolution, and coordinate system in the header information to ensure the correct file is being evaluated.
- View the theme units, ranges, and value distributions to ensure the LCP is valid and contains no corrupted data.
- Determine the dominant surface fuel models in the LCP.

For example, this histogram (Figure 42) shows that fuel models 162, 142, 165, and 122 are the primary surface fuels. Are these the models what you expect? What are the critical inputs for each of these fuel models? Are any dynamic? Do any have a Moisture of Extinction that differs from the climate where you are modeling?

Figure 42. LCP fuel model critique.

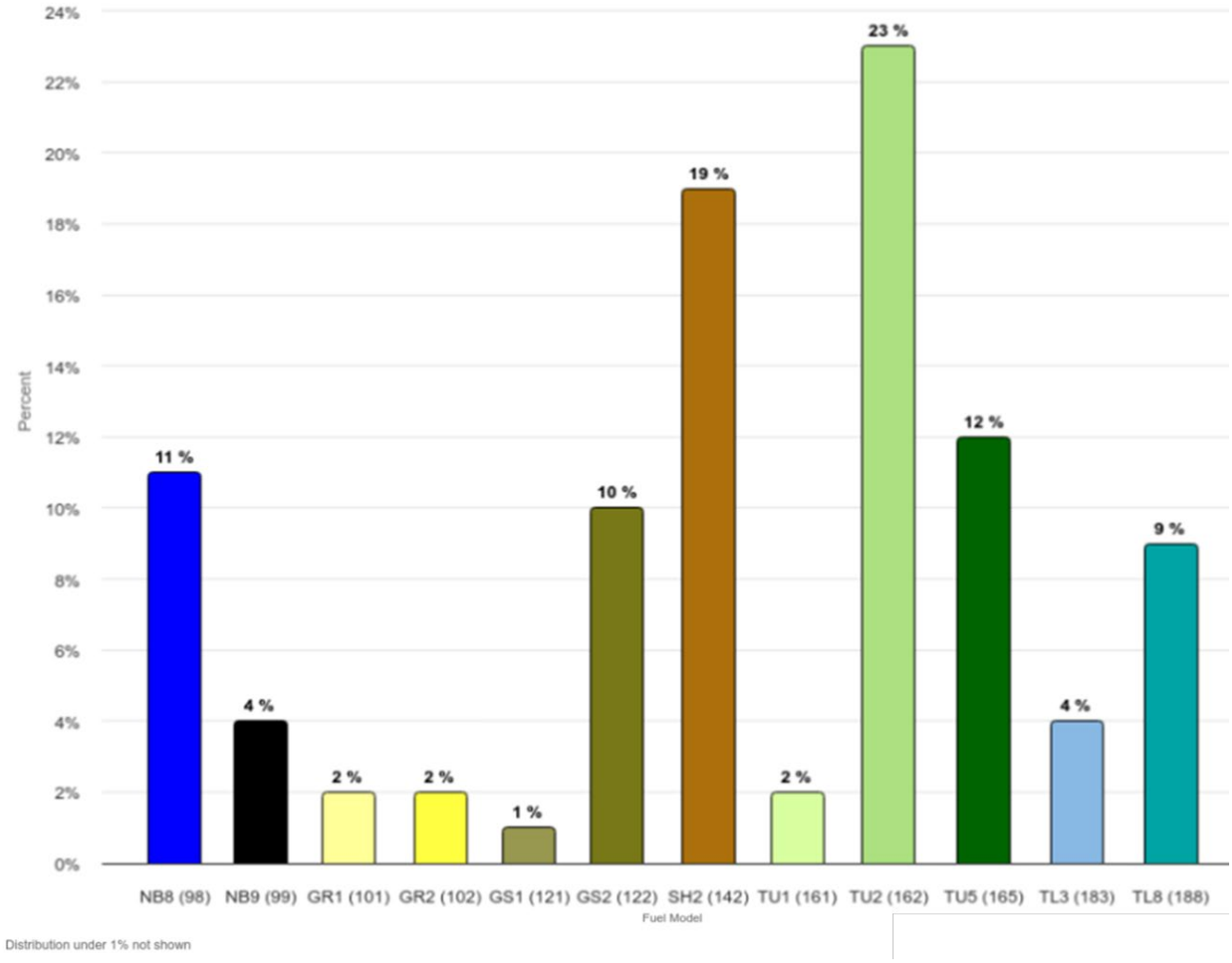


Image and Legend Pages for Each Theme

Theme images can help identify visual data issues (e.g., vertical and horizontal lines in slope themes). Fuel model themes should be compared to areas where ground verification or high confidence classifications exist.

Theme Distributions for each Surface Fuel Models, in order of importance:

- Terrain variables: Evaluate the terrain theme ranges and distributions for elevation, slope, and aspect. Determine whether these values are appropriate for the mapped fuel models. Consider whether fuel models should be adjusted in certain terrain value combinations.
- Canopy characteristics: Assess canopy cover (affects wind adjustment and fuel shading), tree heights (affects wind adjustment and spotting distance), and canopy base height (crown fire initiation). Ensure the distributions make sense for the specific fuel model.
- Canopy bulk density: This affects active crown fire propagation. Values must align with fuel-model characteristics, canopy-tree species, and the crown fire propagation model used surface fire control per Finney versus crown fire control per Scott & Reinhardt. See Crown Fire Initiation and Propagation section for more information.

Editing and Updating the LCP File

Edits may be needed to fix errors or to better model observed and expected fire behavior as part of the model-calibration process. Any errors or necessary adjustments identified during critique should be included in landscape edits before running the initial analyses. Tools for editing LCP files include:

- WFDSS Analysis Edit Landscape
- IFTDSS Landscape Editor
- FlamMap Landscape Editor
- ESRI Raster Editing Tools

Always document any edits made to the standard downloaded LCP.

Topography

Topography significantly influences fire behavior by altering fuel conditions, wind patterns, and heat transfer. These factors affect fire spread and intensity. Understanding these factors is essential for predicting fire movement and planning effective suppression strategies.

Slope

Fires spread more rapidly uphill because rising heat preheating fuels ahead of the flaming front. Steeper slopes accelerate this effect, and narrow drainages magnify this effect even more. Fire position on the slope matters; even on a constant slope, fires spread faster at the top of the slope than at the bottom of the slope, a phenomenon known as fire acceleration, making fire behavior prediction on slopes more difficult.

A fire starting at the top of a slope cannot readily take advantage of the steepness except when burning debris rolls downhill and ignites fire below. Slope reversals, such as when a fire crosses a drainage and transitions from a backing fire to a head fire, can pose threats to firefighter safety. Strong upslope fires that burn to the top of a ridgeline can roll over the ridge with high intensity, creating lee-side vortices where fire quickly burns back upslope or laterally (Finney et al. 2021). There is much to learn and study regarding weather and fire behavior in complex terrain, and fire behavior practitioners are encouraged to study more in publications specifically written for fire managers and fire behavior specialists (Werth et al. 2016, Vol. 1 & 2).

Downslope winds often develop as the sun sets as slopes become shaded. These winds are shallow and typically weaker but can become significantly stronger and long-duration when combined over a larger valley extent.

Inversions are common in mountainous terrain. As cold air drains into valleys, fire behavior may be suppressed at low elevations while higher terrain remains warmer with lower humidities to support active nighttime fire behavior. Aircraft may be grounded if an inversion significantly affects visibility. When inversions break, a significant increase in fire behavior can occur. Anticipate inversions and adjust fire behavior predictions, strategies, tactics, and safety procedures accordingly.

Aspect

South- and west-facing slopes in the northern hemisphere receive more sunlight. This can dry the fuels, increasing fire intensity and increasing ignition likelihood. Conversely, a very dry south aspect may have such sparse fuel that fire does not readily spread, and the more vegetated north aspects may have sufficient fuel to exhibit intense fire behavior.

Elevation

Lower elevations are generally warmer and drier and may support dry, flashy fuels that promote faster fire spread. Although higher elevations may slow fires due to cooler, moist conditions certain times of the year, they can also support heavier fuel loads that burn with more intensity and have higher resistance to control. The effects of elevation on fire behavior change throughout fire season and vary by latitude.

Landforms

Landforms, such as canyons, ridges, and valleys, can channel winds, funnel flames, and promote long-range spotting, leading to erratic fire behavior and rapid spread. More complex terrain, with more

vertical relief and diverse aspects over a large area, creates significant challenges for fire behavior prediction. Each combination of slope, aspect, fuel type, and wind pattern will result in different fire behavior and presents challenges in predicting fire behavior characteristics.

Fuel Moisture

Fuel moistures, for both live and dead fuels, can be determined through three primary methods: direct observation, physical sampling, and predictive modeling. Observed fuel moistures involve visual assessment by experienced personnel. These observations provide immediate, qualitative data useful for rapid initial assessments, though they can be subjective and lack precision. Sampling fuel moistures involves collecting fuel materials, weighing them, and drying them to determine their water content. This method provides highly accurate quantitative data but is labor-intensive, time-consuming, and represents only a single point in time that may not reflect conditions across a broader area. Modeled fuel moistures use meteorological data and other environmental factors to estimate moisture levels. These models offer continuous, spatially extensive estimates, which can be particularly valuable for long-term planning and real-time fire management decisions, but their accuracy depends on the quality of input data and the sophistication of the model and may not capture localized anomalies.

Dead Fuel Moisture Content

Nelson Model 1- and 10-hour Fuel Moisture Estimation Methods

Ralph M. Nelson (2000) developed a fuel moisture model for estimating the diurnal fuel moisture changes in a 10-hour NFDRS fuel stick. The model uses hourly weather observations to produce dynamic estimates that reflect changes in precipitation, humidity, and sunshine better than the Fosberg model. The NFDRS uses Nelson's methodology, and these are the fuel moistures displayed in FEMS. The Nelson model is not typically calculated in the field.

Fosberg Model 1-hour Fuel Moisture Estimation Methods

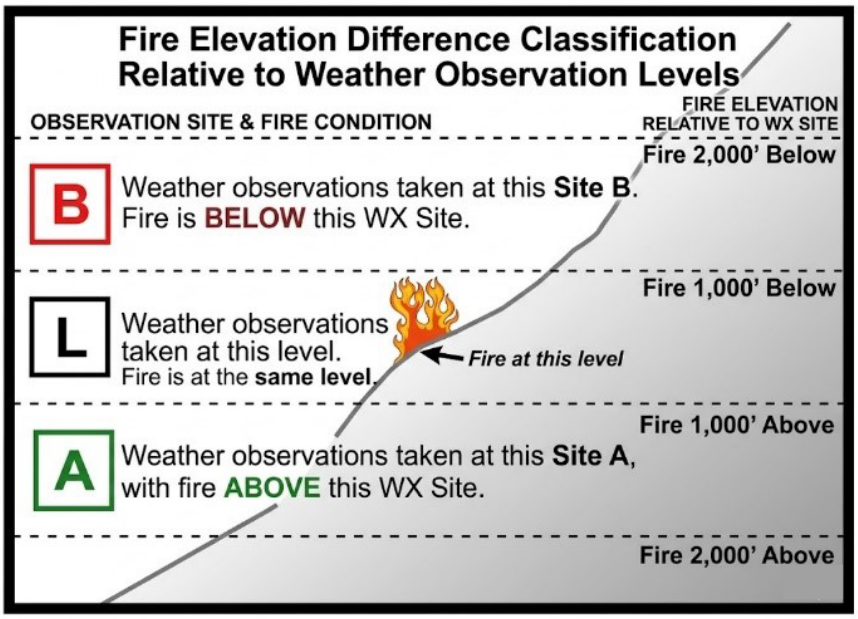
Michael A. Fosberg and John E. Deeming (1971) documented procedures for estimating 1 and 10-hour Time-Lag Fuel Moistures. Their method, along with seasonal adjustment tables, was integrated into Richard Rothermel's (1983) field tools and methods for predicting surface fire behavior.

<u>Daytime Estimation Procedure</u>

- Use Table A to determine the Reference Fuel Moisture (RFM). Record the RFM value from the intersection of temperature and RH.
- Next, select the appropriate foliar moisture content chart for the current month (Table B, C, or D) to adjust the RFM for local conditions.
- If the fine fuels are more than 50% shaded by canopies and clouds, use bottom shade portion of table. If not, use top exposed portion of table.
- Determine the appropriate row based on aspect and slope.
- Determine the appropriate column based on time of day and elevation of the location of interest as compared to the weather site elevation. Use the (A)bove column if the fire is 1 to 2,000 feet above your location, (B)elow if the fire is 1 to 2,000 feet below you, and (L)evel if the fire is within 1,000 feet above or below you (Figure 43).
- Obtain the 1-hour Moisture Content Correction (%) from the intersection of row and column.

- Add the Moisture Content Correction (%) to the RFM (%) to determine the 1-hour.

Figure 43. Topographical effect on fire dead fuel moisture.



Nighttime Estimates of 1-hour Fuel Moisture

Published RFM and Correction Tables for Nighttime Conditions are not included here per recommendations from Pat Andrews at the Missoula Fire Lab. She recommends:

- Estimate Dry Bulb Temperature and RH for the location of interest.
- Use Table A to estimate the RFM.
- Use the appropriate 1-hour Fuel Moisture Correction Tables B, C, or D based on the time of the year.
- Obtain the correction for 0800, shaded conditions, and appropriate aspect from that table, add this correction to the RFM to estimate nighttime 1-hour fuel moisture.

Table A. RFM.

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

Table B. 1-hour FMC for the months of May, June, and 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

Table C. 1-hour FMC for the months of February, March, and April and August, September, and October.

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

Table D. 1-hour FMC for the months of November, December, and January.

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

10-hour, 100-hour, and 1000-hour Fuel Moisture Content

Estimates for 10-hour and 100-hour fuel moisture can be developed in the following ways and applied alongside the Fosberg fuel moisture values in surface fire-behavior predictions. In most cases, 1000-hour fuel moisture is not needed for fire behavior calculations.

- After estimating 1-hour fuel moisture, approximate 10-hour and 100-hour fuel moisture content by adding incremental amounts (e.g. adding 1 to 2% for 10-hour and 2 to 4% for 100-hour).
- Use observations from a local RAWS or the Geographic Area's Predictive Service summaries.
- Check FEMS, https://fems.fs2c.usda.gov/, for nearby sampling locations that provide estimated fuel moisture values.

In NFDRS, if danger rating calculations are suspended in the dormant season, default dormant-fuel moistures are provided when calculations resume in the spring. Default values for 100-hour (10 to 25%) and 1000-hour (15 to 30%) fuel moistures are based on the climate class designation for the location.

It is important to note that the NFDRS, as implemented in FEMS, calculates dead fuel moisture using the Nelson model. It is not appropriate to use these values directly in fire modeling systems, which are designed to use Fosberg-based estimates or field-measured sampling data. However, FEMS does have a section where local units report field-measured samples.

When using fuel moisture data for fire behavior modeling, always check that values correctly correlate to current conditions.

Fuel Moisture: Probability of Ignition

Based on concepts developed by Schroeder (1969) and adapted by Andrews (1989), probability of ignition can be estimated from Figure 44 using:

- Current temperature

- Shading from either forest canopy or cloud cover
- 1-hour fuel moisture content

Figure 44. 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

Live Fuel Moisture Content

Concepts and Methods

Live fuel moisture describes the moisture in living plants and is categorized into herbaceous fuels (herbs and grasses) or woody fuels (shrubs and trees). Use Table 15 to assign appropriate live fuel moisture estimates and to interpret status of live fuels in the field.

With the introduction of the Scott and Burgan 40 standard fuel models, herbaceous fuel moisture (HFM) is emphasized for fuel models that include herbaceous components. Importantly, HFM values below 120% indicate a dynamic transfer of herbaceous fuel load into the dead fuel category with lower fuel moisture. In contrast, the original 13 fuel models are intended for peak-season conditions and assume herbaceous fuels are cured and included as dead fuel.

In NFDRS, live fuel moisture is estimated using the GSI, a weather-based index representing plant development. GSI identifies when green-up begins, how fast it progresses, the maximum live fuel moisture, transition curing, and periods of freeze/frozen dormant conditions.

Table 15. Live fuel moisture content descriptions.

Live Moisture Content (%)	Herbaceous Conditions
Greater than 150 to 300	Maturing foliage is still developing. Fresh foliage fully expanded, vigorously growing. Early in growing cycle.
Greater than 120 to 150	Mature foliage, new growth complete, and comparable to older perennial foliage. Shrubs and grasses resist spread.
Greater than 100 to 120	Mature foliage, new growth complete, and comparable to older perennial foliage. Flammable shrubs should burn. Grasses resist spread.
Greater than 80 to 100	Green color pales. Grass becomes less resistant to spread.
Greater than 50 to 80	Significant yellowing and curing. Live fuels contribute to spread.
Greater than 30 to 50	Mostly to completely cured, treated as dead fuels.

Growing Season Index (GSI)

- The GSI (Jolly et al., 2005) quantifies environmental limits on plant physiological processes, particularly photosynthesis. It is highly correlated with seasonal changes in both the amount and activity of plant canopies, green-up predictions, senescence of live fuels, and the influence of water stress events on vegetation. The GSI integrates temperature, water, and light as the environmental drivers that regulate plant function. Minimum temperature: Low temperatures restrict biochemical plant processes, largely by reducing water uptake in cold soils. Plant phenology is often more closely linked to soil-temperature constraints than to ambient air temperature. Many field studies show variable ecosystem responses over a range of minimum temperatures.

- VPD: High VPD increases atmospheric demand for moisture, causing water stress. Plants respond by closing stomata (partially or completely), reducing leaf development rate, inducing the shedding of leaves, and slowing or halting cell division. Although models are available to calculate soil water balance, they require knowledge of rooting depth, soil texture, latent heat losses, and precipitation. As a surrogate, VPD of the atmosphere provides an index of the evaporative demand without detailed modeling.
- Photoperiod (or day length): Photoperiod provides a plant with a reliable annual climatic cue because it is consistent year-to-year at any location. Photoperiod sets the overall seasonal framework within which other climatic controls may dictate foliar development. Studies have shown that photo period is important to both leaf flush and leaf senescence throughout the world.

More information on GSI can be found in FEMS: https://www.wildfire.gov/application/fems.

Foliar Moisture Content (FMC)

FMC is the moisture content of the conifer needles in tree crowns. It is used along with surface fire intensity and crown-base height as input to the crown fire initiation model. FMC is typically measured using only mature, one-year-old or older conifer needles to reflect flammability of these crown fuels. Depending on the application, FMC may be set to a standard value (commonly 100%) or adjusted within a range of roughly 30 to 300%.

Figure 45. Moisture content for new and old foliage for subalpine fir (Abies lasiocarpa) (Agee et al., 2002).

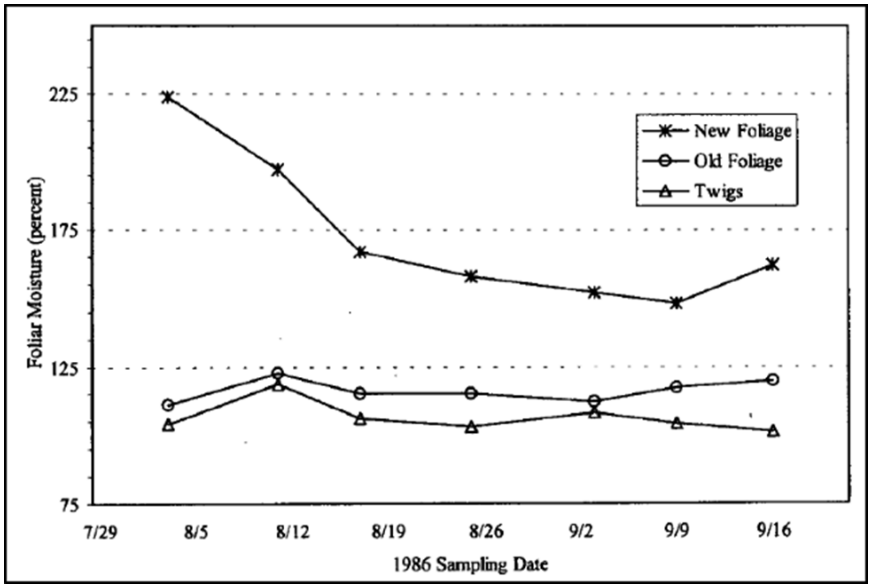
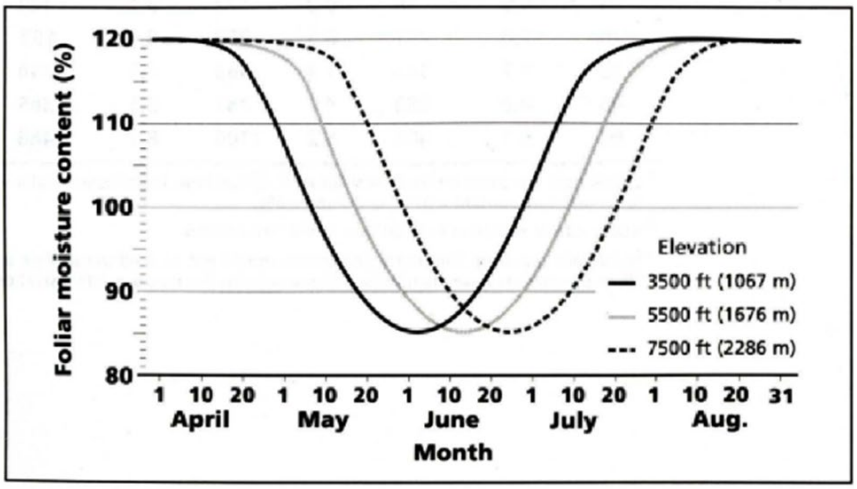


Figure 46. FMC for northern conifers from April to August (Hirsch 1996; Jolly et al., 2014).



Vegetative Greenness

The U.S. Geological Survey Fire Danger site, https://firedanger.cr.usgs.gov/viewer/index.html, provides a comprehensive source of satellite-derived images, data archives, and methods for handling. Weekly images, available since 2017, offer a historical record of vegetation phenology useful for assessing current vegetation greenness conditions. These data can be cross-referenced with drought assessments and other characterizations of plant development, moisture stress, and curing.

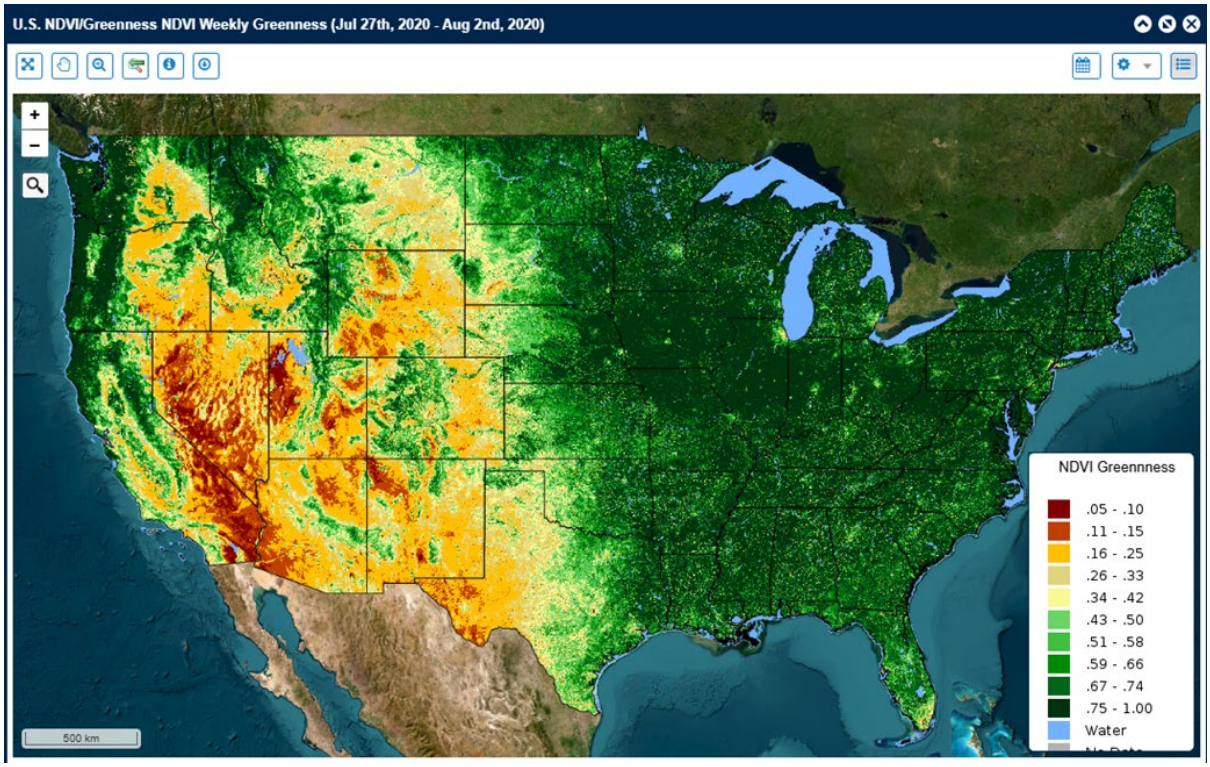
Note that cloud cover can have a significant impact on image quality in portions of the image.

Although not a direct estimate of live fuel moisture, the spatial distribution of Normalized Difference Vegetation Index (NDVI or ND) estimates and its climatological derivatives can provide important insight into past and current vegetative state and overall landscape flammability during the growing season.

Two products are available to evaluate the current NDVI status:

- Normalized Difference Vegetation Index (ND): The raw, current NDVI value from which all the other climatological depictions are derived.
- Relative Greenness (RG): Indicates how green the current vegetation is compared to its historical reference period (1989 to last year). Because each pixel is normalized to its own historical range, both dry and wet ecosystems can appear fully green at some time during the growing season.

Figure 47. Normalized Difference Vegetation Index from July 27 to August 2, 2020.



Fuel Moisture Sampling

1. Online Fuel Moisture Sampling History
2. Fuel Moisture Sampling Procedures

Online Fuel Moisture Sampling History

Consistent fuel moisture sampling throughout the fire season can provide useful insight to current conditions. Sampling results from across the United States are archived in FEMS, where users can view historical records for both live and dead fuel moistures at many locations.

Fuel Moisture Sampling Procedures

General Guidelines

- Record site name, date, time, observer name, observed weather, and a general site description.
- DO NOT collect samples if water droplets or dew are present.
- Keep samples cool and dry.
- Seal containers with non-residue tape.

Live Fuel Samples

- Collect only foliage, needles, and very small twigs; remove flowers, seeds, nuts, and berries.
- Pack containers loosely to avoid spillage but ensure container is full.
- Include stems when sampling herbaceous plants.

- Replace container lids immediately after collecting sample.

Dead Fuel Samples

- Do not collect material still attached to live trees or shrubs.
- Avoid decayed samples that crumble or splinter when rubbed.
- Collect samples from several different plants.
- Ensure containers are full or contain about 20 grams of material.
- Do not collect buried samples.
- Gather a range of sample sizes within the time-lag class.
- Avoid recently fallen material.
- Remove all lichen, moss, and very loose bark from samples.

Duff and Soil Samples

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

Litter Samples

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

Handling and Measuring Samples

- Preheat drying oven between 60°C (140°F) to 100°C (212°F). Record the temperature used.
- Weigh sealed sample containers and record wet weights.
- Remove lids just prior to placing samples in oven. If material is lost, re-weigh sample.
- Dry sample for 24 hours (very wet samples for 48 hours).
- Replace lids immediately after removing samples from oven and record dry weights.
- Calculate fuel moisture using the provided worksheet provided (Figure 48).

Figure 48. Fuel moisture calculation.

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

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

NASA Short-term Prediction Research and Transition (SPoRT) Land Information System

The NASA SPoRT Center has developed a Real-Time Land Information System (LIS), https://weather.ndc.nasa.gov/sport/case_studies/lis_CONUS.html, using satellite-derived datasets, ground-based observations, and model reanalysis to inform land surface influences in weather modeling.

The link above allows you to select data by date and product, but for near real-time observations, this SPoRT Viewer, https://weather.ndc.nasa.gov/sport/viewer, may be easier to navigate and explore.

Products are updated daily and include:

- Volumetric Soil Moisture represents actual moisture in a soil column.
- Relative Soil Moisture represents the soil moisture for a given soil column on a relative scale between soil saturation and wilting levels.
- Column-Integrated Relative Soil Moisture combines for column depths down to 200cm.
- Green Vegetation Fraction-current and trends from the Visible Infrared Imaging Radiometer Suite (VIIRS).
- Land surface temperature and Heat Flux.

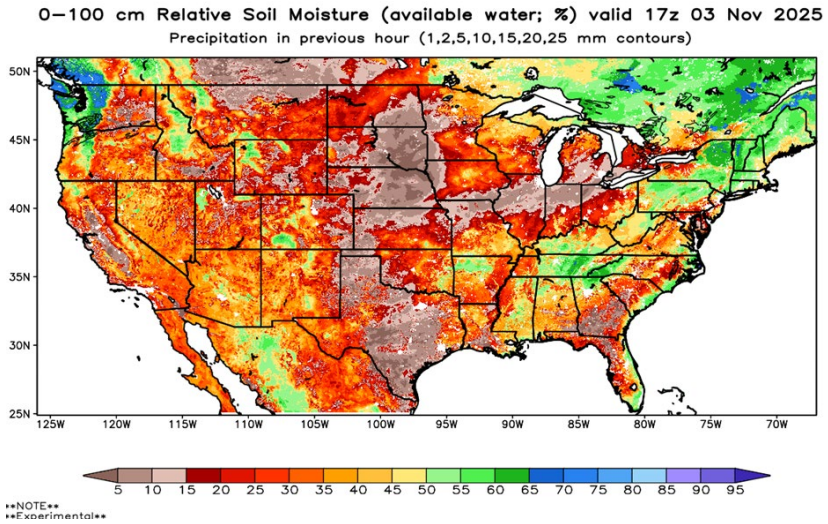
Soil Moisture products evaluate conditions for five depths ranges:

- 0 to 10 cm – Relates most directly to the FWI DMC
- 10 to 40 cm – Relates most directly to the FWI DC
- 40 to 100 cm
- 100 to 200 cm
- 0 to 200 cm Integrated Column

Available at 3 km resolutions for the CONUS, analysts should consider using the following:

- Column-Integrated Relative Soil Moisture products to assess current drought levels and changes over 1-week, 2-weeks, 1-month, 3-months, 6-months, and 1-year.
- Green Vegetation Fraction products that are updated daily in lieu of NDVI which are updated only weekly. Current conditions are augmented by 1-month, 2-month, 3-month, 4-month, and 1-year change products.
- Relative Soil Moisture products that may be correlated to fuel moisture contents applied in fire effects and fire spread models. A 0 to 10 cm, 1-day change product provides an assessment of rainfall effects on the top-soil layer that relates to fuel moisture in carrier fuels.

Figure 49. Example of a relative soil moisture map.



Mapping

Map and Field Measurements

Map Scale and Map Distance

Map scale is printed in the map legend and shows ratio of inches on the map corresponding to inches, feet, or miles on the ground. For example, a map scale 1:24,000 (in./in.) means every 1 inch on the map equals 24,000 inches on the ground. Ground distances are typically expressed in feet or miles.

Table 16. Table of common map scale conversions.

Scale	Representative Fraction	Map (inches per mile)	Map (inches per chain)	Feet per Map Inch
1:253,440	253.44	0.25	0.0031	21,120
1:126,720	126A.72	0.50	0.0063	10,560
1:63,360	63.36	1	0.0125	5,280
1:62,500	62.50	1.01	0.0127	5,188
1:31,680	31.68	2	0.025	2,640
1:24,000	24	2.64	0.033	2,000
1:21,120	21.12	3	0.0375	1,760
1:15,840	15.84	4	0.05	1,320
1:7,920	7.92	8	0.1	660

Slope Estimation

Slope describes terrain steepness. It is easier to calculate slope in percent using a topographic map. Draw a line perpendicular to contour lines between two points. Determine the vertical elevation change (feet) and horizontal distance (feet). Then calculate slope using:

$$\text{Percent Slope} = (\text{Vertical Rise} / \text{Horizontal Run}) \times 100.$$

If you have a compass with a clinometer, you can measure slope angle in degrees by setting the compass to east and holding it parallel to the slope. Then with the compass open less than 90 degrees, look up or down the slope to a point at head-height and read the clinometer in the mirror.

Table 17. Conversion from degrees of slope to percent slope.

Slope (°)	Slope (%)
10	17.6
20	36.4
30	57.7
40	83.9
45°	100
50	119.2
60	173.2
70	274.7
80	567.1
90	∞

Firefighter Math Slope Percent and Slope Angle

For exact degree (°) to percent (%) conversion a scientific calculator is needed.

1. Enter the slope in degrees. Ensure your calculator is in degrees and not radians.
2. Press the Tangent button.
3. Multiply the result by 100 to get slope in percent.

Unit Conversions

Online tools and downloadable applications are available to convert units for distance, temperature, area, volume, weight, time, energy and more. The Firefighter Math Conversions page, https://www.nwcg.gov/course/ffm/conversions/20-conversions-introduction, provides several tables and conversion factors. Additionally, Table 18 provides conversions for a variety of measurements.

Table 18. Measurement conversion table.

Metric Unit	Multiply By	English Unit	Multiply By	Metric Unit
Meters per minute	3.28084	Feet per minute	0.3048	Meters per minute
Meters per minute	2.982582	Chains per hour	0.33528	Meters per minute
Meters per minute	0.03728	Miles per hour	26.8224	Meters per minute
Kilogram per cubic meter	4.460897	Tons per acre	0.22417	Kilogram per cubic meter
Kilogram per cubic meter	0.062	Pound per cubic foot	16.129	Kilogram per cubic meter
Tons per hectare	0.44609	Tons per acre	2.2417	Tons per hectare
Kilowatt per meter	0.28909	BTU per foot per second	3.4592	Kilowatt per meter
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
Hectares	2.4711	Acres	0.40469	Hectares

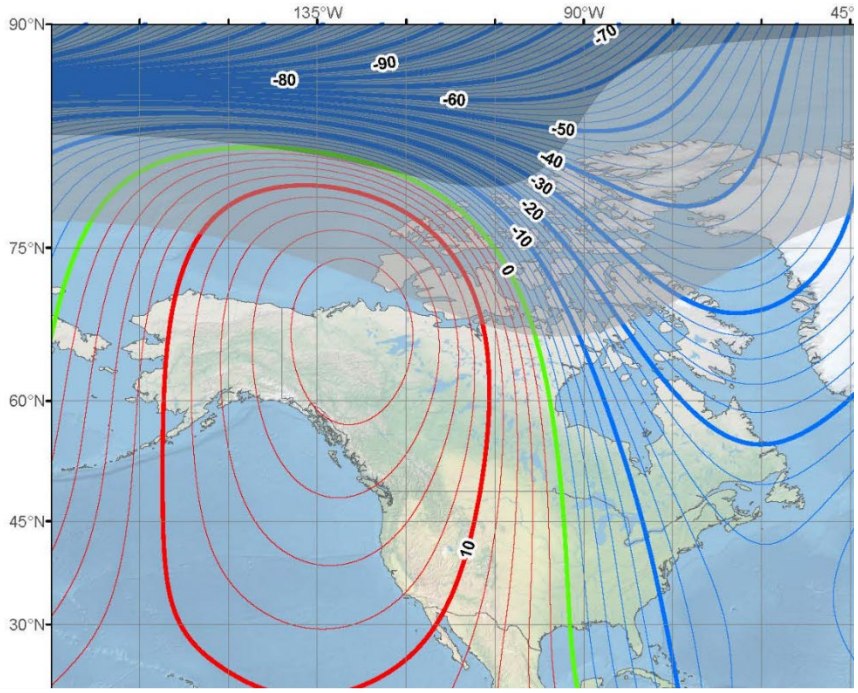
Declination

Magnetic declination, or magnetic variation, is the angle between magnetic north and true north. Declination is positive when magnetic north lies east of true north and negative when it lies west. Magnetic declination changes over time and with location and is necessary to determine true north because compasses align with magnetic north. Additional resources:

- NCEI Magnetic Declination: https://www.ncei.noaa.gov/products/magnetic-declination
- Magnetic Field Calculator: https://www.ngdc.noaa.gov/geomag/calculators/magcalc.shtml

Figure 50 is a December 2024 declination map for North America and shows areas of east declination (red) and west declination (blue). For east declination, subtract from the true compass reading, and for west declination, add to the true compass bearing.

Figure 50. Map of magnetic north across the U.S.



Using Geographic Information Systems (GIS)

Map Datum

Maps use a **datum** to provide a consistent frame of reference for measuring locations on Earth. A datum defines the size and shape of the Earth (usually as an ellipsoid) and anchors the coordinate system to a specific point, ensuring accurate positioning across different regions and mapping systems. Without a common datum, maps from different sources could show the same location in slightly different places.

- Common datums, or Geographic Coordinate Systems (GCS), used in North America include the North American Datum of 1927 (NAD27): a local datum well suited to the United States, Canada, Mexico, and the Caribbean. Although largely replaced by NAD83, it may still appear in legacy topographic maps, historical land surveys, or older GIS data.
- North American Datum of 1983 (NAD83): An Earth-centered datum that corrects NAD27 coordinates based on both Earth and satellite measurements. It is the most regionally accurate datum for North America. This is most likely encountered if using USGS topographic maps. Coordinates are similar to WGS84 coordinates (within 3 to 6 feet) and can be used interchangeably with them.
- World Geodetic System of 1984 (WGS84): An Earth-centered datum common for datasets with a global extent. Uses the WGS84 spheroid. This is the datum that GPS coordinates are based on and will often be the GCS of files created during helicopter reconnaissance flights.

Modern GIS software (e.g., ArcGIS) typically re-projects data “on the fly,” but it is important to know why map layers may not be lining up appropriately, especially when using layers from a variety of sources in desktop software applications. Typically, if a shapefile is uploaded as a zipped file, the projection is included, which allows seamless reprojection. Consult a GIS specialist if datasets do not display correctly.

Map Projections and Coordinate Systems

As noted above, a datum defines Earth's shape and size and the origin point for a coordinate system. A **map projection** mathematically transforms the 3D surface of the Earth (as defined by the datum) onto a flattened 2D map. Examples are Mercator projection, Albers Equal Area Conic Projection, and Transverse Mercator (UTM) projection. Each will produce a different distortion, either in shape, area, distance, or direction.

- LANDFIRE uses the Albers Equal Area Conic projection for national-level data.
- WFDSS, IFTDSS, and FlamMap use a custom Albers map projection to preserve area accuracy and provide consistency across the US.

For more information on using geospatial data in fire modeling applications, see the Fire Modeling section.

A **coordinate system** defines how locations are measured and expressed on the Earth's surface using the datum (and sometimes the projection). There are two main types:

- Geographic Coordinate System (GCS): Uses latitude and longitude based on the WGS84 or NAD83 datum. No projection is applied, so the coordinates are still 3D.
- Projected Coordinate System (PCS): Uses planar XY coordinates in meters or feet and usually combines a datum with a map projection.

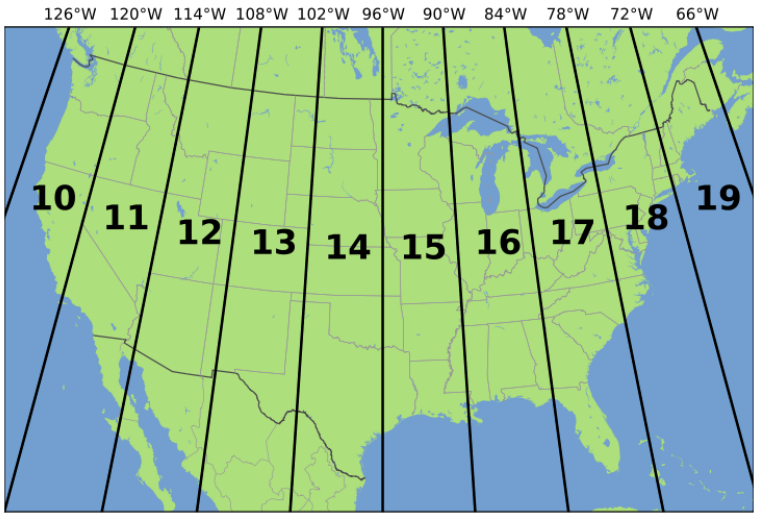
Common PCS examples in fire management include:

- UTM: Divides the Earth into 60 zones that are each six degrees of latitude wide.

When using UTMs, note the datum, such as, "NAD83/UTM Zone 12N." The UTM Zone cannot be adequately expressed without also knowing the associated datum.

- State Plane Coordinate Systems: Units are projected based on the size and extent of each state. (*Lambert Conformal Conic projections* are used for domains with greater east-west extent, and *Transverse Mercator projections* are used for domains with greater north-south extent. Some states use an oblique Mercator projection).

Figure 51. UTM zones for the CONUS.



Mapping Resources

Online Data Sources

- NIFC Enterprise Geospatial Portal (EGP) https://www.wildfire.gov/application/egp
- FSGeodata Clearinghouse https://data.fs.usda.gov/geodata/
- USGS National Map https://www.usgs.gov/programs/national-geospatial-program/national-map
- LANDFIRE https://landfire.gov/
- ArcGIS Web Services are increasingly available in the desktop ArcGIS interface, including ESRI ArcGIS Online (AGOL), which provides password-protected access to agency, interagency, and public content. A NIFC online site provides a home for applications, and access can be requested at https://nifc.maps.arcgis.com/home/index.html.

Google Earth Pro

- Viewing 3D Terrain in Google Earth Pro requires selecting the terrain option from the bottom of the layers portion of the left side menu.
- Active Fire Mapping Bundle https://fsapps.nwcg.gov/afm/data/kml/conus_latest_AFM_bundle.kml
- NWS Data in KML Formats http://www.weather.gov/gis/
- WFDSS Incident, Group, and Analysis Data https://wfdss.firenet.gov/auth/sso
- Public Land Survey (PLSGE) http://www.earthsurvey.us/plss/plss.html
- USGS Topographic Maps http://www.earthpoint.us/TopoMap.aspx

Field Maps Pocket Guide

Field Maps is a mobile GIS application used in the field on many fires. Field Maps works on iOS, Android, and Windows 10, and allows the user to collect and update information in the field, take maps and data offline, sync changes when connected, attribute data collection with easy-to-use map-driven forms, and capture and share photos and videos.

Self-study resources to learn how to use Field Maps can be found here: https://www.esri.com/en-us/arcgis/products/arcgis-field-maps/resources

A NIFC reference guide to using Field Maps is available at https://firenet365.sharepoint.com/sites/WildfireResponse_SharedDrive/Master%20Materials/Forms/AllItems.aspx?id=%2Fsites%2FWildfireResponse%5FSharedDrive%2FMaster%20Materials%2FAGOL%20and%20Field%20Maps%2FField%20Maps%20Field%20Guide%2Epdf&parent=%2Fsites%2FWildfireResponse%5FSharedDrive%2FMaster%20Materials%2FAGOL%20and%20Field%20Maps&p=true&ga=1&LOF=1

Avenza Maps Pro

Avenza Maps Pro, https://www.avenzamaps.com/, provides mobile GIS tools for navigation, information collection, and sharing geographic information and knowledge on Apple, Android, and Windows devices. It displays geospatial PDF, GeoPDF®, and GeoTIFF formats and interacts with the GPS on the device, allowing the user to record GPS tracks, add placemarks, and find places.

Avenza Maps Pro users can import and export shapefiles, and the current capabilities of the Avenza PDF Maps app include support for shapefiles as an import and export format. With the release of the Pro version, users may only access five maps at any time on their device, unless the maps have all been obtained from the Avenza Map Store.

Avenza Maps Pro is a subscription service, requiring registration of individual devices, and may be available to users under an enterprise license contract through individual state, private, and federal agencies.

Other Products

Gaia GPS, https://www.gaiagps.com/, integrates topographical maps, offline navigation tools, and planning features seamlessly across phones and tablets.

You Need a Map, https://itunes.apple.com/us/app/you-need-a-map/id415545903, is a lightweight IOS application providing offline U.S. coverage, including roads, terrain, streams, lakes, and other landmarks.

Theodolite, https://itunes.apple.com/us/app/theodolite/id339393884?mt=8, is a professional grade augmented reality (AR) viewfinder for IOS devices that combines a rangefinder, GPS and mapping, navigation calculator, and geo-overlay camera.

Cal Topo, https://caltopo.com/map.html#ll=38.78835,-98.39355&z=5&b=mbt, is a powerful backcountry mapping and navigation tool that is available on IOS, Android, and online. Users can create custom maps with layers such as topographic maps, slope and angle shading, satellite imagery, and public land boundaries. Offline access and real-time environmental data (snow depth, water gauges, weather forecasts, and fire history) are included.

Observing Current Fire Behavior

Visual Fire Behavior Descriptions

Identifies key terms used to describe fire behavior and provides definitions and reference imagery to support accurate observation.

Figure 52. Key terms used to describe fire behavior with reference imagery.



Observing Flame Length vs. Flame Height

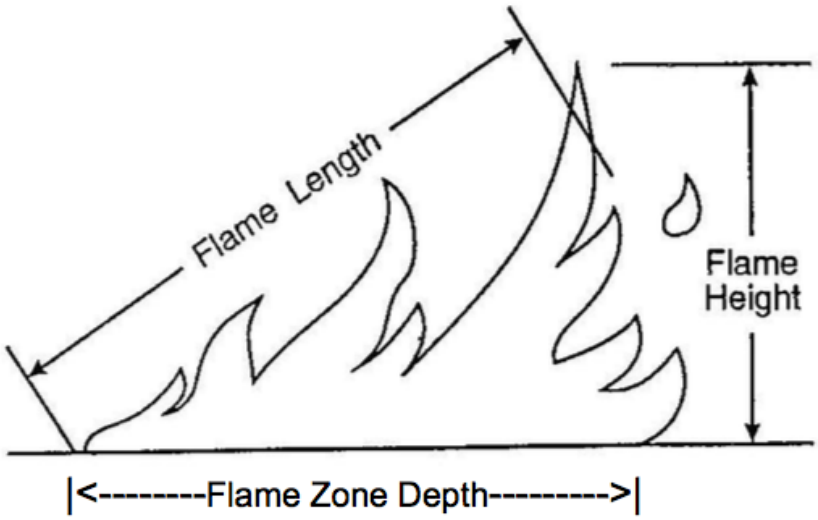
Flame observations help estimate fireline intensity and indicate tactical limitations. Accurate observation depends on distinguishing flame length from flame height. It is also important to identify whether the observation is from the head, flank, or back of the fire.

Flame Length: The distance from the average flame tip to the midpoint of the active flaming zone at the base of the fire. When flames lean due to wind or slope, flame length is measured along the slanted flame angle.

Flame Height: The average height of flames as measured vertically is estimated by comparing the flame to a nearby object of known height. Flame height is needed to estimate spotting distance from burning piles.

Flame length is commonly used as a proxy for fireline intensity experienced at the actively burning perimeter. Flame height, on the other hand, is what most observers commonly report. Encourage observers to identify which measurement they are reporting and to use the appropriate definitions as described here.

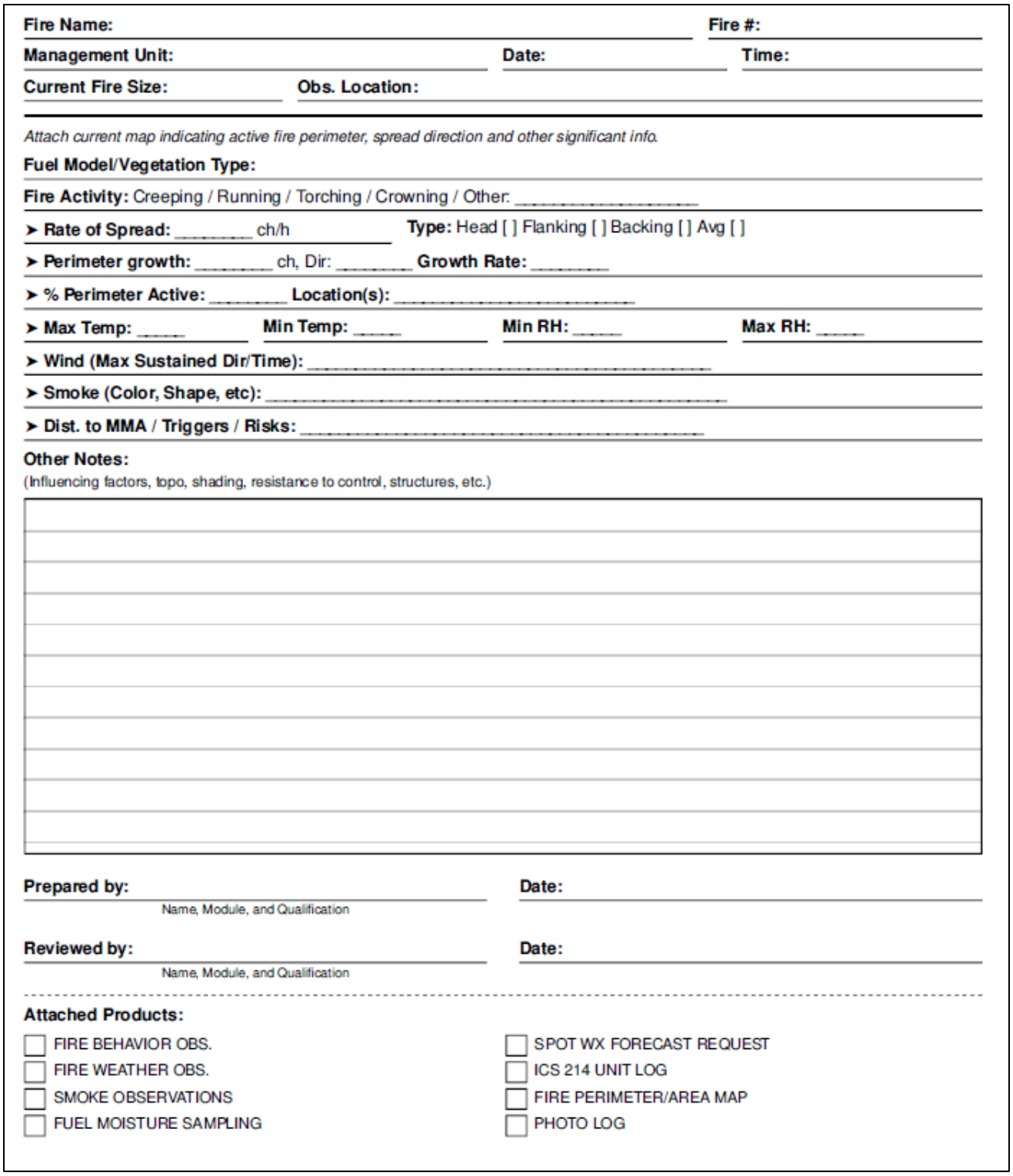
Figure 53. Depiction of flame height and flame length.



Fire Behavior Observation Reports

The Fire Behavior Observation Form is used to document field observations of fire behavior and associated environmental data such as weather, smoke, or values at risk.

Figure 54. Fire behavior observation form.



Fire Name: _____ **Fire #:** _____

Management Unit: _____ **Date:** _____ **Time:** _____

Current Fire Size: _____ **Obs. Location:** _____

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

Fuel Model/Vegetation Type: _____

Fire Activity: Creeping / Running / Torching / Crowning / Other: _____

➤ **Rate of Spread:** _____ ch/h **Type:** Head [ ] Flanking [ ] Backing [ ] Avg [ ]

➤ **Perimeter growth:** _____ ch, Dir: _____ **Growth Rate:** _____

➤ **% Perimeter Active:** _____ **Location(s):** _____

➤ **Max Temp:** _____ **Min Temp:** _____ **Min RH:** _____ **Max RH:** _____

➤ **Wind (Max Sustained Dir/Time):** _____

➤ **Smoke (Color, Shape, etc):** _____

➤ **Dist. to MMA / Triggers / Risks:** _____

Other Notes:
(Influencing factors, topo, shading, resistance to control, structures, etc.)

Prepared by: _____ **Date:** _____
Name, Module, and Qualification

Reviewed by: _____ **Date:** _____
Name, Module, and Qualification

Attached Products:

- ☐ FIRE BEHAVIOR OBS.
- ☐ FIRE WEATHER OBS.
- ☐ SMOKE OBSERVATIONS
- ☐ FUEL MOISTURE SAMPLING
- ☐ SPOT WX FORECAST REQUEST
- ☐ ICS 214 UNIT LOG
- ☐ FIRE PERIMETER/AREA MAP
- ☐ PHOTO LOG

Surface Fire

NWCG defines surface fire as: "A fire that burns surface litter, debris, and other loose material on the ground. Surface fires may spread by wind, rolling or tumbling of burning material, or by creeping along the ground; they may consume low vegetation and small trees but do not carry fire into the canopy."

To estimate surface fire, assume this means within six feet of the ground.

The intent of this section is to explain the fundamentals of surface fire predictions and equip personnel with tools and methods for predicting reliable surface fire behavior, enabling timely, informed, safety and tactical decisions on the fireline.

When applying the Rothermel spread model, keep in mind that it assumes homogeneous fuels, steady-state conditions, and surface (non-crowning) fire; it does not simulate complex 3-D physics.

Surface Model Inputs and Outputs

The Rothermel surface fire spread model (1972) is a mathematical model that predicts the rate of spread and intensity of surface wildfires. It incorporates fuel type, moisture content, wind speed, and slope to estimate how quickly a fire will move across the landscape. The model is widely used in wildfire behavior prediction tools, including Behave, FlamMap, IFTDSS and WFDSS, and remains a foundational part of fire science and operational planning.

Here, the inputs and outputs are described to prepare for using tools that implement the surface fire spread model.

Surface Model Inputs

Reference the corresponding section in this document each bulleted statement for more information.

- Windspeed and Direction from Estimating Winds for Fire Behavior Section (20 foot & Midflame) and (Effective Windspeed Section).
- Fuel Model from Surface Fuel Model Section, https://www.nwcg.gov/publications/pms437/fuels/surface-fuel-model-selection, Canopy Fuel Characteristics).
- Dead Fuel Moisture from Fuel Moisture Section (Temperature, RH, Month, Time, Elevation Difference, Shading, Slope).
- Live Fuel Moisture from Fuel Moisture Section (Herbaceous Moisture Content, Woody Moisture Content).
- Slope and Aspect from Mapping Section (Map and Field Measurements, Slope Estimation).
- Time and Place from Fire Assessment Section (Verification, Calibration, and Validation, Burn Period, Duration).

Surface Model Outputs

- **Rate of Spread** helps evaluate fireline tactics, identify values at risk during the burn period, and assess escape-route limitations.

- **Flame Length and Fireline Intensity** supports decisions to determine what tactics make sense during the peak-burn period, interpret safety zone concerns, suggest spotting potential, and address impacts to natural resources or transportation corridors from flames or smoke.
- **Heat per Unit Area** is useful for understanding burn duration and fire effects, similar to the ERC.

Tools Available to Predict Surface Fire

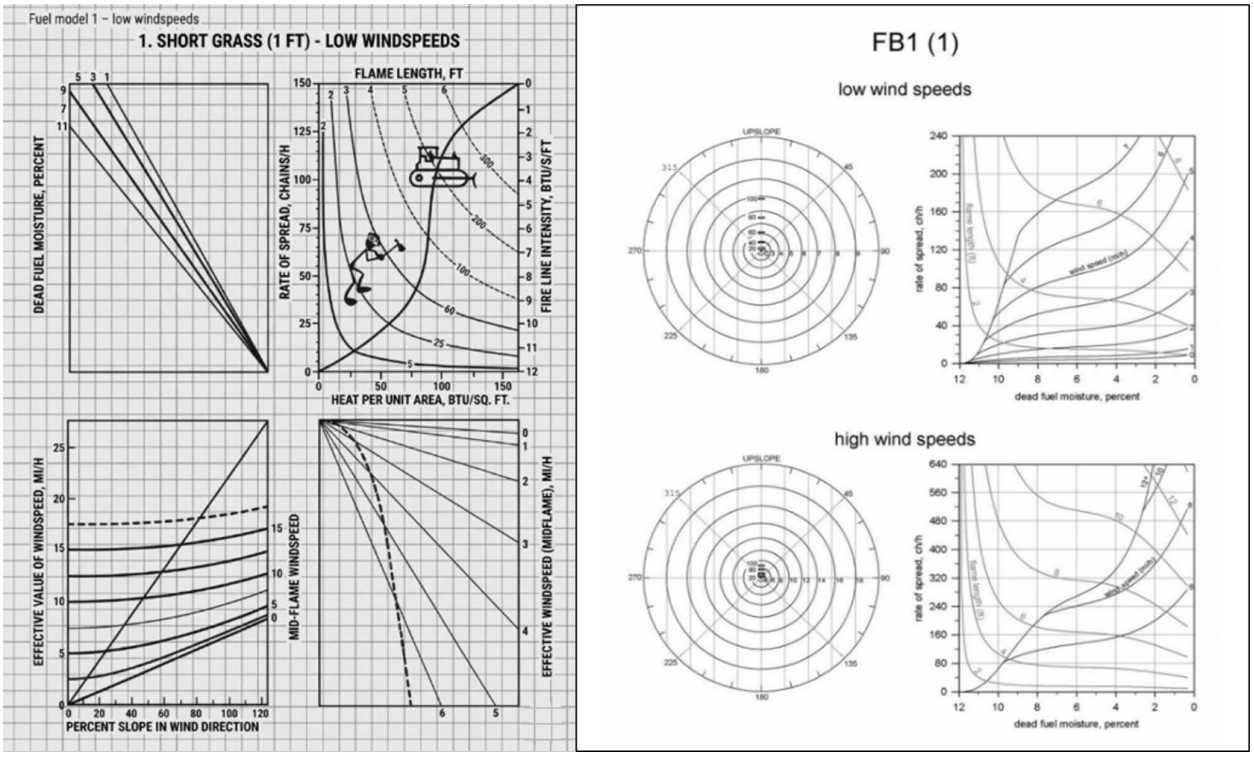
Nomograms and Nomographs

Nomograms (or nomographs) provide a graphical tool to estimate key fire behavior—commonly ROS and FL—by aligning known input variables on graphs. These tools use scaled axes and intersecting lines, allowing users to read predicted behavior immediately in the field. They are used for rapid, practical decision support when time or equipment limits running computer simulations.

For more information about using nomograms and nomographs, refer to the following publications:

- For estimating fire behavior using nomograms for the original 13 fuel models (Anderson, 1982), see *How to Predict the Spread and Intensity of Forest and Range Fires* (Rothermel, 1983), https://www.fs.usda.gov/rm/pubs_int/int_gtr143.pdf, which remains foundational to how fire predictions are calculated. However, Fuel Model 7 was updated after 1983, so the March 1992 set of nomograms should be used for calculations, https://fs-prod-nwcg.s3.us-gov-west-1.amazonaws.com/s3fs-public/publication/pms436-3.pdf, (NWCG, 1992).
- For estimating fire behavior in the 40 standard fuel models (Scott and Burgan, 2005), see *Nomographs for Estimating Surface Fire Behavior Characteristics* (Scott, 2007), https://www.fs.usda.gov/rm/pubs/rmrs_gtr192.pdf.

Figure 55. Examples of nomograms.



Behave

Behave is a fire behavior modeling application (Andrews, 1986) that integrates a suite of mathematical models to simulate fire behavior, fire effects, and environmental conditions based on specified fuel and moisture inputs. Designed for quick and accurate predictions, Behave estimates key fire characteristics such as ROS, spotting distance, scorch height, tree mortality, fuel moisture, wind adjustment factors, and more, making it a valuable tool for fire planning and tactical decision-making.

Behave is a point-based modeling system, generating fire behavior estimates for a specific location on the landscape. It is widely used by fire professionals to assess fire behavior, containment strategies, and potential tree mortality.

Users are encouraged to check for updates and access learning materials at: https://www.frames.gov/behave/home. The current version, Behave7, can be downloaded from Frames but is also available directly in a browser window with no downloads required at https://behave.sig-gis.com.

Behave7 Modules

- Surface – Simulates surface fire behavior
- Crown – Models crown fire activity
- Contain – Estimates fire containment
- Mortality – Predicts tree mortality

Behave7 Calculators

- Probability of Ignition
- 1-Hour Fuel Moisture (Fosberg)
- Slope from Map Measurements
- VPD
- RH
- Safe Separation Distance & Safety Zone Size

Surface Fire Behavior Lookup Tables

Surface fire behavior lookup tables are precomputed charts that show expected fire behavior (e.g., ROS, FL) for combinations of key inputs like fuel model, fuel moisture, slope, and wind. They rely on the Rothermel model and are useful for quick reference to find likely surface fire outcomes without running a computer model. A long set of assumptions apply to these tables, so more sophisticated calculations may require a mobile fire behavior calculator application or Behave.

The detailed process for estimating surface fire behavior with lookup tables is provided in the Predicting Surface Fire Spread Using Lookup Tables section of this document.

Spatial Modeling (FlamMap, FARSITE)

FlamMap and FARSITE are spatial fire modeling programs that use GIS inputs to simulate fire behavior:

- FlamMap – steady-state fire behavior across a landscape
- FARSITE – time-dynamic fire growth simulation

These tools support strategic planning purposes and are not conducive to on-the-fly, field-level tactical operations. See the Fire Modeling section for more information.

Surface Fire Behavior Worksheet

The Surface Fire Behavior Worksheet (Figure 56) is a structured form used to record observations and input to predict surface fire behavior for a specific site and set of conditions. It guides users through entering key variables, applying fire behavior models, and recording outputs for planning and tactical decisions.

Consider using this worksheet as your briefing documentation by incorporating a weather forecast narrative, recent fire activity and observations, a sense of how accurate the predictions seem, and expected changes through the burn period.

Figure 56. Surface Fire Behavior Worksheet.

Surface Fire Behavior Worksheet (with Size & Shape)

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

Time and Place					**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
Fire Size and Shape					**Notes**
35	Spread Distance, chains (66ft)				
36	**Fire Size, acres**				
37	**Fire Perimeter, chains (66ft)**				

Predicting Surface Fire Spread Using Lookup Tables

Lookup tables provide a quick way to assess potential fire spread and flame length. However, they come with limitations and can only be used for rough estimates. Key considerations when using lookup tables:

- Tables only reference the 13 original fuel models (Anderson, 1982).
- Tables do not account for spotting or crown fire behavior.
- The original 13 models were designed for peak fire season and are not well suited for shoulder-season conditions.
- Outputs assume wind is blowing upslope, not across the slope or downslope. When wind is cross-slope or downslope, use a fire spread vectoring process (e.g., Behave), or use the Effective Wind Speed table with an input midflame windspeed (MFWS) of 0 mph for rough estimates.
- The original 13 fuel models treat all live fuels (herbaceous and woody) as a single value. In Fire Behavior Fuel Models 2, 4, 5, 7, and 10, a live fuel moisture of 95% is assumed. If the current situation is significantly wetter or drier than this, the tables may not be useful.
- Tables are valid only for slopes less than or equal to 25%.
- Many tables show declining ROS and FL values at the lower right portion of the table due to implementation of the "wind speed limit function" which is applied to prevent the Rothermel spread equation from overpredictions at high wind speeds (Andrews et al., 2013). Behave7 allows users to override enforcement of this limit.

Using the Surface Fire Behavior Worksheet (Figure 56) helps document assumptions, inputs, and results. Not all worksheet fields apply to the lookup tables since the worksheet is designed for Behave.

Using Surface Fire Lookup Tables

1. Determine the required input variables for the fire-prediction location:
   a. Select the correct fuel model. Consult the Fuel Model Selection Guide in this document, Aids to Determining Fuel Models for Estimating Fire Behavior (Anderson, 1982), or Scott and Burgan (2005, pages 13 to 16) to select one of the 13 original fuel models.
   b. Observe midflame windspeed.
   c. Calculate percent slope.
   d. Calculate fine dead fuel moisture from the fuel moisture lookup tables (requires dry bulb temperature, RH, aspect, slope, and shaded/unshaded, month, day/night).
2. Use the Effective Wind Speed (EWS) table below (Figure 57). Select the table for the correct fuel model. Find the observed MFWS on the left column and the slope along the top. Read the EWS where the row and column intersect.
3. Determine the ROS (chains per hour) using the correct fuel model table by selecting the 1-hour fuel moisture on the left column and the MFWS along the upper gray row. Read the value where the row and column intersect.

Note the columns labeled NWNS (no wind/no slope), Back (backing fire), and Flank (flanking fire) columns apply when winds are not blowing upslope. The next section explains how to estimate flanking and backing fire behavior using head fire outputs.

4. Determine flame length using the flame length table is below the spread table. Use the same inputs of 1-hour fuel moisture and EWS to find the flame length in feet.
5. Document findings on the Surface Fire Behavior Worksheet.

Effective Windspeed (EWS)

EWS integrates the effect of winds and slope on a surface fire behavior for a given fuel model.

These tables apply only when winds are blowing upslope.

For downslope and cross-slope winds, use the zero (0) mph row in the MFWS column to estimate the slope-equivalent windspeed. This value may be used as the MFWS in the lookup tables to approximate fire behavior when wind and slope are not aligned.

Figure 57. EWS conversion.

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

MFWS (mph)	Slope Steepness									
	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

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

MFWS (mph)	Slope Steepness									
	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

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

MFWS (mph)	Slope Steepness									
	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

Grass Fuel Models

Fuel Model 1 (Short Grass – 1 foot)

Fire spreads through fine, very porous, and continuous herbaceous fuels that are cured or nearly cured. Spread is rapid through cured grass and associated material; very little shrub or timber (less and one-third of the area) is present. Examples include grasslands, savanna, stubble, grass-tundra, and grass-shrub combinations. Annual and perennial grasses are included in this fuel model.

Fuel Model 3 (Tall Grass – 2.5 feet)

Fire produces the highest intensity and highest rates of spread under the influence of wind within the grass group. Wind may drive fire into the upper heights of the grass and across standing water. Stands are tall, averaging about 3 feet (1 meter), but considerable variation may occur. 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.

Figure 58. ROS in Fuel models 1 and 3 under different effective windspeeds.

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

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

1-hr Moisture, %	*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		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)

1-hr Moisture, %	*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		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

Grass/Shrub Fuel Models

Fuel Model 2 (Timber – Grass and Understory)

Fire spread is primarily through fine herbaceous fuels—curing or dead—and through litter and dead/down stem wood from open shrub or timber overstories, which contribute to fire intensity. Open shrublands and pine or scrub-oak stands that cover one-third to two-thirds of the area may generally fit this model. Such stands may include clumps of fuels that generate higher intensities and may produce firebrands. Some pinyon-juniper are included here.

Figure 59. ROS in Fuel model 2 under different effective windspeeds.

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

Brush or Shrub Fuel Models

Fuel Model 4 (Chaparral – 6 feet)

Intense, fast-spreading fires burn through foliage and live and dead fine, woody material in the crowns of a nearly continuous secondary overstory. Stands of mature shrubs are approximately 6 or more feet tall. Flammable foliage and dead woody material significantly contribute to fire intensity. The height of stands qualifying for this model depends on local conditions. A deep litter layer may also hinder suppression efforts. Examples include California mixed chaparral, the high pocosin along the east coast, the pine barrens of New Jersey, or the closed jack pine stands of the North-Central States.

Figure 60. ROS in Fuel Model 4 under different effective windspeeds.

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

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

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

Low	Moderate	High	Very High	Extreme

FLAME feet — Effective Windspeed(EWS), mph

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

1-hr Moisture, %; (Woody moist. 120%-80%)	20ft/FCST	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	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 feet)

Fire carries in surface fuels made up of understory shrub and grass litter or forbs. Intensity is low due to light surface fuel loads—young shrubs, little dead material and limited volatile material in the foliage. Typical of short, green, nearly continuous shrub layers (e.g., laurel, vine maple, alder, or even chaparral, manzanita, or chamise) with no dead wood.

Figure 61. ROS in Fuel Model 5 under different effective windspeeds.

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

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

1-hr Moisture, %; (Woody moist. 120%-80%)	*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	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)

1-hr Moisture, %; (Woody moist. 120%-80%)	*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	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)

Fire carries through the older or dominant shrub layers where foliage is more flammable than Fuel Model 5. Moderate winds (greater than 8 miles per hour, 13 kilometers per hour, at midflame height) are required; fire drops to the ground at low wind speeds or openings in the stand. A broad range of shrub conditions are covered by this model. Examples include intermediate stands of chamise, chaparral, oak brush, low pocosin, Alaskan spruce taiga, and shrub tundra. Even hardwood slash that has cured can be considered. Pinyon-juniper shrublands may be represented but may overpredict ROS except at high winds.

Figure 62. ROS in Fuel Model 6 under different effective windspeeds.

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

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

1-hr Moisture, %	*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		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)

1-hr Moisture, %	*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		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)

Fire burns through surface and shrub strata with equal ease. Because live foliage and other live materials are highly flammable, fires can burn at higher dead fuel moistures than in other shrub models. Stands of shrubs typically range from 2 to 6 feet (0.6 to 1.8 m) high. Examples include palmetto-gallberry understory-pine overstory sites, low pocosins, and black spruce-shrub combinations in Alaska.

Figure 63. ROS in Fuel Model 7 under different effective windspeeds.

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

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

1-hr Moisture, %; (Woody moist. 120%-80%)	*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
	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)

1-hr Moisture, %; (Woody moist. 120%-80%)	*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
	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

Timber Litter Fuel Models

Fuel Model 8 (Closed Timber Litter)

Fire is generally slow-burning ground fire with low flame lengths, though occasional "jackpots" or heavy fuel concentrations may flare up. Under most conditions the hazard is low, but severe weather conditions involving high temperatures, low humidities, and high winds increase spread potential. Closed-canopy stands of short-needle conifers or hardwoods that have leafed out support fire in the compact litter layer. This layer is mainly needles, leaves, and occasionally twigs because little undergrowth is present in the stand. Representative conifer types are white pine, and lodgepole pine, spruce, fir, and larch.

Figure 64. ROS in Fuel Model 8 under different effective windspeeds.

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

*Use 20ft/FCST wind only if EWS = MFWS and assumes sheltered wind adjustment (0.2)

1-hr Moisture, %	NWNS/0	Back - ½	Flank - 1	10	20	30	40	50	60	70	80	90	100
*20ft/FCST / EWS				2	4	6	8	10	12	14	16	18	20
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)

1-hr Moisture, %	NWNS/0	Back - ½	Flank - 1	10	20	30	40	50	60	70	80	90	100
*20ft/FCST / EWS				2	4	6	8	10	12	14	16	18	20
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)

Fire spreads through surface litter faster than Fuel Model 8 and produces longer flame height. This model includes both long-needle conifer stands and hardwood stands, especially oak-hickory types. Fall fires in hardwoods are predictable, but high winds can greatly increase the ROS more than predicted due to spotting caused by rolling and blowing leaves. Concentrations of dead and down woody material can contribute to possible torching of trees, spotting, and crowning. Examples include closed stands of long-needled pine like ponderosa, jeffrey, and red pines or southern pine plantations.

Figure 65. ROS in Fuel Model 9 under different effective windspeeds.

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

*Use 20ft/FCST wind only if EWS = MFWS and assumes prtly shelterd wind adjustment (0.3)

1-hr Moisture, %	*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		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)

1-hr Moisture, %	*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		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

Timber Understory Fuel Models

Fuel Model 10 (Timber – Litter and Understory)

Fire burns in surface and ground fuels with greater fire intensity than the other timber litter models. Dead-down fuels— often including greater quantities of 3-inch (7.6-cm) or larger limbs— accumulate on the forest floor due to over maturity or natural events. These heavy fuels increase the likelihood of fire crowning, spotting, and torching, leading to potential fire control difficulties. Any forest type may be considered if heavy down material is present; examples are insect- or disease-ridden stands, windthrown stands, overmature situations with deadfall, and aged light thinning or partial-cut slash.

Figure 66. ROS in Fuel Model 10 under different effective windspeeds.

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

*Use 20ft/FCST wind only if EWS = MFWS and assumes prtly shelterd wind adjustment (0.3)

1-hr Moisture, %; (Woody moist. 120%-80%)	*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		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)

1-hr Moisture, %; (Woody moist. 120%-80%)	*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		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

Slash/Blowdown Fuel Models

Fuel Model 11 (Light Logging Slash)

Fire activity is moderately active, burning in slash mixed with herbaceous vegetation. Fire potential is limited by light fuel loading, shading from overstory trees, or aging of fine fuels. Typical examples include light partial cuts or thinning operations in mixed conifer stands, hardwood stands, and southern pine harvests. Clearcut operations generally produce more slash than represented here. Loads of material less than 3 inches in diameter (7.6 cm) are under 12 tons per acre (5.4 tons per hectare), and fuels greater than 3 inches in diameter (7.6-cm) are represented by no more than ten 4-inch pieces (10.2 cm) along a 50-foot (15 m) transect.

Figure 67. ROS in Fuel Model 11 under different effective windspeeds.

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)

These fuels can support rapidly spreading, high intensity fire capable of generating firebrands. Once ignited, fire spread is typically sustained until a fuel break or change in fuels is encountered. Slash is the dominant visual feature, consisting mostly of material less than 3 inches (7.6 cm) in diameter. Total fuel load is less than 35 tons per acre (15.6 t/ha) and seems well distributed. Representative conditions include heavily thinned conifer stands, clearcuts, and medium to heavy partial cuts. Materials larger than 3 inches (7.6 cm) are represented by encountering eleven 6-inch pieces (15.2 cm) in diameter along a 50-foot (15 m) transect.

Figure 68. ROS in Fuel Model 12 under different effective windspeeds.

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

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

1-hr Moisture, %	NWNS-0	Back - ½	Flank - 1	5	10	15	20	25	30	35	40	45	50
*20ft/FCST													
EWS				2	4	6	8	10	12	14	16	18	20
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)

1-hr Moisture, %	NWNS-0	Back - ½	Flank - 1	5	10	15	20	25	30	35	40	45	50
*20ft/FCST													
EWS				2	4	6	8	10	12	14	16	18	20
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)

Fire is generally carried by a continuous layer of heavy slash. Large quantities of coarse woody material are present. While fine fuels comprise only about 10% of the total load, they carry the initial fires spread quickly, followed by building intensity as large fuels ignite. This model supports active flaming and a wide variety of firebrands, increasing spotting potential. Total fuel load may exceed 200 tons per acre (89.2 t/ha). Stands where the slash still has red needles attached but where total loads are lighter may still be represented, due to high early intensity and quicker area involvement.

Figure 69. ROS in Fuel Model 13 under different EWS.

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

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

1-hr Moisture, %	*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	3	5	6	11	20	30	41	52	63	75	86	98	111
	3	2	4	5	9	16	25	34	43	52	61	71	81	91
	5	2	3	5	7	14	21	28	36	44	52	60	69	77
	7	2	3	4	6	12	18	25	31	38	45	52	60	67
	9	2	2	4	6	11	16	22	28	34	41	47	54	60
	11	1	2	3	5	10	15	20	26	32	37	43	49	55
	13	1	2	3	5	9	14	19	24	29	35	40	46	51
	15	1	2	3	5	9	13	18	23	27	33	38	43	48
	17	1	2	3	4	8	12	17	21	26	30	35	40	45
	19	1	2	2	4	8	11	15	19	24	28	32	37	42
	21	1	2	2	4	7	10	14	18	21	25	29	33	37
	23	1	1	2	3	6	9	12	15	18	22	25	29	32
	25	1	1	2	3	5	7	10	12	15	18	21	23	26
	27	1	1	1	2	3	5	7	9	11	13	15	17	19
	29	<1	<1	<1	1	2	3	4	5	6	7	8	9	10

Low	Moderate	High	Very High	Extreme

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

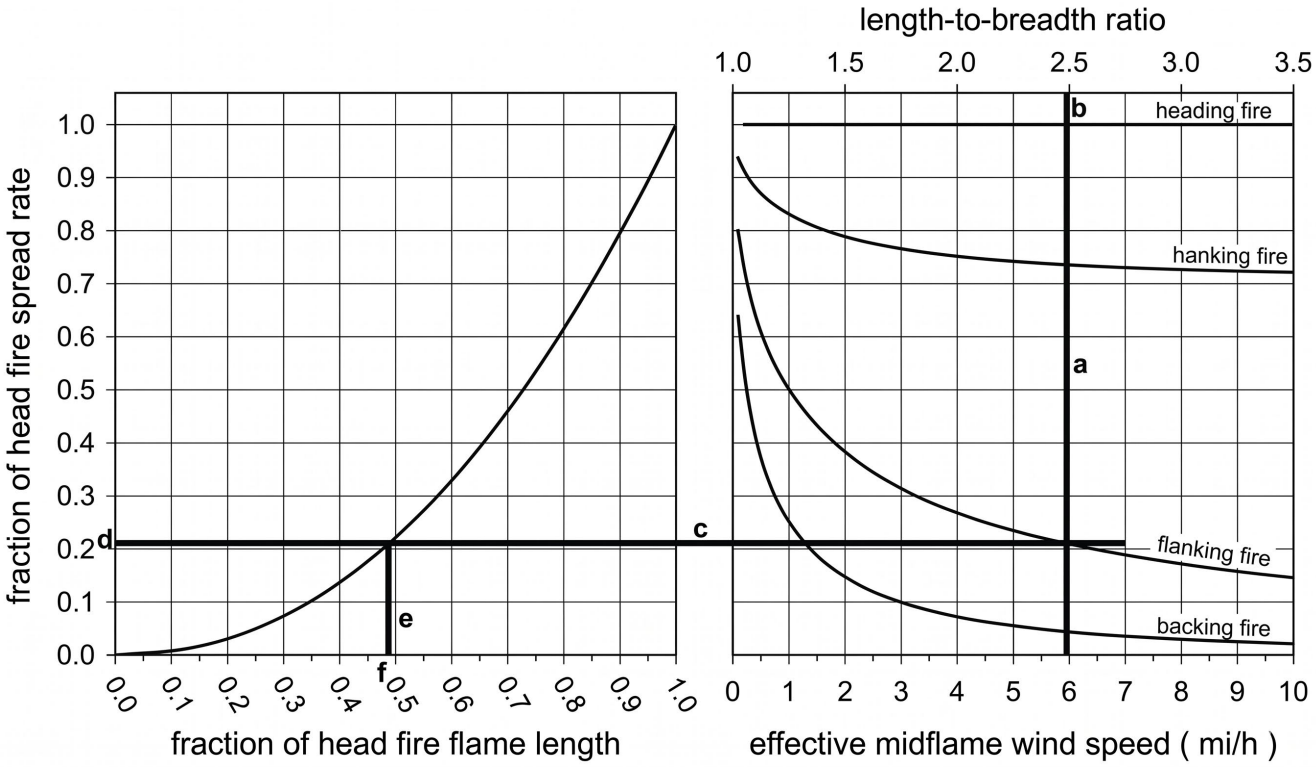
*Use 20ft/FCST wind only if EWS = MFWS and assumes unsheltered wind adjustment (0.5)

1-hr Moisture, %	*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	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

Predicting Flanking and Backing Fire Behavior

Figure 70 is a nomograph that uses EWS to produce adjustment factors for both spread rate and flame length. These factors can then be applied to the head fire behavior outputs to estimate flanking or backing fire behavior.

Figure 70. Rates of spread for flanking and backing fire spread.



1. Find the EWS at the bottom axis of the right-hand chart. Draw a vertical line (a) upward to intersect the top axis. At that point, read the length to breadth ratio (b).
2. Determine the fraction of head fire ROS. From the same intersection point, draw a horizontal line (c) toward the left-hand chart, extending it until it meets the left axis (d) at the chosen spread of direction. Read the fraction from the left axis and multiply it by the head fire ROS to obtain the spread rate in the assumed direction. In the flanking fire example (Figure 70), if the head fire ROS is 10 chains per hour and the flanking fire fraction is 0.2, then: 10 × 0.2 equals 2 chains per hour for the flanking fire.
3. Determine the flame length fraction. From the point where the horizontal line crosses the curve € on the left-hand chart, draw a vertical line downward to the bottom axis (f). Read the flame length fraction from this bottom axis and apply it to the head fire flame length estimate to obtain the flame length in the spread direction assumed. In the flanking fire example (Figure 70), if the head fire flame length is 2 feet and the fraction is 0.5, then 2 × 0.5 equals a 1-foot flanking fire flame length.

Estimating Rate of Spread from Observations

Another useful tool, especially when estimating the ROS on flanks and backing fires, is the ROS estimator chart (Figure 71), which can be used to estimate the ROS based on how long it takes the flaming front to move a given distance.

Figure 71. ROS estimation chart.

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.

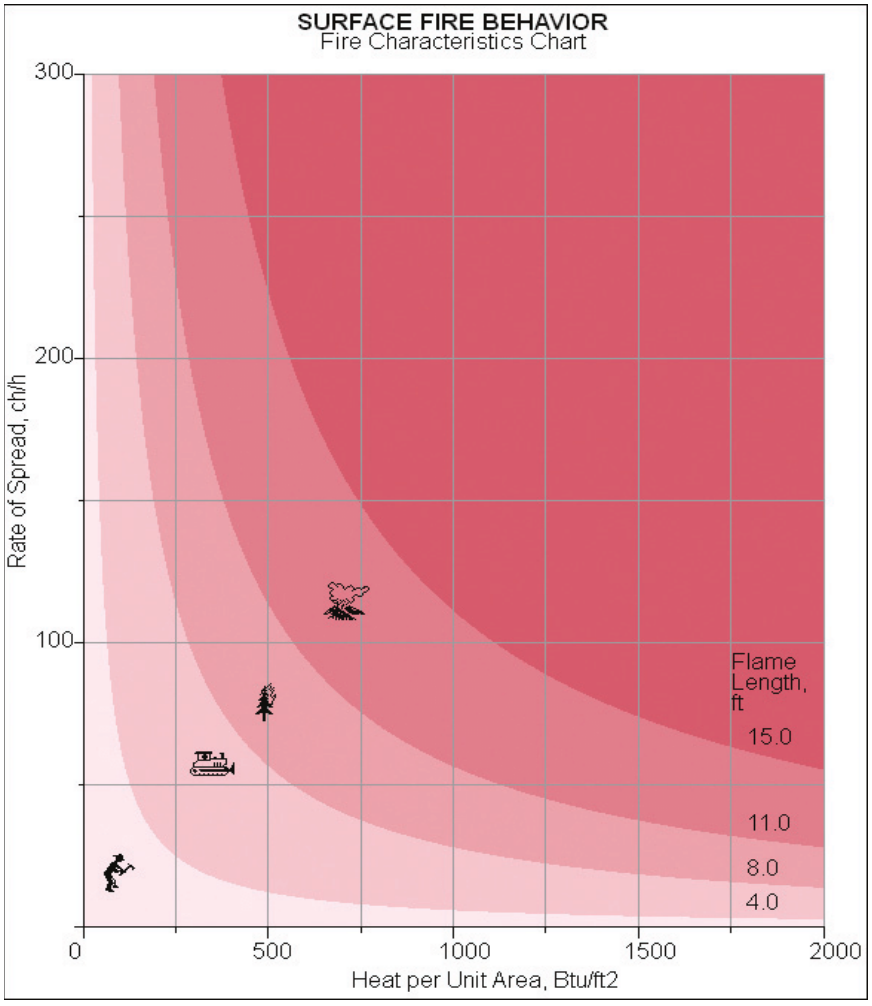
Interpreting Fire Behavior

Once estimates for ROS and flame length have been obtained, use the values in Table 19 to assist in identifying appropriate strategies and tactics as indicated in Figure 72.

Table 19. Suppression options based on expected fire behavior.

Fire Behavior Class	Rate of Spread (chains per hour)	Flame Length (feet)	Tactical Interpretation
Very Low	0 to 2	0 to 1	Direct, Hand
Low	2 to 5	1 to 4	Direct, Hand
Moderate	5 to 20	4 to 8	Direct, Equipment
High	20 to 50	12 to 25	Indirect
Very High	50 to 150	12 to 25	Indirect
Extreme	150 or more	25 or more	Indirect

Figure 72. Hauling Chart.



Estimating Surface Fire Size and Shape

For point-source surface fires, the perimeter, acreage, and general fire shape can be estimated if the following inputs are available and remain constant for the duration of the estimate: fuel type, slope, and wind. You will need two values:

- Total forward spread distance (in chains): To obtain the total forward spread distance, multiply the forward ROS (chains per hour) by the number of hours the fire will burn freely.
  Example: If the forward ROS is 6 chains per hour and the fire will burn freely for 7 hours, then 6 × 7 = 42 chains of forward spread distance.
- EWS: Refer to earlier section on calculating EWS.
- Two tables for fire area (in acres) and two tables for fire perimeter (in chains) are provided. Select the appropriate table based on fuel and wind conditions to complete the estimate.
  - Figure 73. Surface Fire Area Spread Distance 1 to 50 Chains.
  - Figure 74. Surface Fire Area Spread Distance 52 to 165 Chains.
  - Figure 75. Surface Fire Perimeter Spread Distance 1 to 50 Chains.
  - Figure 76. Surface Fire Perimeter Spread Distance 52 to 165 Chains.

Surface Fire Area Estimation from Point Source Fire, in Acres

Figure 73. Surface Fire Area Spread Distance 1 to 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

Figure 74. Surface Fire Area Spread Distance 52 to 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

Surface Fire Perimeter Estimation from Point Source Fire, in Chains

Figure 75. Surface Fire Perimeter Spread Distance 1 to 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

Figure 76. Surface Fire Perimeter Spread Distance 52 to 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

Surface Fire Shape

Fire shape can also be estimated using the total forward spread distance and the EWS. To do this, convert the total forward spread distance into map units:

1. Multiply the forward ROS by the number of hours the fire will burn freely to determine the total spread distance.
2. Convert the total ROS from chains to feet.
3. Convert the map scale into working scale.
4. Divide the total spread distance (feet) by the working scale.

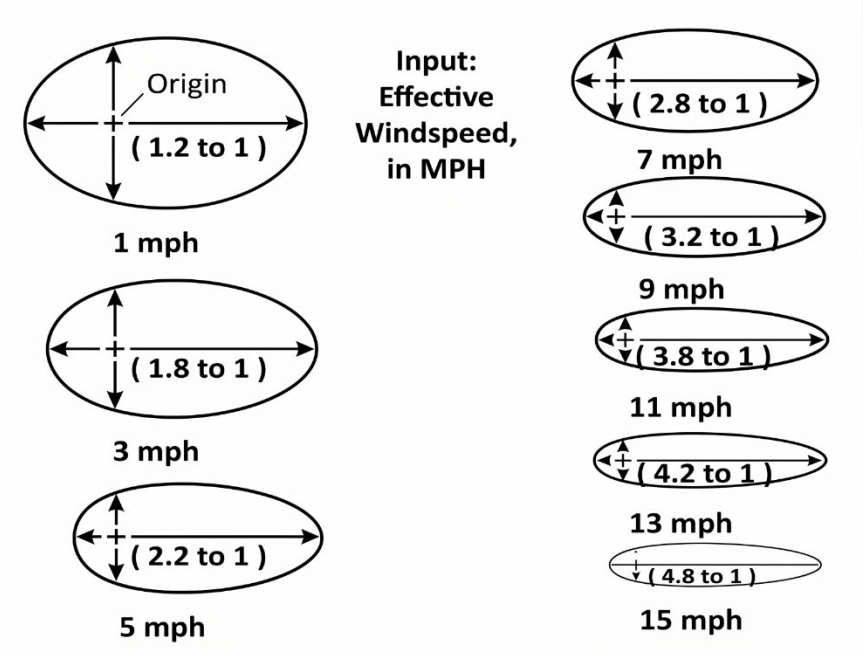
Example (continued from above): If the total spread distance is 42 chains, and the map scale is 1:24,000, then:

1. Forward ROS is 6 chains per hour multiplied by 7 hours that the fire will burn freely, then 6 × 7 = 42 chains of forward spread distance.
2. 42 chains × 66 feet in a chain= 2,772 feet
3. 24,000 / 12 = 12,000
4. 2,772 feet / 12,000 = 0.2 inches of forward spread distance on the map

Using Figure 77, plot the approximate fire size on the map using the ellipse that represents the EWS.

Remember that EWS, as referenced here, is based on midflame windspeed. Images show the length to width ratio in parentheses.

Figure 77. Estimated fire shape based on EWS.



Spotting and Crown Fire

Spotting

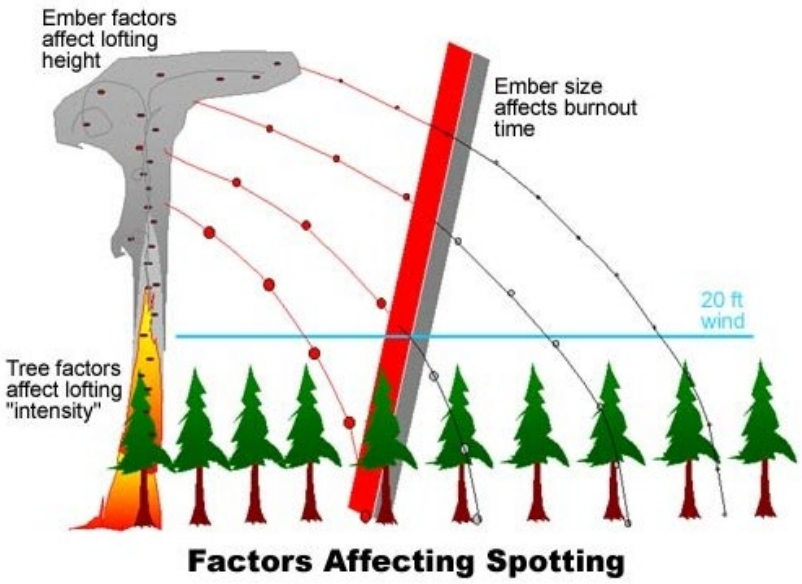
Spotting fire behavior is a specific situation where embers (firebrands) are lofted from the flaming front and are carried by wind ahead of the main fire front, igniting new fires in receptive fuels. Spot fires can significantly increase the spread and intensity of wildfire. Spotting is typically characterized as short-range or long-range, though the breakpoint between the two is not universally defined.

Additional information about spot fire modeling is available in Behave Help.

Short-range Spotting occurs relatively close to the main fire and may not be significant for wildfire growth if the advancing main fire quickly overruns developing spot fires. Spotting distances of a few feet are typically represented in surface fire behavior modeling. Short-range spotting is usually 100 feet to 0.25 miles from the main fire front.

Long-range Spotting differs from short-range spotting because firebrands are lofted by a convection column and carried beyond the immediate fire area. Long-range spotting is usually greater than 0.25 miles to several miles. In 2000, the Cerro Grande Fire was reported to have spot fires 10 miles ahead of the fire front.

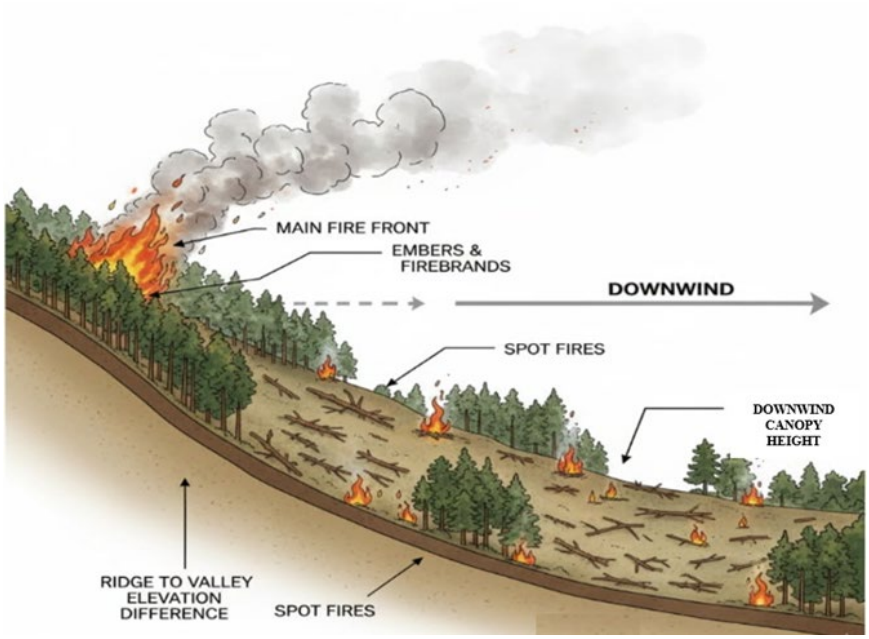
Figure 78. Graphic depicting spotting.



Evaluating spotting fire behavior requires three factors:

- Source: Size, type, and number of firebrands based on source materials.
- Transport: Lofting height and distance the firebrand is carried downwind.
- Ignition probability: Likelihood a firebrand will ignite receptive fuels at the landing location.

Figure 79. Spotting from a fire on a slope.



Estimating Maximum Spotting Distance

Maximum spotting distance is predicted using equations developed by Frank Albini in the 1970s to estimate how far embers (firebrands) can travel and ignite new fires ahead of the main fire front. It considers:

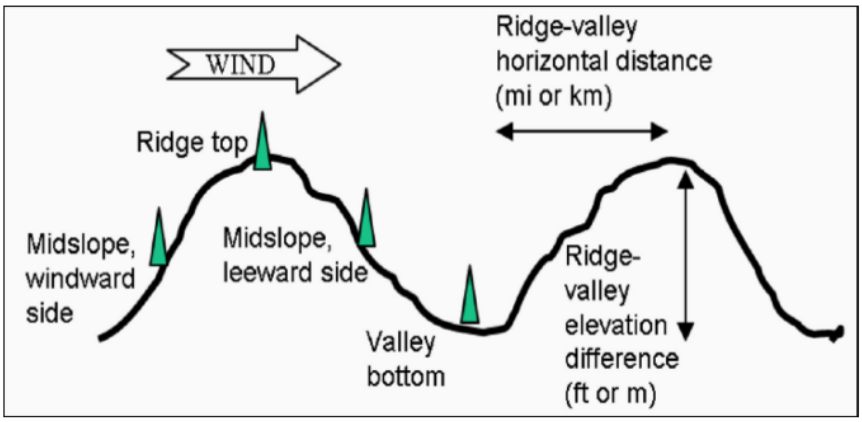
- Firebrand lofting height
- Wind speed and direction
- Topography (e.g., position on slope relative to wind direction)
- Canopy height and tree species

Although the maximum spotting distance is calculated, firebrands may land at all the distances up to that maximum.

These models are implemented in the SPOT module of Behave, which allows users to input conditions and receive estimates of maximum spotting distance under those conditions. If you're working with Behave, the underlying model for spotting remains based on Albini's work.

Figure 80 depicts additional inputs to the Behave spotting module. In mountainous terrain, ridge top winds are used if the wind is blowing across valleys as shown. The shape of the valley is considered with inputs for Ridge-to-Valley distance and elevation difference.

Figure 80. Visual representation of required spotting inputs.



The maximum spotting distance model requires identification of the tree species, height, and Diameter at Breast Height (DBH) of the torching tree to estimate the flame height and duration from the torching tree that will initiate the lofting of the ember into the wind field. Further, the open windspeed is used to suggest how far the firebrand will be transported as it falls back to the ground. The downwind canopy height, or tree cover, (reduced by half for open canopies) is used to factor embers intercepted by the canopy before reaching surface fuels.

Probability of Ignition tables (see Fuel Moisture section) describe only the chance that a landing ember will ignite receptive fuels.

Reference Tables for Maximum Spotting Distance

The reference data below is used in the Behave application SPOT calculator to estimate spotting distances for various tree species. The model assumes in an open stand of 50-foot-tall trees that there are three torching trees each 50 feet tall and 10-inches DBH with downwind canopy cover.

Table 20. Reference table for maximum spotting distances (in miles) for western tree species based on a 20-foot windspeed (in miles per hour).

Tree Species	0	5	10	15	20	25	30	35	40	45	50
Balsam Fir	0	0.1	0.3	0.4	0.6	0.7	0.8	1	1.1	1.3	1.4
Grand Fir	0	0.1	0.3	0.4	0.6	0.7	0.8	1	1.1	1.3	1.4
Subalpine Fire	0	0.1	0.2	0.4	0.5	0.6	0.7	0.9	1	1.1	1.2
Lodgepole Pine	0	0.1	0.2	0.3	0.5	0.6	0.7	0.8	0.9	1	1.1
Englemann Spruce	0	0.1	0.2	0.4	0.5	0.7	0.8	0.9	1	1.2	1.3
Ponderosa Pine	0	0.1	0.2	0.4	0.5	0.6	0.7	0.9	1	1.1	1.2

Table 21. Reference table for maximum spotting distances (in miles) for southern tree species based on a 20-foot windspeed (in miles per hour).

Maximum Spotting Distance, in miles 20ft Windspeed, in mph											
Tree Species	0	5	10	15	20	25	30	35	40	45	50
Shortleaf Pine	0	0.1	0.2	0.2	0.3	0.4	0.5	0.6	0.6	0.7	0.8
Slash Pine	0	0.1	0.2	0.3	0.3	0.4	0.5	0.6	0.4	0.8	0.8
Longleaf Pine	0	0.1	0.2	0.3	0.3	0.4	0.5	0.6	0.7	0.8	0.8
Pond Pine	0	0.1	0.2	0.2	0.3	0.4	0.5	0.6	0.6	0.7	0.8
Loblolly Pine	0	0.1	0.2	0.2	0.3	0.4	0.5	0.6	0.6	0.7	0.8

Comparing Spotting Estimation Tools

Spotting estimation approaches differ among modeling systems and are summarized in Table 22 and Table 23.

Table 22. Non-Spatial Maximum Spotting Distance.

System	Maximum Spotting Distance from Torching Trees Nomograms	Behave
Inputs	Torching tree height Torching tree species Torching tree DBH Average tree height 10-foot windspeed	Torching tree height Torching tree species Torching tree DBH Downwind canopy height 20 foot windspeed Number of torching trees Ridge/valley horizontal distance Ridge/valley elevation difference Spotting source location
Spotting Process	Nomograms published in Rothermel (1983) are based on the model published by Albini (1979). Predictive mathematical model to calculate the maximum distance an ember will travel from a single firebrand lofted from a torching tree to calculate maximum distance.	Spotting from torching trees is based on nomograms with options for multiple torching trees and terrain adjustment (Albini 1979, Chase 1981, Rothermel 1983). Behave7 also calculates spotting from wind-driven surface fire (Albini 1983, Chase 1984, Morris 1987) and spotting from burning piles (Albini 1981). Spotting from crown fire was added in Behave7 (Albini et al. 2012).
Outputs	Maximum spotting distance from a single torching tree on flat ground is read from a nomogram.	Maximum spotting distance from torching trees (single or multiple) is displayed in a table and graph. Probability of ignition is calculated separately.
Assumption & Limitations	Gives maximum distance only. Assumes level terrain, single torching tree. Does not account for likelihood of trees torching, firebrand material availability, the number of spot fires, or the probability of ignition for that firebrand.	Gives maximum distance only. Accounts for terrain and number of torching trees. Number of torching trees is used to calculate firebrand lofting height, higher firebrands travel further, all else equal. Does not account for likelihood of trees torching, firebrand material availability, number of spot fires, or probability of ignition for a firebrand.

Table 23. Spatial Spotting Estimations.

System	FlamMap Basic, MTT, ANDIG	FARSITE	FSPro
Inputs	Canopy characteristics from spatial layers (LCP). Analysts specify FMC. Spotting tree species is always Grand Fir with a DBH of 20 cm (7.9 in.). Analyst sets spotting probability. Windspeed/direction is constant for entire burn period but can use gridded winds that are modified based on topography. Weather is static, though dead fuel moistures can be conditioned. Ignition delay is optional.	Canopy characteristics from spatial layers (LCP). Analysts specify FMC. Spotting tree species is always Grand Fir with DBH of 20 cm (7.9 in.). Analyst sets spotting probability. Distance and perimeter resolutions are determined from the LCP resolution; timestep is 60 minutes. Windspeed/direction input can be changed hourly. Forecast windspeed and direction are every 3 hours. Gridded winds can be applied.	Canopy characteristics from spatial layers (LCP). FMC always 100%. Spotting tree species is always Grand Fir with a DBH of 20 cm (7.9 in.). Analyst sets spotting probability for each fire danger (ERC) bin. Winds can be probabilistic, forecast or a combination. Weather can be probabilistic with forecast combination if desired. Ignition delay is optional.
Spotting Process	Fire behavior is calculated for each cell. Nodes are on a fixed grid equal to LCP spatial resolution. User-set spotting probability determines which predicted crown fire cells (and associated nodes) can produce spots. Those nodes generate a single ember with random zero to the max for that node. For cells predicted to have active or passive crown, 16 incrementally sized embers are lofted. Max ember distance & azimuth are calculated using canopy, CFB, elevation and all available wind information.	Vertices loft 16 incrementally sized embers. The number of vertices depends on perimeter and distance resolutions & timestep. Each ember goes through a random draw process based on user-set spotting probability. Ember distances and azimuth are based on canopy cover, CFB, elevation, winds, and species/DBH. Embers are tracked until they burnout or land. Ignores all embers that land within one cell form where the ember originated, as the main fire would eventually burn over these spot fires. A spotting grid overlaid onto the LCP	Same process as MTT.

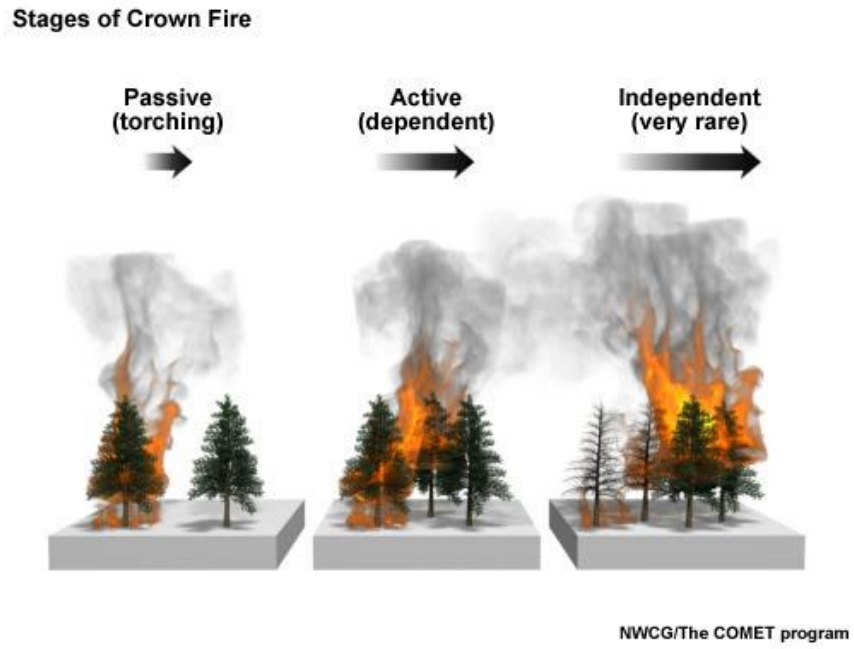
System	FlamMap Basic, MTT, ANDIG	FARSITE	FSPro
	Embers landing on unburnable or already burned substrate do not ignite. Embers landing on burnable substrate always ignite (Finney 2002).	allows the first spot that lands in a burnable fuel model to "seize" that cell so no other spots can land in that cell.	
Outputs	Models fire behavior for every cell simultaneously for a single scenario and uses MTT to calculate fastest fire travel paths. Embers are produced only with passive and active crown fire.	Simulates lofting and downwind travel of individual embers of different sizes from each vertex that exhibits passive or active crown fire.	Fire probability surface output that may or may not distinguish spot fire activity.
Assumptions & Limitations	Spotting only occurs when passive or active crown fire is modeled. Finney and Scott & Reinhardt methods are available for crown fire modeling. Each method calculates CFB differently. CFB and canopy cover are used to determine the "number of torching trees" 91 to 100 used in firebrand lofting height. More embers will be lofted at finer resolutions. Faster ROS will encounter more nodes, but the absolute number of nodes is static. One ember per node; less chance than in FARSITE that an ember will travel the maximum distance. NOTE: Users will probably want to set spotting probability higher in MTT than in FARSITE.	Grand Fir is used as the spotting tree species for the entire landscape. Distance resolution, perimeter resolution, and timestep are automated. The minimum spotting distance (set to the LCP resolution) essentially skips the first cell. For example, on a 60-meter LCP, no spots occur in the first 60-meters from the perimeter, but any viable embers that land beyond 60-meters can produce spot fires. NOTE: Users will probably want to set spotting probability no higher than 15% in FARSITE.	Same as MTT. Scott & Reinhardt crown fire methods are available. Each method calculates CFB differently. CFB and canopy cover are used to determine the number of torching trees used in firebrand lofting height. NOTE: Users will probably want to set spotting probability higher in FSPro than FARSITE. Calibrate FSPro with MTT because of the use of consistent spotting methods.

Crown Fire

Definitions

- **Crown Fraction Burned (CFB)** is a theoretical metric used to model and classify crown fire; it may be observable during post-fire burn severity assessments. It ranges from 0 to 1.
- **Passive crown fire (intermittent or persistent torching)** occurs when surface fire intensity is sufficient to ignite tree crowns (individually or in groups) but winds are insufficient to support sustained crown-to-crown propagation; CFB is typically between 0.10 and 0.90.
- **Active crown fire** occurs when surface and crown fire energies are linked; surface intensity ignites crowns and crown fire spread and intensity reinforce surface fire spread and intensity; CFB is typically greater than or equal to 0.90.
- **Independent crown fire** (rare) occurs when crown fuel loading and flammability alone sustain fire without surface fire contribution under ambient weather and wind conditions; CFB generally approaches 1.0.
- **Isolated tree torching** should not be treated as crown fire, although it may indicate future crown behavior during the burn; it usually results from local anomalies in surface fire behavior, terrain features, or brief wind gusts and corresponds to CFB less than 0.10.

Figure 81. Stages of crown fire.



Active Crown Fire Rate of Spread and Flame Length

Empirical crown fire models (e.g., Rothermel's formulations developed after the 1988 season and refined in 1991) estimate active crown fire ROS and fireline intensity based on fuel, wind, and slope conditions.

Graphs use season, slope, and 20-foot windspeed provide rough estimates of active crown fire-spread rates using the Rothermel crown fire model.

For Fuel Model 10 (FM10) and assuming a 20-foot windspeed of 20 mph, an empirical relationship converts surface ROS to active crown fire ROS; the empirical form is represented conceptually as:

$$ROS_{ActiveCrownFire} = 3.34 \times ROS_{FuelModel10}$$
(Assuming MFWS = 20-foot windspeed × 0.4)

The figures below show predicted active crown fire rates of spread for some common slope conditions; however, model outputs or empirical graphs can be used to quantify slope effects for a specific fuel and wind case.

Figure 82. In situations without slope, a lower ROS is expected for a given windspeed and fuel compared to slope conditions as seen in Figure 83 and Figure 84.

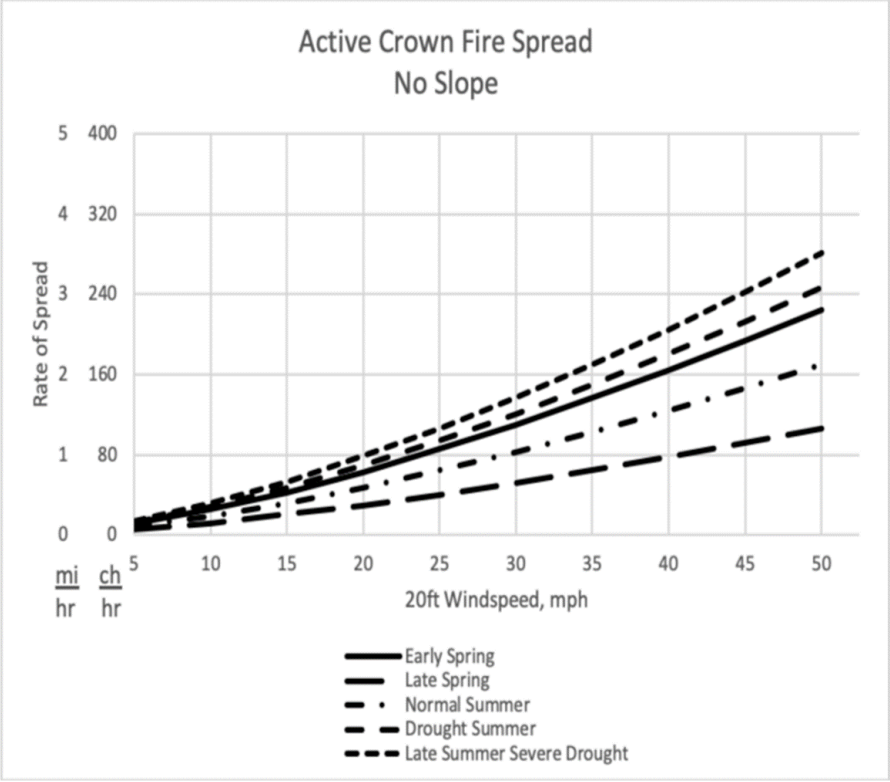


Figure 83. 50% slope: ROS increases relative to no slope due to uphill flame tilt and preheating.

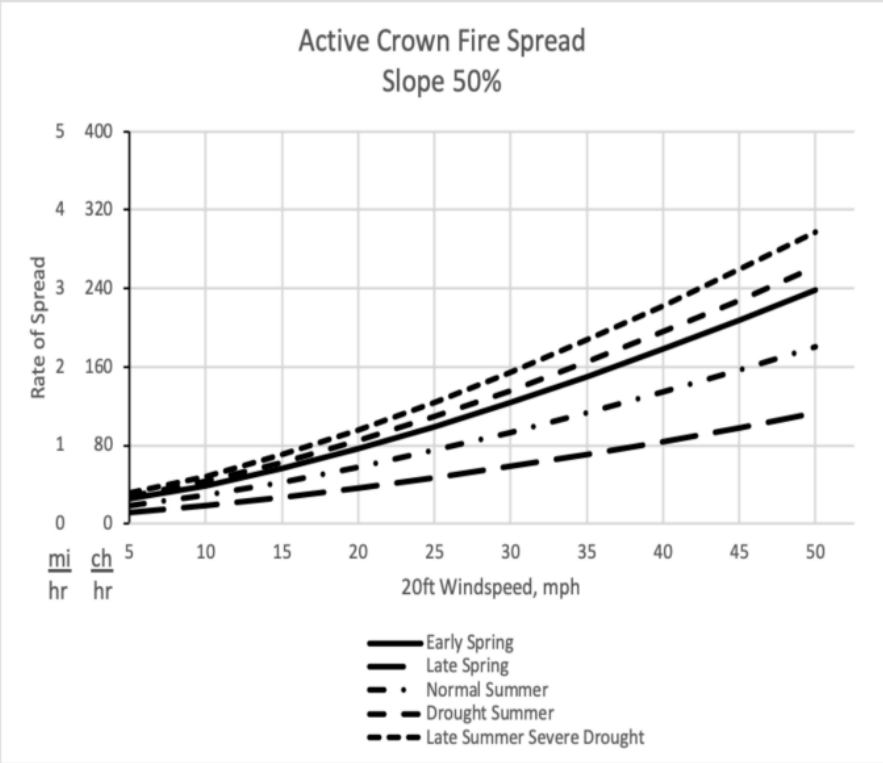
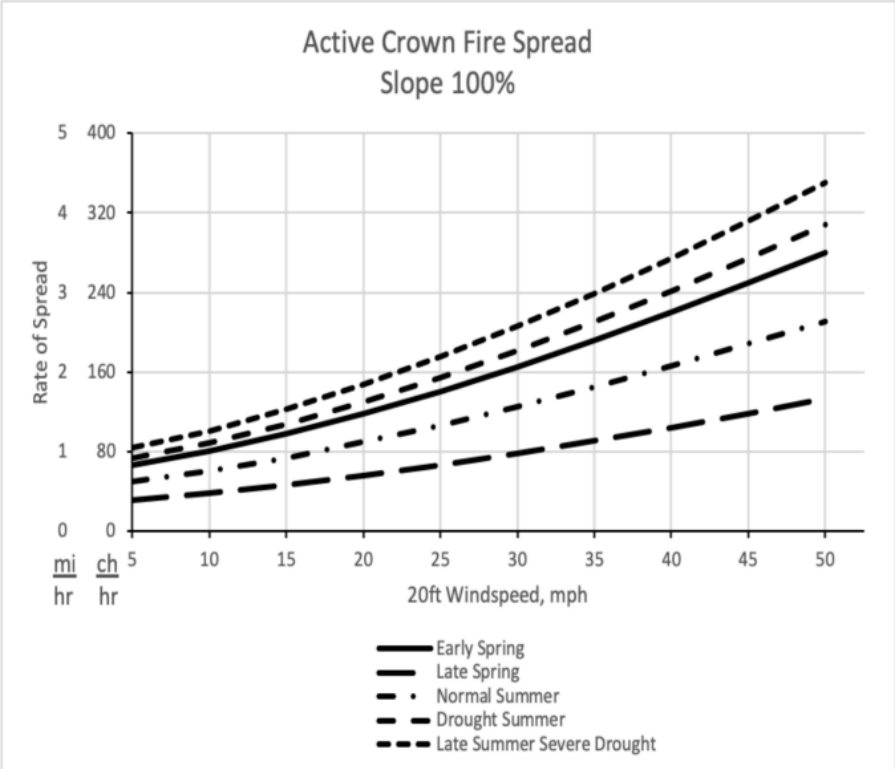


Figure 84. 100% slope: ROS increases further; slope effects can be large and non-linear.



Estimating Active Crown Fire Spread Rate using Surface Shrub Models

In fireline assessments it may be necessary to make quick estimates of crown fire spread from simple inputs. Simple lookup tables or graphs provide rough estimates. Anderson (1982), describing the original 13 surface fuel models, identified several shrub models that can be crosswalked to represent crown fire rates of spread in other forest types:

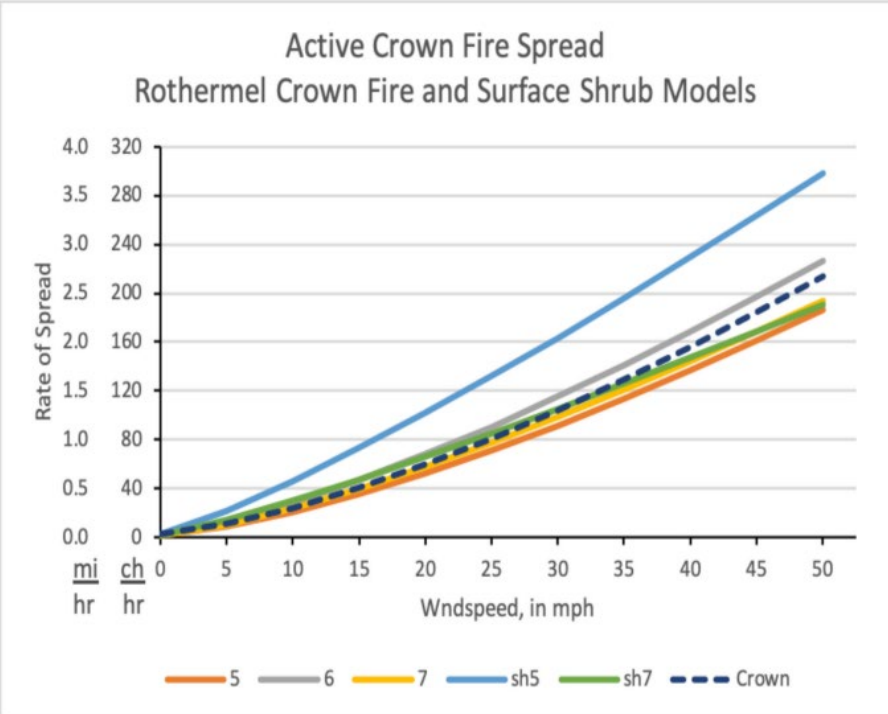
FM4 (Chaparral) – New Jersey Pine Barrens, Lake States jack pine.

FM6 (Dormant brush) – Alaska spruce taiga.

FM7 (Southern rough) – Alaska black spruce/shrub communities.

Fuel models **FM5** and **FM7** have been used similarly in spatial modeling for different situations. Figure 85 demonstrates similarity in spread rates produced by the Rothermel crown fire spread model and several surface shrub fuel models.

Figure 85. Crown fire rates of spread in shrub fuel models.



Caution: Using surface fuel models to represent crown fire behavior may not accurately calculate CFB or model increased spread due to passive crown fire (torching and spotting) in spatial analyses. It may also overestimate spread and intensity under moderate environmental conditions.

Crown Fire Initiation and Propagation

In *Conditions for the Start and Spread of Crown Fire*, Van Wagner (1977), identified crown fire as the interaction between separate fuel layers in forested areas. He described two processes and defined models for estimating their potential.

Crown Fire Initiation indicates the potential for a surface fire to ignite tree crowns and produce passive or active crown fire. Inputs include CBH and canopy FMC. The result is the threshold surface fire intensity required to begin canopy combustion.

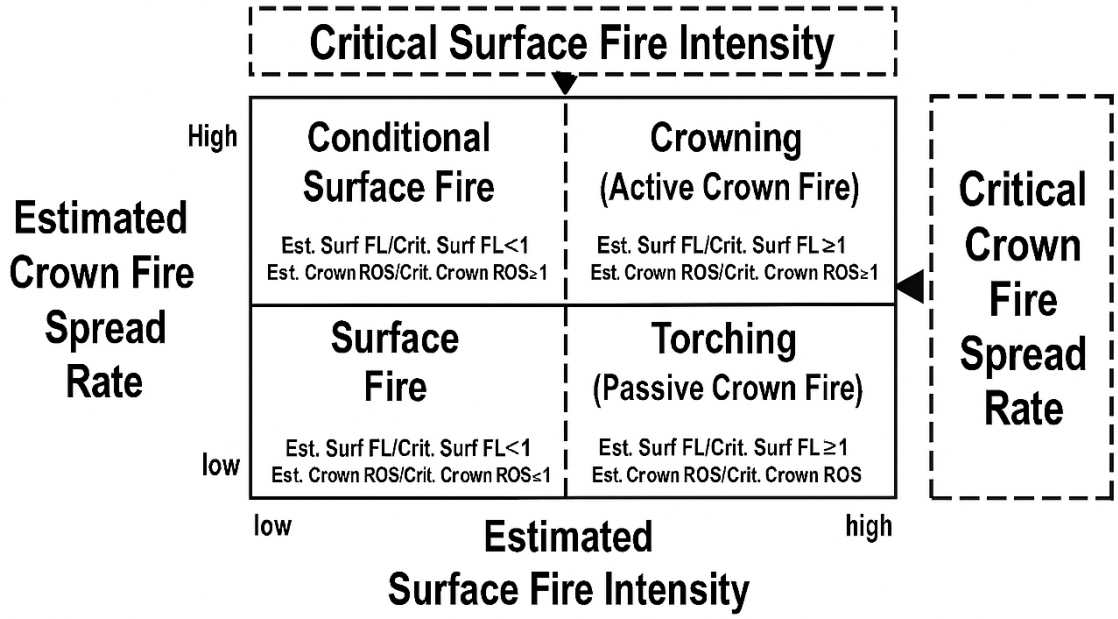
Active Crown Fire Propagation (crown spread) indicates the potential for continuous spread through the crown layer. Inputs include a characterization of canopy fuel density (single numeric value). The result is a threshold ROS required to sustain a solid crown flame with associated horizontal spread.

These models are coarse because they represent highly variable characteristics (CBH and canopy fuel density) as broad averages; their inputs often require adjustment during modeling. Together, initiation and propagation models estimate when fires will remain on the surface, produce torching or passive crown fire, or progress to active crown fire.

Linking Surface and Crown Fire Behavior

Use results from the Crown Fire Initiation and Propagation sections to compare against the surface and crown spread estimates produced under anticipated environmental factors.

Figure 86. Crown fire initiation inputs.



Crown Fire Initiation – Threshold Evaluation

Figure 87 and Figure 88 identify CBH and canopy FMC as critical inputs, resulting in a threshold surface fire intensity or flame length for evaluating crown fire initiation. Use either graph to estimate minimum surface fireline intensity (*I*, expressed as British Thermal Units [BTU] per foot per second or BTU/ft/s) or flame length (FL) that will support at least passive crown fire.

Assessment steps:

1. Determine current or expected surface fire intensity (I or FL) for the landscape.
2. Estimate CBH and FMC for the landscape being evaluated.
3. Use the appropriate graph to determine the threshold surface fire intensity or flame length.
4. If projected intensity exceeds the threshold, crown fire initiation is expected; the ratio of projected to threshold intensity provides a confidence value.

Figure 87. Threshold surface fire intensity for crown fire initiation.

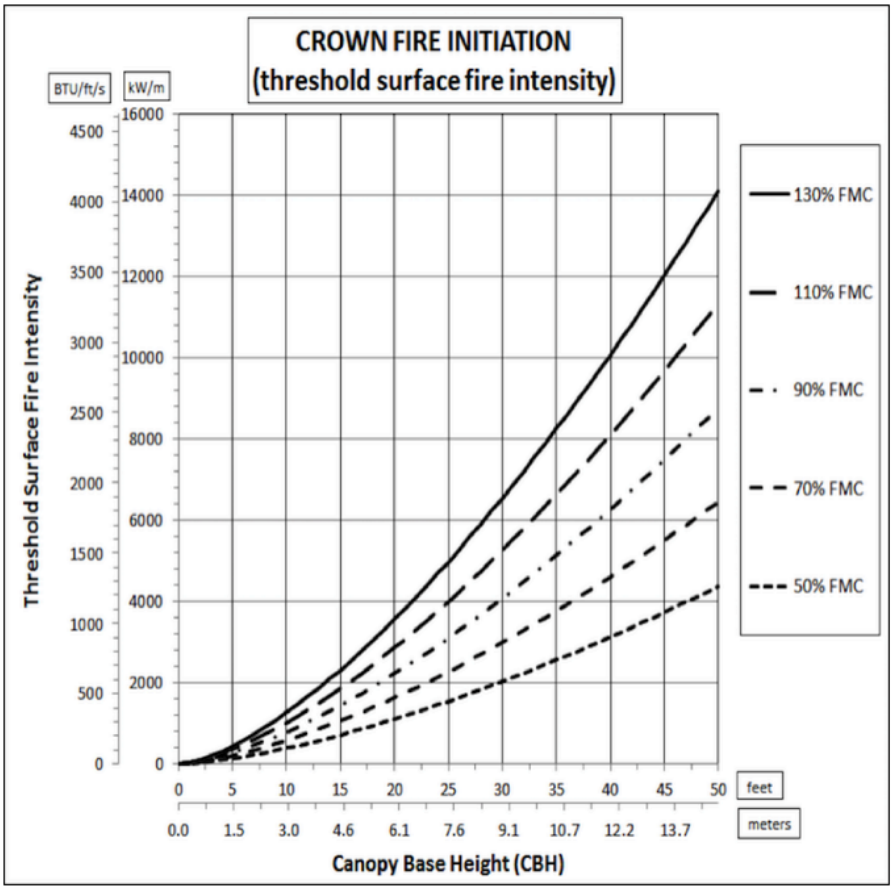
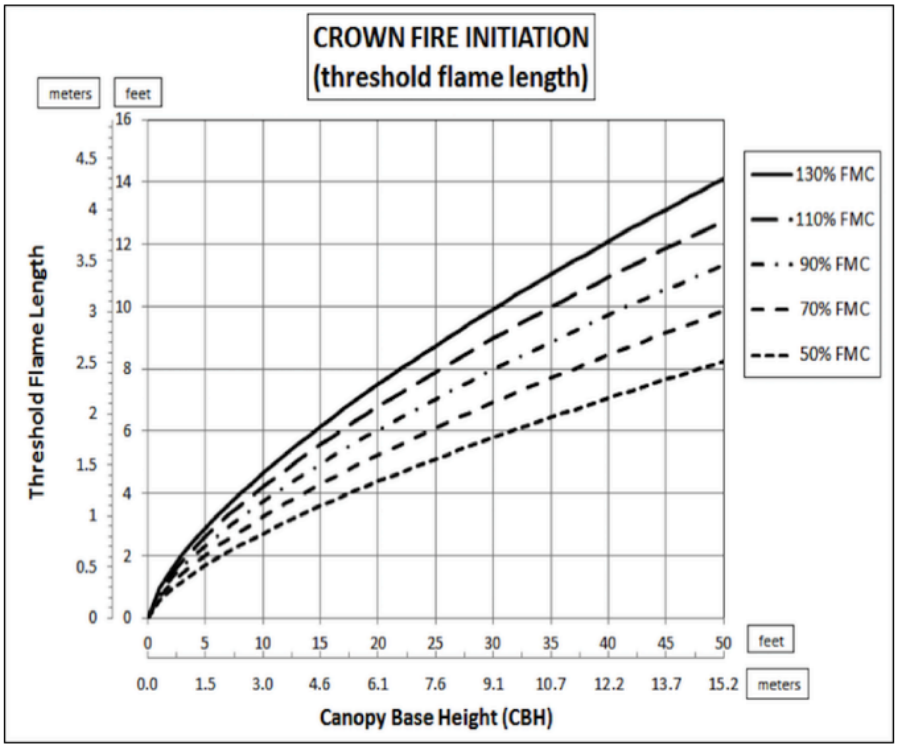


Figure 88. Threshold flame length for crown fire initiation.



Active Crown Fire Propagation and Crowning Index (CI)

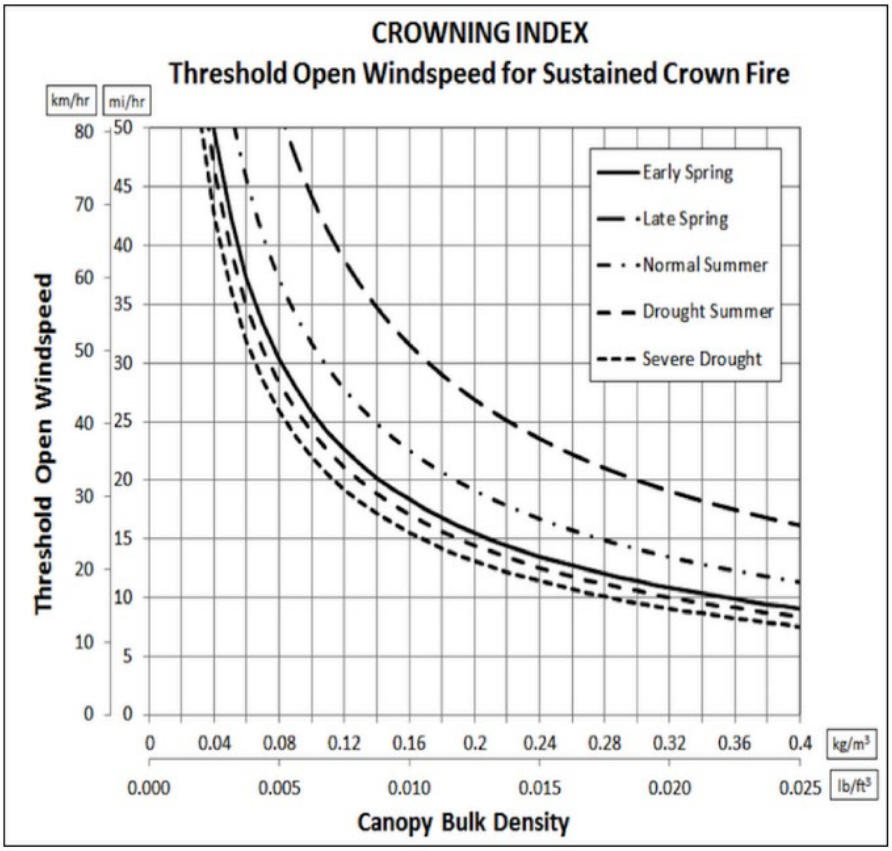
According to Van Wagner (1977), minimum threshold values for canopy bulk density (CBD) are necessary to sustain active crown fire at given spread rates. Because crown fuel is represented by a single model value, the threshold spread rate can be converted to a threshold windspeed or CI.

Threshold evaluation: For a given CBD, if observed or forecast 20-foot windspeed or projected active ROS exceeds the threshold values, sustained active crown fire is expected. The ratio of estimate to threshold provides a confidence measure.

Figure 89. Threshold CBD for crown fire initiation.

Canopy Bulk Density		Threshold Crown Fire Rate of Spread			
Kg/meter^3	Lb/ft^3	Meters/min	Feet/min	Miles/hr	Chains/hr
0.02	0.0012	150.0	492	5.59	447
0.04	0.0025	75.0	246	2.80	224
0.06	0.0037	50.0	164	1.86	149
0.08	0.0050	37.5	123	1.40	112
0.1	0.0062	30.0	98	1.12	89
0.12	0.0075	25.0	82	0.93	75
0.14	0.0087	21.4	70	0.80	64
0.16	0.0100	18.8	62	0.70	56
0.18	0.0112	16.7	55	0.62	50
0.2	0.0125	15.0	49	0.56	45
0.22	0.0137	13.6	45	0.51	41
0.24	0.0150	12.5	41	0.47	37
0.26	0.0162	11.5	38	0.43	34
0.28	0.0175	10.7	35	0.40	32
0.3	0.0187	10.0	33	0.37	30
0.32	0.0200	9.4	31	0.35	28
0.34	0.0212	8.8	29	0.33	26
0.36	0.0225	8.3	27	0.31	25
0.38	0.0237	7.9	26	0.29	24
0.4	0.0250	7.5	25	0.28	22

Figure 90. Threshold open windspeed for sustained crown fire.



Modeling Approaches (Finney; Scott & Reinhardt; Van Wagner)

All approaches identify thresholds for crown fire initiation and active crown fire spread using Van Wagner criteria, but they differ in implementation and outputs for:

- Final spread rates for passive and active crown fire
- CFB
- Final Fireline Intensity
- Fire type (Surface, Passive, Active)

Both the U.S. and CFFDRS systems implement the initiation and crown fire criteria where crown fire is anticipated. Table 24 and Table 25 compare the different ways the criteria are implemented.

Table 24. Comparison of crown fire model implementation in modeling systems.

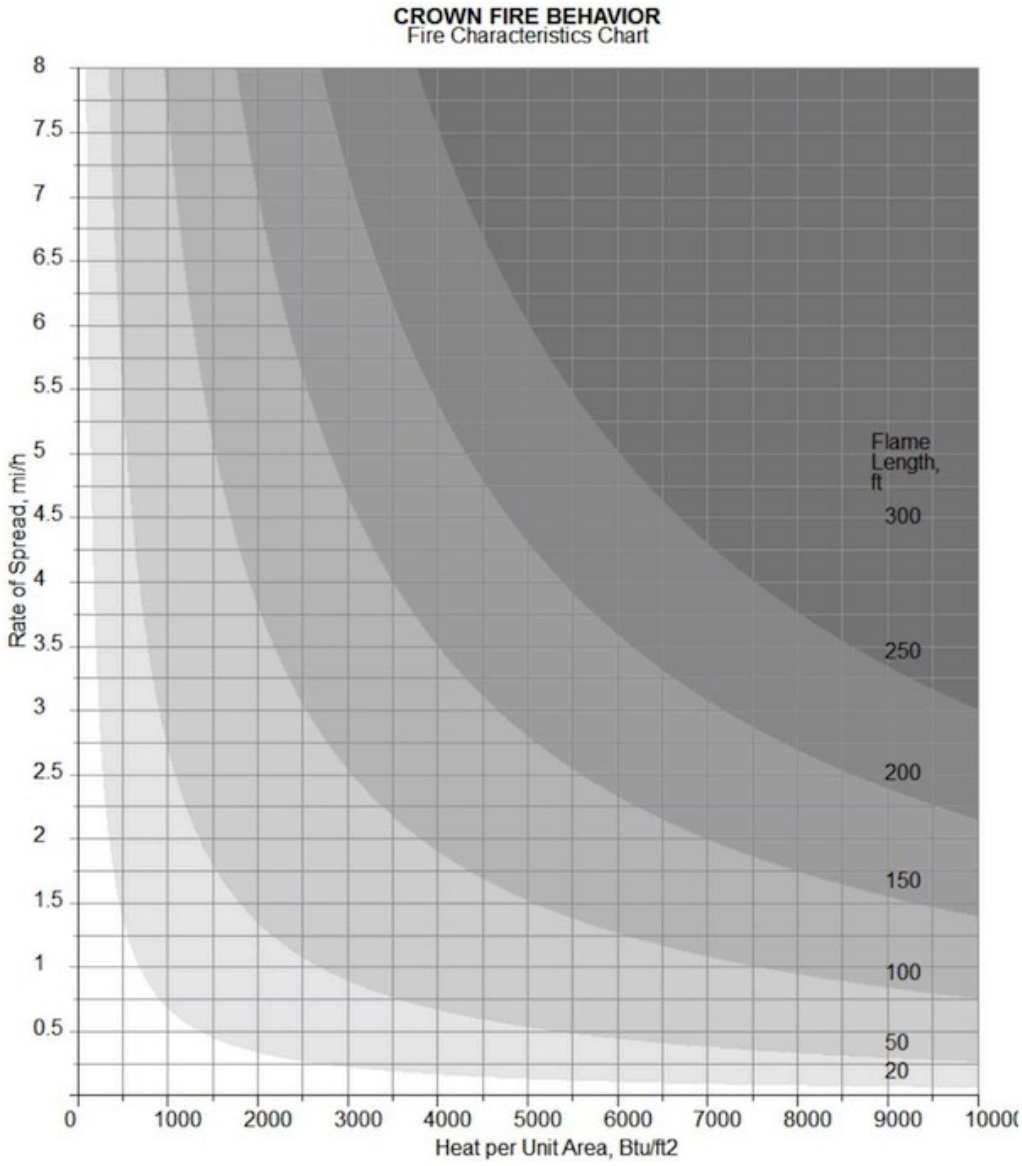
Fire Type	Canadian Forest Fire Behavior Prediction (CFFBP) Van Wagner (1977) Modeling System	Surface Fire Control Finney (1998) Modeling System	Crown Fire Control Scott and Reinhardt (2001) Modeling System
Surface Fire	Van Wagner (1977) Integrated, empirical model	Rothermel (1972)	Rothermel (1972)
Crown Fire Spread	Van Wagner (1977) Integrated, empirical model	Rothermel (1991)	Rothermel (1991)
Crown Fire (Torching) Initiation Threshold Spread Rate	Van Wagner (1977)	Van Wagner (1977)	Van Wagner (1977)
Active Crown Fire Propagation Threshold Spread Rate	Van Wagner (1977)	Van Wagner (1977)	Van Wagner (1977)

Table 25. Comparison of various crown fire modeling methods.

Methods Applied	CFFBP Van Wagner (1977)	Surface Fire Control Finney (1998)	Crown Fire Control Scott and Reinhardt (2001)
Crown Fraction Burned	Natural log function based on the difference between estimated spread rate and Initiation Threshold spread rate. 90% when estimated spread rate is 10m/min greater than Initiation Threshold spread rate.	Natural log function is based on the difference between the estimated surface spread rate and the Initiation Threshold rate. 0.9 when surface spread rate reaches 90% of difference between Initiation Threshold and Active Propagation threshold.	Proportionally intermediate between 0 (surface fire) and 1.0 (active Crown Fire) based on input windspeed and where it falls between windspeeds at Initiation Threshold and Active Propagation Threshold spread rates.
Passive Crown Fire Spread	Integrated within basic spread model for conifer & mixed wood fuel types. Fire type designated as Passive based on estimated CFB (see below).	Surface Fire spread rate plus any spotting spread.	Based on CFB. Proportionally intermediate between surface spread rate and Active Propagation threshold, based on crown fraction burned plus any spotting spread.
Final Spread Rate with Active Crown Fire	Integrated within basic spread model for conifer & mixedwood fuel types of Fire type designated as Passive based on estimated CFB (see below).	Proportionally intermediate between surface spread rate and Rothermel 1991 Model based on CFB. Generally, less than half of Rothermel model rate.	Spread Rate estimated directly from Rothermel 1991 crown fire spread model.
Fire Intensity	Byram (1959)	Byram (1959) for Surface Thomas (1963) for Crown	Byram (1959) for Surface Thomas (1963) for Crown
Fire Type: Surface, Passive, Active	Based on Crown Fraction Burned <0.1 = surface 0.1 to <0.9 = passive .9 to 1.0 = active	Based on Crown Fire Initiation and Propagation thresh olds (see above) Surface if ROS < Init. Criteria Active if ROS > Active Crit. Passive Between	Based on Crown Fire Initiation and Propagation thresh olds (see above) Surface if ROS < Init. Criteria Active if ROS > Active Crit. Passive Between

Interpreting Expected Crown Fire Behavior

Figure 91. Crown fire behavior characteristics chart.



Crown Fire Size and Shape

Figure 92. Crown fire area estimation for point source fires, in acres.

Crown Fire Area Estimation for Point Source Fires, in Acres

Spread Distance, in Miles	Maximum Sustained 20 ft Windspeed, in mph									
	10	15	20	25	30	35	40	45	50	60
	Area, in Acres									
0.25	14	11	9	8	7	6	5	5	4	4
0.5	56	44	36	30	26	23	21	19	17	15
1	223	175	144	122	106	94	84	76	69	59
1.5	503	393	323	274	238	210	188	171	156	133
2	894	699	574	487	423	374	335	303	277	237
2.5	1396	1093	898	762	661	584	524	474	433	370
3	2011	1574	1293	1097	952	842	754	683	624	532
3.5	2737	2142	1759	1493	1296	1146	1026	929	849	724
4	3574	2797	2298	1950	1693	1496	1340	1214	1109	946
4.5	4524	3540	2908	2468	2143	1894	1696	1536	1404	1198
5	5585	4371	3590	3046	2646	2338	2094	1897	1733	1478
5.5	6758	5289	4344	3686	3201	2829	2534	2295	2097	1789
6	8042	6294	5170	4387	3810	3367	3016	2731	2496	2129
8	14298	11190	9191	7799	6773	5985	5362	4856	4437	3785
10	22340	17484	14362	12186	10582	9352	8378	7587	6933	5914
12	32170	25176	20681	17547	15238	13466	12064	10926	9984	8516
14	43787	34268	28149	23884	20741	18329	16420	14871	13589	11591
16	57191	44758	36766	31195	27090	23940	21447	19423	17749	15139
18	72382	56647	46531	39481	34286	30300	27143	24583	22463	19160
20	89361	69935	57446	48742	42329	37407	33510	30349	27733	23654
22	108127	84621	69510	58978	51218	45262	40547	36722	33557	28622
24	128680	100706	82723	70189	60954	53866	48255	43703	39935	34062
30	201062	157353	129254	109670	95240	84165	75398	68285	62399	53222
35	273668	214175	175929	149273	129632	114559	102625	92944	84931	72441
40	357443	279738	229785	194969	169315	149627	134041	121396	110931	94617

Figure 93. Crown fire perimeter estimation for point source fires, in miles.

Crown Fire Perimeter Estimation for Point Source Fires, in Miles

Spread Distance, in Miles	Maximum Sustained 20 ft Windspeed, in mph									
	10	15	20	25	30	35	40	45	50	60
	Perimeter, In Miles									
0.25	1	1	1	0	0	0	0	0	0	0
0.5	1	1	1	1	1	1	1	1	1	1
1	2	2	2	2	2	2	2	2	2	2
1.5	3	3	3	3	3	3	3	3	3	3
2	5	4	4	4	4	4	4	4	4	4
2.5	6	5	5	5	5	5	5	5	4	4
3	7	6	6	6	6	6	5	5	5	5
3.5	8	7	7	7	7	7	6	6	6	6
4	9	8	8	8	8	7	7	7	7	7
4.5	10	10	9	9	9	8	8	8	8	8
5	11	11	10	10	10	9	9	9	9	9
5.5	12	12	11	11	10	10	10	10	10	10
6	14	13	12	12	11	11	11	11	11	11
8	18	17	16	16	15	15	15	14	14	14
10	23	21	20	20	19	19	18	18	18	18
12	27	25	24	23	23	22	22	22	21	21
14	32	30	28	27	27	26	26	25	25	25
16	36	34	32	31	30	30	29	29	29	28
18	41	38	36	35	34	34	33	33	32	32
20	45	42	40	39	38	37	37	36	36	35
22	50	47	44	43	42	41	40	40	39	39
24	54	51	48	47	46	45	44	43	43	42
30	68	64	61	59	57	56	55	54	54	53
35	79	74	71	68	67	65	64	63	63	61
40	91	85	81	78	76	75	73	72	71	70

Table 26. Fire length-to-width ratio for crown fires.

20-Foot Windspeed (mph)	Length-to-Width (x:1)
10	2.2
15	2.9
20	3.5
25	4.1
30	4.8
35	5.4
40	6
45	6.6
50	7.3
55	7.9
60	8.5
65	9.1

Fire Modeling with Spatial Tools

Evaluating Expected Fire Behavior

Understanding potential fire behavior and predicting fire spread requires a solid understanding of weather, fuels, topography, fuel moisture, and key fire behavior terminology—all of which are covered in this guide. Modeling systems and applications provide wildfire analysts with powerful tools for simulating fire potential across landscapes, but using them effectively requires analysts to: (1) identify and understand the problem to be solved, (2) choose an appropriate model, (3) select inputs thoughtfully, (4) interpret outputs correctly, and (5) validate results through field observation and discussions with local fire experts. Because no model can capture every real-world nuance, analysts must compare outputs with on-the-ground observations to judge accuracy.

Watch: *What Makes a Good Analyst* by Mark Finney (https://youtu.be/UIS27uMdfG8)

Spatial Fire Behavior Models

Spatial fire behavior models predict and analyze fire behavior, spread, and likelihood across a geographic area. They rely on spatial datasets describing fuels and topography (landscape file), and on wind, weather and fuel moisture inputs for constant or variable conditions. Models that simulate spread distance require an ignition point.

Spatial fire behavior models are accessed through various fire behavior applications (see Modeling Applications section). While model interfaces differ in location and name, they use the same underlying calculations to generate core outputs.

Table 27. Model names and purposes in the most used applications, FlamMap desktop, IFTDSS and WFDSS.

Model Name	Purpose	FlamMap Desktop	IFTDSS	WFDSS
FlamMap Basic	Estimates potential fire behavior at each cell independently	FlamMap Basic	Landscape Fire Behavior	N/A
Minimum Travel Time (MTT)	Simulates fire growth and spread from an ignition under constant weather	MTT (with set ignition[s])	MTT Fire Spread	N/A
Fire Area Simulator (FARSITE)	Simulates fire growth and spread from an ignition with variable weather	FARSITE	N/A	N/A
Fire Spread Probability (FSPro)	Estimates the probability of fire spread with variable weather	N/A	N/A	FSPro
Random Ignition (RANDIG)	Estimate the probability and intensity of fire under constant weather for a burn period	Conditional Burn Probability (MTT with random ignitions)	Landscape Burn Probability	N/A
Large Fire Simulator (FSim)	Estimate annualized probability and intensity of fire with variable weather for many fire seasons	N/A	N/A	N/A

FlamMap Basic

- Estimates potential fire behavior across a landscape for a single weather scenario.
- Calculates fire behavior independently for each cell for a single point in time and without contagion from neighboring cells.
- Uses a single wind speed, wind direction, and fuel moisture condition for the entire landscape.
- Dead fuel moistures may be conditioned using weather and landscape variables to create variation across the landscape.
- Generates gridded wind speed and direction using WindNinja to spatially vary winds based on topography and vegetation.
- Calculates flame length, ROS, fireline intensity, spotting direction/distance, and crown fire activity for each cell and provides grids of dead fuel moistures and wind when conditioning and WindNinja are used.

Minimum Travel Time (MTT)

- Simulates fire spread from known ignition source(s) for 1 to 3 burn periods under constant weather conditions, or until the entire landscape burns.
- Determines fire growth and behavior by identifying the set of pathways with minimum fire spread travel time from point, line, or polygon ignition sources. In theory, the results are identical to wave-front expansion method used in FARSITE with the exception that MTT holds all weather and fuel moisture conditions constant at the initialized conditions whereas FARSITE allows these conditions to vary over time during the simulation.
- Conditions dead fuel moistures using weather and landscape variables to create variation across the landscape for the initialized condition.
- Generates gridded wind speed and direction using WindNinja to spatially vary winds based on topography and vegetation.
- Typically uses a higher spotting probability for the same conditions than FARSITE (see https://owfflammaphelp62.firenet.gov/index.htm#t=LegacyFARSITE%2FTech_Spotting.htm&rhsearch=spotting&rhhlterm=spotting%20spot%20spots).
- Calculates arrival time, ROS, fireline intensity, influence grid, and flow paths (within the modeled burned area only), and ember landing locations.

FARSITE

- Use for detailed, time-based fire growth simulations of 1 to 5 days that incorporate shifting winds, temperatures, and relative humidities.
- Applies Huygens' principle to simulate a spreading elliptical wave of fire growth from nodes along the perimeter and uses inputs to simulate the next perimeter in the time step by drawing another series of ellipses.
- Dead fuel moistures may be conditioned using weather and landscape variables to create variation across the landscape for each time step in the simulation.
- Generates gridded wind speed and direction using WindNinja to spatially vary winds based on

topography and vegetation for each time step in the simulation.

- Uses a lower spotting probability than MTT for equivalent conditions (see https://owfflammaphelp62.firenet.gov/index.htm#t=LegacyFARSITE%2FTech_Spotting.htm&rhsearch=spotting&rhhlterm=spotting%20spot%20spots).
- Produces time-dependent fire growth including perimeters, spot fire locations, and fire behavior (ROS, FL, fireline intensity, crown fire) inside the modeled fire perimeter area only.

FSPro

- Use to model potential fire spread from 7 to 14 days when the weather forecast is no longer reliable.
- Uses multi-day MTT simulations to run thousands of fire spread scenarios under variable fuel moisture, wind, spotting, and burn period conditions (Monte Carlo simulations based on historic wind and weather observations binned by ERC percentiles) for a given ignition.
- Weather is constant within each burn period or day, with adjustments between periods or days.
- Fuel moisture conditioning is not available in FSPro.
- Gridded wind options are not available in FSPro within WFDSS.
- Spotting is implemented the same as in MTT.
- Provides multiple probabilistic outputs rather than deterministic outputs:
  - Burn Probability – Estimates the probability that fire will reach a given point on the landscape.
  - Average Arrival Time – An estimate of when fire is most likely to reach a given point on the landscape.
  - Average Flame Length – An average of all flame length values from all the simulations for a given point on the landscape.
  - Suppression Effect – An algorithm estimates the probability of fire spread if suppression is applied (Finney et al. 2025).

RANDIG

- Use in project-level planning to evaluate conditional burn probability and intensity, often to assess fuel treatment locations or alternatives.
- Runs thousands of MTT simulations under constant weather conditions. Ignitions can be randomly placed or read in from a list containing starting point location.
- Dead fuel moistures may be conditioned using weather and landscape variables to create variation across the landscape for the initialized condition.
- Generates gridded wind speed and direction using WindNinja to spatially vary winds based on topography and vegetation.
- Spotting is implemented the same as in MTT.
- Calculates burn probability, conditional flame length, fire perimeters, and flame length probability. In addition, FlamMap Basic model outputs can be calculated for the entire landscape.

FSim

- Not typically available for fire analysts to run, but results are available to download and use.
- Use for regional and national risk assessment to evaluate annualized burn probability and intensity.
- Uses MTT simulations to run thousands of fire years under variable weather derived from historic data. Ignitions can be randomly placed or read in from a list containing starting point location.
- Includes an optional suppression algorithm to "trim" fires based on ERC patterns.
- Calculates annual burn probability, conditional flame length, fire perimeters, and flame length probability.

Modeling Applications

Spatial

FlamMap Fire Mapping and Analysis

The FlamMap system, https://research.fs.usda.gov/firelab/projects/flammap, is a desktop fire analysis application used to simulate potential fire behavior characteristics—such as ROS, FL, and I—as well as fire growth and spread and conditional burn probabilities.

- Includes FlamMap Basic, FARSITE, MTT, RANDIG, and Spatial FOFEM (First Order Fire Effects Model).
- Includes a tool to download LANDFIRE landscapes for use with all the available models.
- Includes a tool to download weather stream data for use in FlamMap Basic, MTT, RANDIG and FARSITE.

It is important to consider how results will be shared and documented when not working in a cloud-based system that auto-saves results.

Interagency Fuel Treatment Decision Support System (IFTDSS)

IFTDSS, https://iftdss.firenet.gov/, is a web-based application designed to make fuel treatment planning and analysis more efficient and effective. IFTDSS provides access to data and models through one simple user interface regardless of a user's agency or organizational affiliation.

- Includes FlamMap Basic, MTT, and RANDIG.
- Scalable & Intuitive Interface: Intuitive, map-focused interface to support fuels management from writing burn plans to project-level National Environmental Policy Act (NEPA) assessments and large-scale wildfire risk assessments.
- Landscape Analysis: Visualize vegetation, fuels, and topography using national datasets like LANDFIRE.
- Treatment Comparison: Evaluate impacts of mechanical treatments and prescribed burns on fire behavior using step-by-step workflows.
- Downloadable maps, graphs, and summary reports.

- Robust support system: help center, forums, and ticketing.
- IFTDSS can be used to create and download landscapes for use in FlamMap.

Wildland Fire Decision Support System (WFDSS)

WFDSS, https://wfdss.firenet.gov/help/Content/Home.htm, is a web-based, interagency application designed to support risk-informed decision-making for wildland fire incidents.

- Includes FSPro.
- Scalable & Intuitive Interface: Designed to adapt to fires of varying complexity with a streamlined user experience.
- Map-Centric Design: Prioritizes spatial data visualization for faster, more informed decisions.
- Real-Time Data Integration: Uses live services to populate weather, fire location, and planning data.
- Incorporates new tools and data from RMA and Incident Strategic Alignment Process (ISAP).
- Uses ArcGIS Online (AGOL) for spatial data editing and sharing.
- WFDSS can be used to create and download landscapes for use in FlamMap.

WindNinja

WindNinja, https://research.fs.usda.gov/firelab/products/dataandtools/windninja, is a computer program that computes spatially varying wind fields for wildland fire and other applications requiring high resolution wind prediction in complex terrain. WindNinja can be run in three different modes depending on the application and available inputs:

- Using coarser resolution mesoscale weather model data from the U.S. NWS to forecast wind at future times.
- Using one or more surface wind measurements to build a wind field for the area.
- Using user-specified average surface wind speed and direction.

Non-Spatial

Behave

The Behave fire modeling system (https://www.frames.gov/behave/home) is a computer program that is used to predict fire behavior for any fire management application that involves modeling fire behavior, fire containment, and estimates of tree mortality. It requires site-specific information about the fuel, weather, and topography.

Behave is a point system that calculates fire behavior for an area (or point) with homogeneous fuels.

Alaska Fire Weather and Fire Behavior Prediction Tool

AKFF, https://akff.mesowest.org/tools/fbp/, displays fire danger and weather information but also provides a basic fire behavior calculator using the CFFDRS indices.

- The Fire Behavior Predication Calculator is like Behave and provides fire behavior outputs using FFMC, BUI, windspeed, and a CFFDRS fuel type.

Great Lakes Fire Weather and Fire Behavior Prediction Tool

GLFF, https://glff.mesowest.org/, displays fire danger and weather information but also provides a basic fire behavior calculator using the CFFDRS indices.

- The Fire Behavior Predication Calculator is like Behave and provides fire behavior outputs using FFMC, BUI, windspeed, and a CFFDRS fuel type.

The fire spread and intensity models have been configured in a variety of forms to address fire potential in different temporal and spatial configurations. Find more specific information about fire modeling inputs in the Verification, Calibration, and Validation section.

Mobile Apps

There are many mobile apps available to use on the fireline. Availability is agency specific.

- Wildland Toolkit https://peakviewsoftware.com/wildlandtoolkit.html)
- Wildfire Analyst Pocket Addition https://pocket.wildfireanalyst.com/
- WindNinja Mobile https://research.fs.usda.gov/firelab/products/dataandtools/windninja-mobile

Model Comparison

This table can help guide which model to use depending on the question being asked to support wildland fire decisions.

Table 28. Table comparison models and their best purpose.

	How will fire behavior change with the next big change in fire environment?	**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?**
Model	Behave7 or FlamMap Basic	MTT	FARSITE	FSPro
Best Use	Single Weather Scenario	Incident/Event	Detailed Growth	Risk to values
Processing Time	Minutes	Up to 1 hour	1 to 3 hours.	2 or more hours.
Forecast Horizon	Single Period	Up to 3 days if weather persistent	Up to 5 days based on forecast confidence	7 to 14 days
Weather	Single wind and fuel moisture scenario	Single wind and fuel moisture scenario over duration of run	Hourly, variable wind and fuel moisture over duration of run	Short-term forecast and climatology

	How will fire behavior change with the next big change in fire environment?	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?
Gridded Wind	No (Behave); Yes (FlamMap Basic, WindNinja)	Yes (WindNinja)	Yes (WindNinja)	No
Spotting	Yes Max Spot Distance (Behave7 and FlamMap Basic), Probability of Ignition (Behave7)	Yes Spotting Distance and Frequency (one ember per node; spotting probability value higher than FARSITE; start with 0.1 spotting probability)	Yes Spotting Distance and Frequency (16 embers per vertex; spotting probability value lower than MTT; start with 0.05)	Yes (like MTT)
Principal Output(s)	Not Spatial (Behave7); Spatial (FlamMap Basic) ROS. Flame Length.	Spatial Major flow paths and arrival times. Perimeters. Fire behavior grids.	Spatial Progression Perimeters	Spatial Probability Maps

RANDIG and FSim are also fire behavior models that are used primarily for wildland fire risk assessments. If using these models, help is available in the FlamMap or IFTDSS interface for RANDIG or seeking expert assistance for FSim.

Key Spatial Analysis Factors

Consider which analysis settings and inputs best represent real factors influencing current and expected fire behavior.

Landscape Characteristics

Spatial fire models (FlamMap Basic, MTT, FARSITE, RANDIG, FSPro and FSim) require a landscape file (LCP or GeoTIFF). Landscape files contain spatial data describing topography (elevation, slope, aspect), surface fuels (fire behavior fuel model), and tree canopy characteristics (cover, height, base height, and bulk density). LANDFIRE, https://landfire.gov/, is a common source for landscape data within the United States.

Landscape files should always be evaluated to ensure they represent the conditions being modeled. This can include confirming that recent fires, fuel treatments, or other major disturbances that altered surface fuels or tree canopies are reflected, and that fuels and canopy attributes align with field observations. If

the landscape is not representative, it must be edited. Edits can include modifying any layer within a landscape (e.g., fire behavior fuel model, canopy cover).

Note that changing a fire behavior fuel model only impacts surface fuels; canopy characteristics must be edited separately if needed. Editing tools are available in FlamMap, IFTDSS and WFDSS, or can be applied in a GIS.

Datum, Projections, and Coordinate Systems

1. The Mapping section in this document defines datums, projections, and coordinate systems. When working with data from multiple sources (local data, GPS files, Google Earth, LANDFIRE, WFDSS), ensure you understand the projection used and that a projection file (PRJ) is included in the shapefile. In unique situations, shapefiles or a GeoTIFF may need to be reprojected using ArcGIS or similar software: Open a new **ArcGIS** window (not an existing map) and add the desired shapefile or raster file. Adding the shapefile (or raster) sets the **Data Frame** coordinate system. If the dataset lacks a defined projection, assign one using **Define Projection** under **Projections and Transformations**.
2. Next, add the **shapefile** or **raster** that is stored in the undesired projection.
3. Open the **Analysis** Tab and select **Tools**.
4. Search for **Feature to Shapefile** (for shapes) or **Feature to Raster** (for grids).
5. In the Project window, select the dataset to be reprojected from **Input Dataset or Feature Class**. The Input Coordinate System should automatically default to its projection. If none is displayed, there is no PRJ file accompanying it. If the projection is known, it can be specified here.
6. Specify an output shapefile or raster grid under **Output Dataset or Feature Class**. Click on the button next to **Output Coordinate System**. In the **Spatial Reference Properties** window, click on the **Import** button. Navigate to and select the shapefile that is stored in the desired coordinate system. The new projection properties will load into the **Spatial Reference Properties** window. Click **OK** on the **Spatial Reference Properties** window.
7. Click **OK** in the **Project** window to create a new shapefile that is stored in the chosen UTM projection.

Most landscapes files LCP have been replaced by GeoTIFFs, which embed projection information For those still using LCP landscapes, issues are most common with geospatial data projections when using desktop software, such as FlamMap. FlamMap does not "know" what projection a project is using, and LCPs can be loaded without a projection file. To be clear, this does not mean that a projection doesn't exist for the Landscape—all Landscape files were created with a projection. Any outputs created will have the same projection as the Landscape that was used. Auxiliary files must be created in the same projection as the Landscape to display properly. Problems arise when that projection is unknown, making transformations among projections difficult. See the FlamMap Help section called "Projections" for more information, including helpful resources to troubleshoot projection problems. When PRJ files are included in geospatial data used in FlamMap, the software can automatically transform and re-project data.

Crown Fire Method

Spatial fire models determine resultant fire behavior depending on the fire type (surface, passive crown, active crown). In other words, you cannot choose to only model surface or crown fire spread or flame

lengths. However, the analyst can choose between two different methods for modeling crown fire growth and behavior:

- The **Finney method** produces less active crown fire and models passive crown fire with the spotting module only.
- The **Scott & Reinhardt method** produces more active crown fire and models an intermediate spread rate when passive crown fire is anticipated.

Table 29. Crown fire characteristic differences between the Finney (2004) and Scott and Reinhardt (2001) methods.

Crown Fire Characteristics	Finney Method (2004)	Scott and Reinhardt Method (2001)
Active crown fire ROS	ROS reduced to account for spotting modeled separately (based on Rothermel [1991]).	ROS not modified (based on Rothermel [1991]).
Passive crown fire ROS	Same as surface ROS	ROS scaled to CFB.
CBD inputs	CBD calculated with 15 foot running mean method should be approximately doubled.	Used CBD calculated with 15 foot running mean method.

Spotting

Estimating spread across barriers and from other random movements (e.g. rollout) generally requires a stochastic model that factors in frequency potential or probability. The spotting models implemented in spatial analyses provide a frequency modeling of the firebrand production and movement as well as the likelihood for a new start. See the Comparing Spotting Estimation Tools section to see specific differences.

Integrating Spotting Spread into Fire Growth Projections

Spatial fire models that include fire spread integrate the probability of spot fire ignition to produce spatially explicit spotting and ember landing locations. Both the spotting probability (likelihood of spotting occurring) and spotting delay (time from ember landing to fire spread) can be set in the models. Spotting methods vary among systems: MTT based models (MTT, RANDIG, FSPro, and FSim) typically require higher values than FARSITE.

Consider these adaptations for FSPro inputs:

- Assume a one-day analysis with forecasted ERC, wind speed, and wind direction favorable to spotting spread.
- Run several hundred to several thousand fires using the one-day scenario.
- Ensure the scenario is favorable for torching and spotting behavior; verify the analysis will at least produce passive crown fire.
- The number of fires drives variability in ember source location, ember size (and therefore transport distance), and applied probability.

Fuel Moistures

The spatial and temporal variation of fuel moistures are critical components when calculating fire behavior characteristics. Utilize the help sections of various fire modeling systems to ensure an

understanding of how fuel moistures are initialized and whether they can be conditioned over time and space. Additionally, be aware of how herbaceous fuel moisture affects fuel loading in dynamic fuel models.

Dead Fuel Moistures

Fine dead fuel loading and moisture generally determine day-to-day variability in flammability and responds to temperature, humidity, and precipitation. However, they may not reflect sufficient range in an analysis period to produce the observed variability.

In FEMS, dead fuel moistures (1-hour, 10-hour, 100-hour, 1000-hour) are calculated with the Nelson (2000) method. Field estimates typically use the Fosberg method based on environmental conditions and charts. Typically, the Nelson method results in higher (wetter) values for fine dead fuel moisture than the Fosberg method. Understanding what application uses which method is important, for example, WFDSS retrieves fuel moisture directly from FEMS. In addition, when dead fuels are conditioned in FlamMap or IFTDSS for FlamMap Basic, MTT, RANDIG, and/or FARSITE, the Nelson method is used with the data from a weather file.

Dead Fuel Moisture Conditioning

Initial dead fuel moistures rarely reflect the influences of slope, aspect, elevation, and canopy cover variability across a landscape. To remedy this, a conditioning period (typically 1 to 7 days with an associated weather stream) can be set to allow fuel moistures to represent the range of local site conditions before calculating fire behavior characteristics. Conditioning periods can be set in FlamMap Basic, MTT, RANDIG, and FARSITE, but not in FSPro or FSim. Live fuels are never conditioned, and their initial values remain constant across a landscape for an entire simulation in all modeling systems.

As the conditioning period progresses, the moisture content of the short time-lag finer fuels (1-hour, 10-hour) adjusts to the local site conditions. The Nelson (2010) model is used to vary initial moisture conditions based on the spatial variation in topography and canopy cover, the weather file, and the length of the conditioning period. Because the short time-lag fuels (1-hour, 10-hour) have the most influence on surface fire behavior, longer conditioning periods generally produce little change when weather variability is low. At the end of the conditioning period, the landscape will contain spatial variation in dead fuel moistures.

Key points:

- Fuel moisture conditioning applies to every pixel on the landscape; longer conditioning periods increase processing time.
- Cool and damp prior weather may condition fuels by raising fuel moisture to unburnable levels; consider modifying the past weather record, if needed.
- One to three days will usually condition fuels enough to affect fire behavior outputs. Long conditioning periods do not require exact initial dead fuel moisture values.
- Conditioning periods are typically recommended in mountainous terrain.
- A conditioning period is usually unnecessary unless canopy cover is variable in flat terrain with known fuel moisture.

Live Fuel Moistures

Live fuel-moisture levels can dramatically influence results in fuel models with a live woody or herbaceous fuel moisture component. In dynamic fuel models with live fuels loads, herbaceous fuel

moisture influences curing and load transfer of herbaceous fuel to dead fine fuel (see Scott and Burgan 2005, pp. 6 to 9). Curing is a critical cue to increasing fire potential. Live fuel-moisture levels should be set to simulate current conditions according to their flammability, when possible. Tips when modeling include:

- HFM drives curing levels and load transfer of herbaceous fuel to dead fine fuel in model with live fuel loads.
- Live fuel moistures may need to be manually set to simulate current conditions for one or more fire behavior fuel models when curing is a key driver of fire potential.
- NFDRS-derived live fuels should be validated against field observations, local fuel samples, or expert judgment.
- FEMS calculates live fuel moistures using the GSI (Jolly, 2005) method. These values usually require analyst adjustments to match observed fire behavior.

Foliar Moisture

Foliar moisture is used to determine crown fire initiation thresholds. Default values are 100% in all models and cannot be changed in FSPro or FSim. Adjust these values only when crown fire is significantly underrepresented in the other models.

Burn Period

The NWCG Glossary defines the burn period as that part of each 24-hour period when fires spread most rapidly; typically, this falls between 1000 hours to sundown.

When modeling fire behavior, the burn period is limited to when fire is actively spreading. This period may be shorter than the full window of observed activity. When considering the six categories of visual fire behavior (smoldering, creeping, running, spotting, torching, and flare up), all may occur within the 24-hour day. Field observers should be careful to report and describe their estimate of burn period accurately and purposefully and relate it to the type of fire observed:

- **Smoldering** may continue around the clock for most active fires but does not indicate an active burn period if observed at the head.
- **Creeping** may continue through the night but is generally transitional between smoldering and running fire behavior. Generally, it produces little overall fire spread and is not considered part of the burn period if observed at the head of the fire.
- **Running, torching, and spotting** commonly occur during the burn period when fire spread and overall growth are low to moderate. However, during peak hours, they may signal transitional fire behavior when more significant torching, spotting or crown fire occurs.

Burn period length varies day-to-day:

- Solar radiation heats fuels and reduces RH by warming the air which influences lower fuel moisture, creating conditions favorable for active burning. Slope heating is affected by the sun angle based on the time of year and latitude. Cloud cover and canopy shading can further reduce solar radiation.
- Inversions limit solar radiation below the inversion layer, while heating continues above it, potentially creating a marked difference in solar radiation effects on a slope.

- Fuel bed characteristics influence burn period as well. Moisture content of light fuels (e.g., grasses) respond more quickly to temperature and humidity changes.
- Diurnal fuel moisture trends are affected by the quality of nighttime humidity recovery, inversions, slope, aspect, and recent precipitation.
- Drought can influence the length of the burn period through the heat produced in the burning of heavy fuels.

During validation, tools and criteria are used to help identify the start and end of the burn period:

- Fireline observations are probably the most important source of information to determine burn period but may be incomplete and need correlation with other information.
- Diurnal trends in wind, weather, and fuel moisture can similarly show a periodicity that can suggest timing of active spread. Trend graphs are available at MesoWest, https://mesowest.utah.edu/.
- Fire progression maps suggest the overall daily spread around the fire, and with knowledge of weather conditions, fuels, slope, and spread direction, can be compared to modeled growth.
- Accurately characterizing the burn period duration as the number of hours or minutes in a day allows multi-day growth modeling and supports shortening the burn period when conditions warrant.
- MTT and RANDIG use constant weather (including wind) over the modeled burn period. Outside what-if or worst-case scenarios, burn periods often need adjustments to reflect actual fire spread.
- FARSITE tends to overpredict overnight fire spread; should shorten the burn period when modeling nighttime spread.
- FSPro burn period length differs due to ERC class. Higher ERC bins correspond to longer burn periods to simulate more aggressive burning conditions.

Burn Day Frequency

Most of the area burned across any management unit, geographic area, or ecological region occur on relatively few days over the life of the fires that are included in them. Burn day evaluation can help identify when conditions are receptive to significant fire spread and can indicate important transitions in fire behavior.

The concept recognizes that there are thresholds in environmental conditions below which significant spread is substantially limited, even when fire spread models estimate that spread will continue. A simple classification of burn days and non-burn days can greatly improve estimates of area burned. (Podur and Wotton, 2011). Within- and between-season variation can be substantial.

FSPro includes a threshold ERC for each analysis, below which no fire spread is modeled for the entire day (the WFDSS default is the 60th percentile ERC). FSPro outputs include a distribution of burn days by ERC class. Analysts can define daily environmental conditions most likely to support fire growth and use burn day outputs to assess whether too many or too few burn days are being modeled based on the season:

- If there are too many “no-burn days,” the lower bin threshold should be adjusted to a lower value.

- If there are too many burn days, reduce the number of bins so that the lowest threshold is higher.
- In Alaska, burn days often need to be reduced for accurate modeling. This is done by reducing the number of ERC Classes from five to three (Ziel, 2015).

Figure 94 illustrates Burnable Days, Nonburnable Days, and the proportions of ERC classes, which together help evaluate FSPro model performance.

Figure 94. Example FSPro statistical output.

Event Coverage Report (Excludes Forecasts)

All Days : 7500
Burnable Days : 7079
Nonburnable Days : 421
Completed Fires : 1500
Fires Duration : 7 days
Forecast Days : 2 days
Forecasts:

ERC	WDir	WSpd
52	200	9
53	150	6

ERC Class Distribution

MinERC	MaxERC	proportion of all days	10,000 Sim Distribution
61	250	0.08	0.07
53	61	0.23	0.22
43	53	0.41	0.42
38	43	0.15	0.15
33	38	0.08	0.08
< 33		0.06	0.05

Weather Observations and Forecasts

In most cases, forecast accuracy declines beyond 48 to 72 hours. Confidence in wind and precipitation elements are most important. Review the AFD for insight into the Confidence Horizon.

- MTT is suitable for 1 to 3 days given the static weather input.
- FARSITE hourly weather supports longer analysis periods, but its analysis period should only extend beyond 3 days when there is high confidence in the mid-range forecast.
- FSPro combines forecast and climatology; typically uses 1 to 3 days of forecast weather. Increase the use of forecast days only if the extended forecast confidence is unusually high. Critically examine the wind speed and direction in the forecast. A standard practice is to limit the forecast period to no more than one-third of the total analysis timeframe.

Wind Speed and Direction

Wind speed and wind direction data can come from various sources (e.g., RAWS, ASOS, AWOS).

With a sparse network of RAWS that provide hourly observations in many parts of the country, it may be difficult to find a weather station that accurately represents both wind speeds and directions for an analysis. Review observations and forecasts carefully for both variables and consider deploying an iRAWS in a more representative location if resources allow. ASOS and AWOS may be the only stations available near a fire. Their climatology often shows higher wind speeds than RAWS because they are sited in the open for purposes unrelated to fire danger. Always evaluate the location of any weather station used in a fire analysis.

- Analysts should view wind roses for ASOS and AWOS stations to understand directional patterns.
- This difference is often observed in NDFD forecast wind speeds as well.

In FARSITE, take time to edit wind speed and direction based on observations and fire analysis needs. Run comparisons using different RAWS and seek input from on-site IMETs when available.

In FSPro, the wind matrix must be generated from a RAWS. Even with siting standards, RAWS locations can strongly influence recorded wind speed and direction. Review wind rose information and verify that modeled wind aligns with observed fire spread. FSPro is heavily influenced by wind. Analysts can choose from:

- 10-minute average winds
- Gust wind speeds
- Or both, which typically increases reported wind speeds by approximately 50%

Verification of Analysis Outputs

Verification demonstrates that modeling assumptions have been correctly implemented. Though much of the verification occurs during model development, end users must evaluate large-scale factors to ensure that the range of variability used produces the range of results consistent with observed fire behavior. Learning regional preferences and default analysis inputs is an important first step.

Avoid over-calibration. Aim for accurate results for the right reasons—not just visually appealing outputs. Calibration involves estimating and adjusting model parameters and constants to improve the agreement between model output and observed fire growth.

- Evaluate the modeled fire type.
  - If crown fire is absent where expected, check the fuel model.
  - If passive crown fire is absent but the fuel model is representative, check the CBH and foliar moisture.
  - If active crown fire is absent but the fuel model is representative, check the CBD.
- Check surface fire intensity.
  - If surface fire intensity looks accurate, verify crown fire method, CBH, and CBD.
  - If surface fire intensity is inaccurate, check the fuel models.
- Evaluate spotting modeling.
  - If spotting occurs but does not travel far enough, check wind speed, spotting probability, stand height, or fuel model.
  - If spotting is inaccurate, check crown fire method, wind speed, spotting probability, and CBH.
- Check ROS.
  - If ROS is inaccurate but fuel models are representative, check weather and wind information, fuel moisture conditioning, and live fuel moistures.
  - If ROS is inaccurate, recheck the fuel models.

- Verify fire size and shape.
  - If fire shape is correct but size is inaccurate, check burning period.
  - If the fire shape is incorrect and the fuel models are homogeneous, check the wind information.
  - If the fuel model is not homogeneous, check the fuel model.

Other Considerations

Seasonal and Day-to-Day Factors

Adjust burn period or burning thresholds based on:

- Seasonal changes in daylight
- Drought assessments
- Daily variability

Live Fuel Moisture Trends

Herbaceous and woody fuel moisture should reflect:

- Seasonal factors and curing
- Drought conditions
- Identify most flammable fuel beds

Diurnal Weather-Related Inputs

Weather inputs such as temperature, RH, wind speed and direction, and cloud cover should be:

- Adjusted only within reasonable limits
- Preserved to ensure consistency between observed calibrations and forecast projections

Wind Speed and Direction

The most important factors in fire spread modeling:

- Ensure observed weather streams reflect actual fire spread.
- Confirm wind observations are appropriate for the situation.

Weather Observations and Forecasts

Modeling is only as good as observed and forecasted weather data quality. Limit model run durations based on very high forecast confidence:

- Critically examine wind speed and direction in the forecast to ensure accuracy and relevance to fire spread modeling.
- Ensure precipitation estimates represent fireline amounts accurately.
- Verify forecasted temperature and RH values are close to those observed.

Calibration Iterations

Calibration may require multiple rounds of refinement. Begin by adjusting large-scale constants, then refine smaller inputs including:

- Start with fuel model and canopy characteristics.
- Layers can require local edits due to disturbance, classification errors, and possibly seasonal trends.
- These fuel characteristics can significantly impact on outputs.
- Features that slow or stop fire spread are critical to capture, so ensure recent historical fires are accurately reflected in the landscape file.
- Barriers play a critical role in anticipating fire growth. Ensure they are mapped correctly and reflect real-world fire checks
- Crown fire method and spotting frequency are applied consistently with experience in particular landscapes. As these become standard, they become verified.

Verification, Calibration, and Validation

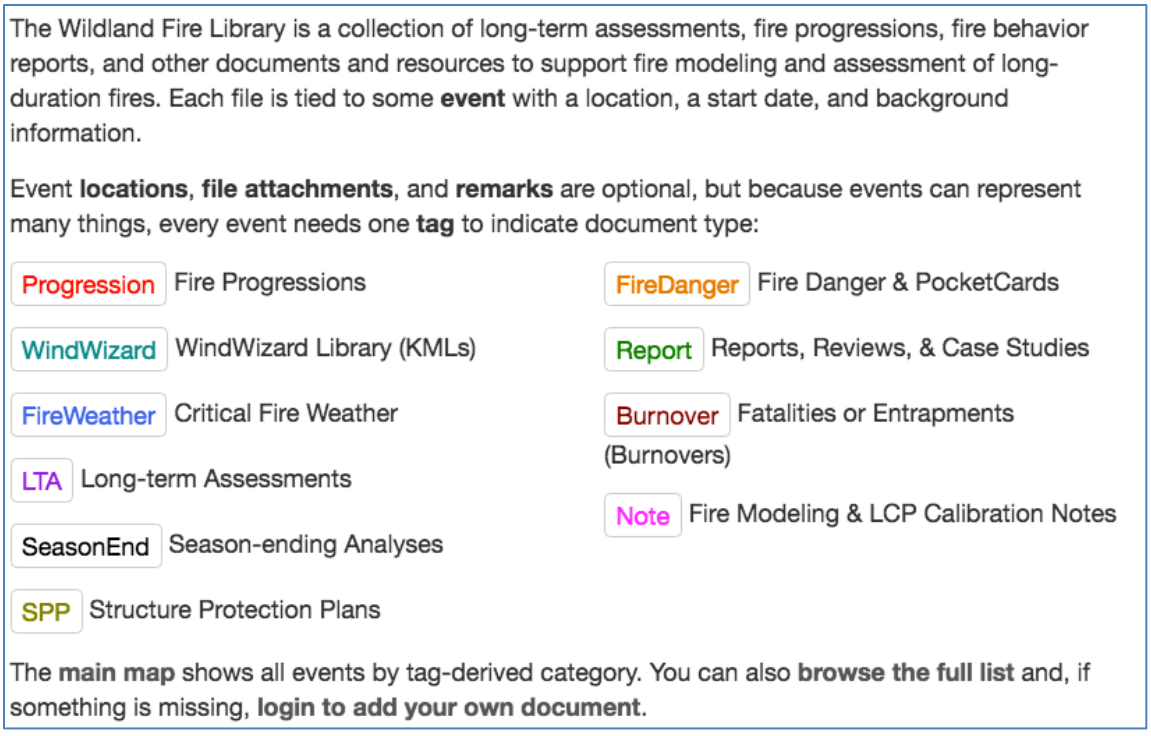
Reference Fire History

Evaluate reference fire history and other local knowledge for insight into current fire situation.

Wildland Fire Library

The Wildland Fire Library (within the RMA Dashboard, https://experience.arcgis.com/experience/f9d7f7f920494c3db43a23a8dffe4664/page/Fire-Library, provides a wide range of historic fire assessment products defined by location and date.

Figure 95. Information available from the Fire Library.



Near Real-Time Remote Sensing Products

- Many different IR platforms, including MODIS, VIIRS, and Hawkeye are available in EGP, https://egp.wildfire.gov/, in WFDSS, https://wfdss.firenet.gov/help/Content/Home.htm, in IFTDSS, https://iftdss.firenet.gov/iftdss2/#/landing, and on Google Earth.
- National Infrared Operations Interpreted Infrared Products (NIROPS), https://ftp.wildfire.gov/public/incident_specific_data/, may be produced to support incident specific needs. And are available in EGP and WFDSS.
- All satellite fire detection data is sourced from NASA FIRMS, https://firms.modaps.eosdis.nasa.gov/.
- Webcams and unmanned aerial systems (UAS or drones) may be assigned to specific incidents, or in some cases, available publicly from airports and other locations.

Evaluating, Finalizing and Sharing Analysis Results

Fire behavior modeling outputs need to be shared to the right people in time to support decision-making. Analysts must balance thoroughness with operational timelines—a perfect analysis that arrives too late is not useful. The following guidance helps ensure all aspects have been evaluated before marking an analysis as "complete" and sharing it.

Evaluation of Any Fire Behavior Analysis (FlamMap Basic, MTT, FARSITE, RANDIG, FSPro, FSim):

- Use tools like Google Earth to zoom out—away from a fire's immediate location—to evaluate broader terrain influences on wind patterns and sheltering, such as major drainages or valleys with extreme daytime heating.
- Identify other large fires burning upwind from the modeled fire that could shade out the local area.
- Verify fuel moistures are set realistically, especially live fuel moistures that are not conditioned in the model.
- Ensure the chosen Crown Fire Calculation Method is set as desired.
- If barrier files are used, confirm they are selected accurately and match the intended input. Barrier width must align with the landscape resolution diagonal (corner-to-corner) pixels will not stop fire spread.
- Evaluate the landscape file, especially if edit rules were applied, and confirm they are functioning as intended.
- Confirm the ignition file selected is correct, placed on ignitable fuels, and reflects any contained segments of the fire.
- Confirm spotting settings are appropriate for the analysis, noting that spotting implementation varies by model.
- If another analyst produced earlier runs, review their notes or request a briefing to understand prior adjustments.
- Critique the results. Review characteristics like flame length, spread rate, crown fire activity, fire size, and spread direction. Are the outputs intuitive? How will you explain them in a briefing?

Judgment and experience are important. If results are not intuitive, how will you explain or brief them to others?

- Document your process and conclusions in the analysis notes or personal notes that can be filed or shared.

Evaluating Deterministic Models (FlamMap Basic, MTT, FARSITE)

- Assess flame length, spread rate, and crown fire activity for reasonableness.
- Re-evaluate the weather inputs (wind direction, wind speed, RH, cloud cover, and precipitation).
- Evaluate past weather used to condition fuels, especially any rainfall that may not have occurred on the fire and prolonged unrealistic overnight temperature or RH recoveries.
- Check forecast weather inputs, including overnight temperature and RH recoveries, cloud cover, and precipitation.
- Verify timing and duration of wind and weather events that were set in the analysis, such as frontal passages.
- Reference Spot Weather forecasts, Incident Action Plan (IAP) forecasts, or other sources to ensure model inputs are aligned with other data.
- For MTT and FARSITE, assess whether the analysis duration aligns with forecast confidence.
- FlamMap and IFTDSS do not include built-in completion tasks—documentation must be created and shared separately (e.g., email, shared file) with decision-makers. The best practice when on an incident is to post results and written documentation where it will be archived with the other fire information. Screenshots or images can be uploaded into a WFDSS Decision.

Evaluating FSPro

- In the General section,
  - Check the Analysis Start Date, Number of Fires (1000 to 2000 for final runs), Number of Days (usually 7 to 14 days), Crown Fire Method, Ignition File, and Barrier File to confirm that they are as intended. Add Notes about rationale for the run set-up.
- In the Landscape section,
  - Check that all relevant rules have been applied correctly. Review the resulting LCP to ensure it displays as intended.
  - Confirm landscape extent, resolution, fuel model set, and data source. The extent should be large enough to contain the full FSPro footprint. In most cases, the 40 Fuel Models are preferred. Use the most recent LANDFIRE data when available.
  - Add Notes to document the rationale for inputs.
- In the Weather section,
  - Ensure ERC stations were properly selected for climatology and ERC Classes; typically use 10 to 20 years of data with a full-year filter.
  - Review the ERC Classes table and evaluate the fuel moistures, especially the Live Fuels, which often have incorrect defaults. Ensure intended edits for burn period or spotting are included.

- Limit forecast days to no more than one-third of total run days (e.g., maximum of 2 forecast days for a 7-day run). Too many forecast days results in too few probabilistic days, negating the unique advantage of FSPro. This will be evident by an output that is nearly entirely red with few rare events.
- Confirm that wind matrix start and end month and day are within a few weeks of the run start date (e.g. best practice is 2 weeks prior through 1 month after the start date).
- Review the wind rose and confirm it matches expected fire behavior and spread direction.
- Add Notes to document the rationale for inputs.

Assessing FSPro Results

- In the Run/Results section, check the Final Fire Size histogram and consider whether fire sizes are reasonable based on expected fire behavior and fire history.
- Download and extract the Complete Model Output.
  - Open the Event Coverage file. Review the Burnable vs Nonburnable Days and confirm they are realistic for the season (e.g., near 100% burnable days in mid-season, gradually decreasing as season-slowing events enter the climatological record).
  - If available, enter the Daily Acres into "WFDSS NG FSPro Histogram Builder.xlsx," a stand-alone Excel spreadsheet (on the Firenet Long Term Fire Analyst [LTAN] site) and review the Daily Acre Pivot Table.
- Evaluate the probability footprint—both high probability events and rare events—considering fire history, spotting potential, and natural barriers.
- To mark the analysis as complete, add any necessary Notes and set the Status to "Completed for Strategic Use" or "Completed for Operational Use." WFDSS-created outputs can be completed and shared in the WFDSS interface.

FSPro Daily Acres Pivot Table

This table (e.g., Figure 96) allows analysts to evaluate expected average acres per day, maximum and minimum acres, and no-burn days to evaluate whether model settings are reasonable.

Figure 96. Example of an FSPro daily acres pivot table.

Simulation Day	Average of Acres	Max of Acres	Min of Acres	No Burn Days
1	48.19	1,057.71	3.56	18
2	124.88	4,070.82	8.90	92
3	260.77	4,925.77	10.67	73
4	326.51	5,787.84	10.67	103
5	384.75	5,464.90	11.56	122
6	482.14	10,299.25	8.90	180
7	601.89	9,944.28	9.79	175

Assessing Need for Reanalysis

When an analysis has aged beyond its useful period or conditions have changed significantly, follow these steps to evaluate its relevance and accuracy:

- Review the weather forecast or climatology used in the original analysis and compare it to observed weather—especially wind, cloud cover, and precipitation—to assess how the forecast influenced the analysis. If the forecast used proved to be accurate, consider whether model settings need to be adjusted.
- In MTT and FARSITE, compare Observed vs. Predicted Fire Perimeters or daily variability, spotting behavior, and spread direction. Identify reasons for differences in size, shape, spotting, or direction of spread.
- In FlamMap Basic, MTT, and FARSITE, check whether the analysis accurately represents observed fire behavior (surface, spotting, crown fire). If not, go back to the calibration key.
- In FSPro, consider whether probability contours offered useful insight for strategy and prioritization. Consider: Did the rare event occur in the place it was predicted? Did spotting occur in real life and was it predicted? Is the fire size inside of the 80^{th} percentile? What factors influenced spread in reality, and how had the model been set up? Determine if any changes to the run set up are needed.
- Consider the burn period, crown fire model, ignition, and barrier files to determine whether they are responsible for significant differences between what was observed and predicted.
- Consider whether any seasonal factors are represented—such as extreme drought or a killing frost—and adjust inputs accordingly.
- Document your evaluation clearly in the analysis notes, including any adjustments made and rationale for updates or re-runs.

Documenting Your Work

Briefing Guidelines and Products

Fireline Briefing Checklist

- Fire Name, Location, and Map Orientation
  - Include nearby incidents and relevant geographic context.
- Terrain Influences
  - Highlight slope, aspect, elevation, and barriers.
- Fuel Types and Conditions
  - Note live vs. dead fuel moisture, curing levels.
- Fire Weather (Previous, Current, Expected)
  - Include: Wind speed and direction, Temperature, RH, Cloud cover, Significant weather events (e.g., frontal passages, thunderstorms).
- Fire Behavior (Previous, Current, Expected)
  - Identify: Times and thresholds for active behavior, Significant spread events, Flame length concerns.

Fire Behavior Forecast Form and Instructions

https://fs-prod-nwcg.s3.us-gov-west-1.amazonaws.com/s3fs-public/2023-06/437-fbforecast-formats.docx

Incident Briefing Outline Form and Instructions

https://fs-prod-nwcg.s3.us-gov-west-1.amazonaws.com/s3fs-public/2023-06/437-briefing-outline-formats.docx

Documentation Records

Incident Fire Behavior Narratives

The fire behavior narrative is an important document that captures key information for the incident. It is often included in the executive summary for the final incident package. It is a dynamic document that is driven by the incident, the fire behavior, and analyses performed.

This may include representative RAWS, assumptions/limitations specific to the incident, local observations, or other relevant information that assisted with your analysis and interpretation.

While there is no strict template, most incident narratives include the following components:

- Header Information – Incident Name, Period of Record, Author/Analyst Name
- Fire Weather and Climatology
  - Summary of weather conditions during the incident
  - Representative RAWS

    - Notable weather events (e.g., wind shifts, temperature extremes)
- Fuels and Fire Danger
    - Description of fuel types and conditions
    - Curing levels, fuel moisture, and fuel model classifications
    - Fire danger indices relevant to the incident
- Fire Behavior
    - Observed flame lengths, spread rates, and spotting
    - Transitions between surface, torching, and crown fire
    - Thresholds for active fire behavior
- Significant Analyses
    - Summary of modeling tools used (e.g., FSPro, MTT)
    - Key assumptions and limitations
    - Calibration and validation notes
- Chronology of Fire Behavior Events (as a timeline of major fire behavior developments)

Fire Behavior Documentation Package

This package is a comprehensive collection of inputs, outputs, analyses, and observations that support fire behavior forecasting and strategic recommendations during a wildland fire incident that is not documented elsewhere. E-Doc. Boxes are the norm with less paper documents being submitted.

Include:

- Fire Behavior inputs and outputs not completed in a system of record.
- Worksheets (filled out with times and dates).
- Assumptions.
- Index of runs and names.
- Maps that are not documented by GIS, such as fuels maps or hand drawn projections.
- Unit logs (e.g., ICS-214).
- Briefing outlines summarizing provided information.
- Fire behavior forecasts (validated), with updates or supplements.
- Specific events with timeframes.
- Significant events.
- Unforecasted weather events and resulting impacts on fire behavior.
- Special or specific operational plans.
- Special prescriptions.
- Long-range forecasts.

- Reference materials used during the assignment.
- Sources of data and rationale for inclusion/exclusion.
- Risks assessed, consequences, and mitigation strategies.
- Notification details (who/when/how) for changes in predictions.
- Fire Behavior Chronology and Narrative

Do not include:

- Fire behavior forecasts documented in the IAP where no changes occurred.
- Pen and ink changes.
- WFDSS is a system of record and completed runs do not need to be included in the documentation package.

Analysis completed in Behave, FlamMap, or other fire behavior calculators do need to be documented. The package must:

- Support and explain the rationale behind recommendations.
- Address conflicting information and how it was resolved.
- Include incident name, date/time, analyst name, and other pertinent metadata.
- Be formatted for preservation under national documentation standards.

Electronic Fire Behavior Documentation

Any or all Fire Behavior Documentation may be produced and submitted in electronic format.

- Ensure, if the documentation is a mix of paper and electronic records, the file naming conventions are consistent and documents are organized in a meaningful way.
- Ensure format is common and readily readable by other users.
- Save highly formatted documents in original and PDF format.
- Document desktop software name, vendor, and version. Consider including the install file.
- Integrate files into the incident digital record and keep a copy of your submissions.
- Organize files meaningfully for easy access.

Fire Danger

Fire Danger ratings are an effective part of daily risk rating and operational preparedness for fire management agencies across the world. Chapter 10 – Preparedness of the Interagency Standards for Fire and Fire Aviation Operations, Red Book, https://www.nifc.gov/standards/guides/red-book, outlines processes and resources applied in the development of standard Fire Danger Operating Plans in the United States. Fire Danger Operating Plans include:

Specification of fire danger ratings.

Identification of climatological thresholds for administrative purposes. Default thresholds include the 90th and 97th percentile values for key indices in the applied system. BLM (Department of Interior) uses the 80th and 95th percentiles instead.

Communication of those danger ratings, including both internal and external forms.

Links to Fire Danger resources:

- NFDRS PocketCards https://www.wildfire.gov/application/pocket-cards
- FEMS https://www.wildfire.gov/application/fems
- National Interagency Coordination Center Predictive Services https://www.nifc.gov/nicc/predictive-services
- NWCG Fire Danger Subcommittee https://www.nwcg.gov/committee/fire-danger-subcommittee

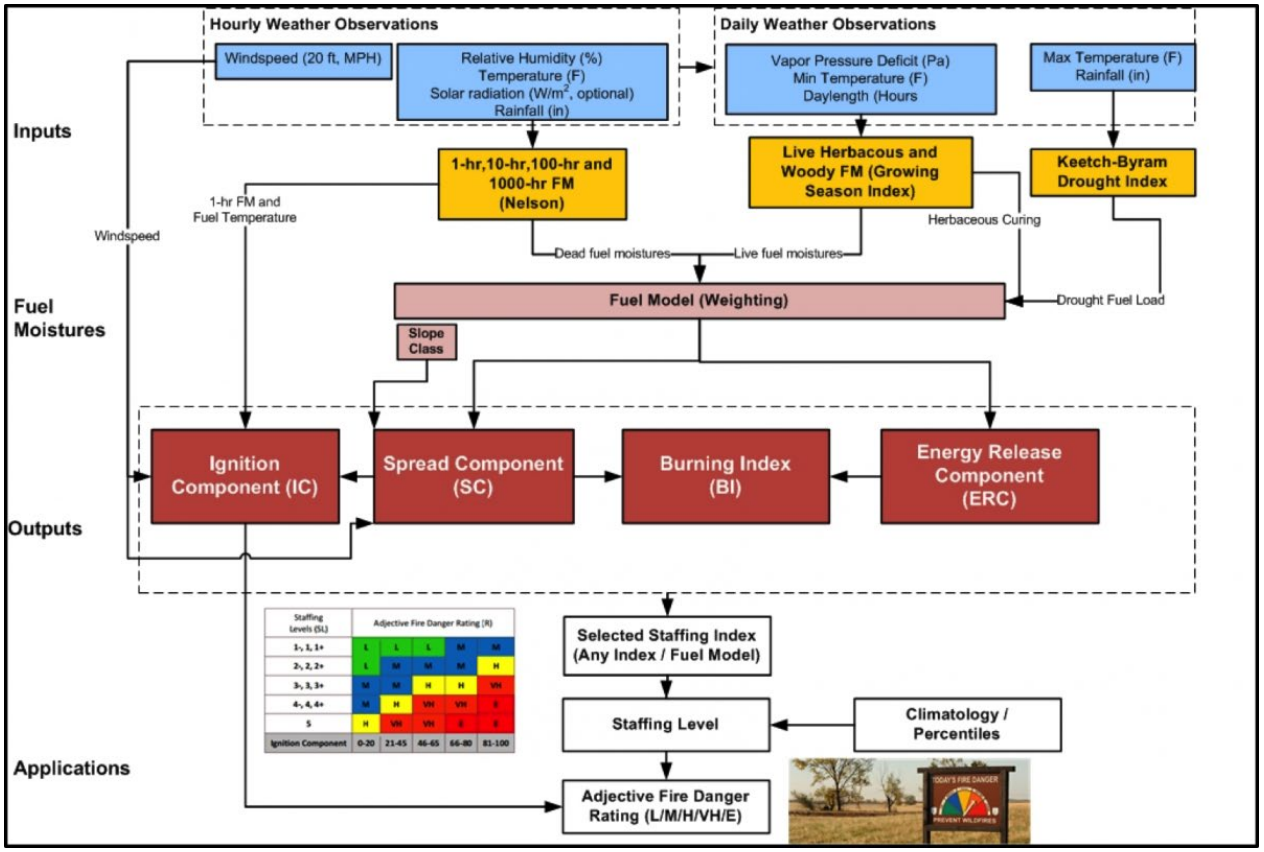
A variety of fire weather systems are applied in danger rating around the United States, though the two primary systems are the NFDRS and the Canadian Forest Fire Danger Rating System.

U.S. National Fire Danger Rating System (NFDRS)

First introduced in 1964, NFDRS has been updated in 1972, 1978, 1988, and 2016 to integrate newer science and improved processing.

NFDRS Structure

Figure 97. NFDRS V4 structure chart.



NFDRS Fuel Models

Figure 98. NFDRS Fuel Models.

NFDRS Fuel Model	Based on Scott and Burgan..	Fuel Loading (tons ac^{-1})							Surface Area to Volume Ratio (ft^{-1})						Fuel Heat Content (BTU lb^{-1})	Moisture of Extinction (%)	Fuel Bed Depth (ft)	Wind Adjustment Factor (DIM)	Maximum SC
		1-hr	10-hr	100-hr	1000-hr	Herbaceous	Woody	Drought	1-hr	10-hr	100-hr	1000-hr	Herbaceous	Woody					
V	GR2	0.1	0	0	0	1	0	0	2,000	109	30	8	2,000	1,500	8,000	15	1	0.6	108
W	GS2	0.5	0.5	0	0	0.6	1	1								15	1.5	0.4	62
X	SH9	4.5	2.45	0	0	1.55	7	2.5								25	4.4	0.4	104
Y	TL1	2.5	2.2	3.6	10.16	0	0	5								25	0.6	0.2	5
Z	SB2	4.5	4.25	4	4	0	0	7								25	1	0.4	19

Note 1: *Drought fuel load is added proportionally to all four dead fuel load classes.*
Note 2: *The Moisture of Extinction becomes 40% to represent humid areas when the "humid" box is checked in the Station Catalog.*

Annual versus Perennial Grass

Fine fuel loading associated with annual grasses shifts from live to dead and remains there for the duration of the season. For perennial grasses, the shift from live to dead is much slower and may even stop or reverse if the right combinations of temperature and precipitation occur during the season. This setting has been set to Perennial for all station catalogs.

Slope Class Setting

Slope class has been standardized to Slope Class 1, 0 to 25%, for Station catalogs from FEMS.

NFDRS System Inputs and Outputs

Observations and Forecasts

Fire Weather Observations are collected and maintained according to standards established in the *NWCG Standards for Fire Weather Stations*, PMS 426-3, https://www.nwcg.gov/publications/pms426-3.

Primary System Components and Indices

Ignition Component (IC)

The IC is a rating of the probability that a firebrand will cause a fire requiring suppression action. Expressed as a probability from 0 to 100, an IC of 100 means that every firebrand that contacts a receptive fuel bed will cause an actionable fire, while an IC of zero means none will.

Note the emphasis is on fires that require action—not just ignition.

Spread Component (SC)

The SC is a rating of the forward ROS of a head fire. As Deeming, et al (1977), states, “the SC is numerically equal to the theoretical ideal ROS expressed in feet per minute. Highly variable from day-to-day, the SC is expressed on an open-ended scale; thus, it has no upper limit.”

Energy Release Component (ERC)

The ERC is a number related to the available energy (BTU per square foot) within the flaming front at the head of a fire. Daily variations in ERC are due to changes in moisture content of the various fuels present, both live and dead. Since this number represents the potential heat release per unit area in the flaming zone, it can provide guidance to several important fire activities. It may also be considered a composite fuel moisture value as it reflects the contribution that all live and dead fuels offer to potential fire intensity. ERC is a cumulative, or buildup, index. As live fuels cure and dead fuels dry, ERC values rise, making it a strong indicator of drought conditions. The scale is open-ended, or unlimited and, as with other NFDRS components, is relative. For example, an ERC value of 24 represents twice the potential heat release resulting in an ERC value of 12.

As a reflection of its composite fuel moisture nature, the ERC becomes a relatively stable evaluation tool for planning decisions that might need to be made 24 to 72 hours ahead of an expected fire decision or action. Since wind does not influence the ERC calculation, the daily variation will be relatively small. The 1000-hour time-lag fuel moisture (TLFM) is a primary entry into the ERC calculation through its effect on both living and dead fuel moisture inputs. There may be a tendency to use the 1000-hour TLFM as a separate index for drought considerations.

Note that any use of the 1000-hour TLFM as a separate index must be preceded by an analysis of historical fire weather data to identify critical levels of 1000-hour TLFM. A better tool for measurement of drought conditions is the ERC since it considers both dead and live fuel moistures.

Burning Index (BI)

The BI is a measure of the contribution of fire behavior to the effort of containing a fire. BI is derived from a combination of Spread and ERCs, producing a numeric value closely related to the flame length (in feet) multiplied by ten. The open-ended scale allows the BI range to adequately define fire potential, even in times of low to moderate fire danger.

BI values represent the upper limit of expected fire behavior within the rating area. In other words, if a fire occurs in the worst fuel, weather, and topography conditions of the rating area, then BI values indicate expected fireline intensities and flame length.

Although flame length is correlated with difficulty of control, containment is more directly related to fireline intensity—the rate of heat release per unit length of fireline (Byram 1959). As BI increases, the difficulty of control grows at a rate greater than the increase in BI itself, though flame length remains a useful indicator because of its connection to intensity.

Keetch-Byram Drought Index (KBDI)

The KBDI is not an NFDRS output but is often displayed by the processors used to calculate NFDRS outputs. It is a stand-alone index that measures the effects of seasonal drought on fire potential. KBDI values estimate of the amount of precipitation (in hundredths of inches) needed to bring the upper eight inches of soil to saturation. A value of zero represents complete soil saturation, while the maximum KBDI value of 800 indicates extreme drought requiring 8.00 inches of precipitation to return to saturation.

As KBDI increases, vegetation experiences increased stress due to moisture deficiency, and live fuels may become part of the dead fuel load through desiccation. More of the litter and duff layer becomes available fuel at higher index values.

When using the 1978 NFDRS fuel models, KBDI values can supplement NFDRS outputs to aid decision-making. For the modified 1988 NFDRS fuel models, KBDI values are a required input to calculate daily NFDRS outputs.

Since most fire danger stations do not begin operation when soils are saturated, an initial KBDI value must be estimated when daily observations begin. Technical documentation describes methods to estimate the initiating value and is included in the attached reference list. Most processors include a default initiation value of 100.

Fire Danger PocketCard

Wildland Fire Application Information Portal (WFAIP), https://www.wildfire.gov/application/pocket-cards, provides access to background, instructions, standards, and approved cards throughout the U.S.

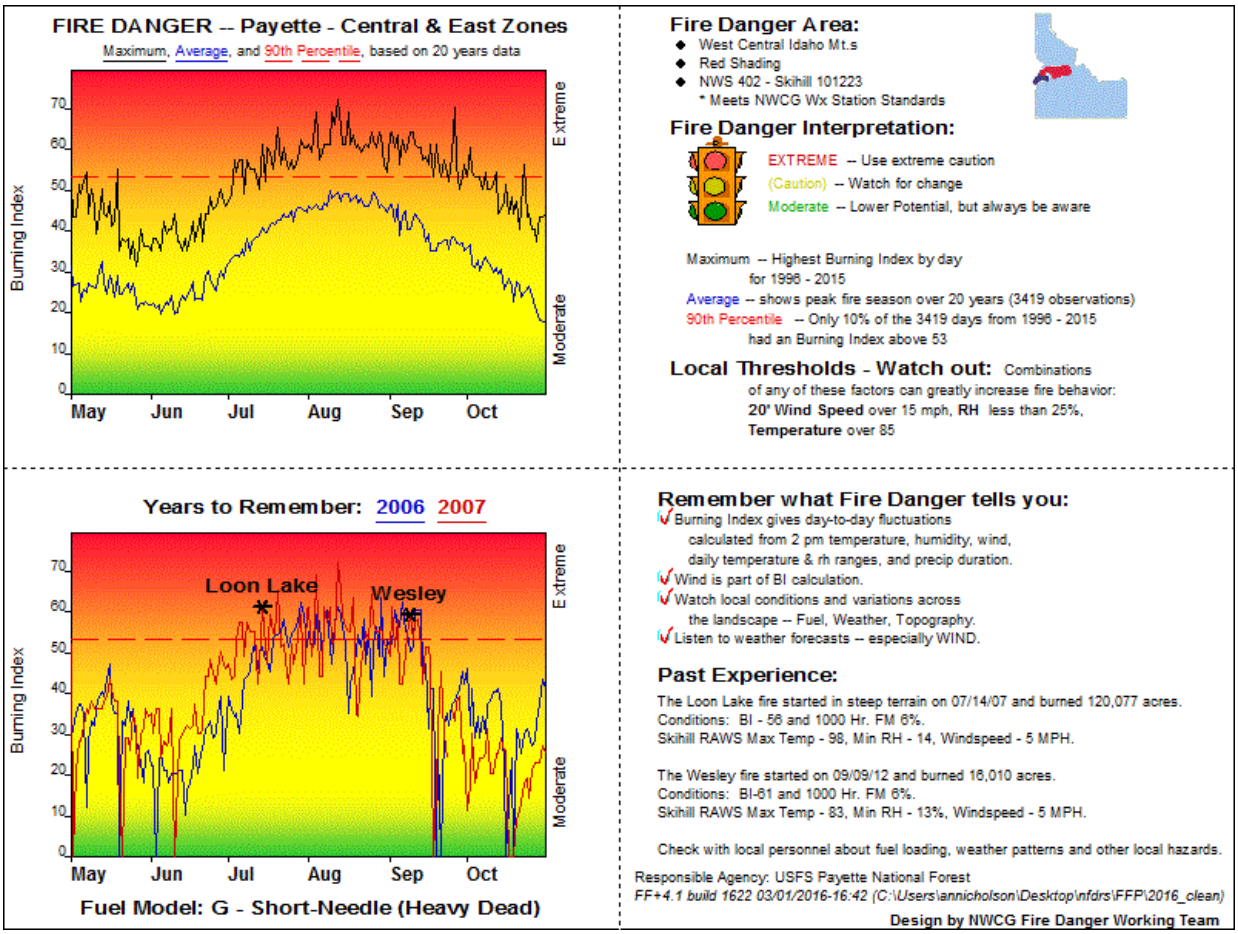
Fire Danger PocketCard provides a format for interpreting and communicating key index values provided by the NFDRS. The objective is to lead to greater awareness of fire danger and subsequently increased firefighter safety. PocketCard provides a description of seasonal changes in fire danger in a local area useful to both local and out-of-area firefighters.

PocketCards have important day-to-day pre-suppression uses. When the morning and afternoon weather is read each day, the actual and predicted indices are announced. Firefighters can reference their card

and assess where today falls in the range of historical values for danger rating. This important information should be discussed at morning crew meetings, tailgate safety meetings, incident briefings, etc.

Local fire management personnel can produce cards using FireFamilyPlus. PocketCards should be developed locally with local fire management involvement to meet local fire management needs.

Figure 99. Example PocketCard.



Interagency Predictive Services

During the active fire season, the National Interagency Coordination Center (NICC) and each geographic area predictive service office is staffed seven days a week to support the assessment needs of fire program managers, incident personnel, and groups coordinating regional fire management resources.

Products can be referenced from https://www.nifc.gov/nicc/predictive-services/outlooks, and a daily national 7-Day Significant Fire Potential Outlook is available at https://fsapps.nwcg.gov/psp/npsg/forecast#/outlooks?state=map.

The 7-day outlook also includes forecasts for the weather elements, fuel moistures, and fire danger indices that are used to produce these potential classifications. 7-day forecasts represent averages for areas defined by the geographic area to be climatologically distinct.

Other standard products include daily, monthly, and seasonal assessments. Several produce multi-media briefings that can be linked from the outlooks page.

Figure 100. Current Geographic Area Boundaries.

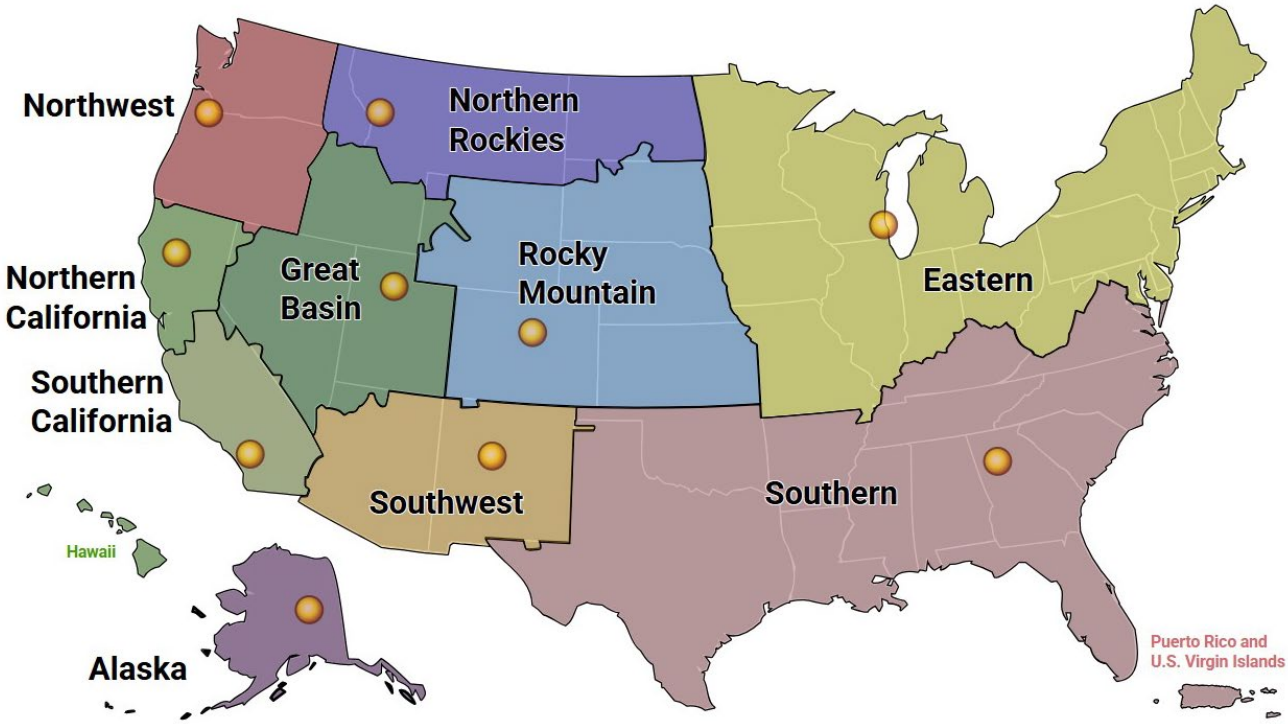
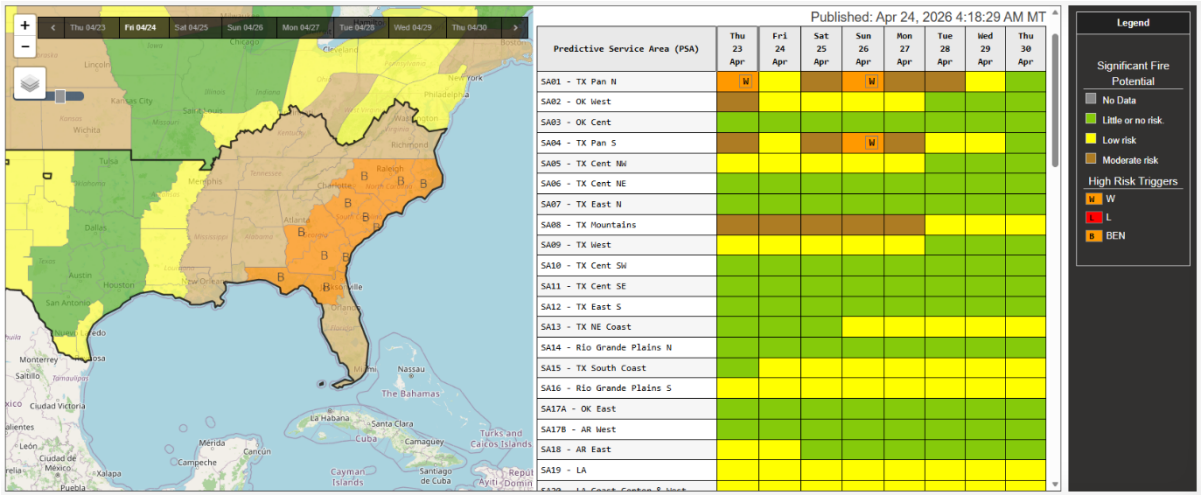


Figure 101. Example of a 7-Day Significant Fire Potential Outlook.



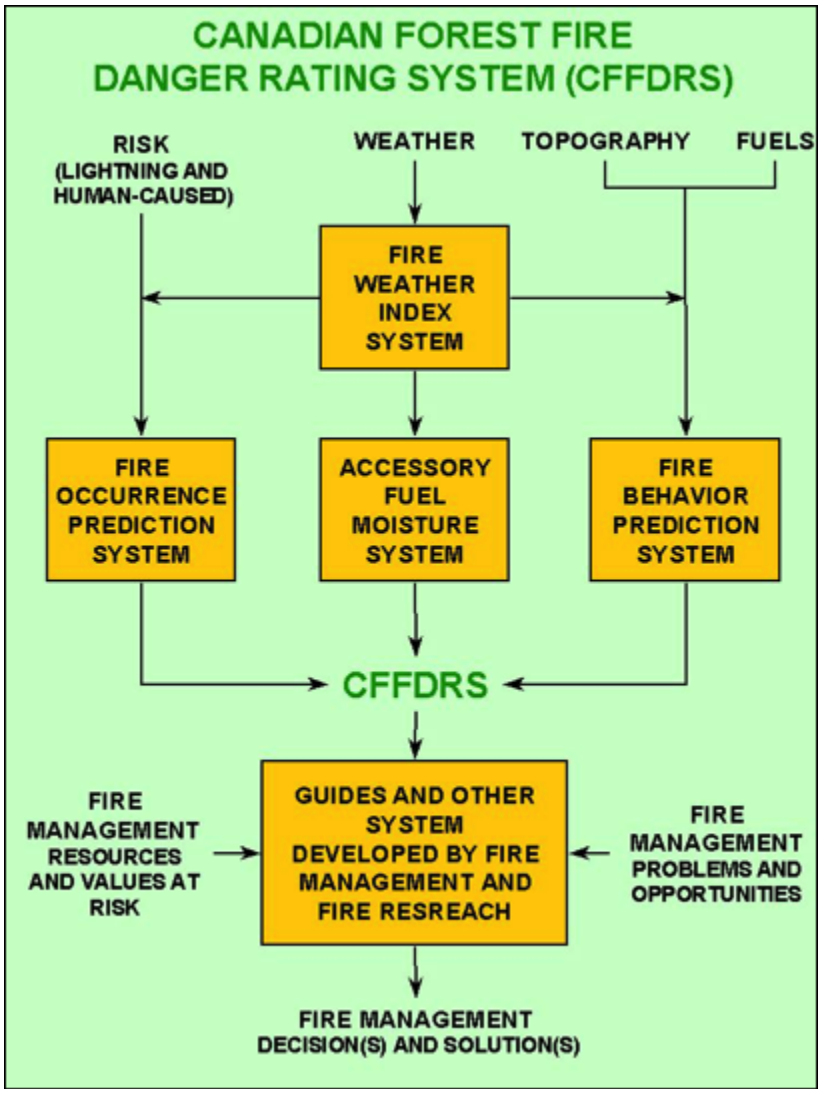
Canadian Forest Fire Danger Rating System (CFFDRS)

The CFFDRS (Figure 102, Figure 103) is a comprehensive system of tools designed to evaluate environmental factors that influence the ignition, spread, and behavior of wildland fire. Additional detail about the system and its subsystems can be learned from an introductory certificate online course and direct access to the YouTube videos that support it: https://wildlandfirelearningportal.net/ and https://www.youtube.com/playlist?list=PLriyD21WeCtKRA2TsWwrInsRmuC0j86HG.

CFFDRS Components

The system traces origins to early fire weather efforts in 1920s, beginning with the Tracer Index, a forerunner of the FFMC.

Figure 102. CFFDRS schematic.



Fire Weather Index (FWI) System

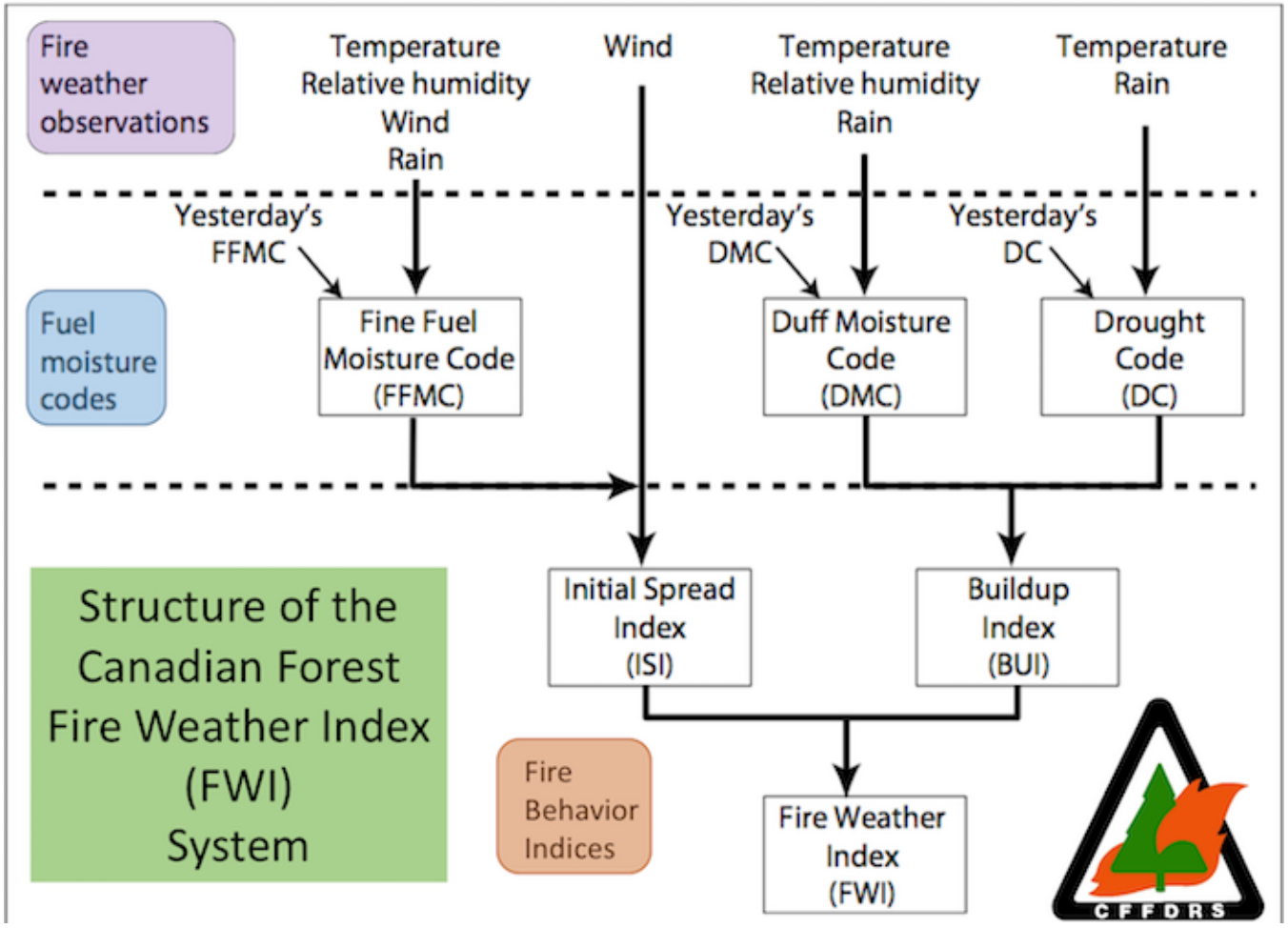
CFFDRS was introduced in Canada in 1970 and later adopted in Alaska, http://akff.mesowest.org/, and the Great Lake States (Michigan, Minnesota, and Wisconsin), http://glff.mesowest.org/, in the early 1990s. Other tools, formulations, and applications are used locally and across the country, with examples highlighted in the Fire Danger section.

All the CFFDRS tools and references produced by the Canadian and Provincial governments—and those produced internationally—use the metric system for all measured values. For ease of use in the United States, measurements referenced here are presented primarily in imperial units.

Fire Weather Index (FWI) System Process Flow Chart

The FWI System is widely used across Canada and internationally due to its simplicity in terms of data required and clear output structure.

Figure 103. FWI schematic.



Winds for CFFDRS

Figure 104 provides a quick reference to aid conversion between 10-meter, 20-foot, unsheltered eye-level (EL Op) observations, and forecast/airport winds.

Figure 104. Windspeed conversions for CFFDRS.

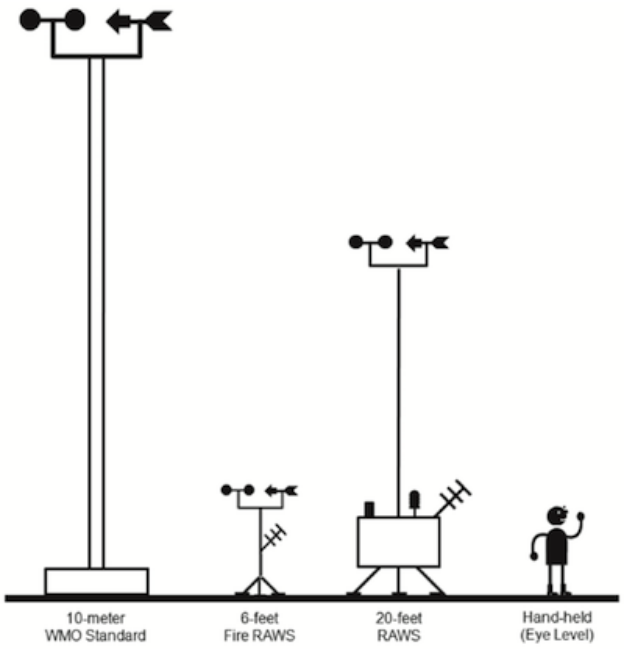
Open Windspeed: Use only 10m For Effective Windspeed

Conversion Factors: **10m** = Fcst (Airport) x 0.7, **10m** = 20 ft * 1.12, **10 m** = Eye Level Open [EL Op] * 1.54

FCST	0	1	4	6	9	10	13	16	17	20	21	24	26	29	30	33	34	37	39	41	44
10m	0	1	3	4	6	7	9	11	12	14	15	17	18	20	21	23	24	26	27	29	31
20ft	0	1	3	4	5	6	8	10	11	13	13	15	16	18	19	21	21	23	24	26	28
EL Op	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20

CFFDRS weather observations for both FWI and Fire Behavior Prediction (FBP) calculations follow standard fire weather practices. These standards can be reviewed in the weather guide (Figure 104). However, wind observation standards conform to the international 10-meter height rather than the 20-foot NFDRS height standard.

Figure 105. Different heights winds are measured (Andrews, 2012).



CFFDRS models and tools do not automatically convert between 10-meter, 20-foot, or eye-level wind measurements—values commonly referenced and reported from U.S. RAWS observing locations and from the fireline.

Further, wind speeds reported from airport ASOS and those in National Weather Service forecasts are often higher wind because they are taken in open, flat environments with little variation in vegetation height or structural interference. These values are typically correlated with forecast wind speed provided in the NDFD (Lawson and Armitage, 2008).

Fire Intensity Measures

In U.S. applications and references, a major adaptation—though with uncertain validity—is the use of flame length for fire intensity outputs in the Fire Behavior Tables. FBP outputs (kilowatt per meter) were converted to BTU per foot per second using standard conversions and then to flame length using the formula:

$$\text{Flame Length} = 0.45 \times \text{BTU per foot per second}^{0.46}$$

Figure 106 identifies the Canadian Forest Fire Behavior Prediction (CFFBP) Fire Intensity thresholds in kW/m, the corresponding values in imperial units (BTU per foot per second), and flame length in feet. These flame length thresholds align with commonly used fire-safety interpretations in the U.S. system.

Figure 106. FBP fire behavior characteristics.

Intensity Class		Flame Length	FLI kW/m	FLI BTU/ft/sec
1	up to	1	10	3
2	up to	4	500	145
3	up to	8	2000	578
4	up to	12	4000	1156
5	up to	18	10000	2891
6	> than	18	10000	2891

Wildland Smoke and Air Quality

Quick Guide for Smoke and Roadway Safety

Smoke from wildland fires can drift onto roads and has contributed to serious and sometimes fatal vehicle accidents. While these incidents have occurred more frequently in the southeastern U.S., they have occurred across the country, and the meteorological conditions can occur in most locations, especially during fall.

Nighttime Smoke Considerations

The following conditions strongly indicate potential for nighttime smoke impacts on roadways:

- Will there be active fire or smoldering within one hour before sunset and/or after sunrise?
- Are there roadways within 10 miles of the fire? If yes, then nighttime smoke is a concern. If roadways are within 3 miles, these concerns should be deemed critical.
- Can surface winds transport the winds toward nearby roads?
- Can topography—such as drainages—channel smoke from the burn area toward any roadways?

If the answer any of these is yes, then assess meteorological variables of temperature, RH, wind speed, and cloud cover.

Probability Thresholds for Nighttime Smoke on Roads

The NWS Weather Table, https://www.weather.gov/wrh/wxtable, allows a 7-day review of the four weather variables for a given location. This helps determine whether more detailed roadway assessment of smoke risk is needed.

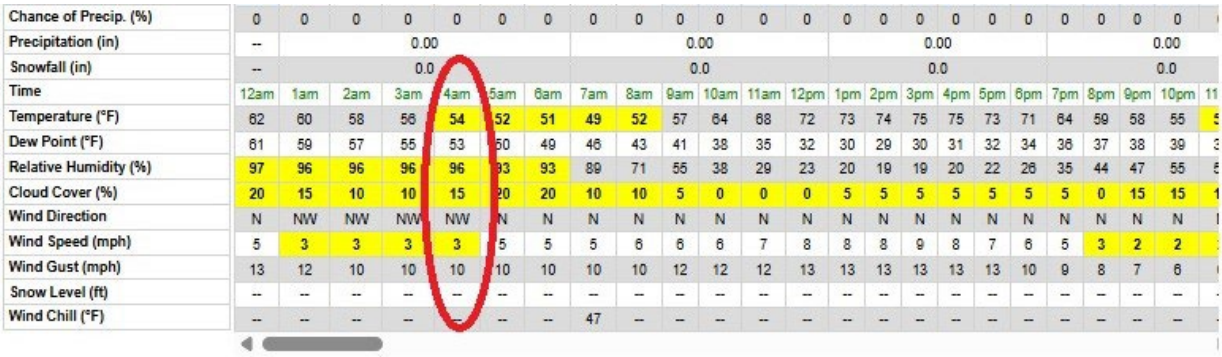
When forecasted values show all four variables at critical threshold (Figure 108) there is a high probability of impacts from nighttime smoke. In these cases, additional analysis—such as running the PB Piedmont model, https://piedmont.dri.edu/—and mitigation planning should be considered.

If the forecast includes a mix of moderate and critical values, further assessment and mitigation may still be warranted. In either case, coordination with IMET, Air Resource Advisor (ARA), Safety personnel, Public Information Officers (PIO), and local agencies (such as the state Department of Transportation and law enforcement) may be necessary to ensure proactive response and public safety.

Figure 107. Nighttime smoke on roads probability thresholds.

	Low Probability: Low impacts from nighttime smoke.	Moderate Probability: Likely impacts from nighttime smoke (Watch out).	High Probability: Predicted Impacts from nighttime smoke (Critical.)
Temperature	Above 70^0 Fahrenheit	Below 70^0 Fahrenheit	Below 55^0 Fahrenheit
Relative Humidity	Below 70% Humidity	Above 70% Humidity	Above 90% Humidity
Wind Speed	Greater than 7 MPH	Less than 7 MPH	Less than 4 MPH
Cloud Cover	Greater than 60%	Less than 60%	Less than 40%

Figure 108. Example of a period with High Probability of nighttime smoke at critical levels.



Chance of Precip. (%)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Precipitation (in)	--	0.00						0.00						0.00							0.00			
Snowfall (in)	--	0.0						0.0						0.0							0.0			
Time	12am	1am	2am	3am	4am	5am	6am	7am	8am	9am	10am	11am	12pm	1pm	2pm	3pm	4pm	5pm	6pm	7pm	8pm	9pm	10pm	11
Temperature (°F)	62	60	58	56	54	52	51	49	52	57	64	68	72	73	74	75	75	73	71	64	59	58	55	5
Dew Point (°F)	61	59	57	55	53	50	49	46	43	41	38	35	32	30	29	30	31	32	34	36	37	38	39	3
Relative Humidity (%)	97	96	96	96	96	93	93	89	71	55	38	29	23	20	19	19	20	22	26	35	44	47	55	5
Cloud Cover (%)	20	15	10	10	15	20	20	10	10	5	0	0	0	5	5	5	5	5	5	5	0	15	15	1
Wind Direction	N	NW	NW	NW	NW	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	
Wind Speed (mph)	5	3	3	3	3	5	5	5	6	6	6	7	8	8	8	9	8	7	6	5	3	2	2	
Wind Gust (mph)	13	12	10	10	10	10	10	10	10	12	12	12	13	13	13	13	13	13	10	9	8	7	6	
Snow Level (ft)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	
Wind Chill (°F)	--	--	--	--	--	--	--	47	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	

Smoke Safety Resources

Smoke & Roadway Safety Guide https://fs-prod-nwcg.s3.us-gov-west-1.amazonaws.com/s3fs-public/publication/pms477.pdf

NWCG Nighttime Smoke Pocket Card https://fs-prod-nwcg.s3.us-gov-west-1.amazonaws.com/s3fs-public/publication/pms477-1.pdf

PB Piedmont Web Application https://piedmont.dri.edu/

Wildfire Lessons Learned- Shanty Pond Prescribed Fire Vehicle Accidents 2023 with Safety Bulletin on Nighttime Smoke Management for Roadways https://lessons.fs2c.usda.gov/incident/shanty-pond-prescribed-fire-vehicle-accidents-2023

Nighttime Smoke and Fog on Prescribed Burns, Southern Fire Exchange https://southernfireexchange.org/wp-content/uploads/2011-2.pdf

Interagency Wildland Fire Air Quality Response Program Smoke Tools https://www.wildlandfiresmoke.net/tools

USFS WRF-GFS 8 km 7-day maps for East, West, and Alaska Domains, including ADI, LVORI, and Superfog Potential Index https://met.wildlandfiresmoke.net/smoke/

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