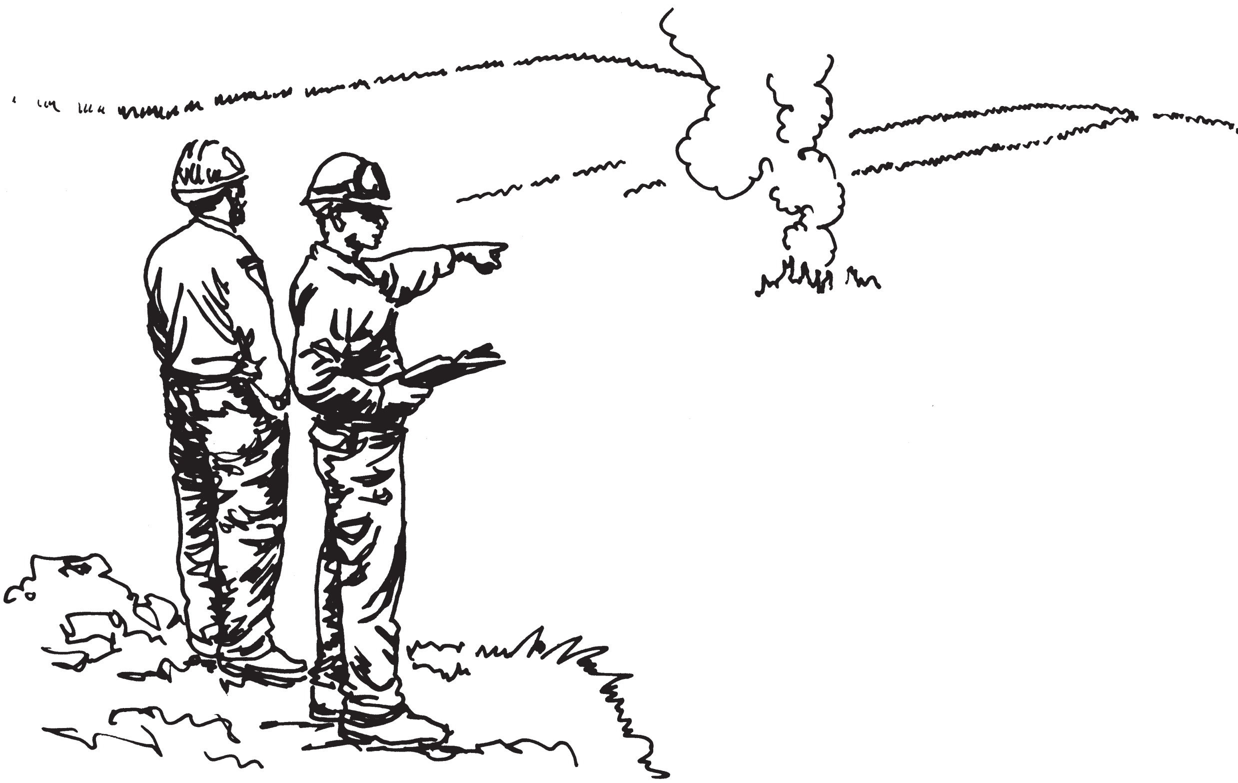
Introduction to Wildland Fire Behavior Calculations S-390



NATIONAL WILDFIRE COORDINATING GROUP

NFES 2931

Student Workbook

SEPTEMBER 2006

CERTIFICATION STATEMENT

on behalf of the

NATIONAL WILDFIRE COORDINATING GROUP

The following training material attains the standards prescribed for courses developed under the interagency curriculum established and coordinated by the National Wildfire Coordinating Group. The instruction is certified for interagency use and is known as:

Introduction to Wildland Fire Behavior Calculations S-390
Certified at Level I

This product is part of an established NWCG curriculum. It meets the COURSE DEVELOPMENT AND FORMAT STANDARDS – Sixth Edition, 2003 and has received a technical review and a professional edit.

Thomas H Dyer
Member NWCG and Training Working Team Liaison

Date 9/18/06

Chairperson, Training Working Team

Date 9/12/06

Introduction to Wildland Fire Behavior Calculations S-390

Student Workbook

SEPTEMBER 2006

NFES 2931

Sponsored for NWCG publication by the NWCG Training Working Team.

Comments regarding the content of this publication should be directed to:
National Interagency Fire Center, Fire Training, 3833 S. Development Ave., Boise, Idaho 83705.
E-mail: nwcg_standards@nifc.blm.gov.

Additional copies of this publication may be ordered from National Interagency Fire Center, ATTN: Great Basin Cache Supply Office, 3833 South Development Avenue, Boise, Idaho 83705.
Order NFES 2931.

PREFACE

Introduction to Wildland Fire Behavior Calculations, S-390, is identified training in the National Wildfire Coordination Group's (NWCG), Wildland and Prescribed Fire Curriculum. This course has been developed by an interagency development group with guidance from the National Interagency Fire Center (NIFC), Fire Training Group under authority of the NWCG, with coordination and assistance of personnel from the following agencies:

Bureau of Land Management
Robert Means

California Department of Forestry and Fire Protection
John Craney

National Park Service
Jim Kitchen

U.S. Fish and Wildlife Service
Chuck Maxwell

Bureau of Land Management
Bradley Washa

Bureau of Land Management
Kato Howard

Michigan Department of Natural Resources
Robert Ziel

USDA Forest Service
Robert Heinsch

NWCG Training Development Unit
Noble Dunn, Deana Parrish, Sue Hickman

CONTENTS

Introduction to Wildland Fire Behavior Calculations, S-390

Unit 0 – Introduction

OBJECTIVES:

During this unit the cadre will:

1. Introduce the instructors and students.

2. Discuss administrative concerns.

3. Explain course purpose and course objectives.

4. Discuss expectations for the course.

5. Review the evaluation process.

6. Explain how this course fits in the fire behavior curriculum.

I. INTRODUCTION

II. COURSE PURPOSE

To provide the student with wildland fire behavior knowledge applicable for safe and effective wildland fire management activities.

This course builds upon the Intermediate Wildland Fire Behavior Course, S-290. The materials in this course, as well as in S-290, are elements of the fire behavior curriculum.

Students will be introduced to various methods of calculating fire behavior characteristics, such as how fast the fire is spreading and how hot the fire is.

Students will be shown how such information can be applied by utilizing two methods: Nomograms and Appendix B of the Fireline Handbook.

III. COURSE OBJECTIVES

Course objectives are stated in broad terms that define what the student will do upon completion of the course.

- List the assumptions, limitations, and appropriate uses of fire behavior prediction models.
- Describe how environmental factors and processes affect fire behavior predictions and safety.
- Define and interpret fire behavior prediction model inputs.
- Calculate fire behavior outputs using available fire behavior processors.
- Interpret, communicate, apply, and document wildland fire behavior and weather information.

IV. EXPECTATIONS

A. Student Expectations

What are your expectations for the course?

B. Instructor Expectations

- Attendance at all sessions.
- Be prepared to start on time.
- Participate and share ideas.

V. EVALUATIONS

A. Student Evaluation

- Final group exercise on Thursday worth 10 points.
- Final exam on Friday worth 90 points.
- 70 total points required to pass the course.

B. Course and Instructor Evaluation

This is an opportunity for students to comment on the course (and the instructors) for the purpose of improving future training sessions.

VI. WHERE DOES THIS COURSE FIT IN THE FIRE BEHAVIOR CURRICULUM?

A. Introduction to Wildland Fire Behavior, S-190

This course is the entry-level course designed around the basics of fuel, weather, and topography.

It examines how these factors affect fire behavior in terms of safety and fire suppression actions.

The course is presented to all individuals who will or could be involved with fire management activities.

B. Intermediate Wildland Fire Behavior, S-290

This course builds upon the basics learned in S-190 with more detailed treatments of fuels, weather, and topography.

It provides a better basis for analyzing variables and understanding how they interact and affect fire behavior for safety purposes.

A good example of the target audience is a tractor/plow operator or single resource boss.

C. Introduction to Wildland Fire Behavior Calculations, S-390

This course introduces fire behavior calculations by manual and electronic methods such as tables, nomograms, and BehavePlus.

It gives students an in depth understanding of the determinants of fire behavior by discussing input (wind, slope, fuels, fuel moisture, etc.) to the prediction process.

Interpretations of the fire behavior outputs are taught to enhance the student's ability to understand fire behavior and provide "tools" to help in fire management decisions.

D. Advanced Wildland Fire Behavior Calculations, S-490

This course is designed to give state of the art capability to determine inputs for fire behavior determination. It provides students with an in depth knowledge of interpretations of model outputs.

The course teaches students to project fire perimeter growth based on weather predictions and knowledge of fuels and topography.

A variety of fire scenarios is presented for students to make fire behavior calculations and interpretations.

Introduction to Wildland Fire Behavior Calculations, S-390

Unit 1 – Topography

OBJECTIVES:

Upon completion of this unit, students will be able to:

1. Identify the different elements referenced in the legend of topographic maps.

2. Identify significant topographic features on a map.

3. Determine map scale and contour interval without the map legend.

4. Determine slope percentages for given slope on a USGS topographic map given scale and contour interval.

I. IDENTIFY THE DIFFERENT ELEMENTS REFERENCED IN THE LEGEND OF TOPOGRAPHIC MAPS

A. Map Legend

Legends are usually found at the bottom of a map.

B. Elements of the Legend

1. Map scale

Map scale is the relationship between distance on a map and the corresponding distance on the ground.

Scale is expressed as a ratio, such as 1:24,000, and shown graphically by bar scales marked in feet and miles, or in meters and kilometers.

a. 1 inch on the map equals 24,000 inches on the ground.

b. 1 inch on the map equals 2000 feet on the ground.

c. 2.64 inches on the map equals 1 mile on the ground.

d. There are 80 chains to a mile and 66 feet to a chain.

e. Approximately 3 chains for every 1/10 inch on the map.

2. Contour interval

   a. The distance in elevation between two adjacent contour lines.

   b. Usually given in feet.

   c. Contour interval is usually found directly under the map scale.

II. IDENTIFY SIGNIFICANT TOPOGRAPHIC FEATURES ON A MAP

Contour Lines:

- Never cross.
- Don’t end at the edge of the map.
- V-shaped contours pointing up hill indicate a drainage or valley.
- V- or U-shaped contours pointing downhill indicate a ridge.
- Complete circle contours indicate the top of hills.
- Complete circle contours with hatcher lines inside indicate depressions.
- Closely spaced contours indicate steep slope.
- Contours spaced far apart indicate gentle or flat terrain.
- Every fifth contour line is printed in a darker color or thicker line.
  – This is called an Index Contour.
  – On most of the index contours, the elevation will be written in.

III. DETERMINE MAP SCALE AND CONTOUR INTERVAL WITHOUT A LEGEND

A. Check the Contour Interval

Contour interval is the distance in feet between two adjacent contours.

1. Find two adjacent index contours with the elevations printed on them.

   - Index contours are every fifth contour line.

   - Index contours are printed thicker for easy identification.

2. Find the difference between the two index contours by subtracting the lower number from the higher number.

   - Divide that number by 5; this gives the contour interval.

B. Determine the Map Scale

Sections are **typically** 1 mile square; however, not **all** sections are 1 mile square. It is important to measure several sections lines.

- Remember: The map you receive may have been copied and reduced in size.

- Checking the size of a section will verify the map distance.

IV. DETERMINE SLOPE PERCENTAGES FOR A GIVEN SLOPE ON A USGS TOPOGRAPHIC MAP GIVEN MAP SCALE AND CONTOUR INTERVAL

A. Calculating Slope: Calculate the Elevation Difference

1. Count the number of contour lines between the two points and multiply by the contour interval 19 contours x 40 foot interval = 760 feet rise.

2. A better way would be to make your measurement of the two points from one index contour to another index contour.

   a. Subtract the lower elevation from the higher number.

   b. The result would be the elevation change.

   c. Make sure the two points you are calculating for **do not**:

      - Cross a ridge or drainage.

      - Go across slope.

3. Measure the distance between two points in the area for which you are calculating slope.

   For example:

   - Measure from point A to point B. You should get approximately 1 inch. Multiply 1 (inch) by 2000 (feet per inches); the distance is 2000 feet.

4. Use the formula:

   RISE
   RUN x 100

B. Review

1. Two adjacent index contours have the following elevations printed on them: 2300 and 2500

   - 2500 – 2300 = 200 feet

   - 200/5 = 40 foot contour interval

2. There are 19 contour lines between points A and B.

   - 19 x 40 = 760 foot elevation difference (RISE)

3. The measured distance is 1 inch.

   - 1 x 2000 = 2,000 feet (RUN)

4. Calculate the slope.

   - 760 ÷ 2000 x 100 = 38%

   Remember: When using a calculator, enter in the top number first, then divide by the bottom number, then multiply the total by 100.

Exercise 1 - Slope Calculations

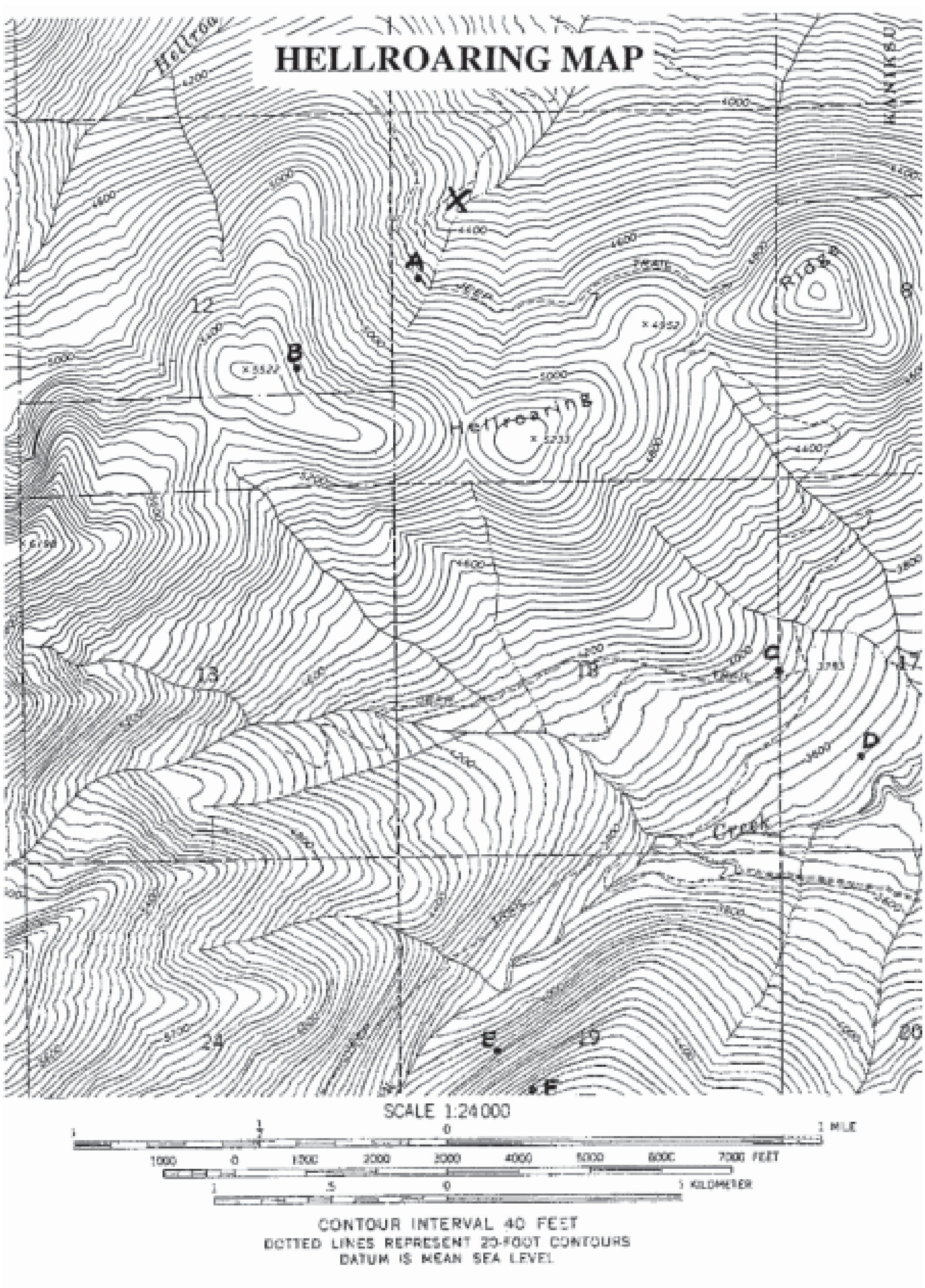
Use the Hellroaring map on the next page to calculate slope percent for each of the three areas (A-B, C-D, E-F).

INPUT

0	Projection Point	A-B	C-D	E-F
1	Contour Interval	_____	_____	_____
2	Map Scale	_____	_____	_____
3	Conversion Factor	_____	_____	_____
4	# of Contour Intervals	_____	_____	_____
5	Rise in Elevation	_____	_____	_____
6	Map Distance, in (btwn pts)	_____	_____	_____
7	Horizontal ground Dist, ft	_____	_____	_____

OUPUT

1	Slope, %	_____	_____	_____


HELLROARING MAP
Hellroaring
Ridge
Creek
X
A
B
C
D
E
F
12
13
18
17
24
19
SCALE 1:24 000
1 MILE
1000 0 1000 2000 3000 4000 5000 6000 7000 FEET
1 .5 0 1 KILOMETER
CONTOUR INTERVAL 40 FEET
DOTTED LINES REPRESENT 20-FOOT CONTOURS
DATUM IS MEAN SEA LEVEL

Introduction to Wildland Fire Behavior Calculations, S-390

Unit 2 – Weather

Lesson A – Atmospheric Stability

OBJECTIVES:

Upon completion of this lesson, students will be able to:

1. Define stable and unstable conditions using lapse rates.

2. Assess the effects of stability of instability on wildland fires.

3. Identify measures of stability and describe how they are computed.

4. Estimate atmospheric stability and probable fire behavior based upon identification of visual indicators.

2A.2

I. INTRODUCTION

Atmospheric stability has a significant influence on the wildland fire behavior environment, but is not as easily assessed or measured as temperature, wind and humidity.

This lesson examines the relationship between stability and fire behavior, and methods of assessing stability.

II. STABILITY AND TEMPERATURE LAPSE RATES

Stability is the degree to which vertical motion in the atmosphere is enhanced or suppressed.

A. Stable

A condition of the atmosphere in which a parcel if displaced, either up or down, will tend to return to its original level. Vertical motion is restricted.

B. Unstable

A condition of the atmosphere in which a parcel of air, if displaced either up or down, will tend to continue in the direction of displacement. Vertical motion is enhanced.

Stability is related to buoyancy, or the tendency or capacity of air to rise. There are degrees of stability; the atmosphere is composed of layers of differing stability.

The stability of an atmospheric layer can be determined by examining the difference in temperature between the top and bottom of the layer. This is compared to the rate at which rising air would cool in the same environment.

C. Lapse Rate

Lapse rate is the change in temperature with altitude within a layer of the atmosphere.

Lapse rate is further defined in two general ways:

1. Environmental

The actual, measured, or ambient temperature change with altitude.

The mean environmental lapse rate is 3.5° F/1000 feet (or 2/3° C/100 meters).

2. Adiabatic

The temperature change with altitude of rising or sinking air caused purely by expansion (cooling) or compression (warming) due to changing pressure.

Adiabatic lapse rates vary depending on whether the air is saturated or unsaturated.

- The dry (unsaturated) adiabatic lapse rate is 5.5° F/1000 feet (or 1° C/100 meters).
- The moist (saturated) adiabatic lapse rate is 3° F/1000 feet (or .5° C/100 meters).

The dry adiabatic lapse rate of 5.5° F/1000 feet represents the upper limit of the capability for air to cool as it rises.

Air rising from the surface almost always cools at the dry adiabatic lapse rate – especially when wildland fire is a concern.

For these reasons, atmospheric stability is defined by environmental lapse rate as follows:

- Unstable: Environmental lapse rate greater than 5.5° F/1000 ft.

  Air rising at the dry lapse rate will remain warmer than the environment and continue to rise on its own.

- Stable: Environmental lapse rate less than 5.5° F/1000 ft.

  Air rising at the dry lapse rate will remain cooler than the environment and will want to return to its original level.

- Neutral: Environmental lapse rate equal to 5.5° F/1000 feet.

  This state is usually a short-lived transition period between stable and unstable conditions.

  Air rising at the dry lapse rate will remain in equilibrium with the environment.

III. EFFECTS OF STABILITY ON WILDLAND FIRE ENVIRONMENT

Stability and changes in stability are related to weather processes and parameters important to the fire environment.

A. General Assumptions Regarding Stability and Associated Weather Parameters and Processes

1. Pressure

   High pressure produces stable conditions through subsidence. This can ultimately lead to an inversion.

   Conversely, low pressure is usually associated with unstable air.

2. Lifting

   Lifting an air mass layer will make it become more unstable. Lifting can be accomplished through:

   - Convection
   - Frontal lifting
   - Orographic lifting

   Typically, air masses are stable far ahead of a front, unstable near the front, and stabilize behind the front.

3. Winds

   Sudden increases in winds can destroy inversions and increase the instability of the air mass.

   During a hot unstable afternoon, winds can be quite light, but are often erratic and gusty. In this case, under the calm conditions, the degree of instability would usually be greater.

After the mixing action by the winds, the lower levels could very well be unstable. However, the degree of instability would be less than the calm wind situation.

The effect of winds on the fire environment is dramatic. Unstable and/or windy conditions contribute to rapid rates of spread and potentially violent fire behavior.

4. Temperature

Heating from below and/or cooling from above will increase instability, while cooling from below and/or heating from above will make the atmosphere more stable.

For example, hot sunny days result in high surface temperatures and thus make the lower levels of the atmosphere unstable. Clear, cool nights produce the opposite effects (inversions).

5. Topography

Topography effects heating/cooling of slopes and valleys, and thus the stability.

For example, south facing slopes are generally warmer and have greater instability above them than north facing slopes.

Be aware that superheated air may build up in poorly ventilated valleys.

Triggering mechanisms such as inversion breakup or a sudden increase in winds could release this instability with violent results.

6. Relative humidity

Normally, relative humidity neither directly affects nor is affected by the stability of the atmosphere.

On the local scale, relative humidity can drop dramatically as the atmosphere destabilizes with the breakup of morning inversions.

B. Daily and Seasonal Changes in Stability

Normal daily changes in stability are related to temperature changes.

Assuming a typical summer day with clear skies and light winds, the lowest layers of the atmosphere are stable at night (greatest stability just before sunrise) and unstable during the late morning and afternoon.

The greatest instability is during the late afternoon (hottest part of the day).

Two important points to remember:

1. When inversions lift, there is usually a pronounced transition to more unstable conditions (visibility quickly improves and winds begin to stir).

2. The greater instability of the air mass above the inversion, the more pronounced the transition is likely to be.

   Beware of days when the Haines Index is 5 or 6.

Normal seasonal variations in stability are related to the seasonal variations in temperature. Winter has more stable conditions than the other seasons due to colder temperatures and longer nights.

Conversely, summer is most unstable due to warmer temperatures and longer hours of sunlight. Spring and fall are harder to define due to greater variability across the country and the fact that these are transition months between winter and summer.

Stability changes frequently and those changes are directly related to surface temperature. The most unstable conditions are associated with the warmest surface temperatures and the atmosphere becomes more unstable as surface temperatures increase.

The local fire weather meteorologist should be consulted for insight into expected changes in stability that could impact your decision making process in the wildland fire environment.

C. Effects of Stability on Wildland Fire Behavior

1. Fires burning under unstable conditions have:

   a. Stronger, more vertically developed smoke/convection columns.

   b. Greater potential to move from surface to aerial fuels (to become three-dimensional).

   c. Greater potential for extreme fire behavior including crowning, long-range spotting and firewhirls.

   d. Better ventilation, so air quality problems are usually minimized.

   e. Normally, more complete fuel consumption due to higher surface and fuel temperatures, stronger winds, and lower fuel moisture.

2. Fires burning under stable conditions have:

   a. Less potential for extreme fire behavior (except in cases where fires burn in poorly ventilated canyons that allow dangerous buildup of gasses and preheat and dry fuels).

   b. Poor ventilation, so air quality may be a significant problem.

   c. The potential for hindering detection of other fires due to reduced visibility by smoke. Air operations may be delayed or precluded by inversions.

   d. The potential for impacting prescribed burns due to overloading areas with smoke.

   The bottom line: The potential for extreme fire behavior increases dramatically when the atmosphere is unstable.

IV. MEASURES OF STABILITY AND HOW THEY ARE COMPUTED

There are several indices used by the fire management community that attempt to put a number, adjective term, or category on stability and the potential for fire behavior to increase and/or smoke to disperse readily.

All of these indices account for temperature lapse rate to one degree or another.

A. Davis Stability Index (Ref. Atmospheric Stability Forecast and Fire Control, R. T. Davis)

   1. Looks at temperature lapse rate in the lowest 5000 ft. above ground level.

   2. Correlates lapse rate to large (Class E or greater) fire occurrence looking at 70 fires in Alabama (most active fire behavior occurs when lapse rate > 5.5°F/1000 ft.).

3. Applicability limited because lapse rate > 5.5°F/1000 ft. occurs routinely below 5000 ft. AGL across most of the U.S. during the active fire season.

4. Used currently in portions of the southeast U.S.

Davis Stability Index		
Stability Class/ Descriptor	Lapse Rate	% of Large Fires Occurring
1 – Stable	3.5°/1000 ft. or less	9 %
2 – Conditionally Unstable	3.5° - 5.4°/1000 ft.	21 %
3 – Unstable	5.5°/1000 ft.	21 %
4 – Absolutely Unstable	> 5.5°/1000 ft.	49 %

B. Haines Index (Ref. The Haines Index and Idaho Wildfire Growth, Werth & Ochoa)

1. Looks at temperature difference and moisture in a layer of the atmosphere above the fire.

2. Three elevation layers (Low, Mid, High) used to account for differing terrain across the country.

    a. Much of the eastern U.S., excluding the Appalachian Mountains, uses a low elevation index computed from a layer approximately 2,000-5,000 ft. MSL.

    b. A mid-elevation index was developed for the Great Plains and Appalachian Mountains using a layer 5,000-10,000 ft. MSL.

    c. A high elevation index is used for the mountainous western U.S. using a layer approximately 10,000-18,000 ft. MSL.

3. Correlates dryness and instability to "worse fire situations" on 74 fires across the country.

4. Has been shown to have application nationwide, though regional interpretation sometimes necessary.

5. Has been shown to relate to higher rates of spread, strong convection columns and extreme fire behavior on going fires.

6. Stability term is directly related to lapse rate.

   Stability Term (1 to 3) + Moisture Term
   (1 to 3) = Haines Index (2 to 6)
   1 = Stable/Moist to 3 = Unstable / Dry

Haines Index		
Haines Index	Large Fire Growth Potential	% of Large Fires Occurring
2-3	Very Low	10 %
4	Low	N/A
5	Moderate	N/A
6	High	45 %

C. Pasquill Stability Index (or Pasquill-Gifford-Turner Stability Index)

1. Looks at combination of surface heating (solar radiation) and surface wind speed.

2. Surface heating based on solar radiation and amount of cloud cover.

3. Used in smoke management, such as Simple Approach Smoke Estimation Model (SASEM) as a quantifier of vertical dispersion potential.

4. Ranges from A (Very Unstable/Excellent Dispersion) to G (Moderately Stable/Poor Dispersion).

5. Dispersion and stability decrease as wind increases.

6. Lapse rate is inferred directly from the amount of incoming solar radiation.

PASQUILL STABILITY TABLE

Surface Wind Speed		Daytime Solar Radiation				Nighttime	
						Thin Overcast	Less Than 50%
m/s ec	mi/hour	Strong	Moderate	Slight	Weak	Or 50%+ Clouds	Cloud Cover
< 2	4 or less	A	A – B	B	C	F	G
2	5	A - B	B	C	D	E	F
4	9	B	B - C	C	D	D	E
6	13	C	C - D	D	D	D	D
> 6	> 13	C	D	D	D	D	D

LETTER	PHRASE	DISPERSION
A (1)	Very unstable	Excellent
B (2)	Moderately unstable	Excellent
C (3)	Slightly unstable	Good
D (4)	Neutral	Fair
E (5)	Slightly stable	Poor
F (6)	Moderately stable	Poor
G (7)	Very stable	Poor

D. Lavdas Dispersion Index (or Lavdas Atmospheric Dispersion Index)

1. More comprehensive index that involves stability, mixing height, and transport winds.

2. Uses Pasquill Stability Index (in a numeric format) as an input, thus surface heating and surface wind speed are considered.

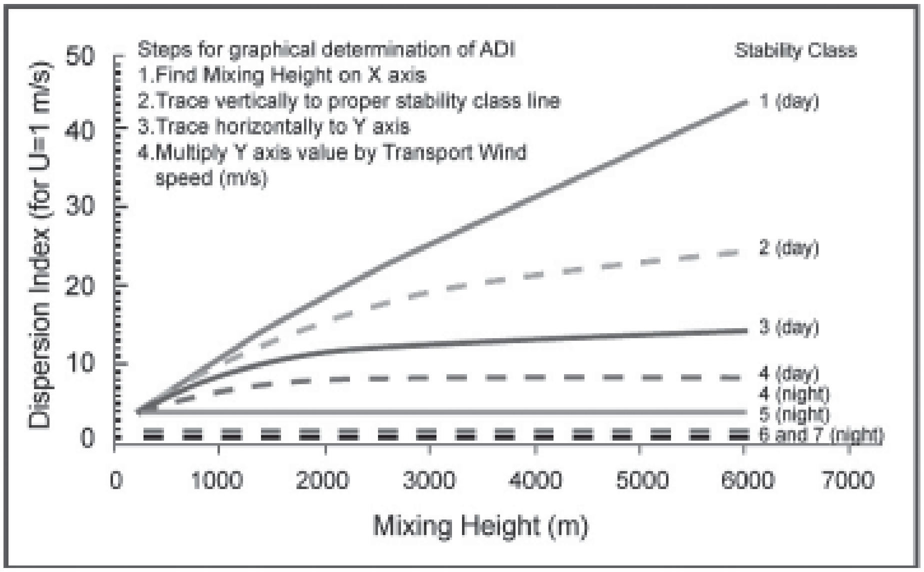
3. Quantifies combination of vertical and lateral dispersion, as opposed to just vertical with Pasquill.

4. Dispersion increases as transport wind increases.

5. Ranges from near zero to over 100.

6. Has been shown to have some correlation to large fire growth in Florida.

7. Lapse rate is included as part of the Pasquill Stability Index input.



Dispersion index	Interpretation
> 100	Very good (but may indirectly indicate hazardous conditions; check fire weather)
61-100	Good (typical-case burning weather values are in range)
41-60	Generally good (Climatological afternoon values in most inland forested areas of the United states fall in this range
21-40	Fair (Stagnation may be indicated if accompanied by persistent low wind speed)
13-20	Generally poor; Stagnation if persistent (although better than average for a night value)
7-12	Poor; stagnant at day (but near or above average at night)
1-6	Very poor (very frequent at night; represents the majority of nights in many locations

E. Review and Comparison of Stability Indices

Index	Major Factors	Primary Utility
Davis	Lapse rate	Basic measure of stability
Haines	Lapse rate (layer temperature difference) and dryness	Large fire growth potential
Pasquill	Solar radiation, cloud cover and surface wind speed (surface based stability)	Smoke dispersion
Lavdas	Pasquill, mixing height, transport wind	Smoke dispersion (also shown to large to fire growth in Florida)

These indices provide simple, quantifiable means for looking at stability related factors in the wildland fire environment.

It is important to recognize that all utilize lapse rate in one way or another and that all have strengths and weaknesses specific to their development and application.

It would be a mistake to believe that any one index held all the answers regarding something as complex as stability.

V. ESTIMATE ATMOSPHERIC STABILITY AND PROBABLE FIRE BEHAVIOR BASED UPON IDENTIFICATION OF VISUAL INDICATORS

A. Best Method

Contact the local fire weather forecaster or consult fire weather forecast.

B. Visual Indicators

STABLE	UNSTABLE
Clouds in layers, no vertical motion	Clouds grow vertically
Stratus-type clouds	Cumulous-type clouds
Smoke column drifts apart after limited rise	Taller smoke column
Poor visibility due to smoke and haze; fog layers	Good visibility
Steady winds	Gusty winds

C. Other Data Sources

1. Aircraft temperature profiles.

If available, temperature readings every 500 feet above ground level will provide a very detailed temperature profile.

Apply the 5.5° F /1000 feet rule to determine stability. Relay the data to a fire weather meteorologist who will be able to predict if and when any inversions will lift.

2. Lookouts, RAWS/NFDRS stations, fireline personnel, and air operations.

These are all good sources of information with regard to the presence or absence of inversions, when inversions begin to break, tops of smoke layer, etc.

Fireline observations taken at different elevations on the same aspect can also be used to estimate lapse rate and stability.

3. The Fireline Handbook has a basic reference to observable fireline conditions that indicated instability.

4. Upper Air data from Internet.

VI. SUMMARY

Atmospheric stability plays a significant role in the wildland fire environment, and can be assessed both objectively and subjectively using computed indices and visual indicators.

Unstable conditions can lead to extreme fire behavior, but excellent smoke dispersion. Stable conditions can lead to subdued fire behavior, but poor smoke dispersion and possible air quality standards violations.

Giving these offsetting concerns, and the fact that stability is always changing, it is critical that fire managers have the ability to assess stability.

Introduction to Wildland Fire Behavior Calculations, S-390

Unit 2 – Weather

Lesson B – Winds

OBJECTIVES:

Upon completion of this lesson, students will be able to:

1. Describe the winds generated on different meteorological scales.

2. Describe both General Winds and Local Winds that are defined as Critical Winds.

3. Describe the effects of atmospheric stability and instability on 20 ft. winds.

4. Estimate 20 ft. winds given General Winds, Local Winds, and stability.

5. Given the 20 ft. wind speed, determine mid-flame wind speed using the wind adjustment tables.

I. INTRODUCTION

Through lecture, demonstration, and exercises, students will be instructed how to determine surface wind speed and direction. Students will be expected to complete a written proficiency exercise on the objectives.

A. Wind – The Problem

The variability of wind both in time and space presents a difficult problem. Mathematically speaking, the wind field is "continuous," in the field.

There are many inconsistencies that are difficult to explain or anticipate. In certain locales, winds behave quite predictably, but when fires become large, it is often because of an unusual or unpredicted wind situation.

This lesson will help students understand the basic principles that drive local surface winds, and provide tools to help make estimates of probable wind speeds and directions.

B. Wind Direction

The wind direction definition has caused some participants problems in the past. Even simple concepts at times need to be restated and emphasized.

Wind direction is the direction the wind is blowing from. For example, a north wind is blowing out of the north.

II. WIND PATTERNS

A. General Winds

All winds blow in response to pressure differences.

In the very broad (Synoptic) scale, the winds that are produced are called “General Winds.”

General Winds can be separated into two distinct zones:

1. Winds aloft

   These are the winds that blow in the “Upper Atmosphere,” unaffected by friction caused by the terrain or other surface characteristics.

   The jet stream at 30,000 ft. MSL is an example of a wind aloft.

2. Free Air (or gradient) winds

   Free Air or gradient winds are those caused by the circulation between large-scale high and low pressure systems.

   Depending on the stability and the surface roughness, these winds can be constrained to 10,000 ft. MSL or higher, or can extend downward to near the surface.

   The southerly wind in advance of an approaching low pressure system is an example of a gradient wind.

B. The Friction Layer

The surface of the earth is characteristically rough and will disrupt the General Wind due to frictional effects.

This creates a turbulent zone, or friction layer, next to the earth's surface that varies in thickness with the roughness of the surface and the speed of the wind.

The average depth or thickness of this layer may be quite shallow over uniform, flat terrain; or it could be as deep as 2,000 to 3,000 feet above ground level in complex, mountainous terrain.

The friction layer also varies in depth from day to night.

The term "General Wind" will be used to describe the winds at the top of the friction layer, which are the combined result of the winds aloft and the gradient winds.

The winds that may be observed at any given point on the surface of the earth are a combination of many factors.

The General Wind will most often contribute to the wind observed at a given locale, thus knowledge of the General Wind is imperative to making a total assessment of the strength and direction of the surface wind.

C. Local Winds

If the effects of the General Wind are ignored, then local winds may be generated totally by small-scale pressure gradients produced by temperature differences.

This type of wind is most pronounced in areas of discontinuous topography. The most significant local winds are:

1. Slope winds

a. Upslope winds begin soon after the suns direct rays begin to warm a slope.

They begin first on east slopes, but are normally stronger in the afternoon on southwest and west aspects.

Upslope winds alone are normally in the range of 3 to 8 mph, and are usually gusty.

It is important to know the local area because typical wind speed values may vary considerably between areas.

b. Downslope winds begin soon after a slope loses the direct solar radiation in the afternoon or evening.

There is normally a transition on any given slope that consists of:

- Dying of the upslope wind.
- A transition period of relative calm.
- The onset of a gentle laminar flow down the slope.

Downslope winds are typically in the range of 2 to 5 mph and are normally quite steady.

c. Slope wind profiles

The strength, duration, and transition period of wind on any slope is a function of its aspect.

It is important to remember the onset, strength, and duration of slope winds on every aspect as this will affect not only fire behavior, but possibly tactics and strategy.

2. Valley winds

a. Up-valley wind

Up-valley winds normally begin later in the morning than the upslope winds, and are the result of slightly larger-scale convective processes.

The up-valley winds normally reach maximum speeds of 10 to 15 mph in the mid- to late-afternoon.

b. Down-valley wind

Down-valley winds normally undergo a transition much as the downslope flow, and usually begins within a few hours after dark.

Down-valley flow seldom exceeds 10 mph, but as in most other weather related phenomena, there are exceptions.

c. Combination of valley and slope wind

The combination of valley and slope wind results in a diurnal turning of the wind on valley sidewalls.

Mid-morning winds on valley sidewalls blow directly upslope before the development of the valley wind.

As the up-valley wind develops and becomes established, it gradually overpowers the slope wind.

Upslope winds begin to blow at an angle, and by mid-afternoon may blow directly across the slope.

This “cross slope” wind continues to shift during the evening, and eventually blows directly downslope after dark.

The up-valley wind then ends and a shallow down-valley wind begins.

After midnight, the down-valley wind becomes deep enough to gradually shift the downslope wind to a “cross slope” wind, this time blowing directly down-valley.

This wind continues until after sunrise when the upslope wind again develops.

This completes a diurnal cycle on the valley sidewall in which the wind direction changes a full 360° during the 24-hour period.

3. Sea/land breezes

a. Sea breezes

Sea breezes are the result of differential heating of the water and land surfaces.

They normally begin around mid-morning on the east coast of the United States, but closer to midday on the west coast.

These winds strengthen during the day and end around sunset, relative to the difference in temperature between the land and water.

The onshore breeze may reach speeds of 10 to 15 mph, but can attain speeds of 20 to 30 mph along the Washington, Oregon, and California coasts.

A period of notably hot, dry, and still conditions can precede the onset of the sea breeze and cause a substantial increase in fire behavior.

b. Land breezes

Land breezes result from the differential cooling rates of the land and water surfaces.

They normally begin 2 to 3 hours after sunset, and are usually on the order of 3 to 10 mph.

D. Critical Winds

Critical Winds are of most concern to firefighters as they are defined as winds that would totally dominate the fire environment.

These are the moderate to strong winds that fan fires out of control, threatening life and property.

These winds include:

1. Frontal winds

Frontal winds are produced by large scale pressure gradients and may be classified in the General Wind category.

The effects of the strong and shifting winds associated with a frontal passage may totally dominate the fire environment.

Since frontal systems may be accompanied by various other weather factors (thunderstorms), it is not possible to quantify wind speeds with frontal passages.

Be aware of the timing of expected frontal passages. Also be alert to the potential of the variable winds that normally are associated with this event.

2. Thunderstorm winds

Thunderstorm winds can be strong and quite gusty.

Strongest winds are usually associated with the mature and dissipating stages of the thunderstorm and speeds of 40 to 60 mph are not uncommon.

Lighter winds are noted in the formative stages of the storm, with inflow winds of 5 to 10 mph.

3. Foehn winds

Foehn winds are associated with major mountain ranges and specific large-scale weather patterns.

These winds can reach speeds in excess of 50 mph and are generally warm and dry.

Some examples of foehn winds are the Chinook, Santa Ana, and East Winds.

4. Glacier winds

Glacier winds are local downslope winds that impact locations adjacent to the base of glaciers.

Highest wind speeds occur around midday, driven by the difference in temperature between the air over the ice and the adjacent land.

The distance glacier winds extend across the adjacent land is related to this temperature difference, in addition to any channeling by the valley where the glacier resides.

Downslope winds of up to 50 mph have been noted to extend 10 miles from the bases of large glaciers in Alaska.

Glacier winds have been known to catch off guard firefighters who were expecting upslope winds as valley temperatures warmed.

5. Whirlwinds

Whirlwinds develop as the result of local effects, both topographic and atmospheric.

They are formed in a highly unstable lower atmosphere, triggered by some mechanical or other disturbance that initiates a whirling motion in the wind flow.

There are various scales of whirlwinds, few of which would totally dominate the fire environment.

They can be a very troublesome phenomenon if they occur near a fire's edge.

6. Reverse wind profiles

Reverse wind profiles are situations where the surface or low level winds are stronger than the winds aloft.

This contrasts to the usual situation where winds increase with altitude.

The implication for fire behavior is that reverse wind profiles allow a strong convection column to develop directly over a fire without being sheared away by stronger winds aloft.

There are two main types of reverse wind profiles:

a. Low level jet

Low level jet streams are currents of relatively fast moving air near the earth's surface that affect areas mainly east of the Rockies.

They are General Winds caused by large scale forcing mechanisms, usually cold fronts or lee-side troughs.

Peak winds range roughly from 25 to 40 mph, and are usually about 1000 to 2500 feet above the surface.

The main threat is for these winds to surface or affect higher terrain and cause rapid rates of spread.

b. Local forcing

Under situations where General Winds are light, moderate to strong Local Winds can lead to a reverse wind profile.

These situations are possible across the intermountain west and also coastal areas, where vigorous Local Wind systems occur under general high pressure.

The strongest winds are at the surface and may only be 10 to 20 mph. This type of reverse wind profile is highly localized, but has caused some of the most significant blowup fires.

III. FACTORS OF STABILITY

The temperature structure in the lower atmosphere changes from day to night. Stability or instability can be measured by the rate of change of the temperature with increasing elevation.

The degree of stability or instability affects the mixing potential of the lower atmosphere; it is normally stable at night with light winds.

During the afternoon, the atmosphere becomes more unstable, with a risk that stronger General Winds aloft could surface. This is because unstable conditions increase the depth of the turbulent friction layer.

Remember: When the atmosphere is stable (inversions), there is usually little wind. When the atmosphere is unstable, there is the potential for stronger surface winds regardless of the time of day.

It is possible for a large fire to modify the stability of the lower atmosphere if terrain and fuel conditions are right. This could enhance convection column development and surface winds.

IV. SOURCES OF WIND INFORMATION

A. Fire Weather Forecaster

The best source of weather information is the fire weather forecaster.

This forecaster may be a direct resource assigned to the project, or may be a forecaster assigned to the local National Weather Service forecast office.

This person can give site-specific wind forecasts.

B. Persistent Patterns

Personnel who are on a fire for several days are often able to develop a feel for wind patterns that are consistently the same, day in and day out.

These are called persistent patterns, and can provide an idea of what will happen in future burning periods if the overall synoptic scale weather pattern does not change.

Use this method of predicting winds only if there is assurance from a knowledgeable fire weather forecaster that the general weather pattern is not expected to change.

C. On-Site Measurements

On-site measurements may be used to make an immediate assessment of what a fire may do.

This technique may be referred to as "Now-casting" and does have limitations.

Be sure that the wind being measured is not being influenced by the fire. It should be taken in a location that is representative of the fuels, topography, and weather that is or will be controlling the fire's behavior.

D. Assessment of Local Conditions

If all else fails, take a general weather forecast from whatever source is available and make a best guess as to what the wind will be.

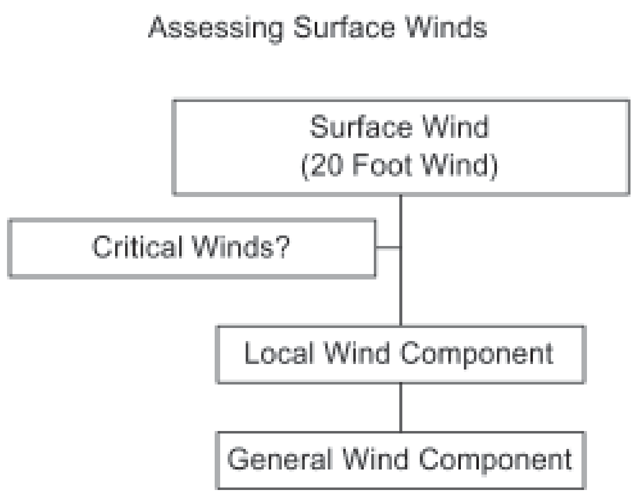
V. PROCEDURES FOR ASSESSING SURFACE WINDS

In order to derive the wind input for fire behavior prediction, follow a systematic procedure and arrive at a reasonable estimate.

If there is a fire weather forecaster available, this weather “Expert” should provide the wind data needed. If not, assess the situation and get on with the task at hand.

The surface or 20-ft wind is the input needed. Recall from S-290 that the wind measured 20 feet above the mean vegetation height is considered as the surface wind standard for fire behavior purposes.

The 20-ft. wind can be described with this simple diagram:



In the absence of a dominating Critical Wind, the surface wind is a combination of the Local Wind and the General Wind.

A. Critical Winds

These winds are defined as those that can totally dominate the fire environment. Consider these winds first!

- Review all forecasts for warnings regarding weather events that may be accompanied by strong winds.
  - Be alert for mention of frontal passages, low level jet, strong glacier winds, thunderstorms, Santa Ana, or other foehn type winds, etc.
- Discuss the situation with knowledgeable locals.
  - Learn about local problem areas that may spawn whirlwinds or other local peculiarities.
- If available, review weather observations from the area, find out what caused the fire to spread rapidly, and note any unusual wind or weather patterns.

B. Local Wind Factor

Use normal local wind patterns to derive an estimate of direction and speed by time of day.

Remember:

- Local winds are best developed under clear/sunny skies.
- Upvalley/upslope winds are gusty.
- Downslope/downvalley winds are steady.
- Valley winds, when fully developed, can overpower slope winds.

C. General Wind Factor

Use the general forecast and overlay the forecast General Wind on the fire area map.

Consider the following stability and terrain effects when assessing the contribution of General Winds at the surface.

- General Winds are more likely to surface when the air is unstable.
- Ridgetop winds are a good indicator of General Winds.
- General Winds have a greater effect on upper slopes than lower slopes.
- Friction slows General Winds.
- General Winds are more likely to surface when parallel to a valley.
- Light General Winds (less than 10 mph) are unlikely to surface.
- General Winds have little impact on sheltered areas, such as the immediate downwind or lee side of sharp topographic features.
  - In reality, this is a much more complex problem dependent on stability and the specific nature of topographic features.
  - For this class, assume little or no General Wind impact on sheltered areas.
- Depending on the amount of instability and the overall exposure, 50 percent or more of the General Wind speed can make it to the surface.

EXERCISE 1.

For this exercise, use pages 2B.29 – 2B.32.

VI. MIDFLAME WIND

Wind data that is required for the computation of fire spread in the USFBPS Model is the "Midflame Wind."

This is the wind at one-half the flame height. To derive this wind, students must know the 20-foot wind, fuel type, and the degree of sheltering.

The degree of sheltering of the fuels is a function of canopy density and the position of the fuel bed on the landscape. It is also a function of the direction and speed of the wind as it relates to the steepness of a slope, as well as the angle of attack of the wind on the slope.

These factors are much easier to assess in the field, and in most cases, it will be intuitively obvious if the site can be physically seen.

An important thing to remember is that nighttime 20-foot drainage winds do not need to be reduced to the midflame level. This is because the cool, stable air is sinking towards the surface, such that the 20-foot and midflame winds are essentially equal. Midflame wind reduction tables are in the Fireline Handbook.

There is some subjectivity involved in figuring midflame winds due to differing assessments of stand density and sheltering. Usually, there will be one or two reasonable answers using the tables, and both will give similar results.

The following example problems are to ensure we are all on the same track:

1. Fuel Model 8. Site on upper third of slope, fuels beneath standing timber, wind blowing directly at slope. 20 ft. wind 12 mph.

   Midflame Wind = ___________

2. Fuel Model 1. Site on upper third of slope, 100 acre meadow of pine grass, wind blowing directly at the slope. 20 ft. wind 15 mph.

   Midflame Wind =______________

3. Fuel Model 10. Dense stand, fully sheltered, site on lower third of slope. 20 ft. winds 18 mph.

   Midflame Wind =______________

EXERCISE 2.

For this exercise, use pages 2B.33 – 2B.35.

VII. REVIEW

Making estimates of local wind patterns is difficult. Even trained and experienced fire weather forecasters usually do not come up with the same answers when looking at problems such as the examples in this unit.

A wind input is necessary to complete the calculations. Firefighters should have a basic knowledge of winds and midflame winds sufficient to make a rough forecast of winds, if necessity dictates.

To begin the analysis of wind on a fire, consider the following factors:

- How much time is available to complete the assignment and make a prediction?
- Is the prediction for daytime or nighttime? Is it necessary to consider the transition from one to the other?
- What is the terrain like?
- Is the fire sheltered beneath standing timber or is it unsheltered to the wind?
- Is there a large body of water or other geographic features that may influence wind speed and direction?
- What has the wind done in previous burning periods?
- What weather data is available?
- Where can additional weather data observed and forecasted be obtained, and how soon?
- Contact knowledgeable locals and check for any unusual wind or weather patterns.

The table below represents typical wind speed ranges. If the given winds are much different than these, proceed with caution.

Wind Speed	Typical Speeds
Frontal Winds	Too variable to be specific.
Foehn	40 to 60 mph common; up to 90 mph not uncommon.
Land Breeze	2 to 3 hours after sunset, 3 to 10 mph.
Sea Breeze	10 to 15 (Ocean type). Locally 20 to 30 mph, Washington, Oregon and California coasts.
Up-Valley	10 to 15 mph afternoons and early evenings.
Down-Valley	Generally less than 10 mph at night.
Upslope	3 to 8 mph with maximum slope warming.
Downslope	2 to 5 mph, midflame height.

Check the assessment procedures and make sure they are on the right track. Note that the "typical" wind speeds are expressed in ranges of values.

This is done because it is a rare occasion when winds are steady; they always vary some.

The following table is the Beaufort Wind Scale. If no other way to measure wind is available, an estimate of speed can be made using the visual indicators described. Become familiar with this scale and have it available when needed.

Range of Speeds mph	Nomenclature
3	Very Light–Smoke rises nearly vertically. Leaves of quaking aspen in constant motion; small branches of bushes sway; slender branchlets and twigs of trees move gently; tall grasses and weeds sway and bend with wind; wind vane barely moves.
4-7	Light–Trees of pole size in the open sway gently; wind felt distinctly on face; loose scraps of paper move; wind flutters small flag.
8-12	Gentle Breeze–Trees of pole size in the open sway very noticeably; large branches of pole-size trees in the open toss; tops of trees in dense stands sway; wind extends small flag; a few crested waves form on lakes.
13-18	Moderate Breeze–Trees of pole size in the open sway violently; whole trees in dense stands sway noticeably; dust is raised in the road.
19-24	Fresh–Branchlets are broken from trees; inconvenience is felt in walking against wind.
25-31	Strong–Tree damage increases with occasional breaking of exposed tops and branches; progress impeded when walking against wind; light structural damage to buildings.
32-38	Moderate Gale–Severe damage to tree tops; very difficult to walk into wind; significant structural damage occurs.
39	Fresh Gale–Surfaced strong Santa Ana; intense stress on all exposed objects, vegetation, buildings; canopy offers virtually no protection; wind flow is systematic in disturbing everything in its path.

VIII. SUMMARY

The “Guts” of the USFBPS Model have not yet been covered in this course. Nonetheless, there are a few wind-related assumptions of the USFBPS that are important to know.

- It is assumed that the local environment that would exist without the fire will control the fire’s behavior (the fire’s influence on the wind is ignored).

- If a burning prescription relies on fire induced indrafts to produce desired fire behavior (burnout or backfire), the model has limited applicability.

- If winds are strong enough (and fuel conditions proper) to produce a running crown fire, the model does not apply.

The job of the fire prediction specialist is difficult and demanding. Without the services of a fire weather forecaster, the job becomes double-tough. When put into the position of having to assess the local surface winds on a project, use every trick possible.

Approach the job with respectful caution and do not forget to assess the entire fire situation before starting to work. Do not get sucked into wasting time on problems that don’t make any difference.

Final reminder: Do not forget which way the wind blows!

Figuring 20 Foot & Midflame Winds

IS THERE A "CRITICAL WIND" THAT WILL DOMINATE THE FIRE ENVIRONMENT? (I.E. FRONTAL, FOEHN, GLACIER, THUNDERSTORM, WHIRLWIND, LOW LEVEL JET)

Yes → 20 foot wind = "Critical Wind" **STOP**

No ↓

Figure Local Wind Component

Wind speed guidelines based on slope/aspect and potential heating/cooling:

Upslope	3-8 mph
Downslope	2-5 mph
Up-valley	10-15 mph
Down-valley	10 mph or less

→ 1. LOCAL WIND COMPONENT (LWC)

DIR.____________ SPEED______

ARE GENERAL WINDS 10 MPH OR LESS? (I.E. OBSERVED OR PREDICTED RIDGETOP WINDS)

Yes → 20 foot wind = Local Wind Component **STOP**

No ↓

Figure General Wind Component

General Wind Component = General wind speed (mph) x wind reduction factor (Zero to .6, based on table below)

Wind Reduction Factor for General Wind
(*Assuming instability and exposure*)

Upper 1/3 of slope <u>or</u> Parallel Drainage	.4-.6
Middle 1/3	.3-.4
Lower 1/3	.2-.3
Sheltered areas	Near Zero

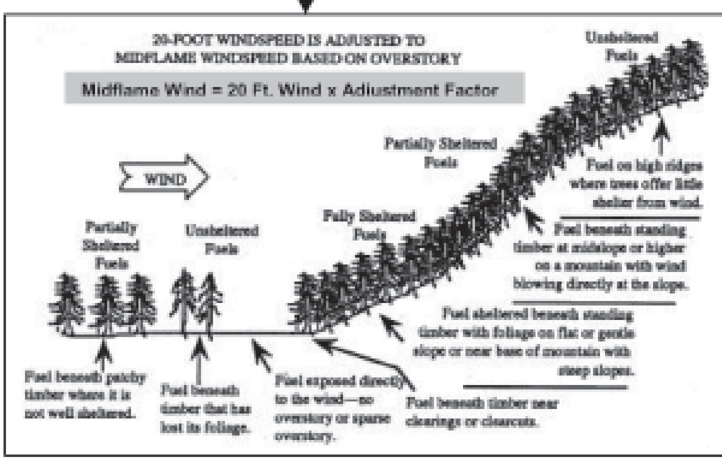
→ 2. GENERAL WIND COMPONENT (GWC)

DIR.____________ SPEED______

20 Foot Wind = Local Wind Component (LWC) + General Wind Component (GWC).

1. ______________ + 2. ______________ = ________________

Local (LWC) General (GWC) 20 ft. Wind



Fuel Exposure	Fuel Model	Adjustment Factor
UNSHELTERED FUELS: Fuel exposed directly to the wind. No or sparse overstory. Fuel beneath timber that has lost its foliage; fuel beneath timber near clearings or clearcuts; fuel on high ridges where trees offer little shelter from the wind.	4 13 1,3,5,6, 11,12 (2,7)[1] (10)[2] (8,9)[2]	0.5 0.5 0.4 0.4 0.4 0.4 0.3
PARTIALLY SHELTERED FUELS: Fuel beneath patchy timber where it is not well sheltered; fuel beneath standing timber at midslope or higher on a mountain with wind blowing directly at the slope.	All Fuel Models	0.3
FULLY SHELTERED FUELS: Fuel sheltered beneath standing timber on flat or gentle slope or near base of mountain with steep slopes.	All Fuel Models	Open Stands 0.2 Dense Stands 0.1

[1]Fuels usually partially sheltered.
[2]Fuels usually fully sheltered.

2B.26

Wind Worksheet for Use With Multiple Map Points

	Local Wind Component	General Wind Component			20 ft. Wind	Midflame Wind	
Map Point	Dir. & Speed	General Wind Dir. & Speed	Reduction Factor	GWC Speed	Dir & Speed	Adjustment Factor	Midflame Wind Speed
			x	=		x	=
			x	=		x	=
			x	=		x	=
			x	=		x	=
			x	=		x	=

	Local Wind Component	General Wind Component			20 ft. Wind	Midflame Wind	
Map Point	Dir. & Speed	General Wind Dir. & Speed	Reduction Factor	GWC Speed	Dir & Speed	Adjustment Factor	Midflame Wind Speed
			x	=		x	=
			x	=		x	=
			x	=		x	=
			x	=		x	=
			x	=		x	=

	Local Wind Component	General Wind Component			20 ft. Wind	Midflame Wind	
Map Point	Dir. & Speed	General Wind Dir. & Speed	Reduction Factor	GWC Speed	Dir & Speed	Adjustment Factor	Midflame Wind Speed
			x	=		x	=
			x	=		x	=
			x	=		x	=
			x	=		x	=
			x	=		x	=

	Local Wind Component	General Wind Component			20 ft. Wind	Midflame Wind	
Map Point	Dir. & Speed	General Wind Dir. & Speed	Reduction Factor	GWC Speed	Dir & Speed	Adjustment Factor	Midflame Wind Speed
			x	=		x	=
			x	=		x	=
			x	=		x	=
			x	=		x	=
			x	=		x	=

EXERCISE #1

This exercise is an example problem that illustrates how to use the assessment procedure. The exercise requires class participation in developing a reasonable assessment of the wind at each point.

Remember: The wind that is developing is the 20-foot wind – that is the wind at 20 feet above the average ground cover. The only exception is that the downslope wind at night is considered to be close to the surface.

There is no single correct answer; the procedure will produce a range of reasonable solutions. You should be able to estimate 20-foot winds within 45 degrees on direction and 5 mph on speed using the methodology described.

Use the quad map on page 2B.32 to complete the following:

1. With no (calm) free air winds, 3 p.m. midsummer conditions:

   Give 20 ft. wind directions at points A, B, C, D, and E. Assign 20 ft. wind speeds for these points at the same time.

   A=
   B=
   C=
   D=
   E=

2. Free air winds are SW 20 mph, all else as in question 1 above:

   Determine General Wind Component at all points.

   A=
   B=
   C=
   D=
   E=

Show 20 ft. wind directions at all points.

A=
B=
C=
D=
E=

Assign 20 ft. wind speeds for these points.

A=
B=
C=
D=
E=

3. Free air winds are SE at 20 mph and the airmass is very unstable, all else as in question 1:

Determine General Wind Component at C, D, E.

C=
D=
E=

Show 20 ft. wind direction at these points.

C=
D=
E=

Assign 20 ft. wind speeds for these points.

C=
D=
E=

4. Free air winds are SW 20 mph. A vigorous dry cold front is forecast to move through the area around 5 p.m.

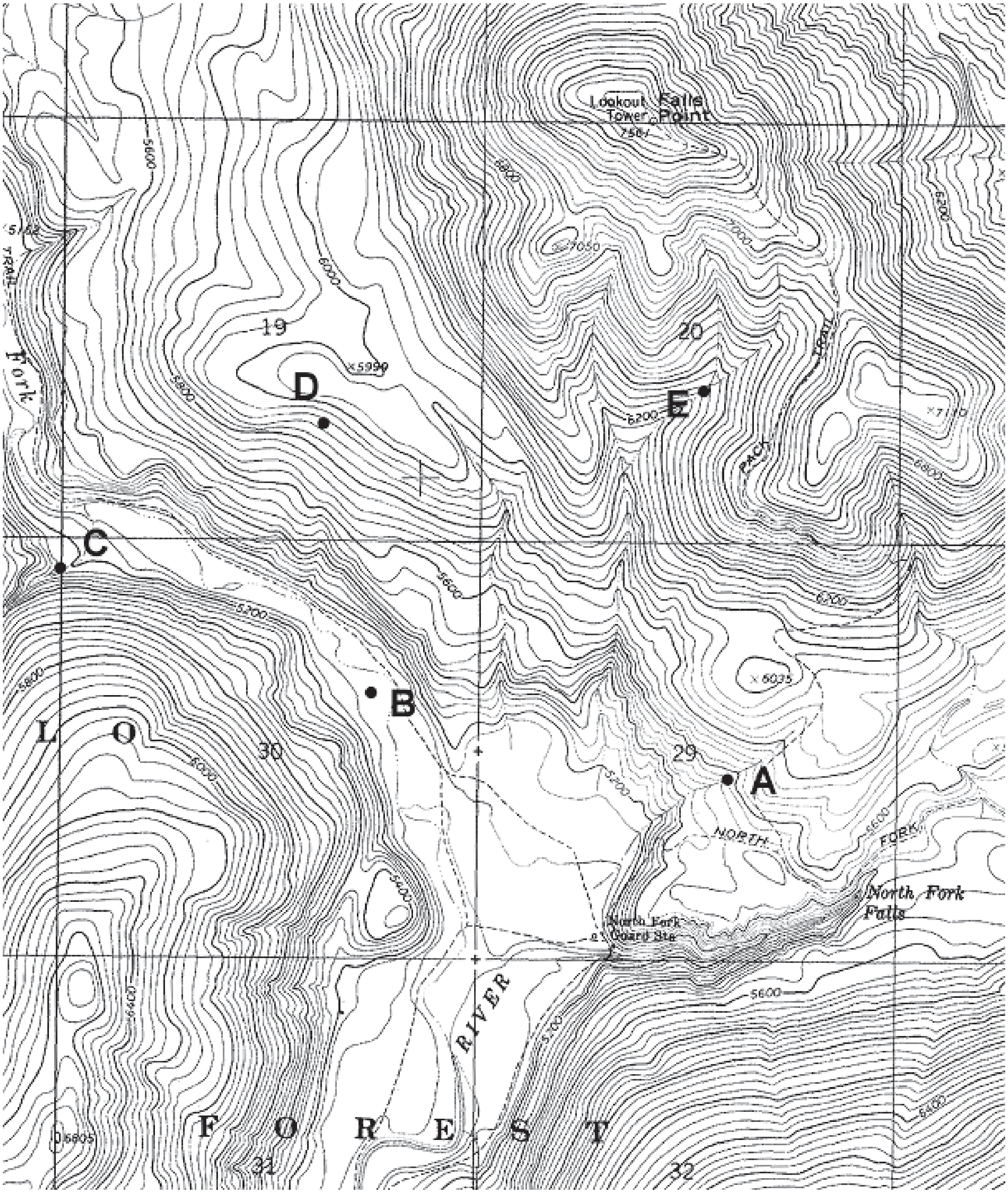
Give expected 20 ft. wind directions at all points one hour before expected frontal passage.

A=
B=
C=
D=
E=

Give expected 20 ft. wind directions one hour after frontal passage.

A=
B=
C=
D=
E=

When and where would you expect the 20 ft. winds to be the strongest between one hour before and one hour after frontal passage?


Lookout Falls
Tower Point
D
E
C
B
A
19
20
29
30
31
32
North Fork Falls
North Fork Guard Sta
NORTH FORK
RIVER
PACK TRAIL
L O
F O R E S T
Fork
TRAIL

EXERCISE #2

The “No-See-Um” fire (see quad map on page 2B.35) was started by a careless camper along the North Fork Trail on August 15. It has grown to about 250 acres and is burning actively in the understory of an open spruce-fir community (Fuel Model 8). It has spotted over onto a southwest slope (Point D) into about a 50 acre patch of red needled blowdown timber (Fuel Model 13).

The general forecast calls for stable morning conditions to give way to hot temperatures and unstable lapse rates in the North Fork canyon this afternoon. The free air wind is south 18 mph.

1. For 11 a.m., estimate the surface (20 ft.) wind speed and direction at points A, B, C, and D.

   A=
   B=
   C=
   D=

2. Using known methods, determine the “midflame” wind speed for each point for 11 a.m.

   A=
   B=
   C=
   D=

3. For 4 p.m., estimate 20 ft. wind speed and direction for each point.

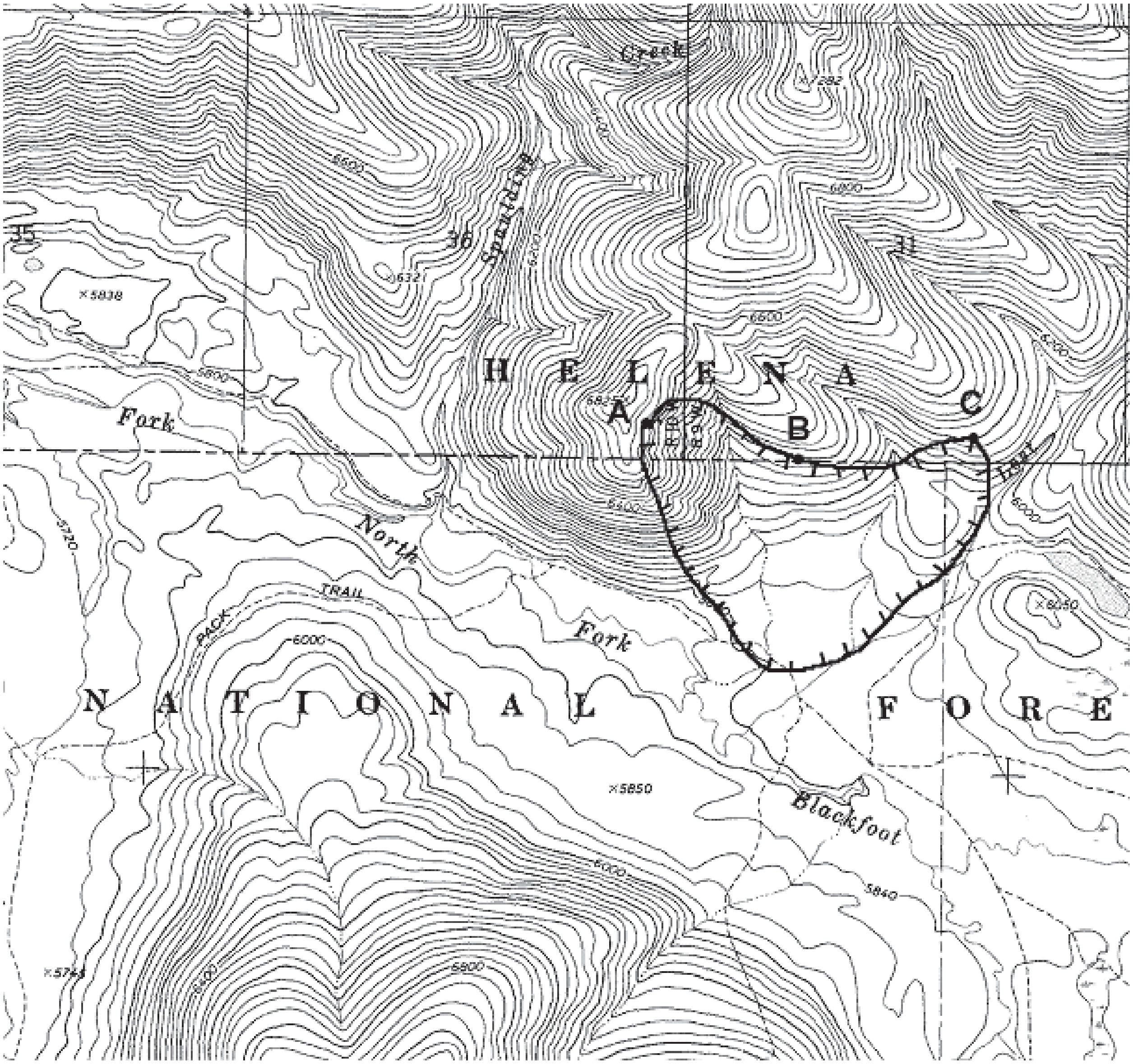
   A=
   B=
   C=
   D=

4. Determine “midflame” wind speeds for 4 p.m.

A=
B=
C=
D=

5. For 2 a.m., determine 20 ft. wind speed and direction as well as the “midflame” winds for each point.

A=
B=
C=
D=



Creek
35
36
31
Spaulding
HELENA
NATIONAL
FORE
A
B
C
Fork
North
Fork
PACK
TRAIL
Blackfoot
×5838
×5850
×6050
×5745

2B.36

EXERCISE #3 (Optional)

It is late May in northern New Mexico (see quad map on page 2B.38). Daytime temperatures are quite warm and afternoons are very unstable due to daytime heating.

1. High pressure is dominant across the region, such that "free-air" winds are variable at less than 10 mph. Figure 20 ft.wind speed and direction at all points for mid-afternoon.

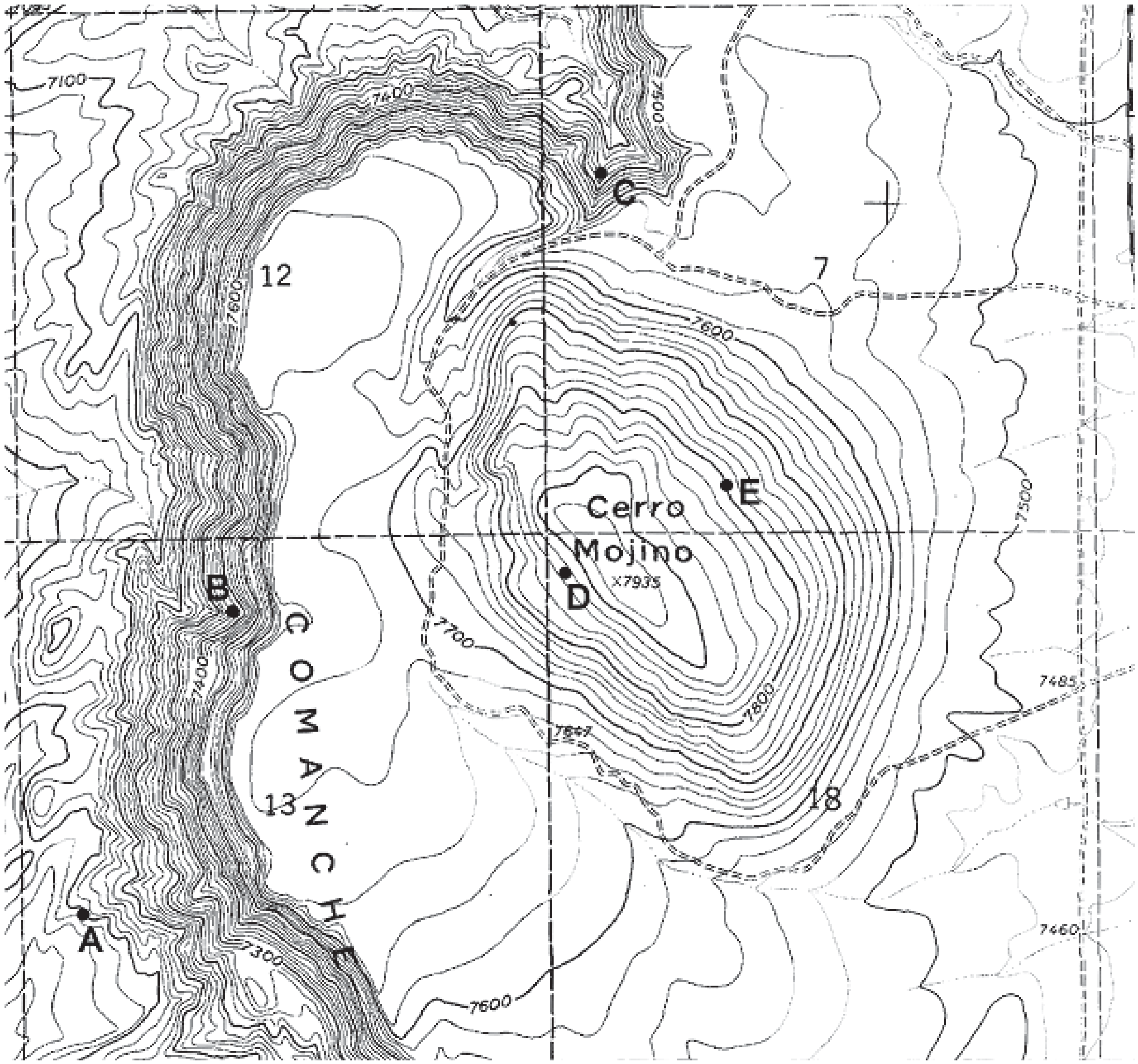
   A=
   B=
   C=
   D=
   E=

2. The high pressure area has moved east, such that "free-air" winds across the area are now from the southwest at 20 mph. Figure 20 ft.wind speed and direction at all points for mid-afternoon.

   A=
   B=
   C=
   D=
   E=

3. Using 20 ft. winds from problem 2, figure midflame winds at the following points assuming a dense Pinyon-Juniper stand (FM 6).

   A=
   B=
   D=



7100
7400
7500
C
12
7600
7
7600
E
Cerro
Mojino
B
D
×7935
7500
C
O
M
A
N
C
H
E
7700
7400
7800
7485
7847
13
18
A
7460
7300
7600

Introduction to Wildland Fire Behavior Calculations, S-390

Unit 2 – Weather

Lesson C – Weather Information and Forecasts

OBJECTIVES:

Upon completion of this lesson, students will be able to:

1. Identify various weather products available to assist the firefighter, who provides them, and how to obtain them.

2. Evaluate factors that can affect forecast accuracy and methods to mitigate them.

3. Describe importance of timely and accurate on-site observations and providing feedback to local weather office.

4. Identify indicators of significant weather changes and evaluate whether a provided forecast is valid.

5. Describe methods for adapting forecasts to better reflect local conditions.

2C.2

I. INTRODUCTION

With the inception of the National Fire Plan, the fire management agencies and the National Weather Service (NWS) assumed joint responsibility for the provision of fire weather services.

In addition to information provided by meteorologists, advancing technology and the Internet have provided access to a staggering amount of weather forecast and analysis information.

Tools and information available only to meteorologists 10 or 20 years ago are now available routinely to anybody in the fire management community.

This lesson will review major sources of weather information and forecasts and how they can be best utilized to meet fire management purposes.

II. WEATHER OBSERVATIONS AND ANALYSIS

A. Surface Observation Data

Surface weather observation data is accessible in real time over the Internet. This includes parameters such as:

- Temperature
- Relative humidity
- Wind speed and direction
- Dew point

Among the information available is the hourly data from the fire management agency's Remote Automated Weather Station (RAWS) network.

Hourly airport observations from the NOAA/FAA/DOD Automated Surface Observation System (ASOS) are also readily available.

Data from RAWS and ASOS are the most accessible and frequently utilized by the fire management community.

1. RAWS observations.

    RAWS observations meet specific NWCG standards for the National Fire Danger Rating System Forecasts (NFDRS).

    They are designed and placed accordingly to record weather for direct application to fire management.

    Twenty-foot winds, used as input for NFDRS and the Fire Behavior Prediction System (FBPS), are recorded at RAWS.

2. ASOS (Airport) observations.

    ASOS observations meet specific NWS, FAA and DOD standards, and are placed almost exclusively at airports.

    Information from ASOS stations is used to facilitate the takeoff and landing of aircraft, as well as to maintain a general climatic database of general weather parameters.

3. RAWS and ASOS data access and interpretation.

    RAWS data are accessed mostly through web sites hosted by either BLM or NWS.

    In almost all cases, ASOS observations made available to the public are fully decoded into a “friendly” format for ease of interpretation.

B. Comparison of Wind Information Between RAWS and ASOS

Utilizing and comparing wind data from different observation systems is a complex issue due to the differing standards for measuring wind speed.

The two main sources used for forecasting or observing wind for fire management application are ASOS (used at airport locations) and RAWS (used extensively in remote locations).

Observation System	Tower Height	Time Period Averaged for Sustained Wind	Gust Determination
ASOS	33 feet	2 minutes	5 second average
RAWS	20 feet	10 minutes	Instantaneous

1. Effect of tower height on observed wind speed.

   Because winds aloft decrease exponentially towards the surface due to frictional effects, higher towers generally record stronger wind speeds.

   Considering tower height only, ASOS will measure stronger winds than RAWS under a given situation because ASOS units have higher towers.

   Differences in measured wind speed caused by tower height are greatest when the surface is rough (forest) and least when the surface is smooth (grasslands and airport runways).

2. Effect of wind averaging on observed wind speed.

The gusty nature of wind is a result of mechanical turbulence, which is a function of surface roughness and atmospheric instability.

For this reason, winds are gustier over rough surfaces on unstable days and are minimally gusty over smooth surfaces during stable situations.

The gustier the character of the wind, the stronger winds sampled over short time periods (2 minutes) are relative to those sampled over longer time periods (10 minutes).

Because of wind averaging, sustained winds measured by ASOS are higher than those measured by RAWS stations due to ASOS units averaging over a shorter time period.

C. ASOS vs. RAWS Wind Speeds

1. Sustained wind speeds measured by RAWS are consistently less than those measured by the ASOS network.

This is due to differences in measuring standards between the two systems, which exacerbate the differences in station siting standards.

2. Differences in measured sustained wind speed are most pronounced on windy, unstable days, especially when comparing airport ASOS to RAWS sited in forested areas.

RAWS should have ample clearing to reduce the effects of friction. The cleared area rarely approaches the size or smoothness of the airport environment where the ASOS units are sited.

3. Differences in measured sustained wind speed are least pronounced on smooth surfaces (open rangeland or plains) under stable situations (like downslope winds or winds during nighttime).

   ASOS often measures the general wind, while RAWS are often subject to both general and local wind components due to siting considerations (complex terrain).

   Due to the complexity involved, there are no hard and fast rules for comparing RAWS and ASOS winds that can work across the entire county, under all available fuel types, and any possible environmental conditions.

D. RAWS vs. Eye-level or Midflame Winds

When using 20 ft. wind observational and forecast information operationally, it is important to recall the differences between 20 ft. winds and the wind data collected on the fireline.

For example, most fire weather forecasts provide 20 ft. winds, while fireline wind observations are at eye-level.

In the same way that 20 ft. winds must be reduced to midflame for fire behavior calculations, eye-level (midflame) winds must be increased to be compared to 20 ft. wind observations or forecasts.

During afternoon burn periods:

1. Eye-level/midflame winds observed on-site will always be less than 20 ft. winds (unless there are 40 ft. flame lengths).

2. Depending on sheltering and fuel type, eye-level/midflame winds range from 10% to 60% of the 20 ft. wind (20 ft. winds at 20 mph could be observed anywhere from 2-12 mph at midflame).

3. In most cases, eye-level/midflame winds are roughly 30% of 20 ft. winds.

   Example: An accurate 20 ft. wind forecast of 20 mph would be measured at 6-7 mph in the field with a belt weather kit.

III. FIRE WEATHER FORECAST INFORMATION

Under the national interagency agreement, fire weather services are provided jointly by the NWS and the Geographic Area Coordination Center's (GACCs) Predictive Services.

Predictive Services' focus is mainly strategic. It combines weather, fuels, and fire danger information into integrated assessments.

NWS' focus is mainly tactical and contains purely weather information. There is overlap, which varies from region to region.

National level relationship between NWS and Interagency Wildland Fire Agencies is defined under the "Interagency Agreement for Meteorological Services."

Regional variability allowed under the national agreement will be defined in Geographic Area Memorandums of Understanding (MOU) and will be reflected in all Fire Weather Annual Operating Plans.

Copies of these should be available from the local NWS office or the appropriate GACC.

A. The Fire Weather Annual Operating Plan (AOP)

The AOP is the procedural guide for all fire weather services provided by NWS and GACC Predictive Services.

It contains information such as:

- Which forecasts are available.
- Observation and forecast schedules.
- Communications
- Procedural steps to acquire services.
- A map and description of the areas served.
- Identifies normal seasonal responsibilities and how, where, and when products and services will be available.

The AOP is made available to all fire management units each year, in either hardcopy or electronic format.

All fire management units should have access to the AOP for their area.

B. Predictive Services

Predictive Services is a combination of Fire Intelligence and Fire Meteorology with the purpose of providing assessments of the overall fire environment.

Predictive Services monitors, analyzes and predicts fire weather, fire danger/potential and interagency fire management resource impact. This is accomplished through a range of combined fire weather/fire danger outlooks.

Products are targeted to aid resource related decision-making at the geographic area and national levels, and increase safety overall through an enhanced awareness of expected fire danger.

Each GACC has a Predictive Services group to meet the needs of the Geographic Area, and information from the GACCs is integrated into national level outlooks by NICC Predictive Services.

All Predictive Services products can be accessed via the NICC web site.

Updated information on GACC Predictive Services products can be found in Section 25 of the National Mob Guide at: http://www.nifc.gov/news/mobguide/chapter_20.pdf

1. Weather outlooks for Incident Management Situation Report (IMSR).

   Daily: May through the end of October and as activity warrants.

   Weekly: November through the end of April.

   This report is prepared by NICC from information and data on the Interagency Situation Report, submitted by the GACCs.

   This report will be prepared daily and distributed at 0530 MDT (0800 on weekends and holidays) from May through October, and at 1000 MST on Friday November through April.

   When GACCs report large fires and/or very high to extreme fire danger, a brief weather outlook for the Geographic Area will be produced by GACC Predictive Services for inclusion in the national situation report.

2. Weekly Fire Weather/Fire Danger Outlook.

Weekly: During significant wildland fire activity.

This outlook is to be posted on each GACC website every Tuesday at the close of business.

It contains information on current and projected fire weather, fire danger, and fire management resources.

3. Monthly Fire Weather/Fire Danger Outlook.

Monthly: Year-round

This outlook and map shall be completed for every month by each GACC, and submitted to the NICC five days prior to the beginning of that month.

GACCs shall include within their narratives the following information:

a. A brief discussion of predicted general weather / fire danger for the entire GA for the reporting period.

b. A brief discussion on current GA fuel anomalies / fuel moisture conditions.

c. A brief discussion on predicted temperature ranges and precipitation for the GA for the reporting period.

4. National Wildland Fire Outlook.

Monthly: Year-round

This report is issued on the first days of each month and is compiled from the GACCs Monthly Fire Weather / Fire Danger Outlook.

It consists of a national map delineating areas of below normal, normal, and above normal fire potential along with narratives for each Geographic Area.

5. Seasonal assessments

Seasonal: Prior to fire season onset with mid-season update(s).

Seasonal assessments will be issued periodically by GACCs, with the first report issued prior to the onset of their primary fire season.

A minimum of one update will be completed during their fire season, or as deemed necessary.

National Seasonal Assessments will be produced by NICC upon request by NMAC or the WO.

NICC staff will assist GACCs with seasonal assessments. Content will include:

- Executive Summary
- Introduction and Objectives
- Current Situation (leading up to time report is written)

- Comparison of Current and Historical Conditions
- Climate, Weather, Fire Forecasts/Outlooks
- Predicted Fire Occurrence and Resource Needs
- Future Scenarios and Probabilities
- Considerations, Concerns and Management Implications
- Summary and Recommendations

6. Other products and services

Different GACCs provide a variety of other products and services that may be useful such as:

- Internet weather briefing pages.
- Daily summaries of NWS fire weather forecasts, both graphical and text.
- Long term precipitation monitoring.
- Smoke management summaries.
- Technical Specialists support by GACC meteorologists.

C. National Weather Service Fire Weather Program

Updated information on the NWS Fire Weather Program and services can be found in NDS 10-4 at: http://www.nws.noaa.gov/directives/010/010.htm

The NWS Fire Weather Program is the operational program that provides specialized forecasts, warnings, and consultation services.

These services are for the prevention, suppression, management of forest and rangeland fires, and land management activities.

1. Current Structure of the NWS Fire Weather Program.

   The NWS core product suite includes a variety of local forecasts issued by local NWS offices, as well as several national outlooks produced by NWS national centers.

   Most all NWS fire weather products are available online from the NWS National Fire Weather Page as well as the internet home pages of local NWS Weather Forecast Offices (WFOs) nationwide.

   a. Guidance and weather model data are generated from national centers.

      - Guidance products during the fire season are issued daily by the Storm Prediction Center.

      - The guidance products are used by the local WFO as a heads up for the next several days for potential severe fire weather in their area.

   b. Meteorologists at WFOs issue fire weather products for their area of responsibility, focusing on potential red flag.

      - Zone forecasts are issued twice a day with updates as needed.

      - SPOT forecasts are issued upon request.

      - Fire Weather Watches and Red Flag Warnings are issued as needed.

c. On-site meteorological support, by the NWS, consists of an Incident Meteorologist (IMET).

- The NWS has over 60 IMETs across the country, with over two-thirds positioned along and west of the Rocky Mountains.

- The Fire Weather Annual Operations Plan contains complete information on available NWS products and services, including procedures for ordering an IMET and IMET support equipment.

2. Regional Fire Weather Program.

3. Routine WFO Fire Weather Forecasts (FWF).

a. Fire weather (pre-suppression) forecasts (fire weather zones).

A zone-type product used by land management personnel primarily for input in decision-making related to pre-suppression and other planning.

Issued at least once daily during the local fire season.

Updated when a Fire Weather Watch or a Red Flag Warning is issued or when the meteorologist feels the current forecast has become unrepresentative of expected weather conditions.

- Contains any Fire Weather Watches or Red Flag Warnings in effect, headline, discussion, weather, temperature, and humidity; 3-7 day outlook.

- Issued in either tabular or narrative format.

b. National Fire Danger Rating System Forecasts (NFDRS).

Coded forecast issued for valid NFDRS observations to provide weather elements necessary for computation of next day fire danger indices.

c. Spot Forecasts

This is a site-specific 24-36 hour forecast that is available on request for:

- Wildfires
- Prescribed burns
- Spray projects
- Tree planting
- Search and Rescue
- HAZMAT incidents
- Other special projects

Emphasis is placed on forecast elements in the first 12-24 hours.

An interactive web-based program called NWS Spot is the national standard for requesting and issuing spot forecasts and should be used when possible.

NWS Spot requires entry of a variety of information about the forecast location, including a complete on-site weather observation.

The spot forecast should include:

- Time period for which the forecast is valid

- Brief weather discussion

- Forecast weather/sky conditions

- Temperature
- Relative humidity
- Wind speed and direction(20-foot or eye level)
- Stability and smoke dispersal potential (optional)

d. Red Flag Warnings / Fire Weather Watches.

Issued based on locally/regionally established criteria indicating when the combination of dry fuels and weather conditions support extreme fire behavior.

This criteria is determined each spring at the AOP meetings. Also if ignition is occurring or expected to occur.

Criteria includes:

- Fire danger
- Lightning after an extended dry period
- Significant dry frontal passage
- Strong winds
- Very low relative humidity
- Dry thunderstorms
- Initial Attack

When the established criteria are met, it is know as a "Red Flag Event."

(1) Fire Weather Watch

Issued when there is a high potential for the development of a Red Flag Event.

A Fire Weather Watch should be issued 24 to 72 hours in advance of the expected onset of criteria.

A Watch may be issued (or continued) in the first 12-hour time period for dry thunderstorm events.

(2) Red Flag Warning

Used to warn of an impending or occurring Red Flag Event.

Its issuance denotes a high degree of confidence that Red Flag Event criteria will occur in 24 hours or less.

e. Land Management Forecast.

A general-purpose, miscellaneous-type product with content, format, issuance, etc., determined per locally established requirements.

f. Smoke Management Forecast Product.

WFO meteorologists issue smoke management forecasts at the request of land management agencies.

They may be issued on a routine or as needed basis, and may be narrative or tabular in format, or a combination of both.

Meteorologists may include the smoke management forecast as part of another weather product (for instance, the FWF) or as a separate product.

The requester and the responsible NWS office should establish the content, format, frequency of issuance, dissemination method, etc.

This product may contain:

- Forecasts of the transport winds.
- Variability of transport winds with height and time.
- Air mass stability.
- Air dispersion.
- Measures of dispersion.
- Mixing depths and variations with time.
- Other smoke management related parameters.

g. Rangeland/Grassland Fire Danger Statement.

A miscellaneous product which provides advisory information on rangeland and/or grassland fire potential or conditions.

Land management and NWS personnel should establish the contents, format, frequency of issuance, dissemination, etc.

This product may be issued on a routine or non-routine basis.

4. Routine National Level Forecast Services.

   a. Storm Prediction Center (SPC) Fire Weather Outlook.

      The SPC will issue routine one and two Day Fire Weather Outlooks (Day 1 and Day 2) for the lower 48 states on the Internet.

      These outlooks describe large-scale meteorological conditions which favor the rapid growth and spread of a fire, should a fire ignition occur.

   b. Monthly and Seasonal Outlooks.

      These forecasts are issued for the next 30 or 90 day period by the Climate Prediction Center.

      The monthly forecast is issued twice a month, around the 1st and 15th, for the next 30 day period.

      Seasonal outlooks are issued the first of each month for the next three month period.

5. On-site incident support.

   Certified IMETs can be requested to provide on-site fire support for Incident Command Teams.

   IMETs issue detailed incident specific forecasts written only for the immediate area of the incident.

   These forecasts include all the meteorological parameters of other forecasts but with the added emphasis on time and location differences.

   In the field, the meteorologist can personally observe the influence fuels and topography have on the weather at the site. As a result, this is the most specific and accurate type of forecast available.

D. Fire Weather Forecast Flow Chart

The "Fire Weather Forecast Flow Chart" illustrates how forecasts are developed, the relationship between forecasts, and for what purpose they should be used.

1. Emphasis on short range (tactical) planning.

   National Weather Service forecast offices provide information appropriate for local operational decision making in the 1 to 3 day time period, and local planning out to about 7 days.

   This includes routine fire weather forecasts, spot forecasts, and Red Flag Warnings/Fire Weather Watches.

2. Emphasis on mid to long term (strategic) planning.

   GACC Predictive Services integrates all available forecast information, including NWS local and national level forecasts, and outlooks appropriate for regional and national scale strategic planning on weekly, monthly, and seasonal time frames.

IV. FACTORS AFFECTING FORECAST ACCURACY

A. Verification of Forecast Products

Verification of NFDRS forecasts by a number of fire weather offices indicates accuracy within the following ranges:

Forecast Element	Range	Improvement over Persistence
Temp	3-5° F	25-40%
RH	5-10%	15-25%
Wind	3-5 mph	10-20%
10 hr. FM	1-2%	15-20%

B. Interpretation of Forecast Accuracy and What to Expect

Meteorologists have strengths and weaknesses when it comes to weather forecasting.

Temperature and fuel moisture forecasts are the most accurate, followed by wind and RH; however, with every weather element there is substantial improvement over persistence.

Meteorologists do extremely well in forecasting trends.

C. Factors That Can Affect Forecast Accuracy

1. Forecast time range

   Accuracy decreases the further out in time one goes. Generally, the first 24 hours of a forecast are more accurate than the forecast for days 5 through 7.

2. Size of forecast area

   Accuracy for a small area such as a particular ridge or canyon decreases as the area for which the forecast is created increases.

   A zone forecast is a general forecast that covers a large area. A spot forecast is for a specific place.

3. Variable terrain

   Major variations in terrain, such as elevation or aspect changes can affect the forecast.

4. Changing weather pattern

   A transition period, such as from high pressure to low pressure can produce challenges in forecasting timing and strength of the transition.

5. Timing of significant features

   The exact time of day the front passes can have a dramatic impact on wind, temperature and humidity.

6. Availability of Data and Observations

   In order to make an accurate forecast, a meteorologist needs data and observations from that area to gain a baseline understanding of what is going on locally with the weather.

   Without this data, it becomes more difficult to apply local effects to a general forecast.

   For the reasons above, short-term/site-specific spot and onsite incident forecasts are generally the most accurate fire weather forecasts available.

V. RECEIVING BETTER SPOT FORECASTS

Of the various types of fire weather forecasts, fire managers have the greatest impact on the accuracy of spot forecasts.

Unlike other larger scale forecast products, spot forecast accuracy rests largely on specific information provided to the meteorologist from on-site.

To a significant extent, you control your own destiny with regard to the quality of spot forecasts received. You have the maximum opportunity to mitigate the factors that can affect forecast accuracy.

A. Requesting Spot Forecasts

In recent years, development of an Internet based spot forecast request program has helped smooth and speed up the process.

Essentially, the required elements of the spot request page are completed and then submitted.

A nice feature of the web-based spot request system is that it automatically checks for vital information and gives notification of any omissions.

The information required is rather basic and there are steps that will ensure more accurate forecasts.

B. Establish Effective Communications with Forecast Office

1. Notify the forecast office as far in advance as possible of planned prescribed fire activity that will require spot forecast support.

   This could include sending a topographic map and a portion of the burn plan to the appropriate office.

   This lets the office know in advance where the burn will be and what weather elements and scenarios are most critical.

2. Establish a spot forecast schedule with the local forecast office.

   This can be done with either wildfires or prescribed fires, but is probably most applicable to prescribed fires.

   If the forecast office knows when to expect spot forecast activity, staffing may be adjusted so that more time can be dedicated to preparing the forecast.

   Normally, spot forecasts should be returned to the requestor within 30 to 60 minutes.

3. Ensure that good communications between the meteorologist, the dispatcher, and the forecast office are established.

   When information is relayed for the spot forecast request to the dispatcher, ask the dispatcher to read the information back to make sure it is correct.

   It is frustrating to receive a request where the legal description does not match the elevation or aspect, or to have an observation that is obviously out of line with the rest of the area's weather.

4. Communicating with NWS offices.

   a. Ask for specific information when needed.

      Don't assume the meteorologist knows exactly what is needed.

   b. It is your responsibility to get an updated spot forecast if you feel the forecast is unrepresentative.

      Many times the spot is for an area that has no nearby observations; therefore, the meteorologist is counting on you to supply the observation data necessary in order to give you a quality product.

   c. Due to staffing, you may not deal with the same forecaster on consecutive days.

      The bottom line: YOU have more responsibility and have to be more proactive.

C. Provide Quality On-site Weather Observations

1. The field observation taken for the spot forecast request should be quality controlled.

   Make certain the observation is taken according to standard procedures and that it is representative of the fire or burn.

   Make sure the wet bulb temperature is read at its lowest point.

2. The wind is a critical element.

   If using the hand-held meter to measure the wind, be sure to stand there long enough to capture both the lulls and peak gusts in the wind.

   This will provide the meteorologist with a true measure of the wind.

3. Remarks to the observation (cumulus cloud development, peak wind gusts, and percentage of cloud cover), can be extremely helpful to the meteorologist.

4. Observations taken the day before the initial spot request, especially during the peak burning period, can be the most important information provided with the spot forecast request.

   They can help meteorologists do two things:

   - Fit the site’s weather into the large-scale weather pattern.

   - Establish a trend for the site.

D. Provide Forecast Feedback and Validation of Accuracy

With more strict policies in recent years, spot forecasts are required for a more extensive scope of fire operations and the number of spot forecasts done by some forecast offices has more than doubled.

Your feedback on NWS forecasts is very important and much appreciated. The NWS uses this in validating their products and ensuring that you receive the best service possible.

1. Meteorologists have no means to improve day-to-day forecast accuracy without knowing what happened the previous day.

   - Recurring forecast inaccuracies that cause operational fire management problems are a liability if communicating fireline conditions to the people who are forecasting them are not effective.

   - At the bare minimum, extremes of temperature, humidity, and wind on the fireline need to be communicated to the forecasters.

   - The mandatory feedback requirement from the Southwest Area AOP is offered below as an example of what is required and how it can be provided.

   Requirement: The character of temperature, humidity, and wind during the burn period made available to NWS within 12 hours of forecast issuance (before issuance of next spot forecast).

2. At a **minimum**, the following must be included (assuming daytime burn):

- Maximum temperature
- Minimum relative humidity
- Significant afternoon winds (speed and direction)

Example of minimum required feedback for daytime period:

- Maximum temp = 61
- Minimum RH = 18 %
- Afternoon winds = South 2-4G8 (eye-level), shifting to west at 1500.

In the event of nighttime burning, conditions affecting the burn period could include minimum temperature and maximum relative humidity.

3. Acceptable methods of providing feedback:

- Submission of required information (see above) via "Feedback" section of Internet spot forecast.
- Faxed copies of fireline (belt weather) observations.
- Phone call to appropriate NWS office.
- Faxed or electronically transmitted copies of hourly weather data from an on-site portable weather station.
- Notification of deployment of a portable Geostationary Operational Environmental Satellite (GOES) telemetered RAWS onsite, so NWS can download data from the Internet.

E. Use Portable Weather Stations (RAWS)

Many units now directly own or have access to portable RAWS.

These can be set up on an important project weeks in advance and monitored by both the fire management unit and the appropriate NWS forecast office before, during and after the project.

Having a portable RAWS properly sited and deployed at a project location provides:

1. Observations prior to ignition to assist in establishing weather trends.

2. Continuous, quality observations throughout the project which can be used when requesting spot forecasts.

3. Automatic forecast feedback, since forecasters can access the past 36 hours of weather observations.

4. An automatic archive of weather information that can be used for documentation.

VI. KNOWING WHEN TO ADAPT OR REQUEST A NEW SPOT FORECAST

A. Changes to the Forecast

Do not attempt major changes in fire weather forecasts. Leave it to the meteorologist who has the scope of information to make a forecast. However, due to local weather variability, minor changes to the forecast can be successfully made by a person at the site by:

1. Adjusting temperature or humidity for changes in elevation or aspect.

   - Average lapse rate of 3.5° F per 1,000 feet of elevation.
   - North aspect coolest, south and west aspects warmest and driest.
   - Use adjusted temperatures to recalculate humidity.
   - Compare current reading with previous day to show a trend.

2. Adjusting wind direction and speed to correspond with terrain.

   - Slope and valley.
   - Saddles or passes that can channel winds.

   The specific information provided in spot forecasts is based on the location where the fireline observation is taken.

   Especially in complex terrain, differences from forecast values should be expected at slopes, aspects, and elevations that vary from that specific location.

   Other times, local terrain effects cannot explain differences from the forecast.

B. General Rule for Adapting Spot Forecasts or Requesting New Ones

- Adapt if differences from forecast values can be attributed to local terrain effects (elevation, aspect, slopes/valleys, saddles/passes).

- Request an update if forecast values differ significantly from the observed weather and cannot be attributed to local terrain effects (a changing weather pattern).

VII. VISUAL CLUES THAT INDICATE WHEN A FORECAST NEEDS TO BE UPDATED

Clouds are one of the best indicators of what type of weather to expect.

- Cumulus clouds that begin to build may mean a threat of thunderstorms.

- Lenticular clouds are a sign of strong winds aloft, which may surface later.

- Cirrus clouds are the forerunners of fronts.

- Altocumulus castellanus indicate moisture and instability aloft, which usually develop into thunderstorms later in the day.

Clouds also shade the sun, resulting in cooler temperatures, higher humidity, and higher fuel moistures.

Know the visual signs of a stable or unstable atmosphere. The sudden and dramatic break-up of an inversion is a sure sign that fire behavior is going to increase.

The smoke column and its shape can tell a great deal about the winds aloft and the stability of the atmosphere. Changes in the column can indicate coming wind shifts or increases in wind speed.

EXERCISE.

This exercise involves a number of spot forecasts. The problem is to evaluate the spots and determine whether or not the forecast can be adapted or if an updated forecast should be requested. Give reasons for the action taken, possible reasons why the forecaster missed the forecast, and information that may have helped the forecaster.

VIII. SUMMARY

While the Internet and GACC Predictive Services offer new weather information to aid in decision making, much of the information presented in this lesson is not new.

- Be informed of the services available through the National Weather Service fire weather program.

- Know which types of forecasts are available from the appropriate fire weather office and how to obtain them.

- Know which type of forecast is best suited for the purpose. At times, you may have to adapt a general or spot forecast for your needs.

- Know when you can safely adapt a forecast and when it is better to request an updated forecast.

Remember: Cooperative interaction between you and the forecasters will always result in the best service to you.

DATA FROM NWS SITE:

Station	GOES ID	Elev	Lat	Long
TX SAN BERNARD	837544E8	21	28:51:53	095:34:04

	Day/Time	Tmp	Dew Pt	Wind	Pcpn	Rh	Fuel Temp	Peak Wind	Bat Volt	Fuel Moist
TX SAN BERNARD	12/0107Z	58/	55/	0606/	39.54	RH 92	FT 58/	06G09	12.4	FM 17
TX SAN BERNARD	12/0007Z	57/	54/	0605/	39.54	RH 90	FT 57/	07G11	12.4	FM 17
TX SAN BERNARD	11/2307Z	56/	52/	0606/	39.54	RH 89	FT 56/	07G18	12.4	FM 17
TX SAN BERNARD	11/2207Z	58/	53/	0806/	39.54	RH 85	FT 57/	06G15	12.5	FM 16
TX SAN BERNARD	11/2107Z	59/	52/	0909/	39.54	RH 80	FT 60/	07G20	12.5	FM 16
TX SAN BERNARD	11/2007Z	61/	53/	0714/	39.54	RH 75	FT 65/	08G23	12.8	FM 16
TX SAN BERNARD	11/1807Z	60/	50/	0813/	39.54	RH 72	FT 68/	07G22	12.9	FM 18
TX SAN BERNARD	11/1707Z	62/	52/	0712/	39.54	RH 70	FT 73/	08G18	12.9	FM 19
TX SAN BERNARD	11/1607Z	56/	50/	0608/	39.54	RH 83	FT 64/	05G13	12.9	FM 22

Most of this is self explanatory, but a few things require clarification.

Day = Day of the current month.
Time = Time of latest observation relative to Universal Time Coordinated (formerly Greenwich Mean Time or Zulu Time).
Wind/Peak Wind = Direction and speed in tens of degrees and mph.
0605 = Direction of 060 degrees (east-northeast), speed of 5 mph.
2312 = Direction of 230 degrees (southwest), speed 12 mph.
23G25 = Gust direction 230 degrees (southwest), peak gust 25 mph.
Fuel Temp/Fuel Moist = Measured fuel temperature and 10 hr. fuel moisture.
Bat Volt = Battery voltage of battery powering the RAWS.

Decode of 11/1607Z (11th day of month/1007 AM CST) observation from San Bernard:

Temp 56, dewpoint 50, wind NE 8 mph gusts to 13 mph, RH 83%, fuel temp 64, fuel moisture 22%

BASIC DATA FROM BLM SITE

Arizona, LAKESIDE - 12/17/2002 00:00 - 12/17/2002 15:55 MST

TIME	RNIN	WSM	WDD	ATF	FTF	RHP	BVV	FMP	WSMP	WDDP	SRW
0:16	2.77	13.0	202.0	42.0	41.0	37.0	12.5	8.3	26.0	175.0	0.0
1:16	2.77	14.0	201.0	40.0	40.0	49.0	12.5	8.4	27.0	194.0	0.0
2:16	2.77	13.0	209.0	40.0	39.0	52.0	12.5	8.5	25.0	203.0	0.0
3:16	2.77	17.0	180.0	34.0	35.0	86.0	12.5	8.8	31.0	184.0	0.0
4:16	2.77	12.0	185.0	32.0	33.0	100.0	12.4	9.4	24.0	165.0	0.0
5:16	2.77	11.0	179.0	32.0	33.0	100.0	12.4	10.7	24.0	178.0	0.0
6:16	2.77	9.0	191.0	32.0	33.0	100.0	12.4	11.8	22.0	182.0	0.0
7:16	2.77	7.0	196.0	32.0	33.0	100.0	12.4	13.7	15.0	201.0	0.0
8:16	2.77	8.0	195.0	32.0	33.0	100.0	12.4	15.6	15.0	197.0	8.0
9:16	2.77	10.0	201.0	33.0	34.0	100.0	12.4	17.5	17.0	206.0	66.0
10:16	2.77	12.0	223.0	33.0	34.0	100.0	12.4	20.6	22.0	213.0	70.0
11:16	2.77	12.0	214.0	34.0	38.0	100.0	12.4	23.6	25.0	190.0	755.0
12:16	3.01	13.0	218.0	36.0	42.0	94.0	12.6	24.0	26.0	201.0	618.0
13:16	3.02	10.0	217.0	36.0	40.0	80.0	13.2	20.9	30.0	204.0	212.0
14:16	3.02	10.0	237.0	32.0	34.0	99.0	13.0	19.2	26.0	216.0	33.0
15:16	**3.02**	**12.0**	**252.0**	**31.0**	**33.0**	**98.0**	**12.8**	**20.6**	**25.0**	**266.0**	**62.0**
Max		17.0		42.0	42.0	100.0	13.2	24.0	31.0		755.0
Min				31.0	33.0	37.0	12.4	8.3			0.0
Tot	0.25										

- TIME is the time of day that the measurement was taken (15:16 = 3:16 pm MST).

- RNIN is the data element abbreviation for rain accumulation in inches (3.02 = 3.02 inches total accumulation since last reset).

- WSM is the data element abbreviation for sustained wind speed in miles per hour (12 = 20 ft wind of 12 mph).

- WDD is the data element abbreviation for sustained wind direction in degrees (252 = WSW).

- FTF is the data element abbreviation for air temperature in degrees Fahrenheit.

- FTF is the data element abbreviation for fuel temperature in degrees Fahrenheit.

- RHP is the data element abbreviation for relative humidity in percent.

- BVV is the data element abbreviation for battery voltage in volts (12.8 volts).

- FMP is the data element abbreviation for fuel moisture in percent. This is a measured fuel moisture, rather than a calculated value.

- WSMP is the data element abbreviation for wind speed in miles per hour for the hourly peak (high).

- WDDP is the data element abbreviation for wind direction in degrees for the hourly peak (high) speed.

- SRW is the data element abbreviation for solar radiation in watts per meter squared.

- MAX, MIN and TOT are for respective elements over indicated time period.

Current Weather Conditions:
Albuquerque, Albuquerque International Airport, NM, United States

(KABQ) 35-02-30N 106-36-53W 1618M

Conditions at	Dec 17, 2002 - 05:56 PM EST 2002.12.17 2256 UTC
Wind	from the W (270 degrees) at 25 MPH (22 KT) gusting to 31 MPH (27 KT)
Visibility	10 mile(s)
Sky conditions	mostly cloudy
Temperature	44.1 F (6.7 C)
Dew Point	26.1 F (-3.3 C)
Relative Humidity	48%
Pressure (altimeter)	29.63 in. Hg (1003 hPa)
ob	KABQ 172256Z 27022G27KT 10SM SCT048 SCT065 BKN100 07/M03 A2963 RMK AO2 PK WND 28031/2201 SLP004 MTN TOPS OBSCD DSNT N-SE T00671033

Maximum and Minimum Temperatures

Maximum Temperature F (C)	Minimum Temperature F (C)	
45.0 (7.2)	39.9 (4.4)	In the **6 hours** preceding Dec 17, 2002 - 12:56 PM EST / 2002.12.17 1756 UTC
54.0 (12.2)	28.9 (-1.7)	In the **24 hours** preceding Dec 17, 2002 - 01:56 AM EST / 2002.12.17 0656 UTC

Precipitation Accumulation

Precipitation Amount	
A trace	In the **6 hours** preceding Dec 17, 2002 - 12:56 PM EST / 2002.12.17 1756 UTC

24 Hour Summary

	Time EST (UTC)	Temperature F (C)	Dew Point F (C)	Pressure Inches (hPa)	Wind MPH	Weather
Latest	6 PM (23) Dec 17	44.1 (6.7)	26.1 (-3.3)	29.63 (1003)	W 25	
	5 PM (22) Dec 17	48.0 (8.9)	25.0 (-3.9)	29.6 (1002)	W 26	
	4 PM (21) Dec 17	48.0 (8.9)	25.0 (-3.9)	29.58 (1001)	W 28	
	3 PM (20) Dec 17	48.9 (9.4)	28.0 (-2.2)	29.59 (1002)	W 28	
	2 PM (19) Dec 17	48.0 (8.9)	30.9 (-0.6)	29.62 (1003)	W 18	
	1 PM (18) Dec 17	45.0 (7.2)	30.9 (-0.6)	29.67 (1004)	WSW 18	
	Noon (17) Dec 17	42.1 (5.6)	32.0 (0.0)	29.69 (1005)	WSW 10	light rain
	11 AM (16) Dec 17	39.9 (4.4)	32.0 (0.0)	29.69 (1005)	WSW 7	
	10 AM (15) Dec 17	41.0 (5.0)	30.9 (-0.6)	29.69 (1005)	W 8	
	9 AM (14) Dec 17	42.1 (5.6)	28.9 (-1.7)	29.7 (1005)	WSW 5	
	8 AM (13) Dec 17	41.0 (5.0)	28.9 (-1.7)	29.68 (1005)	Calm	
	7 AM (12) Dec 17	43.0 (6.1)	28.0 (-2.2)	29.67 (1004)	WSW 8	
	6 AM (11) Dec 17	44.1 (6.7)	25.0 (-3.9)	29.72 (1006)	WSW 10	
	5 AM (10) Dec 17	45.0 (7.2)	24.1 (-4.4)	29.74 (1007)	WSW 8	
	4 AM (9) Dec 17	46 (8)	21 (-6)	29.78 (1008)	WNW 10	
	3 AM (8) Dec 17	48.0 (8.9)	19.9 (-6.7)	29.81 (1009)	W 16	
	2 AM (7) Dec 17	48.0 (8.9)	19.9 (-6.7)	29.83 (1010)	W 8	
	1 AM (6) Dec 17	50.0 (10.0)	17.1 (-8.3)	29.87 (1011)	W 16	
	Midnight (5) Dec 17	48.9 (9.4)	18.0 (-7.8)	29.87 (1011)	WSW 7	
	11 PM (4) Dec 16	50.0 (10.0)	18.0 (-7.8)	29.87 (1011)	SW 8	
	10 PM (3) Dec 16	51.1 (10.6)	19.0 (-7.2)	29.88 (1011)	W 10	
	9 PM (2) Dec 16	52.0 (11.1)	18.0 (-7.8)	29.89 (1012)	W 13	
	8 PM (1) Dec 16	52.0 (11.1)	18.0 (-7.8)	29.89 (1012)	WSW 9	
Oldest	7 PM (0) Dec 16	48.9 (9.4)	19.0 (-7.2)	29.89 (1012)	S 9	
	Time EST (UTC)	Temperature F(C)	Dew Point F(C)	Pressure Inches(hPa)	Wind (MPH)	Weather

25 PREDICTIVE SERVICES

The GACC predictive service units are responsible for preparing and submitting data and reports to NICC regarding current and projected information on wildland fire, weather, fuels, fire danger, and resource status. NICC uses this information to prepare and distribute the Incident Management Situation Report, National Wildland Fire Outlook, and other reports and products.

25.3 INCIDENT MANAGEMENT SITUATION REPORT

Daily: May through the end of October and as activity warrants.
Weekly: November through April.

The Incident Management Situation Report is prepared by NICC from information and data on the Interagency Situation Report, submitted by the GACCs. This report will be prepared daily and distributed at 0530 MDT (0800 on weekends and holidays) from May through October, and at 1000 MST on Fridays, November through April.

When GACCs report large fires and/or very high to extreme fire danger, a brief weather outlook is required to be submitted (e-mail: NICC_Intell@nifc.blm.gov) to NICC for inclusion in the IMSR outlook section. See exhibit 28.10 for required format; a copy of the form may also be found on the NICC web site.

25.5 WEEKLY FIRE WEATHER / FIRE DANGER OUTLOOK

Weekly: During significant wildland fire activity.

The Weekly Fire Weather / Fire Danger Outlook is to be posted on each GACC web site every Tuesday at the close of business (see Chapter 20, Section 28.11 for content and format). This product contains information on current and projected fire weather, fire danger and resources. A copy of the form may be found on the NICC web site.

25.5 MONTHLY FIRE WEATHER / FIRE DANGER OUTLOOK

Monthly: Year-round

The Monthly Fire Weather / Fire Danger Outlook and map shall be completed by each GACC and submitted to NICC five working days prior to the end of each month. The monthly outlook will be prepared for the next month (see Chapter 20, Section 28.12 for content and format). GACCs shall include within their narratives the following information:

1. A brief discussion of predicted general weather / fire danger for the entire geographic area for the reporting period.

2. A brief discussion on geographic area current fuel anomalies / fuel moisture conditions.

3. A brief discussion on geographic area predicted temperature and precipitation for the reporting period.

4. A map delineating areas of below normal, normal and above normal fire potential (with respect to expected fires/acres) for the reporting period. For example, above normal fire potential means the anticipated number of fires and/or acres in the geographic area will exceed that normally occurring for the reporting period. Map templates may be found on the NICC web site.

25.6 SEASONAL FIRE WEATHER / FIRE DANGER OUTLOOK

Seasonal: Prior to fire season onset with mid-season update(s)

Seasonal Outlooks will be issued periodically by the GACCs, with the first report issued prior to the onset of their fire season. A minimum of one update will be completed during their fire season, or as deemed necessary. The NICC staff will assist GACCs with seasonal assessments as needed.

25.7 NATIONAL WILDLAND FIRE OUTLOOKS

Monthly Outlook: Year-round
Seasonal Outlook: As needed

The monthly National Wildland Fire Outlook Report is prepared and distributed by NICC on the first day of each month and is compiled from the GACCs Monthly Fire Weather / Fire Danger Outlook. This report consists of a national map delineating areas of below, normal, and above normal fire potential along with narratives for each Geographic Area. Similarly, National Wildland Fire Outlooks will be issued seasonally as needed and utilize information from GACC Predictive Services as well as other sources of weather and fire danger data.

OUTLOOK

Red Flag Warnings:

Fire Weather Watches:

Geographic Area Weather	High Temperatures	Min. Relative Humidity	Wind

Weekly Fire Weather / Fire Danger Outlook For: (specify dates of 7 to 10 day period) (Geographic Area name) Predictive Services Issued (date)

Weather Discussion:

Day	*Fire Danger*	*Weather*

Resources:

MONTHLY FIRE WEATHER / FIRE DANGER OUTLOOK

1. REPORTING UNIT:

2. DATE:

3. POTENTIAL FOR SERIOUS/CRITICAL FIRE PROBLEMS

THIS COMING MONTH	BELOW NORMAL		NORMAL		ABOVE NORMAL	
THIS SEASON	BELOW NORMAL		NORMAL		ABOVE NORMAL	

COMMENTS:

4. FIRE WEATHER OUTLOOK (To address the following factors)

   DROUGHT CONDITIONS:

   PRECIPITATION ANOMALIES AND OUTLOOK:

   TEMPERATURE ANOMALIES AND OUTLOOK:

5. FUELS

FINE - GRASS STAGE	GREEN		CURED			
NEW GROWTH	SPARSE		NORMAL		ABOVE NORMAL	

   LIVE FUEL MOISTURE (sage, deciduous, conifer):

   1000 HOUR DEAD FUEL MOISTURE:

   NORMAL/AVERAGE FUEL MOISTURE FOR THIS TIME OF YEAR:

6. AVERAGE FIRE OCCURRENCE/ACRES BURNED (to date 5 year average):

7. ACTUAL OCCURRENCE/ACRES BURNED (to date this year):

8. WRITTEN SUMMARY (The text from this summary will be used in the National Wildland Fire Outlook).

9. FIRE POTENTIAL MAP

   A geographic area outline map showing areas of below, normal and above normal fire potential shall be submitted along with the Monthly Fire Weather / Fire Danger Outlook report. The map template can be found at: www.nifc.gov/news/intell_predserv_forms/national_map.html.

Examples of National Weather Service Routine Fire Weather Products

1. Fire Weather Forecast Product (FWF).

1.1 Narrative Format.

```
FNUS55 KBOI DDHHMM
FWFBOI

FIRE WEATHER FORECAST
NATIONAL WEATHER SERVICE BOISE IDAHO
930 AM MDT SAT JUL 14 2001

...SHOWERS AND THUNDERSTORMS TODAY AND SUNDAY...MAINLY AFTERNOON/EVENINGS...
...COOLER WITH SHOWERS MONDAY THROUGH WEDNESDAY...

.DISCUSSION...MOIST AND UNSTABLE SOUTHWESTERLY FLOW ALONG WITH WEAK
DISTURBANCES WILL CONTINUE TO TRIGGER MAINLY AFTERNOON AND EVENING
THUNDERSTORMS THROUGH SUNDAY. A LOW PRESSURE AREA IN THE GULF OF ALASKA WILL
ENTER THE PACIFIC NORTHWEST SUNDAY EVENING BRINGING COOLER CONDITIONS ALONG
WITH SHOWERS MONDAY THROUGH WEDNESDAY.

IDZ011-013-142200-
WEST CENTRAL IDAHO MOUNTAINS.(ZONES 401-404) INCLUDES PAYETTE NF AND BOISE NF

.TODAY...
SKY/WEATHER.........PARTLY CLOUDY.  A CHANCE OF AFTERNOON SHOWERS AND
THUNDERSTORMS.
MAX TEMPERATURE.....UPPER 70S TO NEAR 90.
   24 HR TREND......LITTLE CHG.
MIN HUMIDITY........15-25 PCT.
   24 HR TREND......NO CHG.
WIND (20 FT)........
   VALLEYS..........LIGHT MORNING WINDS THEN UPSLOPE 4-8 MPH IN THE
AFTERNOON.
   RIDGES...........WEST-SOUTHWEST 5-10 MPH.
HAINES INDEX........3 VERY LOW.
LAL.................3.
MIXING HEIGHT.......7000 FT AGL.
TRANSPORT WIND......NORTHWEST AROUND 5 MPH.

.TONIGHT...
SKY/WEATHER.........MOSTLY CLOUDY WITH A CHANCE OF EVENING SHOWERS AND
THUNDERSTORMS.
MIN TEMPERATURE.....45-55.
   24 HR TREND......LITTLE CHG.
MAX HUMIDITY........65-75 PCT. MODERATE-GOOD RECOVERY.
   24 HR TREND......DOWN 5 PCT.
```

```
WIND (20 FT)........
   VALLEYS..........DOWNSLOPE 3-7 MPH AFTER SUNSET.
   RIDGES...........SOUTH TO SOUTHWEST 5-10 MPH.
HAINES INDEX........3 VERY LOW.
LAL.................3.
MIXING HEIGHT.......LOWERING TO 1000 FT AGL.
TRANSPORT WIND......NORTHWEST 5 TO 10 MPH.

.SUNDAY...
SKY/WEATHER.........MOSTLY CLOUDY AND COOLER WITH A CHANCE OF SHOWERS.
MAX TEMPERATURE.....75-85.
MIN HUMIDITY........28-38 PCT.
WIND (20 FT)........
   VALLEYS..........LIGHT MORNING WINDS THEN SOUTHWEST 10-15 MPH IN THE
AFTERNOON.
   RIDGES...........SOUTHWEST 10 TO 15 MPH.
HAINES INDEX........3 VERY LOW.
LAL.................3.
MIXING HEIGHT.......LOWERING TO 1000 FT AGL.
TRANSPORT WIND......NORTHWEST 5 TO 10 MPH.

[forecast for next geographical descriptor and fire weather zone group]

.FORECAST DAYS 3 THROUGH 7...
.MONDAY THROUGH WEDNESDAY...COOLER WITH SHOWERS.  LOWS IN THE 40S TO NEAR 50.
HIGHS IN THE 70S TO NEAR 80. AFTERNOON NORTHWEST WINDS 10 TO 20 MPH.
.THURSDAY AND FRIDAY...PARTLY CLOUDY AND WARMER. LOWS NEAR 50. HIGHS IN THE
80S.
.OUTLOOK FOR SATURDAY JULY 21 2001 THROUGH FRIDAY JULY 27 2001...TEMPERATURES
AND PRECIPITATION ARE EXPECTED TO REMAIN NEAR NORMAL THROUGH THE PERIOD.

NAME (OPTIONAL)
```

1.2 Tabular Format.

```
FNUS52 KTBW 051200
FWFTBW

FIRE WEATHER FORECAST
NATIONAL WEATHER SERVICE TAMPA BAY AREA RUSKIN FL
730 AM EST TUE FEB 5 2002

...A FIRE WEATHER WATCH IS IN EFFECT TODAY ACROSS THE ENTIRE AREA FOR LOW
AFTERNOON RH DURATION...

.DISCUSSION...HIGH PRESSURE WELL NORTH OF THE AREA TODAY WILL GRADUALLY SHIFT
EASTWARD ALLOWING LOW LEVEL NORTHEAST WINDS TO BECOME EAST BY AFTERNOON.  A
STORM SYSTEM WILL DEVELOP OVER THE NORTHERN GULF AND WESTERN FLORIDA
PANHANDLE BY WEDNESDAY AFTERNOON RESULTING IN SOUTHEAST FLOW...HIGHER
HUMIDITIES AND WARMER TEMPERATURES.  WEAK SHOWER CHANCES WILL RETURN OVER THE
NORTH NEAR A DEVELOPING WARM FRONT AS WELL AS OVER THE INTERIOR PORTIONS OF
THE CENTRAL AND SOUTH WEDNESDAY AND THURSDAY.
```

FLZ042-043-048-052030-
CITRUS-HERNANDO-SUMTER-
730 AM EST TUE FEB 05 2002

...A FIRE WEATHER WATCH IS IN EFFECT TODAY FOR LOW AFTERNOON RH DURATION...

PARAMETER	TODAY	TONIGHT	WEDNESDAY
CLOUD COVER	PCLDY	MCLDY	MCLDY
CHANCE PRECIP (%)	NONE	NONE	20
PRECIP TYPE	NONE	NONE	RAIN
TEMP (24H TREND)	64 (-2)	49 (-3)	72
RH % (24H TREND)	30	85	46
20FT WND MPH	E 11	E 6	SE 9
PRECIP DURATION	NONE	NONE	1
PRECIP BEGIN	NONE	NONE	4 PM
PRECIP END	NONE	NONE	CONTINUING
PRECIP AMOUNT	NONE	NONE	0.25
MIXING HGT (MSL)	2400	700	3100
TRANSPORT WIND(KTS)	E 15	E 8	SE 10

REMARKS...NONE.

[forecast for next geographical descriptor and fire weather zone group]

.FORECAST FOR DAYS 3 THROUGH 7...
.THURSDAY AND FRIDAY...CLOUDY AND COOLER WITH SCATTERED SHOWERS. LOWS 45 TO 50. HIGHS IN THE MID 60S. WINDS BECOMING NORTH 15 TO 25 MPH THURSDAY AFTERNOON.
.SATURDAY THROUGH MONDAY...PARTLY CLOUDY AND WARMER. LOWS IN THE 50S. HIGHS IN THE 70S TO NEAR 80. WINDS GENERALLY BELOW 15 MPH.

2. National Fire Danger Rating System Product (FWM).

FNUS85 KBOI DDHHMM
FWMBOI

ZONE,403,011027,13,1,-3,0,1,1,0,0,,,,,0,0,N
ZONE,404,011027,13,0,3,0,1,1,0,0,,,,,0,0,N
ZONE,408,011027,13,0,4,-5,1,1,-3,0,,,,,0,0,N
FCST,102709,011027,13,0,4,-5,1,1,-3,0,,,,,0,0,N

3. Spot Forecasts for a Wildland Fire (FWS).

FNUS75 KBOI DDHHMM
FWSBOI

SPOT FORECAST FOR THE ROUGH DIAMOND FIRE...BOISE DISPATCH
ISSUED BY NATIONAL WEATHER SERVICE BOISE IDAHO
113 PM MDT MON AUG 27 2001
VALID UNTIL 913 PM MDT MON AUG 27 2001
IF CONDITIONS BECOME UNREPRESENTATIVE, CONTACT THE NATIONAL WEATHER SERVICE.

...HOT AND DRY WITH AFTERNOON HUMIDITY BELOW 10 PCT...

DISCUSSION...UPPER RIDGE WILL KEEP CONDITIONS AT THE FIRE SITE HOT AND DRY AGAIN TODAY. WINDS WILL GENERALLY BE WEST TO NORTH...BUT SOME ERRATIC EDDIES MAY OCCUR IN THE LOWEST VALLEY BOTTOMS WHERE UPSLOPE WINDS WILL CONFLICT WITH THE FLOW ALOFT. AFTERNOON HUMIDITIES WILL BE VERY LOW...DROPPING BELOW 10 PERCENT.

REST OF TODAY
SKY/WEATHER.........SUNNY AND CONTINUED HOT.
TEMPERATURE.........HIGH 92-95.
HUMIDITY............MIN 7-9 PCT.
WIND - EYE LEVEL....NORTH 5-10 MPH WITH GUSTS TO 15 MPH IN VALLEYS. RIDGETOP AND UPPER SLOPE WINDS NORTHWEST TO NORTH 10-15 MPH WITH GUSTS TO 20 MPH POSSIBLE. ERRATIC EDDIES POSSIBLE IN VALLEY BOTTOMS.
HAINES INDEX........5 MODERATE.

TONIGHT
SKY/WEATHER.........CLEAR.
TEMPERATURE.........LOW 50-55.
HUMIDITY............MAX NEAR 30 PCT.
WIND - EYE LEVEL....VALLEYS: DOWNSLOPE 5-10 MPH. RIDGETOP/UPPER SLOPES: NORTHWEST TO 10 MPH AFTER EVENING GUSTS TO 20 MPH.
HAINES INDEX........4 LOW.

TUESDAY
SKY/WEATHER.........SUNNY AND A LITTLE COOLER.
TEMPERATURE.........HIGH 86-89.
HUMIDITY............MIN 11-13 PCT.
WIND - EYE LEVEL....VALLEYS: NORTH 7-13 MPH. RIDGETOP/UPPER SLOPES: NORTHWEST 10-20 MPH WITH AFTERNOON GUSTS TO 25 MPH.
HAINES INDEX........4 LOW.

FORECASTER...(optional)

4. Fire Weather Watch/Red Flag Warning. Examples are located in Exhibits 2-6 and 2-7.

Exhibit (2-6) - Format/example of a FIRE WEATHER WATCH MESSAGE (RFW):

WWUS85 KSLC DDHHMM
RFWSLC

FIRE WEATHER WATCH
NATIONAL WEATHER SERVICE SALT LAKE CITY, UT
0830 MDT TUE SEP 02, 2001

UTZ002>005-015>017-019-020-DDHHMM

...FIRE WEATHER WATCH FOR STRONG SOUTHWEST WINDS AND LOW HUMIDITIES WEDNESDAY AFTERNOON FOR WESTERN UTAH...**(headline of what, where, when)**

FIRE WEATHER ZONES (or COUNTIES) INCLUDED IN THIS WATCH ARE **(optional)**:

429...431...435...WEST PORTIONS 433...436...437

DISCUSSION: A STRONG COLD FRONT WILL BE APPROACHING THE STATE LATE WEDNESDAY. VERY LOW HUMIDITIES AHEAD OF THE FRONT AND STRONG WINDS ACCOMPANYING THE FRONT COULD REACH RED FLAG CRITERIA. **(Focus on adverse weather conditions; comments on fuels are not recommended)**

PLEASE ADVISE THE APPROPRIATE OFFICIALS OR FIRE CREWS IN THE FIELD OF THIS FIRE WEATHER WATCH. **(optional call to action)**

Exhibit (2-7) - Format/example of a RED FLAG WARNING MESSAGE (RFW):

WWUS85 KSLC DDHHMM
RFWSLC

RED FLAG WARNING
NATIONAL WEATHER SERVICE SALT LAKE CITY, UT
0830 AM MDT TUE SEP 02 2001

UTZ002>005-015>017-019-020-DDHHMM

...RED FLAG WARNING FOR STRONG SOUTHWEST WINDS AND LOW HUMIDITIES FROM NOON UNTIL SUNSET FOR WESTERN UTAH... **(headline of what, where, when)**

FIRE WEATHER ZONES (or COUNTIES) INCLUDED IN THIS WARNING ARE **(optional)**:

429...431...435...WEST PORTIONS 433...436...437

DISCUSSION: A STRONG COLD FRONT WILL MOVE INTO NORTHWEST UTAH BETWEEN 1700-1900 MDT AND THROUGH THE WASATCH FRONT BETWEEN 2000- 2300 MDT. THE STRONGEST WINDS WILL BE ON SOUTHERN ASPECTS AND FLAT TERRAIN IN THE WESTERN UTAH DESERTS DURING THE LATE AFTERNOON. WIND SPEEDS WILL INCREASE IN THE AFTERNOON TO 15-30 MPH WITH GUSTS TO 45 MPH. **(Focus on adverse weather conditions; comments on fuels are not recommended)**

PLEASE ADVISE THE APPROPRIATE OFFICIALS OR FIRE CREWS IN THE FIELD OF THIS RED FLAG WARNING. **(optional call to action)**

Exhibit (2-8) - Format example of text version of SPC Fire Weather Outlook Product.

FNUS21 KWNS 021909
STORM PREDICTION CENTER...NWS/NCEP...NORMAN OK
400 AM CDT MON JUL 02 2001

DAY 1 FIRE WEATHER OUTLOOK...REF AWIPS GRAPHIC PMWE98 KWNS
VALID 021200-031200

```
...EXTREMELY CRITICAL FIRE WEATHER AREA FOR - ERN AZ...
...CRITICAL FIRE WEATHER AREA FOR - ID / WRN MT...
...CRITICAL FIRE WEATHER AREA FOR - OK

...SYNOPSIS...
(TEXT)

...EXTREMELY CRITICAL FIRE WEATHER AREA 1 - AZ...

PRIMARY CONDITIONS:  STRONG WINDS AND EXTREMELY LOW HUMIDITY
(TEXT)


...CRITICAL FIRE WEATHER AREA 2 - ID AND WRN MT...

PRIMARY CONDITIONS:  DRY THUNDERSTORMS.
(TEXT)

CRITICAL FIRE WEATHER AREA 3 - OK...

PRIMARY CONDITIONS:  STRONG WINDS AND LOW HUMIDITY
(TEXT)

(TEXT)

..FORECASTER..

SPC FIRE WEATHER OUTLOOKS ARE AVAILABLE AT WWW.SPC.NOAA.GOV/FIRE
```

2.8.2 Content. The outlooks (text and graphic) will highlight:

a. Significant Dry Thunderstorm Critical Fire Weather Areas (areas of numerous cloud-to-ground lightning strikes with generally less than one-tenth inch or rain across the area, scalloped lines on graphic).
b. Critical Fire Weather areas (based on fuel conditions and forecast weather, hatched area on graphic).
c. Extremely Critical Fire Weather areas (issued infrequently for only the most severe forecast and fuel conditions, hatched area on graphic).

The Day 1 and Day 2 text and graphics should be similar. Areas that are a marginal threat (lacking one critical element) should be depicted by SEE TEXT on the graphic and discussed last in the text message.

Introduction to Wildland Fire Behavior Calculations, S-390

Unit 3 – United States Fire Behavior Prediction System (USFBPS) Fuel Models

OBJECTIVES:

Upon completion of this unit, students will be able to:

1. Identify inputs needed for a fuel model.

2. Identify the characteristics of the standard United States Fire Behavior Prediction System fuel models.

3. Identify appropriate fuel models using resource materials.

I. FUEL MODEL

Actually measuring fuel properties is too slow and laborious for wildland fire predictions. An alternate method is to use predetermined fuel arrangements called fuel models.

A fuel model is a series of mathematical fuel bed inputs needed by a particular wildland fire behavior or fire effects processor.

Although identified by biological names, fuel models are mathematical models. The goal is to select the mathematical model that best predicts observed or experienced wildland fire behavior.

The biological name of the model may not reflect the vegetation, but the model's mathematics reflects the wildland fire behavior when that vegetation burns.

Fuel models are simply tools to help the user realistically estimate wildland fire behavior.

A. Inputs Needed for a Fuel Model

- Fuel loading or mass of fuel per unit area, live and dead, grouped by particle size classes – tons per acre.
- Fuel moisture content (discussed more in Unit 4).
- Surface area to volume ratio of each size group.
- Fuel bed depth – ft.
- Compactness or bulk density – lb/ft3.
- Heat content of fuel – Btu/lb.
- Moisture of extinction – upper limit of fuel moisture content beyond which the fire will no longer spread with a uniform front.
- Vertical arrangement.
- Horizontal continuity.
- Chemical content, ash, and volatiles.

B. Various Fuel Modeling Systems

1. NFDRS – National Fire Danger Rating System

   - 20 fuel models

     – Identified by an alpha character (A, L, S, C).

     – Are part of a computer data processing system that presently is not suited to real-time, in-the-field prediction of wildland fire behavior.

     – Differences in calculations require the use of different fuel models than those used for wildland fire behavior predictions.

     – Will work with these fuel models in S-491 Intermediate National Fire Danger Rating System.

2. CFFDRS – Canadian Forest Fire Danger Rating System

   - 16 fuel models

     – Identified by alpha-numeric characters (C1, S3, M4).

     – Fuel models are used in the Canadian Forest Fire Behavior Prediction (FBP) System, a sub-system of the CFFDRS.

     – Are being used in Alaska, several Great Lake States (Michigan and Minnesota), and some other northern states.

3. USFBPS – United States Fire Behavior Prediction System

- 255 fuel models are now possible

  - Identified by a numeric character (1, 13, 100, 219).

  - Used as fuel model inputs to Rothermel's surface fire spread model, as exemplified in BehavePlus, Fire Behavior Nomograms, and Fireline Handbook Appendix B.

  - Simulates surface wildland fire behavior at the flaming front only, not residual combustion that takes place after the flaming front has passed.

  - The fuel model parameters presented by this set should not be used as fuelbed characteristics for fuel consumption models.

  - Fuelbed assumptions of homogeneity and continuity apply to these models.

  - Assumes steady state weather and topography for the prediction period.

II. FUEL MODELS FOR UNITED STATES WILDLAND FIRE BEHAVIOR PREDICTION SYSTEM (USFBPS) – STANDARD 13 FUEL MODELS

A. Fuel Models

- Were developed by Rothermel and Albini in the 1970s.
- Are for the severe period of the fire season when wildland fires pose greater control problems.
- Works well for predicting spread rate and intensity of active fires at peak of fire season, in part because the associated dry conditions lead to a more uniform fuel complex, an important assumption of the underlying model.

1. Fuel models have deficiencies for:
   - Other purposes such as prescribed fire and wildland fire use for resource benefit.
   - Simulating the effects of fuel treatments on potential wildland fire behavior.
   - Simulating transition to crown fire using crown fire initiation models.
2. Classified into four types
   - Grass (3 fuel models)
   - Shrub (4 fuel models)
   - Timber Litter (3 fuel models)
   - Logging Slash (3 fuel models)

B. Description of Fuel Models

1. Dead and live fuel components

- For a particular model, fuel loading is fixed; it does not change with time or location.

- Fuel loading does change between models in a group, and between groups.

  This is reflected in wildland fire behavior outputs such as Heat per Unit Area and Fireline Intensity.

- Five fuel models have a live fuel component. Which ones are they?

- The standard 13 models are static; the fuel model does not change to account for curing or greening of herbaceous fuels.

  For instance, as live fuel moisture drops, loading is not transferred from live fuel loading to dead fuel loading. A grass fuel model may not work well when the grass is green, but will work well when the grass is cured.

2. Moisture of extinction

- Moisture content of fuels is directly related to their potential to ignite.

- Moisture of extinction is the moisture content of a specific fuel type above which a fire will not propagate itself, and a firebrand will not ignite a spreading fire.

- Only a few of these models are applicable for fuelbeds in high humidity (> 35%) areas that burn well at relatively high dead fuel moistures. Fuel Model 7 is a classic example.

III. FUEL MODELS FOR UNITED STATES WILDLAND FIRE BEHAVIOR PREDICTION SYSTEM (USFBPS) – DYNAMIC 40 FUEL MODELS

A. Dynamic Fuel Models

1. The standard 13 USFBPS fuel models stand alone; they are not repeated in this new set.

2. All fuel models with an herbaceous component are dynamic.

   - With lowering or curing of the live herbaceous moisture content, live herbaceous fuels are transferred to dead.

   - It transfers to a newly created dead herbaceous class instead of the 1-hour time-lag class to preserve the surface area to volume ratio.

   - The effect of live herbaceous moisture content on rate of spread and fireline intensity is very strong.

3. Wildland fire behavior modeling processors are being changed to use the dynamic fuel models.

4. Grouped by fire-carrying fuel types

   - (NB) Non-burnable
   - (GR) Grass
   - (GS) Grass-shrub
   - (SH) Shrub
   - (TU) Timber-understory
   - (TL) Timber litter
   - (SB) Slash-blowdown

   Note the unique category of Non-burnable Fuel Type Models. It is included to provide consistency in fuel model maps; not intended to be used in a wildland fire behavior or fire effects processor.

B. How to Select an Appropriate Fuel Model

- Estimate which type of surface fuels is most likely to carry the fire (grass, shrub, timber litter, or slash).

- Note the general depth, compactness, and size of the fuel, and the relative amount of live vegetation.

- Determine which time-lag fuel moisture classes are present and estimate their influence on wildland fire behavior.

- Using these observations, use a fuel model key and/or descriptions to select a fuel model. Do not restrict your selection by fuel model name or fuel type.

- Be sure predicted wildland fire behavior agrees with observations. If not, try another fuel model.

EXERCISE: Fuel model selection from the standard 13 USFBPS fuel models.

Use the fuel model identification table on the next page to identify the fuel models. You may reference:

- Appendix B of the Fireline Handbook.

- “Aids to Determining Fuel Models for Estimating Fire Behavior.”

Fuel Model Identification Table

Type of Surface Fuels Most Likely to Carry Fire	Notes: Fuel bed depth, Live fuels present, Compactness, Size of fuel, etc.	Fuel Model Number (1 – 13)
Photo A:		
Photo B:		
Photo C:		
Photo D:		
Photo E:		
Photo F:		
Photo G:		
Photo H:		
Photo I:		
Photo J:		
Photo K:		

Introduction to Wildland Fire Behavior Calculations, S-390

Unit 4 – Fuel Moisture

OBJECTIVES:

Upon completion of this unit, students will be able to:

1. Define and characterize fuel moisture.

2. Discuss the importance of dead fuel moisture, the time lag concept, and moisture of extinction. Estimate inputs used by NFDRS and USFBPS.

3. Evaluate live fuel moisture and estimate inputs for NFDRS and USFBPS.

4. Identify alternative methods for measuring and estimating moisture contents of various fuels.

5. Describe drought, its relationship to wildland fire behavior, and some important drought indices.

6. Compare and contrast the NFDRS and CFFDRS methods of estimating fuel moisture and drought.

I. INTRODUCTION

The FLAME method of fire behavior assessment emphasizes the “Big Change” factors in estimating the changes in fire behavior during the burning period.

Changes in fuel, wind, and terrain are the factors that can dramatically change fire growth and flame lengths during the day. As a result, these are the factors considered during the initial FLAME assessment.

Fuel moisture is only a secondary consideration, because its influence on the spread model is much less dramatic. However, it plays a critical role in understanding the fire potential on any given day or week, or month.

At extremely low fuel moisture, extreme fire behavior becomes more likely and needs to be factored into any assessment.

Assess the moisture(s) in the fuels of concern and make sure that those devising and implementing strategy and tactics understand what it may mean to fire behavior.

II. DEFINE AND CHARACTERIZE FUEL MOISTURE

Fuel moisture content is the weight of water present in a fuel expressed as a percent of the dry weight of that fuel.

$$\text{FMC (\%)} = \frac{\text{Wet Weight-Dry Weight}}{\text{Dry Weight}} \times 100$$

III. DEAD FUEL MOISTURE

The fuel moisture content in dead fuels is governed by the size and shape of the fuel as well as several external factors:

- Temperature
- Relative humidity
- Precipitation
- Solar radiation
- Wind

Generally, dead fuels acquire and give up moisture to the atmosphere depending on the current state of those external factors.

The longer that atmospheric conditions remain constant or the smaller the relative changes in those conditions, the moisture content of dead fuels approaches a conceptual value called the Equilibrium Moisture Content (EMC).

A. Equilibrium Moisture Content

Equilibrium moisture content is the moisture content dead fuels reach when subjected to constant atmospheric conditions until there is no more exchange of moisture.

The EMC is rarely reached in the real world because atmospheric conditions such as temperature and relative humidity rarely remain constant enough over long enough periods for most dead fuels to reach equilibrium.

Only the smallest dead fuels, such as fine cured standing grasses, ever approach EMC under normal conditions.

Because the size and shape of dead fuel is so important to the moisture content they exhibit at any time, a classification system based on size was developed to track the variability associated with it.

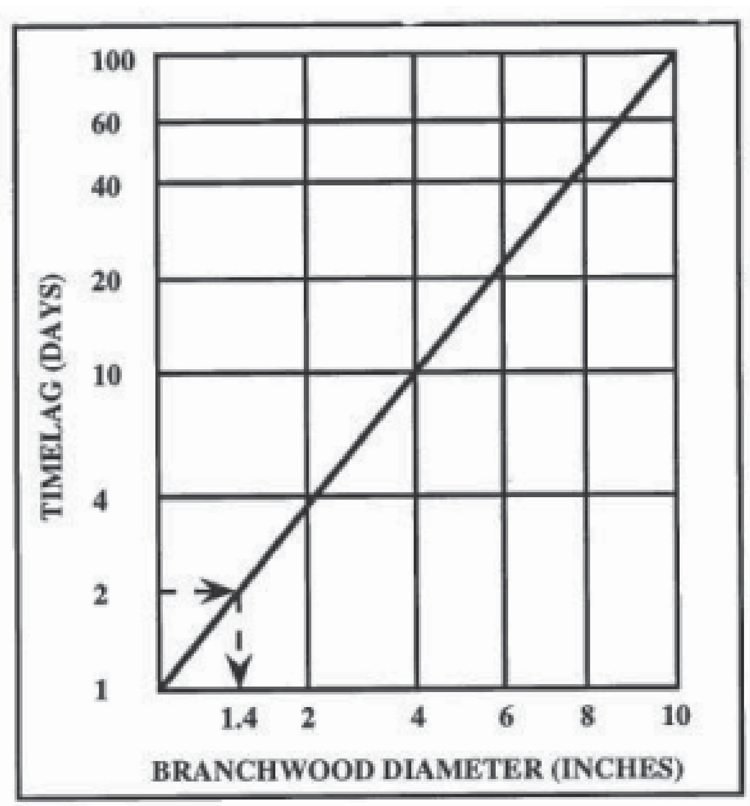
This classification is based on a concept called time lag.

B. Time Lag

Time Lag is the time it usually takes a dead fuel to reach 63% of the difference between the current moisture content and the conceptual equilibrium moisture content.

This time lag is dependant on fuel size and for the purpose of wildland fuels is characterized by the diameter of fuels.

In general, as dead fuels increase in diameter they require more time to reach equilibrium with the atmosphere.



This chart shows the relationship between fuel diameter and its characteristic timelag. Though the relationship occurs along a continuum of fuel diameter, characteristic time lag classes have been developed to characterize its importance to any fuel complex. This was discussed in Unit 3 on fuels.

Time Lag Category	Characteristic Fuel Size	Examples of Wildland Fuel
1 Hour (0.04 days)	< ¼" diameter	Cured grass, leaves and needles
10 Hour (0.4 days)	¼" to 1" diameter	Twigs and small branches
100 Hour (4 days)	1" to 3" diameter	Larger dead branches
1000 Hour (40 days)	3" to 8" diameter	Downed dead poles
10,000 Hour (400 days)	> 8" diameter	Downed tree trunks

Though the estimated fuel moisture content for these classes are generally quite different for any set of atmospheric conditions, the National Fire Behavior Prediction System combines them into a single characteristic fuel moisture called Dead Fuel Moisture.

C. Dead Fuel Moisture

Dead fuel moisture is the weighted average fuel moisture for the combination of time lag fuels present in a given fuel complex.

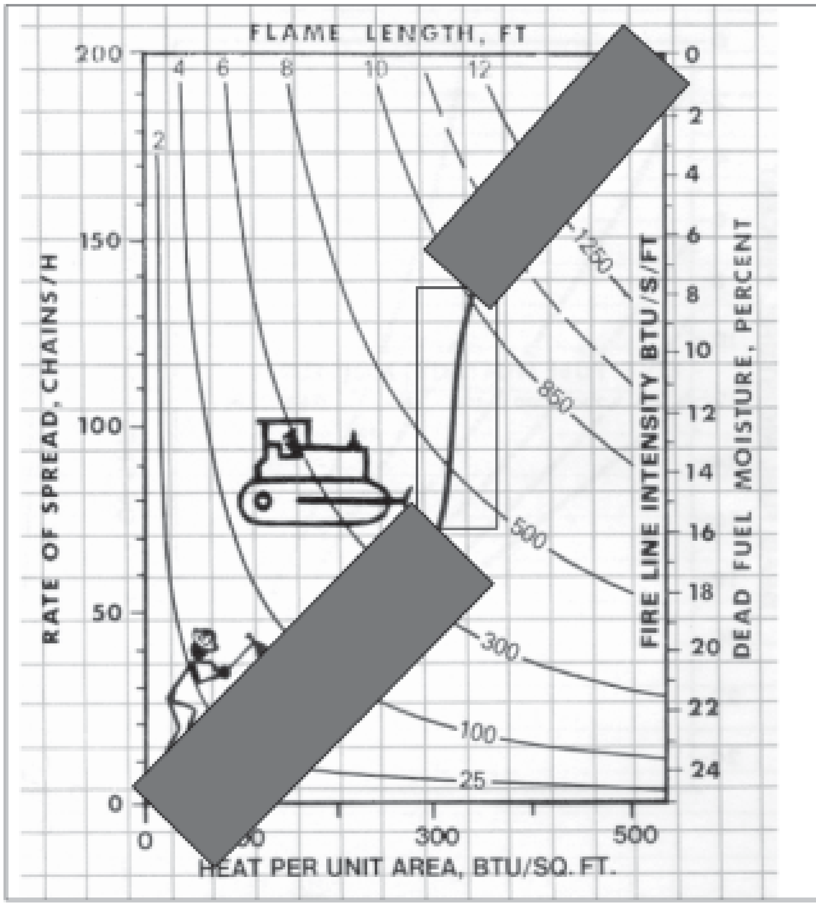
Though a mix of dead fuel sizes usually occurs in most real world situations, most fire behavior prediction systems assume that moisture of small, or fine, fuels is the most important factor.

This is because much of the larger fuel classes remain "unavailable" to the flaming fire front except under extreme conditions, leaving the fine fuels as most important based on surface area.

As a result, the more simple fire behavior processors (nomograms and lookup tables) tend to assume that dead fuel moisture is equal to the fine fuel, or 1-hr time lag, fuel moisture.

In characterizing the FLAME assessment system, fuel moisture is not a "big change" maker during a given burn period. However, that may not always be the case.

Look again at the upper right quadrant of the fire behavior nomogram, where the influence of dead fuel moisture is captured.



Heat per Unit Area changes are much more dramatic for each 1% change in dead fuel moisture between 0% and 8% and between 16% and 25% than for a corresponding 1% change in fuel moisture between 8% and 16%.

The moisture of extinction for a given fuel model (Fuel Model 9 in this case) can be determined from this quadrant of the fire behavior nomogram. It is simply the fuel moisture found at the bottom line where the Rate of Spread is 0. In this case, the Moisture of Extinction for FM 9 is 25%.

D. Moisture of Extinction (MOE)

Moisture of extinction is the moisture content of a specific fuel type above which a fire will not propagate itself, and a firebrand will not ignite a spreading fire.

Each fuel model has its characteristic MOE.

As these values are examined for each fuel model, consider that those with higher MOE are “hotter” fuel models (the greater the difference between dead fuel moisture and MOE, the greater the predicted intensity).

E. Fine Fuels

Fine Fuels are the 1-hr time lag fuels that exist in a given fuel complex. They generally consist of grasses, leaves, needles, and the smallest twigs.

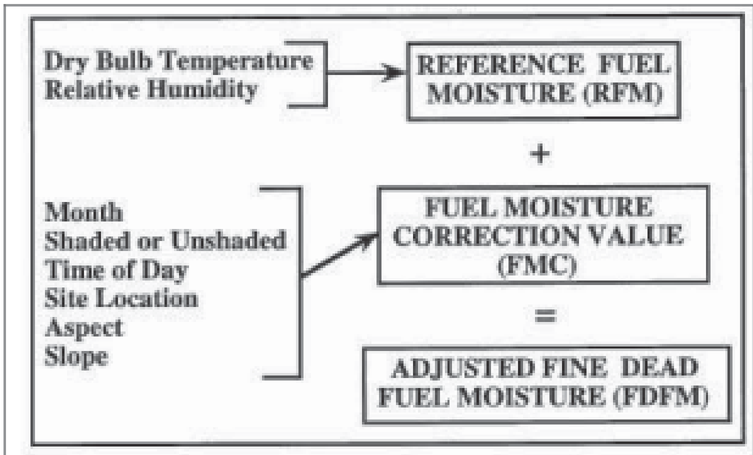
In nearly all fire situations, fires are "carried" through the landscape in these fine fuels. The loading and arrangement of these fine fuels are primary determinants of ignition, spread, and intensity of most fires.

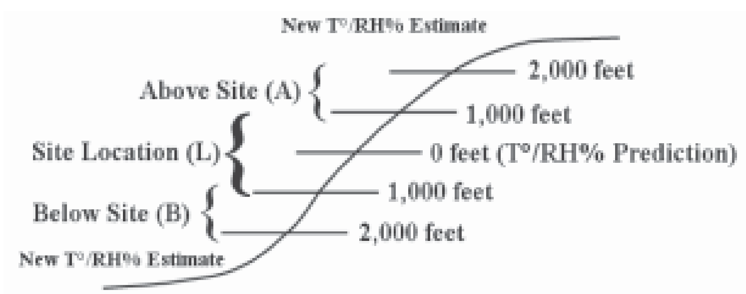
The importance of fine fuel moisture is highlighted in the fire severity chart shown here and in the Fireline Handbook, Appendix B.

Note that the one here includes both the corresponding probability of Ignition and CFFDRS Fine Fuel Moisture Code (FFMC).

Relative Humidity	Fine Fuel Moisture			Relative ease of spotting and ignition, general burning condition.
	NFDRS & NFBPS	CFFDRS FFMC	PROB of IGNITION	
>60%	1-hr > 20% 10-hr > 15%	Less than 80	<10%	Very little ignition, some spotting may occur with winds above 9 miles/hour.
45-60%	1-hr = 15-19% 10-hr = 12-15%	80-84	10-20%	Low ignition hazard campfires become dangerous; glowing brands cause ignition when relative humidity is less than 50%.
30-45%	1-hr = 11-14% 10-hr = 10-12%	85-88	20-30%	Medium ignition hazard matches become dangerous; "easy" burning conditions.
26-40%	1-hr = 8-10% 10-hr = 8-9%	89-92	30-50%	High ignition hazard Matches are dangerous; occasional crowning, spotting caused by gusty winds; "medium" burning conditions.
15-30%	1-hr = 5-7% 10-hr = 5-7%	93-95	50-70%	Quick ignition; rapid buildup, extensive crowning; any increase in wind causes increased spotting, crowning, loss of control; fire moves up aerial fuels; long distance spotting in pine stands; "dangerous" burning conditions.
<15%	1-hr < 5% 10-hr < 5%	Greater than 95	80-100%	All sources of ignition dangerous; aggressive burning, spot fires occur often and spread rapidly, extreme fire behavior probable; "critical" burning conditions.

To estimate fine fuel moisture, or 1-hr time lag fuel moisture, reference the Lookup tables and the Fine Dead Fuel Moisture worksheet in the Fireline Handbook, Appendix B.





FINE DEAD FUEL MOISTURE & PROBABILITY OF IGNITION

INPUT

0. Projection Point
1. Day Time Calculations
2. Dry Bulb Temperature, °F
3. Wet Bulb Temperature, °F
4. Dew Point, °F
5. Relative Humidity, %
6. Reference Fuel Moisture, % (from table 2)
7. Month
8. Unshaded(U) or Shaded(S)
9. Time
10. Elevation Change
    B = 1000'-2000' below site
    L = within 1000' of site location
    A = 1000'-2000' above site
11. Aspect
12. Slope
13. Fuel Moisture Correction, % (from table 3, 4, or 5)

OUTPUT

1. Fine Dead Fuel Moisture, % (Line 6 + Line 13)
2. Probability of Ignition, % (Table 12)

1. Determine Reference Fuel Moisture.

   Be careful to avoid mixing the lookup values for temperature and relative humidity.

2. Determine Fuel Moisture Correction Value.

   Once the Reference fuel moisture is determined, the remaining inputs for your situation need to be collected.

   All of the following items reference the fire location, not the site where the weather data was collected:

   - Month and Time of Day: Make sure to go to the right table based on the month (3, 4, or 5 in Appendix B).

   - Aspect and Slope: Consider the area that is expected to burn during the projection period.

   - Shading is based on a combination of tree and cloud shading.

   - Fire Site Location: Is the fire above, below, or within 1000 ft of weather observation elevation. If difference is more than 2000 ft, get a better weather observation.

3. Estimate Adjusted Fine Dead Fuel Moisture (1-hr TL Fuel Moisture) by combining the Reference Fuel Moisture and Correction Value.

EXERCISE 1.

After reading the scenario, use the worksheet on page 4.13 to answer the questions.

Scenario:

You are assigned to a fire in northern California. The fire is burning in a combination of dense white fir (Fuel Model 10) and manzanita brush fields (Fuel Model 4). As you make your first fire behavior projections, you find that you need a number of dead fuel moisture values for both fuel types. You have taken the weather at your location near the fire perimeter at 5,000 feet elevation and recorded the following values:

Dry bulb temperature:	80º F
Relative humidity:	20%
Slope percent:	35%
Aspect:	South
Site exposure:	Open
Month:	August
Time:	1500
Sky:	Clear

1. You want to verify rate of spread in the brush field at your location. What is the dead fuel moisture?

2. You wish to determine the probability of ignition of a location 800 feet higher on the same slope. What is the 1-hour timelag fuel moisture?

3. You would like to determine the crowning potential of the white fir stands on a north slope directly opposite you. What is the 1-hour timelag fuel moisture of the fine dead fuels under the forest canopy?

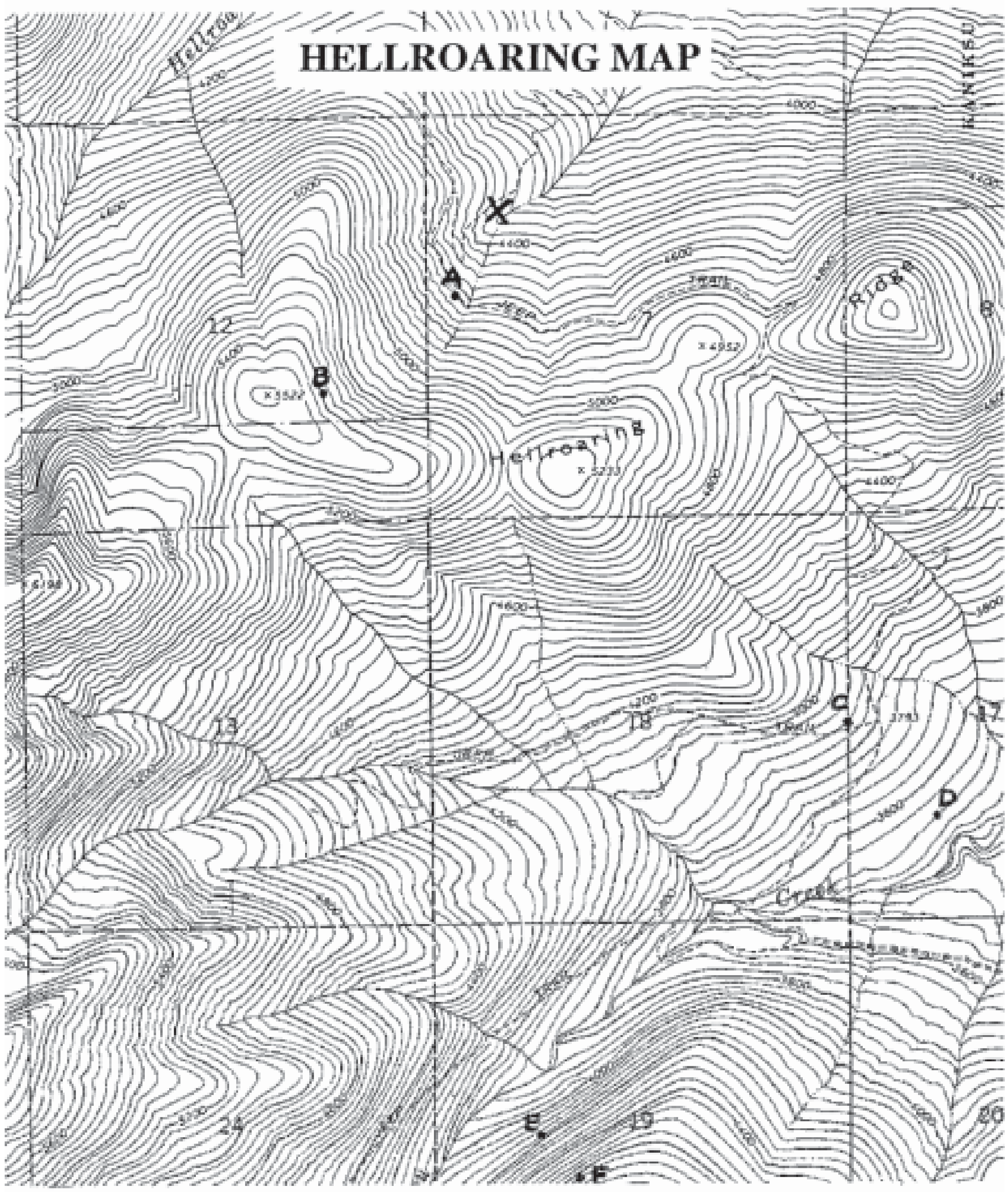
4. What is the fine dead fuel moisture on a shaded east-facing slope 1,500 feet below you? The slope is 70 percent.

5. You wish to determine flame length in a brush field at 7,500 feet on a southeast-facing slope. Determine the fine dead fuel moisture.

Use the map and the worksheet to answer questions 6 and 7.

6. You've helitacked a fire and are on the ridge top next to Point B on the map. Your weather at 1030 is DBTemp 79º F, WBTemp is 59º F, the sky is clear, and the fire is in a dense closed stand. What is your fine fuel moisture?

7. Time is now 1430. Your location is the same. There is a new smoke downhill from your fire at about the 4320 foot contour level (at the X on the map). Your weather is DBTemp 92º F, WBTemp 63º F, Sky has 15% cloud cover and the fire is in an open grassy area. What is your 1-hr TL Fuel Moisture?



FINE DEAD FUEL MOISTURE & PROBABILITY OF IGNITION WORKSHEET

INPUT

	Q.1	Q.2	Q.3	Q.4	Q.5	Q.6	Q.7
0. Projection Point							
1. Day Time Calculations							
2. Dry Bulb Temperature, ° F							
3. Wet Bulb Temperature, ° F							
4. Dew Point, ° F							
5. Relative Humidity, %							
6. Reference Fuel Moisture, % (from table 2)							
7. Month							
8. Unshaded(U) or Shaded(S)							
9. Time							
10. Elevation Change B = 1000'-2000' below site L = within 1000' of site location A = 1000'-2000' above site							
11. Aspect							
12. Slope							
13. Fuel Moisture Correction, % (from table 3, 4, or 5)							

OUTPUT

1. Fine Dead Fuel Moisture, % (Line 6 + Line 13)							
2. Probability of Ignition, % (Table 12)							

IV. LIVE FUEL MOISTURE

Fuel moisture in live fuels is controlled by the physiological processes within the plant itself. These live fuel moistures are lowest during dormant periods, especially in cold winter months leading into early spring.

Plants integrate seasonal and long term moisture conditions, being one of the first visible indicators of developing drought conditions.

Moisture content related to the stage of plant development during growing season, affected by bud flush, flowering, senescence, and other periodic developments.

Elevation affects plant development, with higher elevations generally having shorter period of high live fuel moisture beginning later in the spring.

Live fuel moisture is measured in the same way that dead fuel moisture is, using the fuel moisture formula described at the beginning of the lesson.

For the purposes of NFDRS and USFBPS, there are three categories of live fuel moisture:

A. Herbaceous Fuel Moisture

Herbaceous fuel moisture is the moisture content of live portions of grasses and forbs, generally the first live plants to respond to moisture stress with lowered moisture levels.

B. Woody Fuel Moisture

Woody fuel moisture is the moisture content of live portions of woody plants. These include small stems, branches, and foliage of shrubs and tree seedlings found in the surface fuel complex.

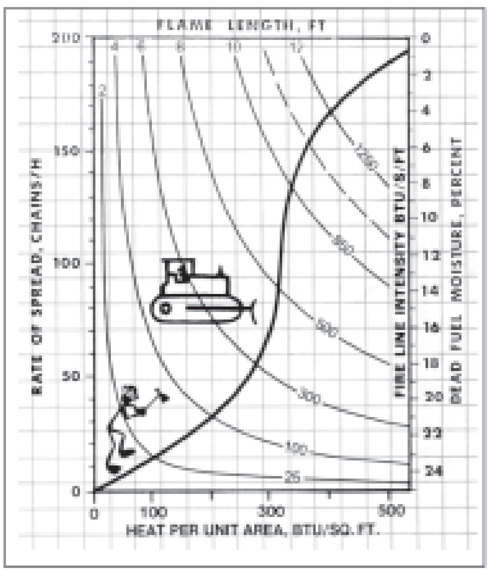
Though these surface shrubs and seedlings may include some mature foliage (if evergreen), the estimated fuel moisture is generally dominated by current season foliage and its developmental stage.

C. Foliar Moisture

Foliar moisture is the moisture content of small stems, branches and foliage of aerial fuels, including trees and tall shrubs.

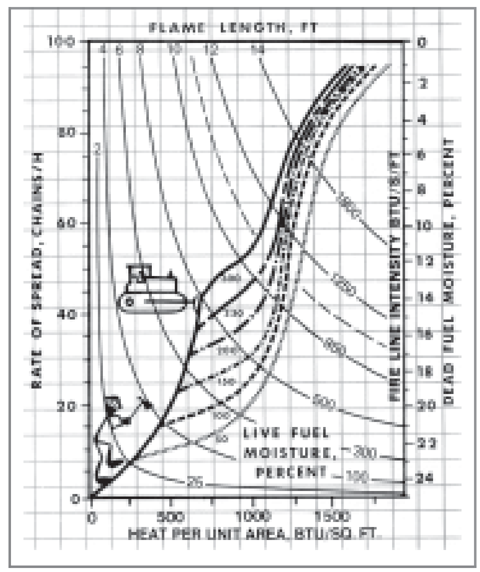
With respect to evergreen plants that retain leaves for several years, this fuel moisture is based on a mixture of mature and immature foliage. Consider what portion of the foliage is immature and at what stage of maturation that portion is before making the final estimate.

Among the fuel models described in the last lesson, live fuel moisture is an input when using fuel models 2, 4, 5, 7, and 10. Note the difference between these two upper right quadrants of FM 9 and FM 10 nomograms respectively.



Fuel Model 9, without live fuels has only a single moisture curve.

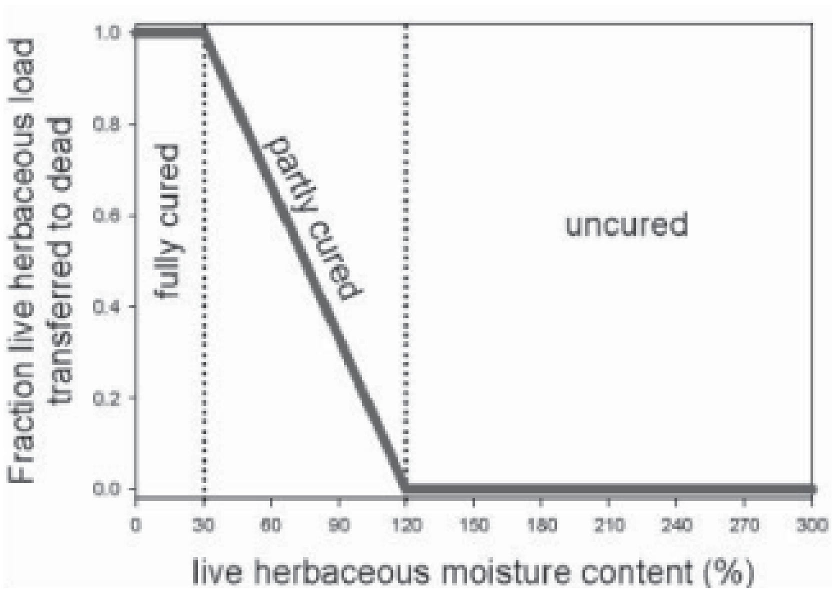
Fuel Model 10 includes multiple fuel moisture curves, based on the live fuel moisture.



However, with the advent of 40 additional fuel models, herbaceous fuel moisture will become a much more important input.

NFDRS has long had dynamic fuel models, using the herbaceous fuel moisture to indicate a transfer of a portion of the herbaceous fuel load to the dead fuel category.

Many of the 40 new models will also have this feature, using the estimated fine fuel moisture instead of the live fuel moisture for the portion transferred.



V. OTHER MEANS OF ESTIMATING AND MEASURING FUEL MOISTURE

To this point we have discussed methods to estimate fuel moisture indirectly. However, it is possible to collect fuels and measure their fuel moisture content. Further, it is possible to take advantage of field observations to improve these indirect measures. Remote Sensing techniques can also be important.

At times, in the field, it may not be possible to conduct any of the formal estimates. At that time, rough estimates may be the best available. Some of those rely on field observations, perhaps being better than any calculated value.

Approximation # 1:
Fine Fuel Moisture = Relative Humidity ÷ 5

Approximation # 2:
Visual Cues for Live Fuel Moisture

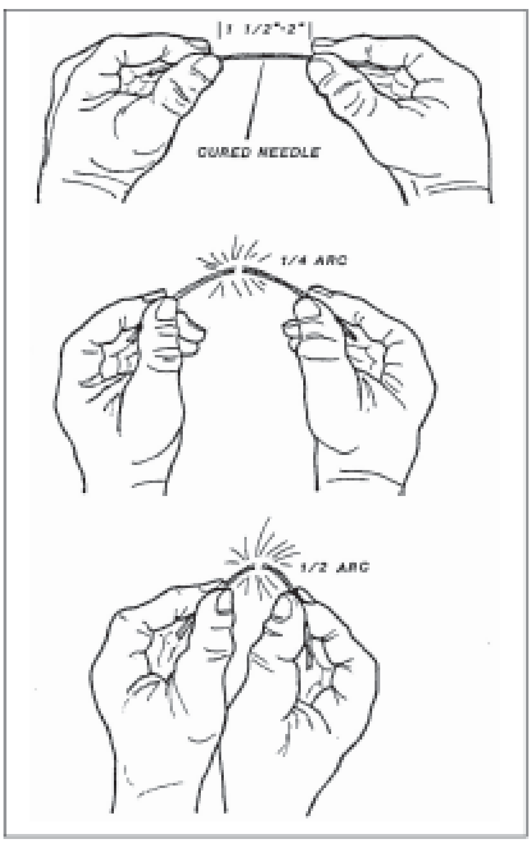
Many live fuels have been studied over the years, with fuel moistures related to growth and development processes.

Many of these growth processes have visual cues such as color changes to indicate some critical moisture levels.

Examples:

- Chamise - red leaf tips/begins to drop leaves at 60%
- Buckeye - begins to drop leaves at 80%
- Poison Oak - turns red/gold at 60%
- Some manzanita develops yellow stems and the leaves turn dirty green at 80%

Approximation # 3: Ponderosa Pine Needle Moisture



- Randomly select cured brown pine needle from forest floor.
- Hold needle between thumbs and forefingers. Slowly bend ends of needle in a circle. Move thumbs down and together.
- If needle breaks within ¼ arc, moisture content is 4-7%. Burning conditions are very favorable.
- If needle breaks within ½ arc, moisture contents is 8-11%. Burning conditions are favorable.
- If needle bends beyond ½ arc without breaking, burning conditions are marginal or unsatisfactory

Direct measurement of any of the fuel moistures discussed to this point is possible. Drying ovens are used to remove the moisture within fuels.

Fuels are measured before drying and again afterward. With those two values, the fuel moisture content is calculated with the formula mentioned at the beginning of the lesson.

Electronic probes have been used by sawmills and kiln operators for years to sample the moisture content of wood products.

These same tools can be used to directly measure fuel moisture of any woody fuels, generally more than ¼ inch in diameter.

With both techniques, multiple samples are necessary to minimize any bias based on the condition of any particular sample.

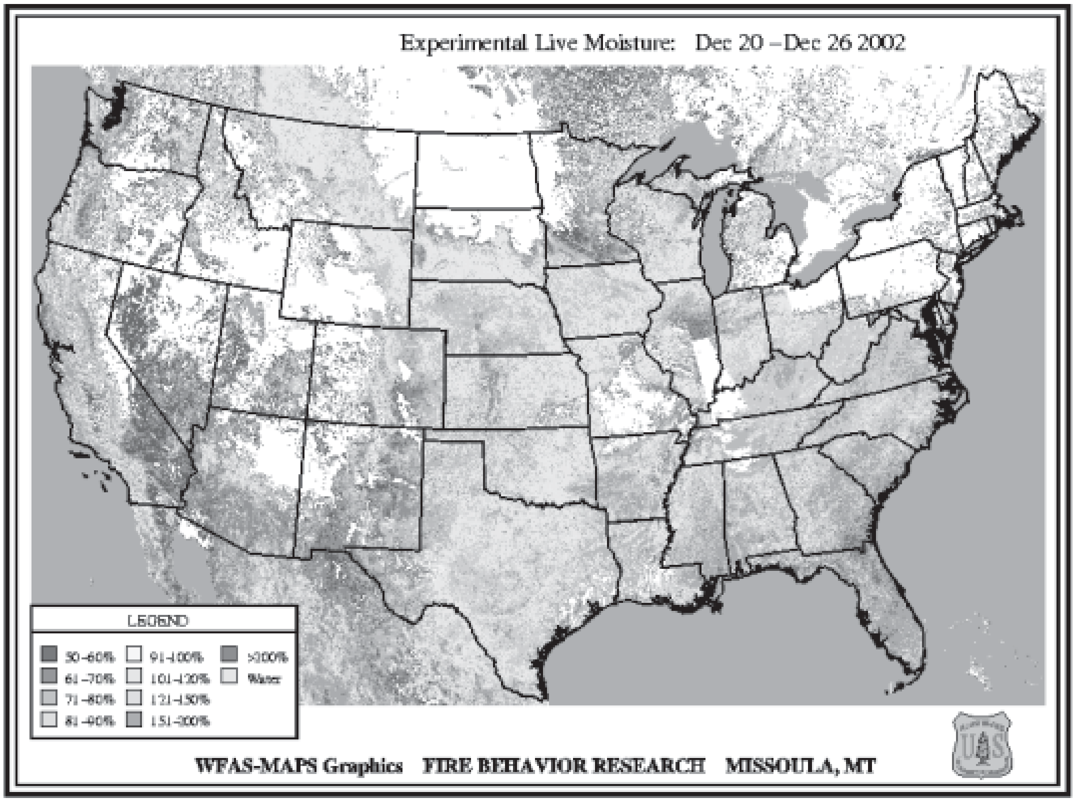
Remote Sensing allow for subjective evaluation of live fuel moisture conditions. These techniques involve both satellite imagery and RAWS weather data.

The primary satellite imagery tool is the **Normalized Differential Vegetation Index (NDVI)**.

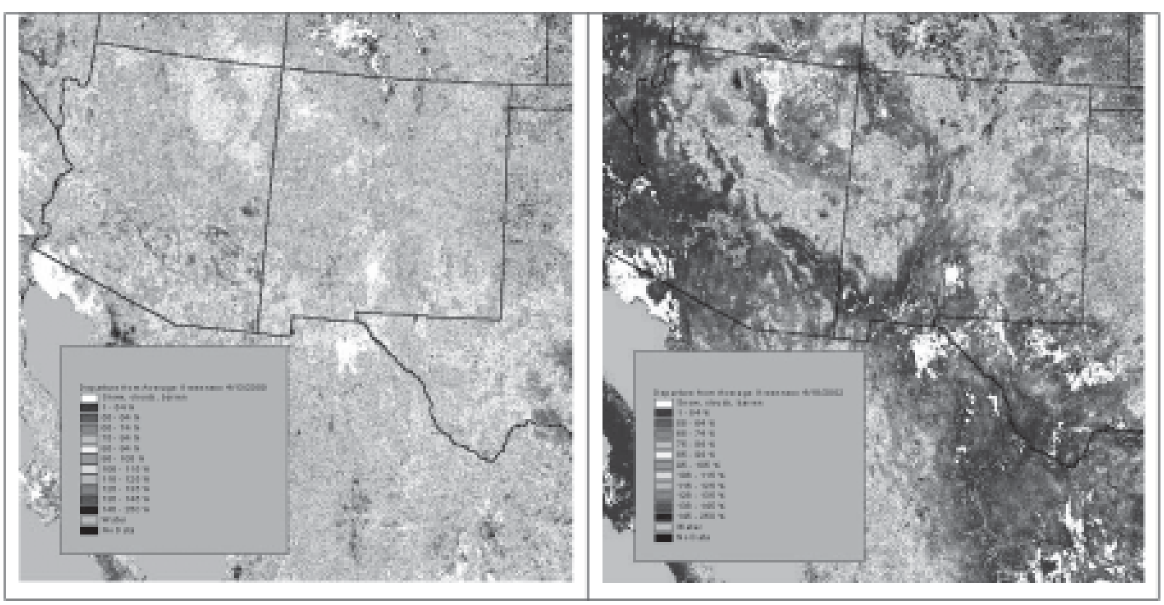
The NDVI data is collected each day, averaged for seven day periods, and distributed on the Wildland Fire Assessment System (WFAS) managed by the U.S. Forest Service.

There are five different images produced from the data collected:

- NDVI – Current Condition.
- Visual Greenness – related to theoretical overall maximum value.
- Relative Greenness – related to maximum value for that location.
- Experimental Live Moisture – estimate of live fuel moisture.
- Departure from Average – related to historic normal (average).



Departure from Average Greenness: 2000 and 2002.
Which year was drier?



There is an historic record of NDVI sampling dating back to 1991. Among those, the experimental live moisture image produces an estimate of live shrub moisture contents and will give best estimates in plant communities that are dominated by shrubs.

With many RAWS being established throughout the country, many fire situations will have one or more stations nearby.

These stations, and the associated NFDRS outputs calculated each day, provide indications of both dead and live fuel moistures that may be used to calibrate estimates used for fire behavior calculations.

VI. DROUGHT AND FIRE BEHAVIOR

Drought conditions are NOT a prerequisite for fires to occur and spread, but there is a close association between drought conditions and extremely difficult fire suppression.

Observation shows that relatively few large and destructive fires or severe fire seasons occur without drought being a significant factor.

Though not a direct input into the fire spread model, most fire managers agree that drought increases the potential for extreme fire behavior by causing abnormally low moisture levels in both dead and live fuels.

A. Drought

Drought is a protracted period of deficient moisture, based upon an established climatological normal, which has a significant social, environmental, or economic effect.

Drought is a normal, recurrent feature of climate, although many erroneously consider it a rare and random event.

Three main types of drought are commonly referenced:

1. Meteorological drought

   Meteorological drought is usually defined on the basis of the degree of dryness (in comparison to some "normal" or average amount), and the duration of the dry period.

   It may relate actual precipitation departures to average amounts on monthly, seasonal, or annual time scales.

   Definitions of meteorological drought must be regionalized due to wide ranges in precipitation patterns.

   For example, a rainfall deficiency of five inches in the year might pass unnoticed in a moist climate, but could have significance in an arid climate.

2. Hydrological drought

   Hydrological drought is associated with the effects of periods of precipitation shortfalls on surface or subsurface water supply such as:

   - Streams
   - Reservoirs
   - Lake levels
   - Ground water

   In essence, hydrological drought is the impact of meteorological drought on water supply.

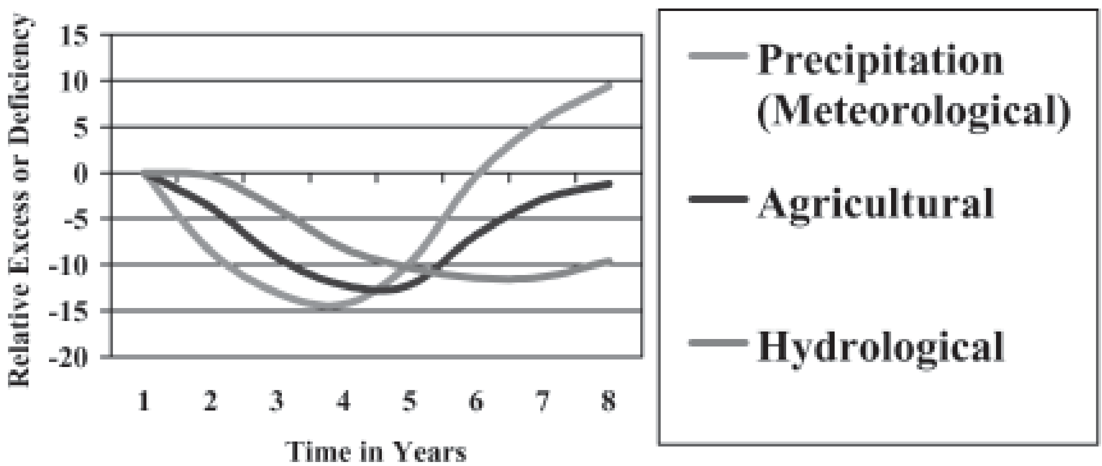
   Hydrological drought usually lags behind meteorological and agricultural drought, since it takes longer for precipitation deficiencies to show up in the water supply.

3. Agricultural drought

Agricultural drought links various characteristics of meteorological or hydrological drought to agricultural impacts.

The focus is on the moisture available from precipitation and/or the water supply in relation to plant water demand.

Plant water demand depends on prevailing weather conditions, biological characteristics of the specific plant, its stage of growth, and the physical and biological properties of the soil.



Notice the relative "time lag" for these three types of drought. As the graph indicates, drought can take several years to develop and several to be mitigated.

However, wildland fuels and the associated fire behavior respond more quickly than indicated by this graph, frequently within weeks or months. Consider the historic record and how to use it when evaluating the current situation.

The value of any measure, whether it is accumulated rainfall or particular fuel moisture, can be evaluated only if it can be compared to other values in a meaningful way.

This referencing to historic data is called climatology.

When comparing current measures of drought to the historic record, there are **four objective measures** to make the comparison:

- The **actual measure**, such as inches of rainfall in the past 30 days.

  This can be informative if it is a starkly abnormal amount, such as “0.0 inches of rain in the last month in Florida.”

- The **anomaly (departure from average)** helps the user by identifying the difference between current value and normal.

  However, it does not inform the user how important that departure is. Five inches departure out of 10 inches is much more important than 5 inches out of 40 inches.

- The **percent of normal (average)** gives the user an idea of how important the departure is.

  However, 20% of 10 inches is much less (2 inches) than 20% of 40 inches (8 inches).

- The **ranking or percentile** of the current year when compared the set of historic years indicates how significant historically the departure is.

  “The 6 inches of rainfall received this year is the lowest total recorded in the last 30 years.”

These objective measures require specific knowledge of the item measured and how it responds to local conditions. The user is responsible for developing the thresholds for the local area.

Though each of these ways of presenting climatology associated with the current situation, none of them provide a means of comparing different parts of a large management area, such as the United States.

Though they will be discussed later, NFDRS and CFFDRS outputs are good examples of objective measures of drought conditions.

Drought indices are objective measures of net moisture deficiency. Indices provide a simple number or category to aid in analyzing the complex drought process.

Regarding agricultural drought, John Keetch and George Byram say:

> "A drought index can be defined as a number representing the net effect of evapotranspiration and precipitation in producing cumulative moisture deficiency in deep duff or upper soil layers."

B. What Makes a Good Drought Index for Fire Managers?

- Available historic record (Climatology) to reference and compare with current values.

- Geographic Reference to "localize" it. Not all indices are good for all climates.

- Captures seasonal trends rather than day to day variations. Consider its "timelag."

- Changes in the index correlate to changes in fire potential. Are there valuable thresholds?

C. Normalized Index

To compare different parts of the country, drought indices must be normalized. A normalized index expresses drought relative to what is normal for each analysis area and time period.

These normalized indices make it much easier to compare conditions in dry climates to conditions in wet climates by eliminating the unit of measure.

Good examples are the Palmer Drought Severity Index (PDSI) and the Standardized Precipitation Index (SPI).

As a normalized index, a PDSI of -4 should mean the same level of drought whether it is recorded in Alaska or Wyoming.

D. Objective Measure

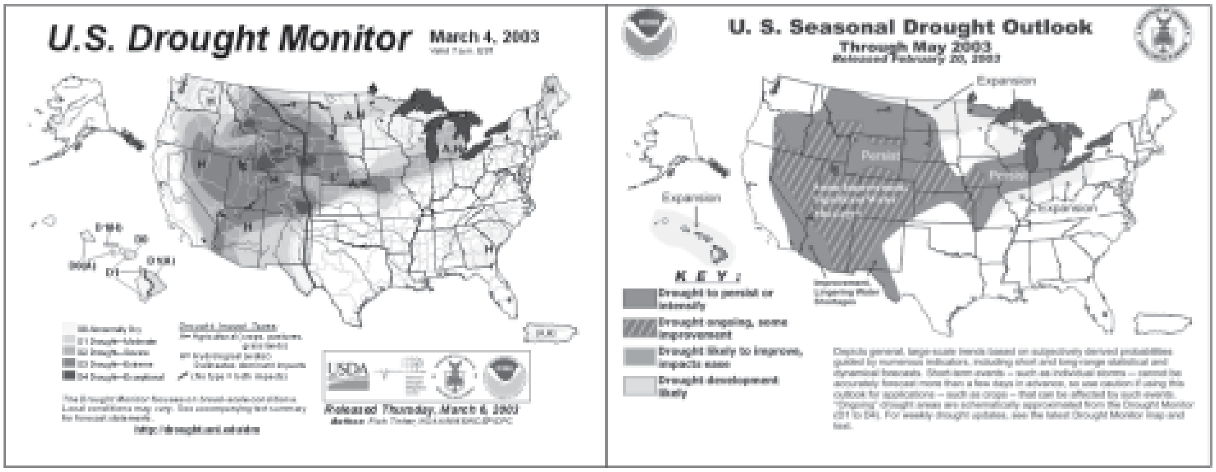
Objective Measure indices require specific knowledge of responses to local conditions.

- Thresholds are developed for a specific area.
- Not as useful for comparing parts of a large area (U.S.).
- NFDRS and CFFDRS outputs.

E. Drought Monitor

Further, no single normalized index alone tells the entire story. The National Oceanographic and Atmospheric Administration (NOAA) produce the **Drought Monitor** each week.

Knowledgeable and experienced climatologists evaluate a number of drought indices and produce an interpreted map of overall drought severity.



The Drought Monitor includes data from five different indices and measures throughout the year including:

- Palmer Drought Severity Index
- Standardized Precipitation Index
- Weekly Streamflow
- Percent of Normal Precipitation
- Satellite Vegetative Health Index

Others used in the summer include:

- Keetch-Byrum Drought Index
- Crop Moisture Index
- Topsoil Moisture Index

Most important and familiar among these are:

1. Palmer Drought Severity Index (PDSI):

   Considered a meteorological drought index, updated weekly by the Climate Prediction Center, it is based on rainfall, temperature, and historic data.

It is computed base on a complex formula devised by W.C. Palmer in 1965. Although the Palmer is the main drought index used by the U.S. Government, it is slow to detect fast-emerging droughts.

It also does not reflect snow pack, an important component of water supply in the western United States.

Interpretation and Products:

- PDI of 6+ means extremely moist, -6 means extreme drought.
- Many PDI products are available from the National Climatic Data Center.
- Weekly updates available from NOAA Climate Prediction Center.
- Considered a Normalized Index.

2. Standardized Precipitation Index (SPI):

Precipitation deficits have different impacts on groundwater, reservoir storage, soil moisture, snow pack, and Streamflow.

Soil moisture conditions respond to precipitation anomalies on a relatively short scale. Groundwater, streamflow, and reservoir storage reflect the longer-term anomalies.

The SPI was designed to quantify the precipitation deficit for multiple time scales to help assess these resources.

A meteorological index based on the probability of precipitation for any time scale, it can provide early warning of drought and help assess drought severity.

Interpretation and Products:

- Index ranks from –3.0 to +3.0
- Wetter and drier climates can be compared with SPI.
- National Climatic Data Center has SPI for 1, 2, 3, 6, 9, 12 month and multi-year time periods.
- Considered a Normalized Index.

VII. DANGER RATING AND EVALUATING FUEL MOISTURE

Fire Order # 1: Base all actions on current and expected fire behavior.

How can drought be incorporated into fire behavior assessment?

In making fire behavior calculations, the first challenge is to estimate and/or predict dead and live fuel moisture inputs for the fire model. However, if drought is to be effectively considered, it needs to be at least subjectively incorporated in the fire behavior calculation.

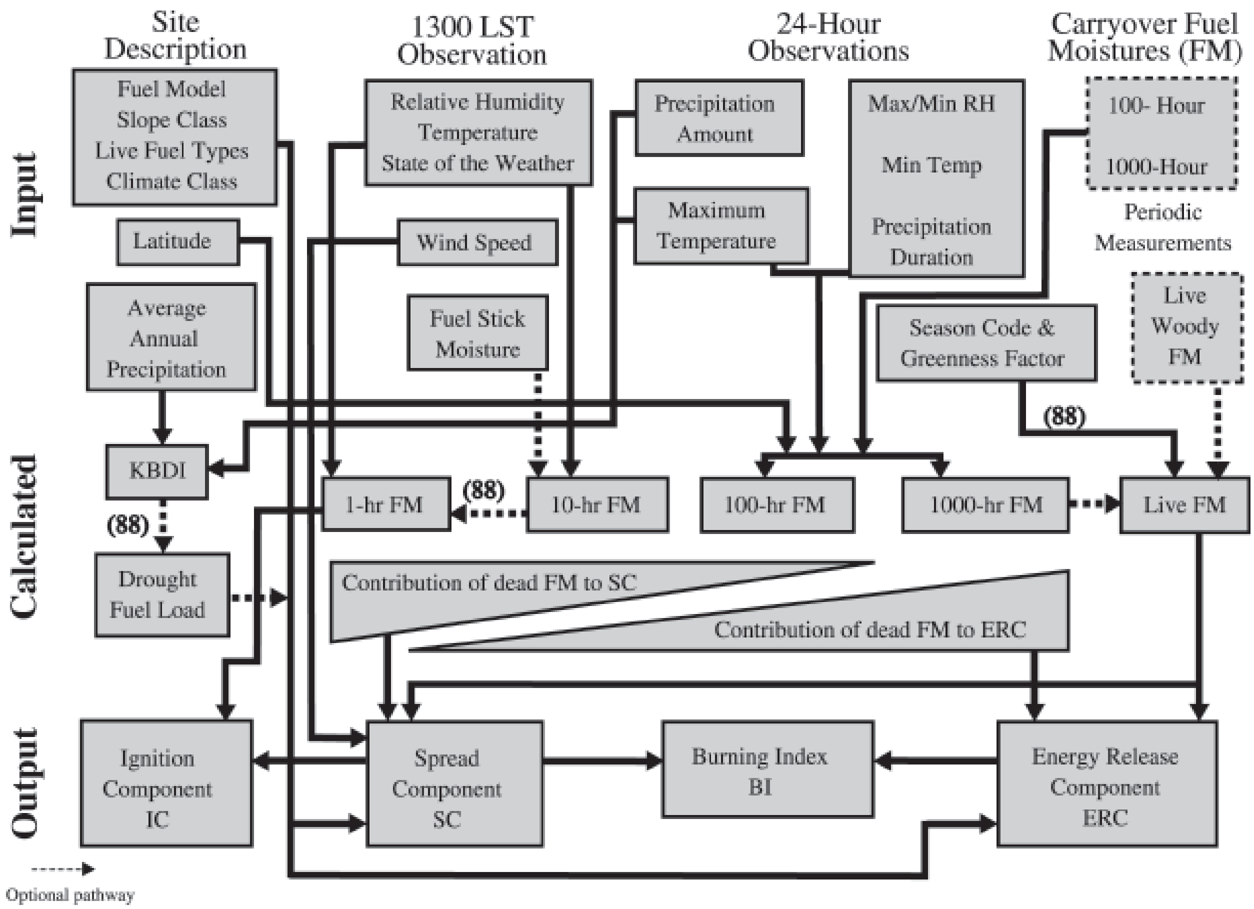
When fighting fires in North America, firefighters will encounter two sets of danger rating tools. Both the NFDRS and the CFFDRS produce both a set of fuel moisture values and fire behavior indices.

Outputs from these representative stations (RAWS) can be used to approximate the fuel moistures and interpret fire potential for the fire situation. Both systems assume that daily inputs have been made, and that weather observations are accurate and representative.

Their outputs represent peak burning conditions for that day at that location. It may even be valuable to combine outputs from several representative stations.

None of the danger rating fuel moisture values and fire behavior indices is considered normalized indices.

NFDRS Structure



NFDRS includes several fuel moisture tools that may be effective in assessing drought in a local area:

A. 1000 hour Fuel Moisture (1000 hr)

Used to indicate the slowly changing fuel moisture of larger dead fuel classes.

Inputs include max/min temp, max/min RH, precipitation duration and day length over the last 7 days. These are used to adjust yesterday's 1000-hr fuel moisture.

NFDRS developers noticed that the 1000-hour moisture showed a seasonal fluctuation similar to that of live fuels. Therefore, the "driver" in the model that causes changes in calculated live fuel moisture values is the 1000-hour fuel moisture.

In other words, if the 1000-hour fuel moisture value stays up, it means there has been adequate moisture throughout the season, which also keeps the herbaceous and woody vegetation growing.

If the 1000-hour moisture drops throughout the season, it means reduced moisture, which also tends to cause the live vegetation to move toward a cured or fall "dormant" condition.

In more humid areas of the eastern U.S., RH minimums seldom drop below 15 percent and nighttime recovery generally produces RH maximums of greater than 80 percent.

Thus, even though there may be no rainfall, the 1000-hr fuel moisture rarely drops below the mid-range even though there may have been no precipitation for several months.

As a result, the user must interpret smaller variations in 1000-hr values, which are more subject to bias of weather inputs.

B. Keetch-Byrum Drought Index (KBDI)

KBDI is a numerical model representing the net effect of evapo-transpiration and precipitation in producing cumulative moisture deficiency in deep duff and upper soil layers.

It relates to the flammability of organic material in the ground. Inputs include average annual precipitation amount, daily maximum temp and 24 hour rainfall amount. These are used to adjust yesterday's KBDI value.

Ranges from 0 to 800 and expresses the NET rainfall needed for full soil moisture recharge (KBDI = 650 means 6½ inches needed).

Cool temps and short summers of north keep KBDI lower than hot and dry summers of southwest, indicating that it is not to be considered a normalized index.

C. Energy Release Component (ERC)

ERC is a dimensionless number related to the 24-hr potential worst case total energy released per unit area within the flaming combustion stage.

It is based on a loading-weighted reaction intensity rather than surface area weighted. This gives the larger fuels more influence than they have in fire behavior predictions that focus on energy released only in the flaming front.

In the flaming front, energy released is assumed to be only from the quickly burning fine fuels. ERC relates to the amount of fuel available to burn, using the load of the selected fuel model and dryness of those fuels in the calculation.

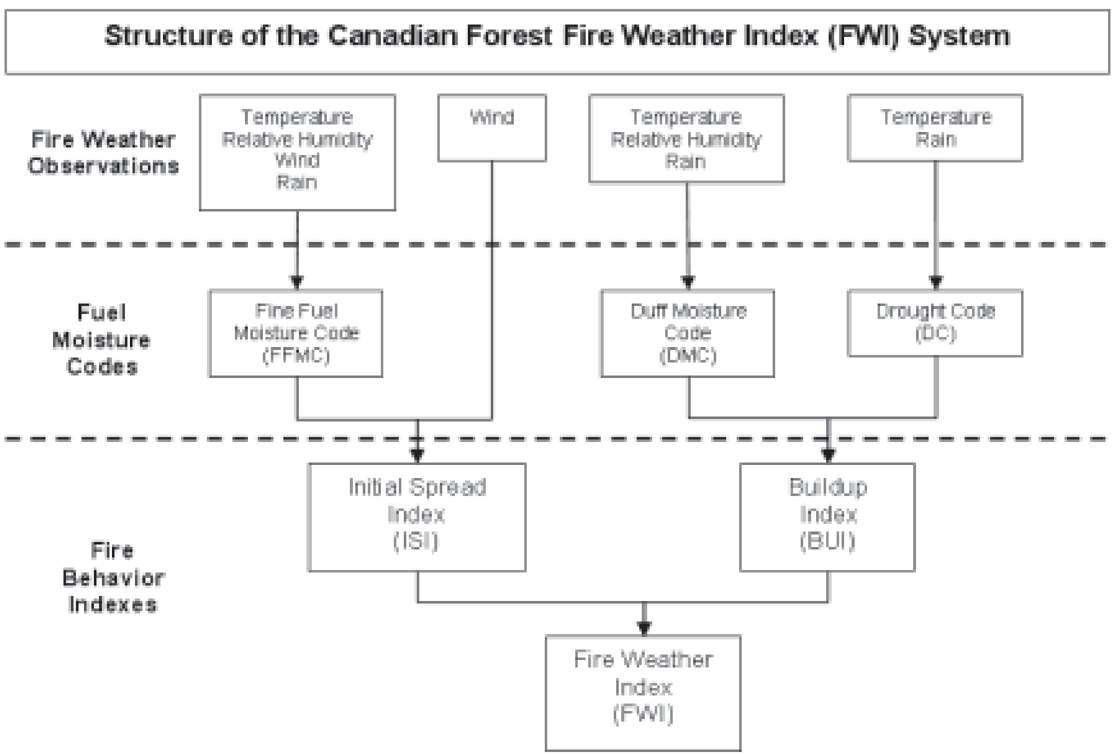
Moisture content of large fuels changes very slowly, so ERC in fuel models containing large fuels, such as fuel model G, change slowly with the fuel availability. As a result, ERC-G is a fairly good indicator of moisture deficits over one to several weeks.

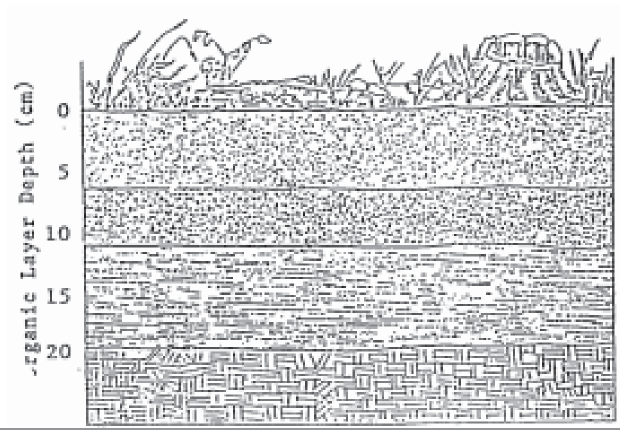
D. Canadian Forest Fire Danger Rating System (CFFDRS)

The Canadian Fire Weather Index (FWI) was developed using weather and fire data in northern boreal forests dominated by coniferous trees such as spruce, fir, and pine.

Values are not normalized climatologically and are not adjusted for particular fuel models. It is up to the user to determine which of the values are important and what thresholds are important for the local situation.

Duff moisture code (DMC), drought code (DC), and buildup index (BUI) will all have lower overall values in the cool, short summers of northern climates.





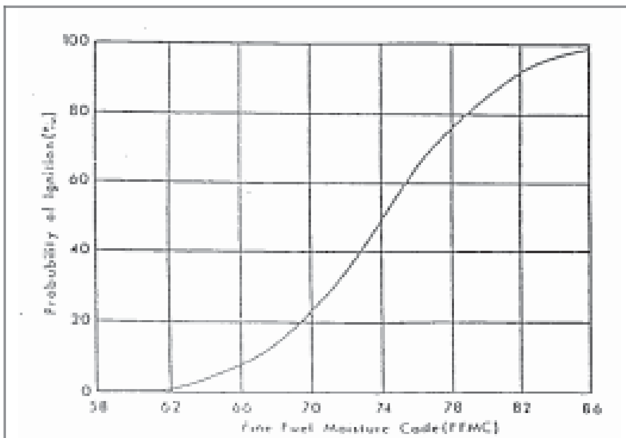
	Weight	Fuel Moisture Code
Duff Layer	5 t/ha	FFMC
Upper	50 t/ha	DMC
Middle	440 t/ha	DC
Lower		
Mineral Soil		

E. Fine Fuel Moisture Code (FFMC)

Because fires usually start and spread in fine fuels, the FFMC is used to indicate ease of ignition, or ignition probability. The FFMC scale ranges from 0-99 and is the only component of the FWI System which does not have an open-ended scale.

Generally, fires begin to ignite at FFMC values near 70, and the maximum probable value that will ever be achieved is 96. At the high end of the scale, a general rule of thumb is that the fuel moisture content is 101 minus the FFMC value.

Of importance is the fact that fire starts increase exponentially with an increase in FFMC values at the high end of the scale. In the boreal forest, a high potential for fire starts exists once the FFMC reaches 86-89.



Ignitability of 'shaded' slash pine needle litter under 'no wind' conditions as a function of the Fine Fuel Moisture Code (adapted from Blackmarr 1972 by M.E. Alexander based on Van Wagner 1987).

F. Duff Moisture Code (DMC)

The DMC fuels have a slower drying rate than the FFMC fuels, with a timelag of 12 days or nearly 300 hours.

There really is no timelag analog for the DMC in NFDRS. Although the DMC has an open-ended scale, the highest probable value is in the range of 150.

Inputs include noon observations for temperature, relative humidity and 24 hour precipitation total. These are used to adjust yesterday's DMC. Due to the slower drying rate, a seasonal day-length factor has been incorporated into the drying phase of the DMC.

G. Drought Code (DC)

The DC is an indicator of moisture content in deep, compact organic layers. It is analogous to 1000-hr fuel moisture and KBDI from NFDRS.

Temperature and rain affect the DC, although wind speed and relative humidity do not because of the depth of this fuel layer.

The DC fuels have a very slow drying rate, with a timelag of 52 days. Therefore, a seasonal day-length factor is also incorporated in the drying phase. The DC scale is open-ended, although the maximum probable value is about 800.

Mop-up recommendations as determined by the Drought Code (Adapted after Muraro and Lawson 1970; Canadian Forestry Service, 1971).

DC	INTERPRETATION
< 300	Moisture will increase with depth. Usual attention to mop-up and patrol, with closer attention to critical perimeters as a DC value of 300 is approached.
300 - 500	Moisture content may decrease with depth. Extensive mop-up of edges should be initiated as control problems could be posed by critical edges.
> 500	Moisture content will most likely decrease with depth. Extensive mop-up and patrol of all edges is required.

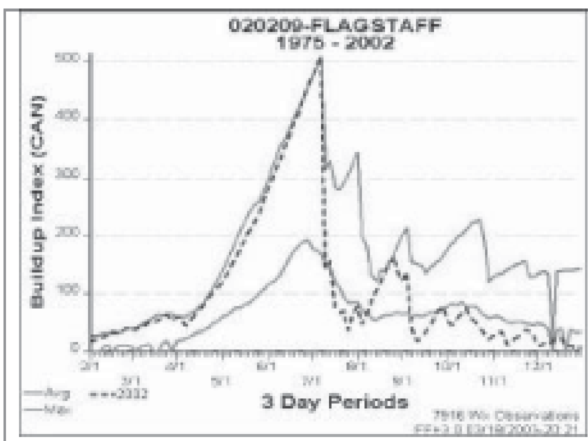
H. Buildup Index (BUI)

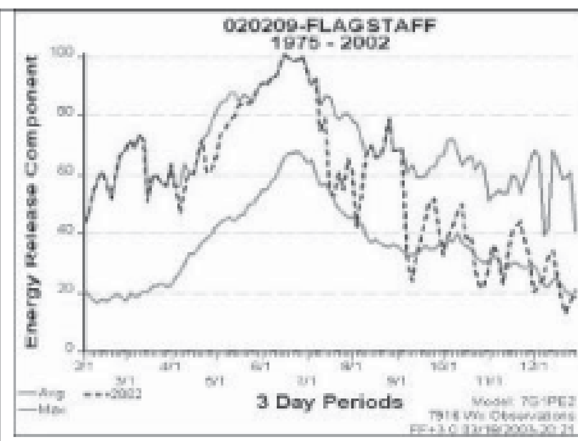
The BUI is a weighted combination of the DMC and DC to indicate the total amount of fuel available for combustion by a moving flame front.

Like the DMC, it is an open-ended index with a realistic maximum value of 200. It has a similar track to the DMC for the same location, though values are somewhat higher.

BUI is frequently compared the NFDRS ERC. However, unlike ERC, fine fuel moisture plays no role in it, making it less sensitive to day to day variations.

Because it combines DMC and DC, its timelag is assumed to be somewhere between 12 and 52 days, probably representing a timelag of between 2 and 3 weeks.





I. Interpreting Drought and Fire Danger Indices

Both the NFDRS and CFFDRS-FWI Systems produce relative numerical ratings of fire potential over a large area – often represented by weather observations from a single weather station.

Unlike the NDVI remote sensing tool, which collects data from many points in the area of concern, extrapolation of fuel conditions from a single weather observation can lead to some obvious biases.

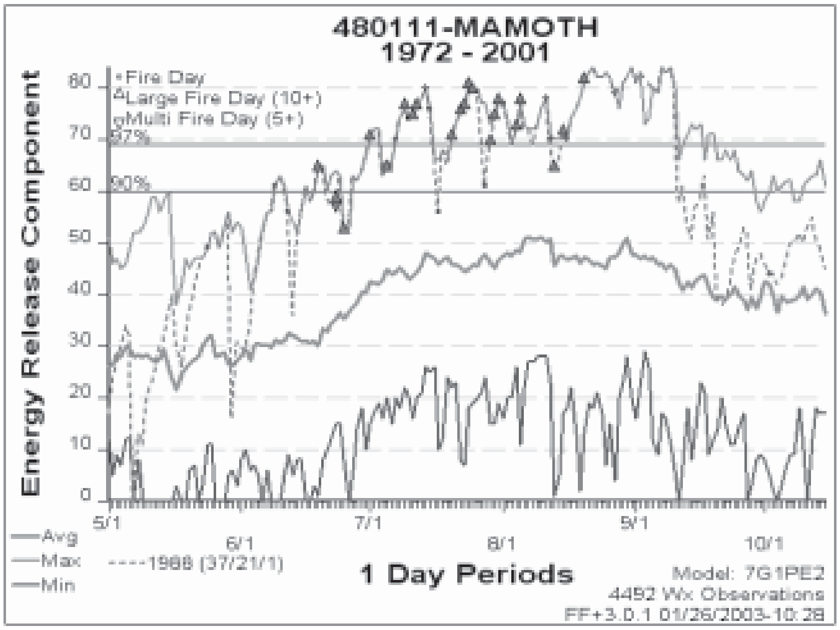
Consider the situation where a local thunderstorm drops precipitation over a localized area around the weather station with most of the area remaining dry. Similarly, the single daily observation is based on the assumption of regular diurnal changes in temperature and relative humidity.

If a frontal system passes either just before or just after the daily observation, rapid swings in temperature and humidity can result. In both cases, the outputs will be biased and perhaps critically in error. Keeping this in mind will prevent misinterpretation.

Danger rating outputs can be more valuable than the frequently referenced tools such as PDSI and SPI because the user can select the data set and pick the particular index that represents the fire situation. Software tools like Fire Family Plus gives complete control of the data and calculations.

Because these values are not normalized, tracking and comparing current fuel moistures with other locations and corresponding times from other years is important to understanding how critical the burning conditions are. It is especially important for those fuels that change more slowly, responding over days, weeks, months and even years.

Among the most common techniques for evaluating these tools is simply graphing a track of this year's values against a historic set of maximum and average values, with some reference to fire activity if at all possible.



Notice the maximum line (red), the average line (gray), and the minimum line (blue), allowing the user to identify significant historic trends.

Current and/or representative years (1988 in green) can be plotted with associated fire activity overlaid.

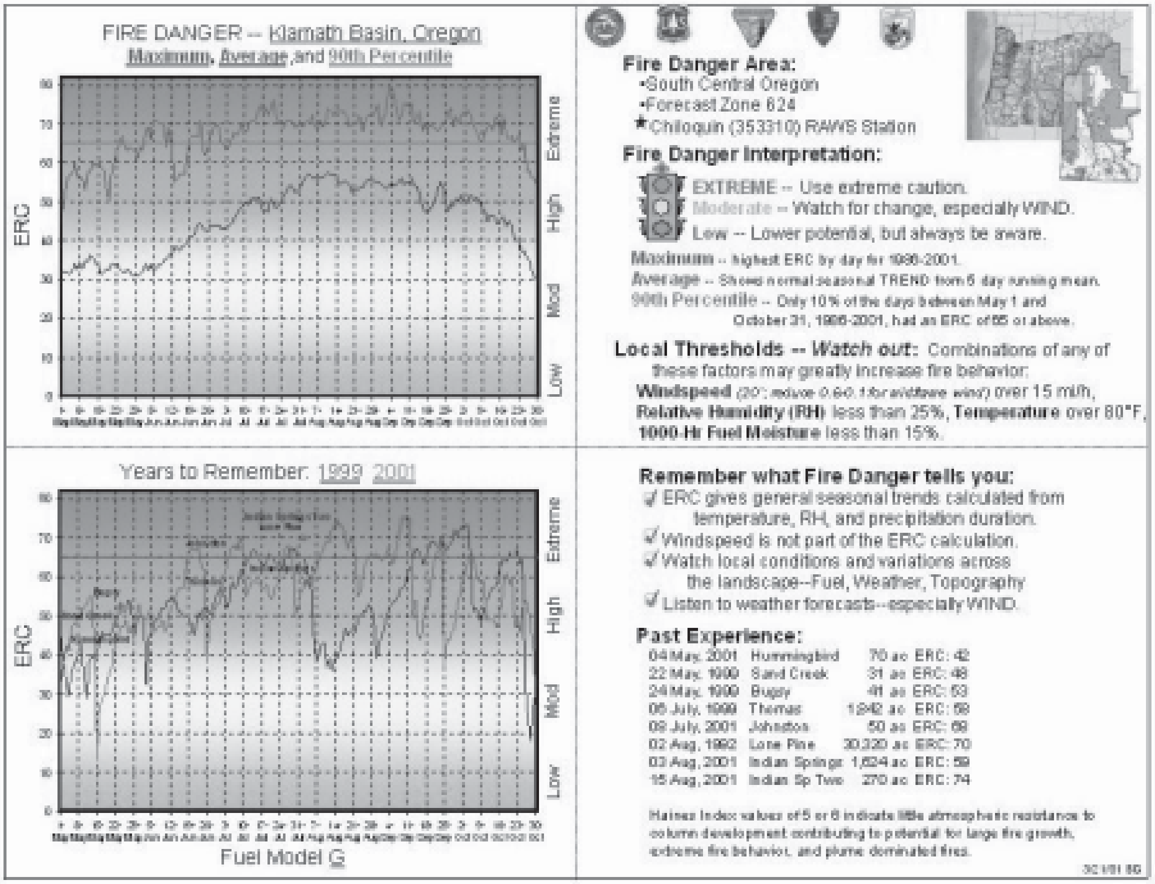
Do you see a threshold for fire occurrence?

J. Pocket Cards

Pocket Cards are now part of the briefing process. They are an assessment tool to give firefighters a reference to useful fire danger codes by presenting current values in context.

Included are:

- Identification of the area represented, such as South Central Oregon, and the data used, such as Chiloquin RAWS.
- Day by day, maximum and average values as well as a percentile line for the selected fire danger code (example: ERC-G).
- Local Thresholds to aid in interpretation.
- Other representative years and past fire experiences related to corresponding values.


FIRE DANGER -- Klamath Basin, Oregon
Maximum, Average, and 90th Percentile
ERC
Extreme
High
Mod
Low
Fire Danger Area:
•South Central Oregon
•Forecast Zone 624
★Chiloquin (353310) RAWS Station
Fire Danger Interpretation:
EXTREME -- Use extreme caution.
Moderate -- Watch for change, especially WIND.
Low -- Lower potential, but always be aware.
Maximum -- highest ERC by day for 1996-2001.
Average -- Shows normal seasonal TREND from 5 day running mean.
90th Percentile -- Only 10% of the days between May 1 and October 31, 1996-2001, had an ERC of 65 or above.
Local Thresholds -- Watch out: Combinations of any of these factors may greatly increase fire behavior:
Windspeed over 15 mi/h,
Relative Humidity (RH) less than 25%, Temperature over 80°F,
1000-Hr Fuel Moisture less than 15%.
Years to Remember: 1999 2001
ERC
Extreme
High
Mod
Low
Fuel Model G
Remember what Fire Danger tells you:
ERC gives general seasonal trends calculated from temperature, RH, and precipitation duration.
Windspeed is not part of the ERC calculation.
Watch local conditions and variations across the landscape--Fuel, Weather, Topography
Listen to weather forecasts--especially WIND.
Past Experience:
04 May, 2001 Hummingbird 70 ac ERC: 42
22 May, 1999 Sand Creek 31 ac ERC: 48
24 May, 1999 Bugsy 41 ac ERC: 53
06 July, 1999 Thomas 1,242 ac ERC: 59
09 July, 2001 Johnston 50 ac ERC: 69
02 Aug, 1992 Lone Pine 30,320 ac ERC: 70
03 Aug, 2001 Indian Springs 1,624 ac ERC: 59
15 Aug, 2001 Indian Sp Two 270 ac ERC: 74
Haines Index values of 5 or 6 indicate little atmospheric resistance to column development contributing to potential for large fire growth, extreme fire behavior, and plume dominated fires.

K. Adjusting Fire Behavior Calculations

In the end, any of this information can be used subjectively to alert firefighters to safety concerns.

However, if the goal is to calculate fire behavior, fuel moisture considerations can only influence the model in three ways:

1. Adjustments to dead and live fuel moisture inputs can be based on:

    - Direct measurements

    - Lookup tables or danger rating outputs

    - Subjective evaluation of drought

2. Different fuel models may be selected using an evaluation of drought conditions.

    Drought conditions can influence fire behavior by adding fuel load and transferring live loads to dead categories, resulting in greater intensity.

    Consider switching to fuel models that have a higher Moisture of Extinction and/or lower live fuel loading.

3. Consider the potential for extreme fire behavior.

    Will spotting be a problem? Can crown fire be expected? How would these be predicted? Both of these will increase growth rates and fireline safety.

There are a number of indicators of drought that provide information relevant to extreme fire behavior potential. All have strengths and weaknesses, but none accurately reflect drought under all circumstances.

There is no single drought index that can fully reflect both the short and the long-term changes in fire potential. Select the best indicator for characterizing the fire's potential today.

Introduction to Wildland Fire Behavior Calculations, S-390

Unit 5 – Fire Behavior Models

Lesson A – Non-Electronic Wildland Fire Behavior Processors

OBJECTIVE:

Upon completion of this lesson, students will be able to:

- Use Appendix B of the Fireline Handbook and Fire Behavior Nomograms to calculate rate of spread, fireline intensity, heat per unit area, and flame length.

I. INTRODUCTION

This lesson introduces two tools for predicting surface wildland fire behavior. Students will be given the tools to become proficient using Appendix B and Fire Behavior Nomograms.

We will not be using BehavePlus; however, there is a tutorial for BehavePlus that can be downloaded from: http://www.fire.org.

A. Rothermel's Surface Fire Spread Model

A mathematical model primarily intended to describe the flaming front, advancing steadily in surface fuels within six feet of, and contiguous to, the ground.

B. Assumptions/Limitations of the Surface Fire Spread Model

1. Fuels are uniform and continuous.

2. Fire is free burning, and is no longer affected by the source of ignition.

3. Severe wildland fire behavior is not predicted by the model.

4. Describes behavior at the head of the fire where fine fuels carry the fire.

C. Aids in Calculations

Several wildland fire behavior processors have been developed to aid in calculations. All are based on the same mathematical algorithms.

1. Fireline Handbook Appendix B
2. Fire Behavior Nomograms
3. BehavePlus

The various processors give slightly different numerical outputs based on their assumptions and physical methods of determining the numbers.

II. APPENDIX B OF THE FIRELINE HANDBOOK

The tables in Appendix B represent the same outputs that can be found through other wildland fire behavior processors. The mathematical models behind the numbers are the same.

A. Needed Inputs

1. Standard USFPBS Fuel Model (1 – 13).

2. Slope Class – 0%, 30%, 45%, 60%, or 90%.

3. 1-Hour Time Lag Fuel Moisture.

4. Mid-flame wind speed – the wind should be blowing within ± 30 degrees of upslope.

5. Live Fuel Moisture for those models that have that component.

In these examples, the needed inputs are given. In real life, the inputs will have to be obtained or calculated.

B. Slope

Can use the slope class that is closest to the actual recorded slope or interpolate between slope classes.

C. Live Fuel Moisture

1. Needed for Fuel Models 2, 4, 5, 7 and 10.

2. Using a range of 120% to 90% for each 1-Hour Time Lag Fuel Moisture value.

3. Note corresponding range of both Rate of Spread and Flame Length.

4. Can interpolate if warranted.

D. Outputs

1. Rate of Spread (Chains/Hour)

2. Flame Length (Feet)

3. Fireline Intensity (Btu/Foot/Second)

By using the tables, one can visualize the effect of fuel moisture, mid-flame wind speed, slope, and fuel loading (Fuel Model) on wildland fire behavior.

EXERCISE 1.

Determine what information you have and what information you need to obtain or calculate. It is OK to mark in Appendix B; it is only a tool. Document on the Fire Behavior Worksheet.

Given: FM 3, 1-Hr – 6%, LFM – None,
MFWS – 6, SLP – 0%

Outputs: Table 25
Rate of Spread – 148 Chains per hour
Flame Length – 14.9 Feet

Table 14
Fireline Intensity – 1,000+

EXERCISE 2.

Do Exercise 1 again, but increase SLP to 90%.

Outputs: Table 29
Rate of Spread – 278 Chains per hour
Flame Length – 19.9 Feet

Table 14
Fireline Intensity – 1,000+

Can see the effect of slope on effective wind speed, close to doubling the predicted rate of spread.

EXERCISE 3.

Given: FM 4, 1-Hr – 9%, LFM – 120%,
MFWS – 1, SLP – 0%,

Outputs: Table 30
Rate of Spread – 11.5 Chains per hour
Flame Length – 7.4 Feet

Table 14
Fireline Intensity – 100 - 500

EXERCISE 4.

Given: FM 2, 1-Hr – 3%, LFM – 120%,
MFWS – 4, SLP – 10% (student needs to interpolate)

Outputs: Table 20 (at 0% slope)
Rate of Spread – 28 Chains per hour
Flame Length – 6.2 Feet

Table 14
Fireline Intensity – 100 - 500

Table 20 (at 10% slope, interpolated)
Rate of Spread – 30 Chains per hour
Flame Length – 6.4 Feet

Table 14
Fireline Intensity – 100 - 500

III. NOMOGRAMS

A. What is a Nomogram?

A nomogram is a group of interconnecting graphs that can be used to solve a mathematical equation or series of equations.

The surface wildland fire behavior nomogram allows us to predict wildland fire behavior by this method.

The magic is in the nomogram itself, not in working the solution. It is a relatively simple process.

How to Predict the Spread and Intensity of Forest and Range Fires (NFES 1573) is an excellent reference on working nomograms (pages 43 – 49).

B. Needed Inputs

1. Standard USFBPS Fuel Model (1 – 13).
2. Mid-flame windspeed – the wind should be flowing within ± 30 degrees of upslope.
3. Fine Dead Fuel Moisture (1-Hr Time-lag).
4. Live fuel moisture, if needed for that particular fuel model.
5. Maximum slope.

C. Outputs

1. Effective windspeed (mph).

2. Heat per Unit Area (BTU/Ft²).

3. Rate of Spread (Chains/Hour).

4. Fireline Intensity (BTU/Second/Ft).

5. Flame Length (Feet).

D. Low Windspeed/High Windspeed Versions

There are two nomograms for each of the 13 USFBPS Fuel Models: a low windspeed version and a high windspeed version.

Both give the same answers, but better resolution can be obtained from the low windspeed version, so it should be used whenever possible.

E. Nomogram Parts

The nomogram consists of four primary parts (quadrants) named for their relative position on the nomogram:

- Upper left
- Upper right
- Lower left
- Lower right

Note that there is a ¼-inch grid underlying the nomogram. This enables the lines to be kept straight (parallel with grid) and to easily determine right-angled turns inside each quadrant.

After initial preparation, a continuous line is drawn in a clockwise direction, starting and finishing in the upper right quadrant.

In each quadrant the line makes a right-angled turn at a determined point. Upon reentering the upper right quadrant, all output values will have been identified.

A clear plastic ruler allows the grid to be seen as the lines are drawn. It is important to keep the drawn lines straight but do not be concerned with exact values in this course.

IV. NOMOGRAMS WITH ONLY DEAD FUEL MOISTURE

The following scenario illustrates the necessary steps to predict wildland fire behavior, using a fuel model with only fine dead fuel moisture (no live fuel moisture component).

A. Scenario 1 Inputs:

- Short, dry grass (FM 1)
- Slope – 40%
- MFWS – 3 mph
- Fine Dead Fuel Moisture – 4%

Use of the “Fire Behavior Worksheet” will facilitate keeping track of the input and output values as you proceed through the nomograms.

Copy the necessary input values from the scenario to a worksheet.

Next, select the correct nomogram. Always start with the low windspeed nomogram unless it is apparent that the effective windspeed range you need is not included in the lower right quadrant.

Work on a flat surface.

The next seven steps are used for all nomograms for fuel models that do not use live fuel moisture as part of the calculation (1, 3, 6, 8, 9, 11, 12, and 13).

1. Step 1. Determine Effective Windspeed.

   In the lower left quadrant, find the percent slope and draw a vertical line to the top of the quadrant.

   Find the midflame windspeed on the right-hand side of the same quadrant. If the midflame windspeed lies between the indexed values on the edge (as they do in our situation), make an approximation of the location.

   Follow the curved line down to the left until it intersects the vertical slope line you have drawn. For approximated values, you will have to establish that curved line.

   From this intersection, draw a horizontal line to the left side of the lower left quadrant and read the effective windspeed.

   Record the effective windspeed on the worksheet.

   Effective windspeed for this example is a little over 4 mi/h. Once this value has been determined, the construction lines drawn in the lower left quadrant will not be used again.

2. Step 2. Prepare Lower Right Quadrant.

   Locate the line which represents the effective windspeed determined in the first step.

   A line may need to be drawn approximating the effective windspeed value if it does not appear along the outside edge of the lower right quadrant.

In most cases, it will need to be drawn. This line will be a turning point in the continuous line drawn around the nomogram.

Notice the dashed, or “high wind limit line” in this quadrant. The note reads:

Wind-driven fires of low intensity may behave erratically. If vertical line from chart above intersect effective windspeed line to the left of the dashed line, rate of spread and fireline intensity may be overstated.

When you intersect this dashed line before reaching the effective windspeed line, stop at the intersection with the dashed line, and use that as your turning point.

3. Step 3. Prepare the Upper Left Quadrant.

Prior to reaching its ignition point, the fuel requires heat to drive off moisture. This step takes into account a portion of the heat energy reduction (called heat sink).

Fuel models with dead fuels only require that we find, or approximate, a line in the upper left quadrant for the fine dead fuel moisture.

If an approximation is needed, start drawing the line in the lower right corner of this quadrant and estimate where the moisture value lays in relationship to the indexed values along the edge.

This fuel moisture line in the upper left quadrant will serve as another turning point for the continuous line about to be drawn.

All preparations have now been made, and we can begin our run around the nomogram.

4. Step 4. Begin Continuous Line and Determining Heat Per Unit Area.

Begin the continuous line which will calculate wildland fire behavior outputs.

Starting in the upper right quadrant, draw a horizontal line from our fine dead fuel moisture content, intersecting the S-shaped curve in that quadrant.

This curved line is sometimes called the “moisture dampening curve.”

Where this curve intersects the lower left-hand corner of the quadrant, the Rate of Spread and Heat Per Unit Area are zero.

Note that the value of the Dead Fuel Moisture is the moisture of extinction for that fuel model.

At this intersection, turn a right angle and draw a vertical line up to the top of the quadrant and down into the lower right quadrant, stopping at the effective windspeed line identified in Step 2.

Notice that as the line exited the bottom of the upper right quadrant, a wildland fire behavior output was obtained.

Heat Per Unit Area is the total amount of heat released in each square foot of the flaming fire front, expressed as Btu per square foot.

All of the heat given off in the flaming front is included in this value, regardless of the length of time that the flaming front persists.

For a given area with a specific amount and distribution of fuel (fuel model), heat per unit area is inversely related to fuel moisture content.

Heat released in flaming combustion that occurs as fuels burn out after the flaming front has passed is not included in the heat per unit area value.

The intersection in the lower right quadrant is determining how much of the energy is being transferred by wind and/or slope to the fuels ahead.

5. Step 5. On to the Lower Left Quadrant.

From the effective windspeed intersection in the previous step, draw a horizontal line to the diagonal line in the lower left quadrant.

All that is being accomplished in this step is changing direction for the return into the upper quadrants. Pay no attention to the previously constructed lines from Step 1.

6. Step 6. Accounting for the Heat Sink Effect of Fuel Moisture.

Draw a vertical line into the upper left quadrant to the intersection of the fine dead fuel moisture ray identified or drawn in Step 3.

Notice that as fuel moisture increases the rays move lower in the quadrant thereby moving this turning point lower in the quadrant.

7. Step 7. Completion.

Draw a horizontal line from the intersection in Step 6, to the right and intersecting the vertical line constructed in Step 4, inside the upper right quadrant. Draw a small circle at this intercept.

We have drawn our line through all four quadrants, filled in all inputs, and are ready to read the remaining outputs.

Rate of Spread is read at the left hand edge of the upper right quadrant where the horizontal line from Step 7 enters the quadrant.

Notice that if a higher fuel moisture had been used, the turning point in the upper left quadrant would have been lower in the quadrant resulting in a lower rate of spread.

Record rate of spread on the worksheet.

Fireline Intensity is read from the numbers embedded in the curved rays in the upper right quadrant.

Find the small circle that you drew in Step 7 and estimate the fireline intensity by the location of your circle to the nearest curved rays.

Record fireline intensity on the worksheet.

Flame Length is read as follows: Find the small circle in the upper right quadrant that you drew in Step 7. Follow the curved ray that lies nearest your circle to the top of the quadrant. Flame lengths are read to the nearest foot at the top of the quadrant.

Record flame length on the worksheet.

With Flame Length and Fireline Intensity both being on the same curved line in the upper right hand quadrant, you can deduce that there is a mathematical relationship between the two values.

Fireline intensity and its related flame length are the best indicators of the fire’s destructive force and resistance to control.

B. Scenario 1 Outputs:

- Heat per Unit Area – 95 Btu/Ft^2
- Rate of Spread – ≈72 Chains/Hour
- Fireline Intensity – 110 Btu/Second/Ft
- Flame Length – 4+ Feet

It is important to always use your experience to check the outputs. This will allow you to begin to gain confidence in the nomogram as well as become sensitive to the various input factors.

V. CALCULATIONS FOR MODELS THAT HAVE A LIVE FUEL COMPONENT

A. Scenario 2 Inputs:

- Timber with litter and understory (FM 10)
- Slope – 20%
- MFWS – 3 mph
- Fine Dead Fuel Moisture – 4%
- Live Fuel Moisture – 150% (new foliage is almost mature and comparable to older foliage)

Find the correct nomogram and remember to use the worksheet to record your inputs and outputs.

You should have selected the low windspeed nomogram for Fuel Model 10.

It will take seven separate steps to tour through the nomogram. The addition of the live fuel moisture to the calculation will change Steps 3 and 4 a little. The remainder of the steps is the same as for the dead fuel only models.

These seven steps will remain the same for all fuel models that use live fuel moisture as part of the calculation (Fuel Models 2, 4, 5, 7, and 10).

Steps 1 and 2 are the same as for a dead fuel nomogram calculation.

1. Step 1. Determine Effective Windspeed.

   Go to the lower left quadrant and enter the slope and midflame windspeed and read the effective windspeed along the left hand margin.

   The effective windspeed for this example is about 3.5 mi/h. Record effective windspeed on the worksheet.

2. Step 2. Prepare Lower Right Quadrant.

   Identify by writing the effective windspeed if needed on the right axis of the quadrant. Circle the effective windspeed value.

   Draw a new ray for the effective windspeed calculated in Step 1.

   Remember that the dashed line in this quadrant indicates the limiting windspeed at which point a faster wind does not necessarily imply faster spread rates.

   This windspeed limit varies with fuel model and fuel moisture.

3. Step 3. Prepare the Upper Quadrants.

Fuel models with both live and dead fuels require a horizontal line to be drawn.

Locate the fine dead fuel moisture values on the outer axis of both upper quadrants. Draw a horizontal line across both quadrants.

From where this horizontal line intersects the live fuel moisture curve in the upper left quadrant draw a straight line to the lower right corner of that same quadrant. This line is referred to as the "K" line.

A number of live fuel moisture curves will not be curved much, consequently, the line you draw will not vary much from the live fuel moisture curve that was already there.

Note that the dash-dot patterns in the upper right quadrant representing live fuel moisture are patterned the same in the upper left quadrant.

Note: It is possible that the horizontal line you have just constructed does not intersect the correct live fuel moisture curve. In this case, the live fuel moisture line should be extended in approximately the same arc until it intersects the fine dead fuel line.

Then proceed drawing your line from this intersection to the lower right corner of the quadrant even if the fine dead line intersects the live line to the left of the quadrant.

This becomes critically important when dealing with nomograms having greater curve in the live fuel lines (Fuel Model 5 and 7).

Later, when calculating with the nomograms, the intersection of the continuous line with the angled “K” line that was constructed in this step will indicate where the continuous line will take the right turn in this quadrant.

4. Step 4. Determining the Heat Energy Output.

Begin the continuous line that will calculate the fire characteristics desired.

Locate in the upper right quadrant the point where the fine dead fuel moisture line you drew in Step 3 intersects the appropriate live fuel moisture curve. The live fuel moisture for our situation is 150 percent.

From this point draw a vertical line into the lower right quadrant to intersect the correct effective windspeed ray. Remember to stop if you hit the wind limit (dashed) line.

5. Step 5. On to the Lower Left Quadrant.

From the effective windspeed intersection in the previous step, draw a horizontal line to the diagonal line in the lower left quadrant.

Again, pay no attention to the previously constructed lines from Step 1.

6. Step 6. Accounting for the Heat Sink Effect of Moist Fuels.

From the intersection in the lower left quadrant, draw a vertical line into the upper left quadrant intersecting the “K” line drawn in Step 3.

7. Step 7. Completion.

Draw a horizontal line, from the intersection in Step 6, to the right and intersecting the vertical line constructed in Step 4 inside the upper right quadrant.

Now the nomogram is complete!

We have completed the tour of the nomogram using the appropriate inputs and it's time to read the outputs.

Rate of Spread is read from the left edge of the upper right quadrant at the point intersected by the line drawn in Step 7.

Record the rate of spread on the worksheet.

Flame Length is read the same as for dead fuel only models. Locate the curved ray in the upper right quadrant nearest the point you circled in step seven. Follow that ray to the top of the page and record the flame length to the nearest foot on the worksheet.

Fireline Intensity is read from this same point by estimating its distance from the nearest curved lines. Fireline intensity values are associated with the curved lines.

Record fireline intensity on the worksheet.

Heat Per Unit Area is read at the lower margin of the upper right quadrant where the line constructed in Step 4 exits. Record heat per unit area on the worksheet.

B. Scenario 2 Outputs:

- Heat per Unit Area – 1,450 Btu/Ft^2
- Rate of Spread – 4.5 Chains/Hr
- Fireline Intensity – 95 Btu/Second/Ft
- Flame Length – ≈ 4 Feet

NOMOGRAM EXERCISE #1.

Complete the exercise on slide 44. You may refer to your workbook or "How to Predict the Spread and Intensity of Forest and Range Fires" for guidance.

NOMOGRAM EXERCISE #2.

Complete the exercise on slide 46. You may refer to your workbook or "How to Predict the Spread and Intensity of Forest and Range Fires" for guidance.

5A.22

Introduction to Wildland Fire Behavior Calculations, S-390

Unit 5 – Fire Behavior Models

Lesson B – Spotting Model

OBJECTIVE:

Upon completion of this lesson, students will be able to:

1. Define the spotting model.

2. Identify the inputs needed for probability of ignition calculations.

3. Calculate the probability of ignition.

4. Identify the limitations, assumptions, and inputs needed for maximum spotting distance.

5. Calculate the maximum spotting distance.

I. DEFINE THE SPOTTING MODEL

A wildland fire is said to be spotting when it produces sparks or embers that are carried by the wind and start new fires beyond the zone of direct ignition by the main fire.

A. Methods for Estimating Severity of the Spotting Problem

1. Probability of ignition.

2. Spotting distance.

B. Factors Related to the Spotting Problem

1. Probability of production of firebrands.

2. Windspeed

3. Fire intensity.

4. Number of firebrands.

5. Type of firebrands.

6. Fuel that is receptive to ignition.

7. Weather and fuel conditions favorable for fire spread.

C. Probability of Ignition

1. Definition, assumptions, and use.

   a. Probability of ignition is the chance that a firebrand will cause an ignition when it lands on receptive fuels.

   b. Values from 0 to 100.

   c. Assumes that the right kind of firebrand lands on the right kind of fuel.

   d. If probability of ignition is 80, then 80% of the number of “appropriate” firebrands that land on “receptive” fuel will result in ignition.

2. Probability of ignition is calculated for the point of ignition from:

   a. 1-hour dead fuel moisture.

   b. Air temperature.

   c. Fuel shading.

3. Use the chart found in the Appendix B of the Fireline Handbook.

   a. Shading of the fuels due to cloud cover or canopy cover.

   b. Dry bulb temperature in degrees Fahrenheit.

   c. 1-hour timelag fuel moisture percent.

II. CALCULATE THE MAXIMUM SPOTTING DISTANCE

A. Concept of Optimum Firebrand Size

1. Large enough to sustain fire for a time, yet small and light enough to be lofted high into the air.

2. Aerodynamic shape aids in downwind transport.

B. Firebrand Source Affects Spotting Distance

1. Source strength affects maximum lofting height. Convection column strength directly affects the lofting height.

2. Source character affects trajectory of firebrand.

   Torching trees loft firebrands from the top of the tree, providing additional altitude prior to downwind transport.

C. Nomograms Predict Maximum Spotting Distance

1. If a fire produces 80 spots within 2 chains of the fireline and one spot a mile away, the nomogram will predict "one mile."

2. Nomograms were developed for conditions of intermediate fire severity in which spotting distances up to a mile or two might be encountered. Spotting for short distances of tens of yards is not considered.

3. Other situations not considered are those extreme cases in which spotting may occur up to tens of miles from the main front as in:

   - Running crown fires.
   - Fires in heavy slash or chaparral under extreme winds.
   - Fires in which firewhirls loft burning material high into the air.
   - Multiple torching trees.

4. The spotting distance model does not include:

   - The likelihood of firebrand production.
   - Availability of optimum firebrand material.
   - The probability of spot fire ignition.
   - The number of spot fires.

D. Spotting Distance Nomograms

1. Required information

   - Torching tree height, in feet.
   - Torching tree species.
   - Torching tree diameter at breast height (DBH is commonly measured at about 4 feet above the surface), in inches.
   - Average treetop height where the firebrand may fall, in feet.
   - Windspeed at 20-foot height, in miles per hour.

2. Assumptions

   - Level terrain.
   - Firebrand source is a single torching tree.
   - The firebrand will be transported over uniform forest terrain.
   - The torching tree species is from the Intermountain West.

3. The mean treetop height is intended to characterize the general forest cover of the terrain as it influences the wind field that will transport a firebrand.

   If the area has broken forest cover, use half the treetop height of the forest-covered portion.

SPOTTING WORKSHEET EXERCISE.

Refer to the spotting worksheet on page 5B.11. Fill in the input information:

- Torching tree height = 150 feet
- Torching tree species = grand fir
- Torching tree DBH = 20 inches
- Average tree cover height = 130 feet
- Windspeed at 20-foot height = 20 mph

NOMOGRAM #1 INSTRUCTIONS

- On nomogram #l, find 20 inches DBH on the horizontal axis.
- Go up until you hit the line for grand fir; the top diagonal dashed line.
- Go to the left to find flame height on the vertical axis.
- Write the flame height (77) on the worksheet in the appropriate box.
- Just to the right of that box a calculation has to be completed. Divide box A by box B. Write in that number as shown (1.9).

NOMOGRAM #2 INSTRUCTIONS

- On nomogram #2, find 20 inch DBH on the horizontal axis.
- Go up until you hit the GF line; the middle line.
- Go to the left to find flame duration on the vertical axis.
- Write the flame duration (4.6) on the worksheet.

NOMOGRAM #3 INSTRUCTIONS

- On nomogram #3, find flame duration of 4.6 on the horizontal axis.
- Since the ratio of tree height to flame height is 1.9, move up to the "More than 1.5" line.
- Move to the left to find the ratio of lofted firebrand height to flame height on the vertical axis.
- Write the answer (7.1) on the worksheet on line (C).
- Divide the value on line (A) by 2.
- Write the answer (150/2 = 75) on line (D). This number represents the average height above the ground that a firebrand will start its upward flight.
- Multiply the value on line (B) by the value on line (C). Write the answer (77 X 7.1 = 547) on line (E). This value represents height above the tree to which a firebrand will be lofted.
- Add the values on lines (D) and (E).
- Write the answer (547 + 75 = 622) on the worksheet. The sum of these two values is the expected height above the ground that a firebrand will be lofted. This completes the ascension phase of the model. Now, how far will this firebrand travel downwind before landing?
- If the forest is open, divide average tree cover height by 2 and enter effective height; if not, enter the average of the cover height. For this example, we will assume that the forest has a closed canopy. Enter 130 for effective tree cover height.
- Multiply the windspeed of 20 feet on line (F) by 2/3. Use the maximum expected windspeed as you are trying to predict the maximum spotting distance. Also, the highest likelihood that severe fire behavior will occur resulting in the creation of firebrands is when the wind is at maximum speed.
- Write the answer (20 X 2/3 = 13) on the worksheet.

NOMOGRAM #4 INSTRUCTIONS

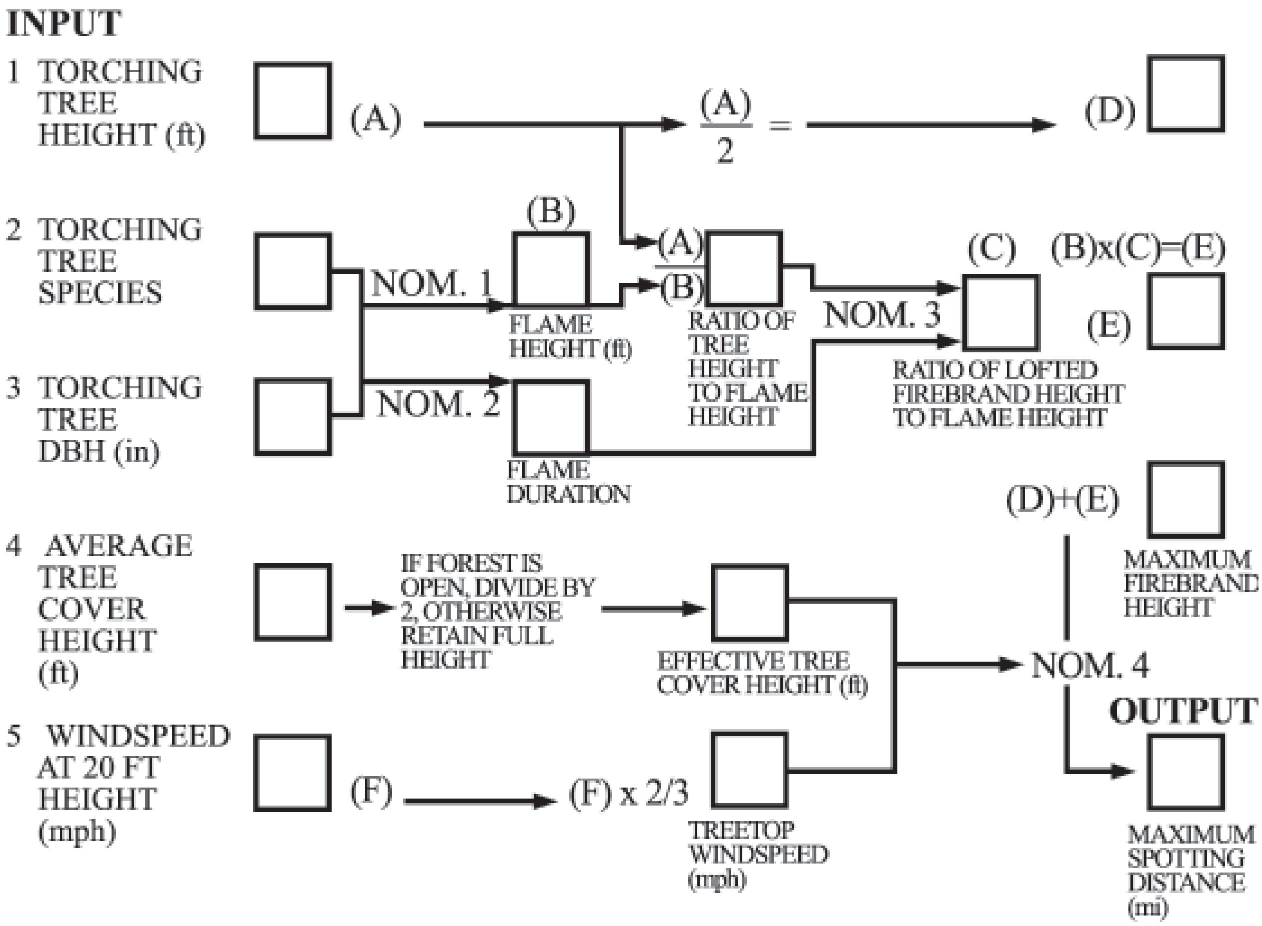
- On nomogram #4, find the Maximum Firebrand Height of 622, on the right portion of the horizontal axis.
- Go up to the effective tree cover height of 130. Interpolate between 100 and 200.
- Go to the left to the treetop windspeed of Interpolate between 10 and 15.
- Go down to find the maximum spotting distance of 0.36 mile.
- Enter that number in the box on the worksheet.

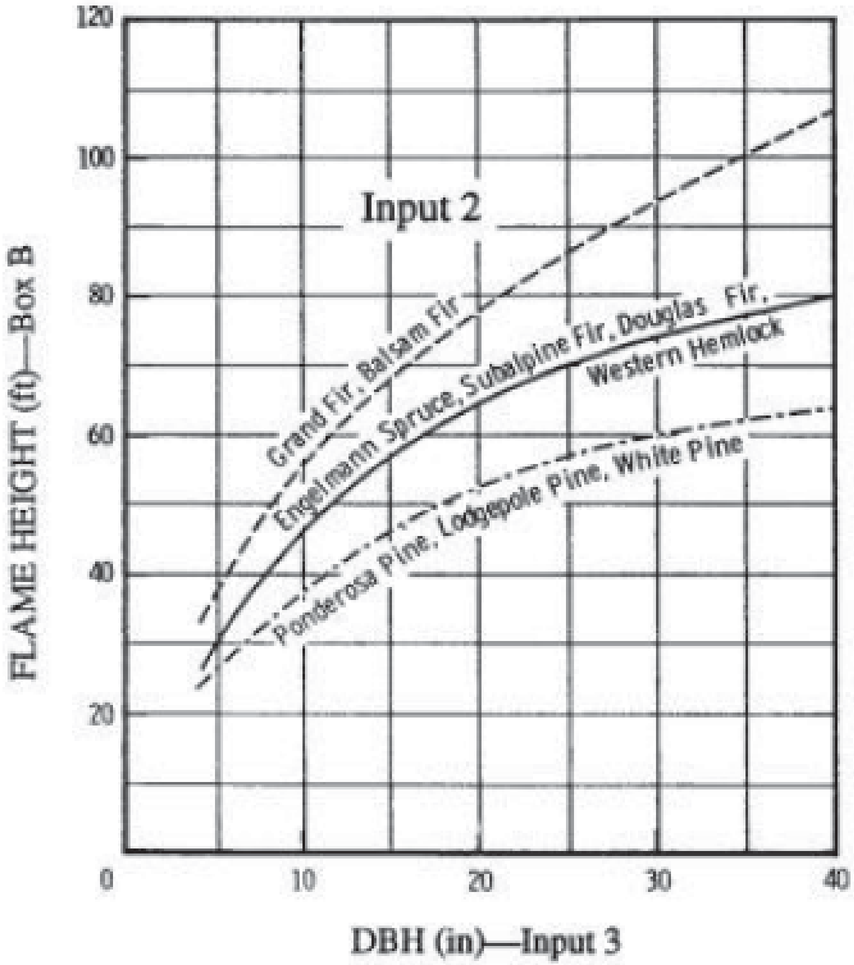
EXERCISE:

Refer to pages 5B.15 - 5B.29 to complete problems 1-4. Use the following inputs:

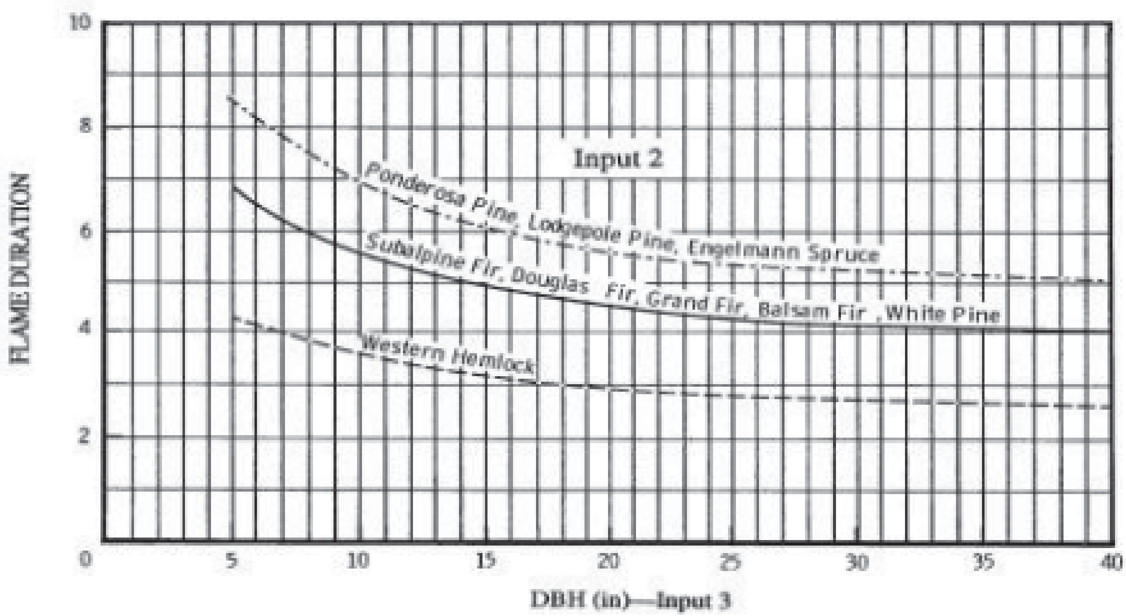
	Problem 1 Nomogram	Problem 2 Nomogram	Problem 3 Nomogram	Problem 4 Nomogram
Average Tree Cover Height	110	96	120	100
Open/Closed	Open	Open	Closed	Closed
Windspeed at 20 FT Height	10-20	24	12	16
Torching Tree Species	Doug Fir	Grand Fir	Pond Pine	Lodge Pole
Torching Tree D.B.H. (IN)	40	35	30	24
Torching Tree Height (FT)	120	100	80	95

SPOTTING WORKSHEET EXERCISE

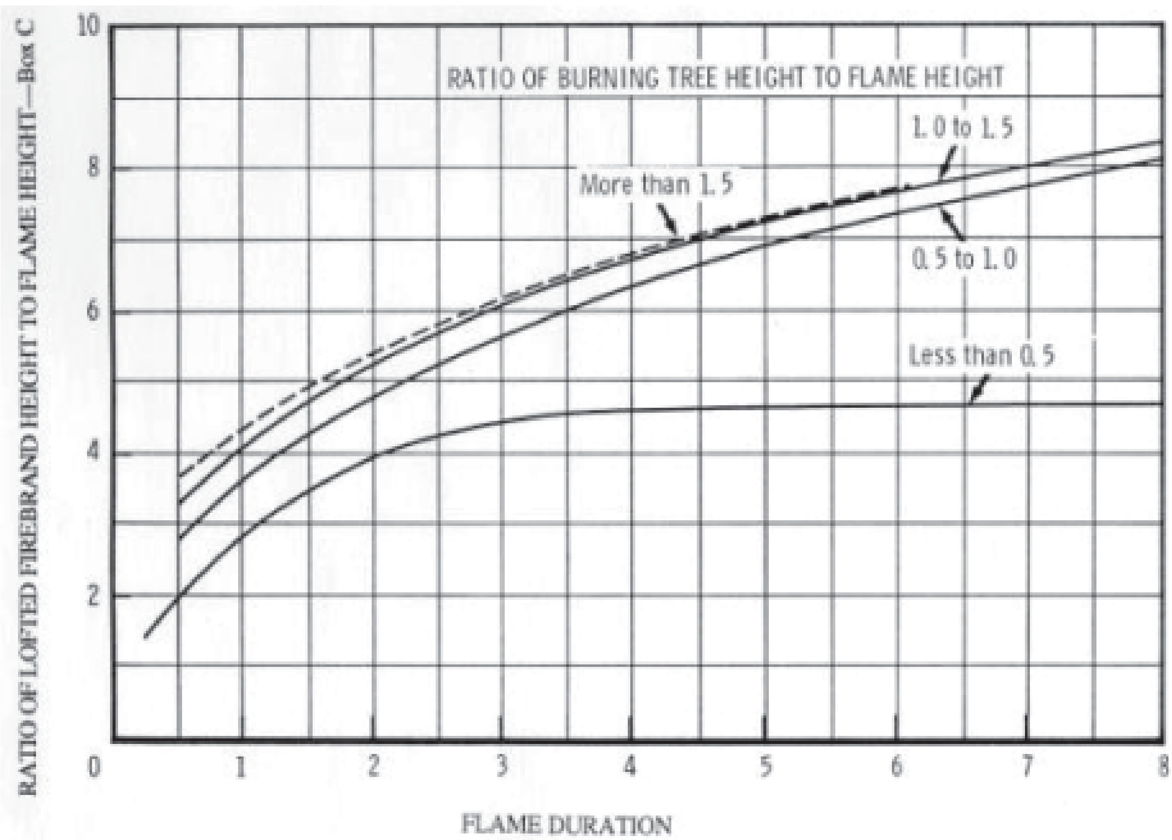


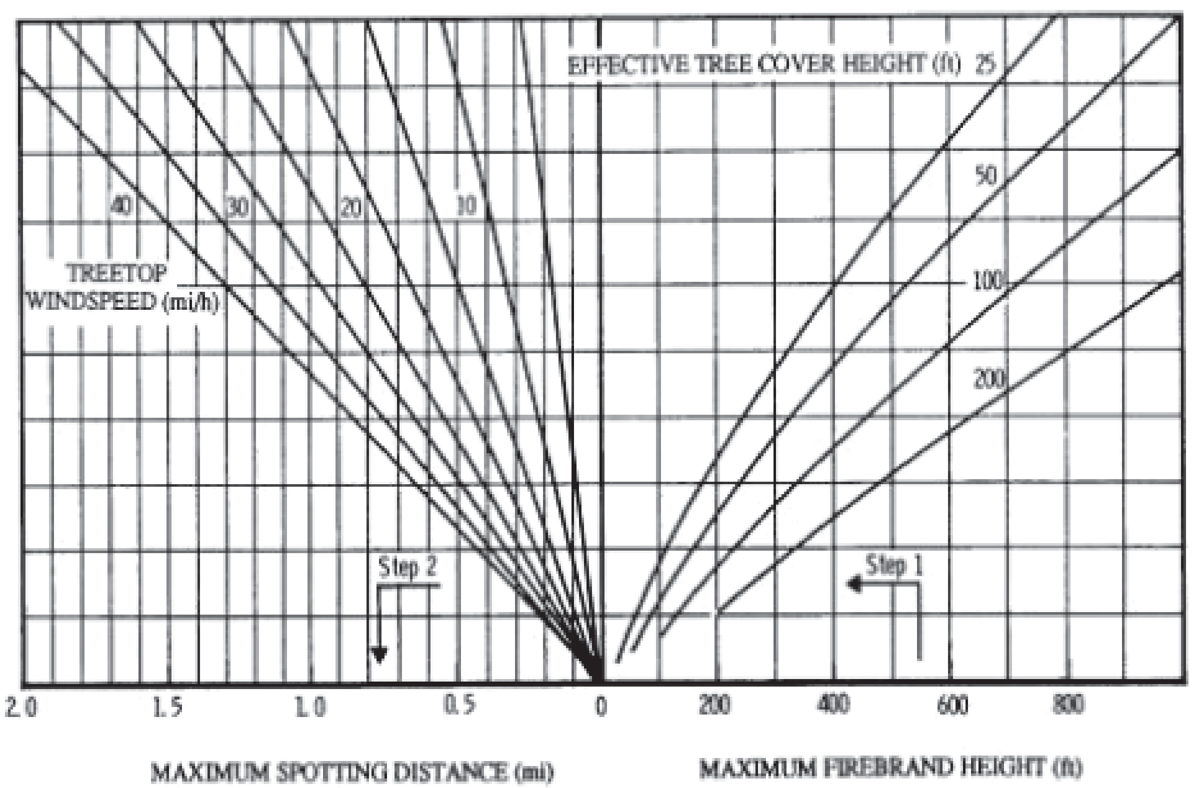


Input 2
Grand Fir, Balsam Fir
Engelmann Spruce, Subalpine Fir, Douglas Fir,
Western Hemlock
Ponderosa Pine, Lodgepole Pine, White Pine
FLAME HEIGHT (ft)—Box B
DBH (in)—Input 3
120
100
80
60
40
20
0
10
20
30
40

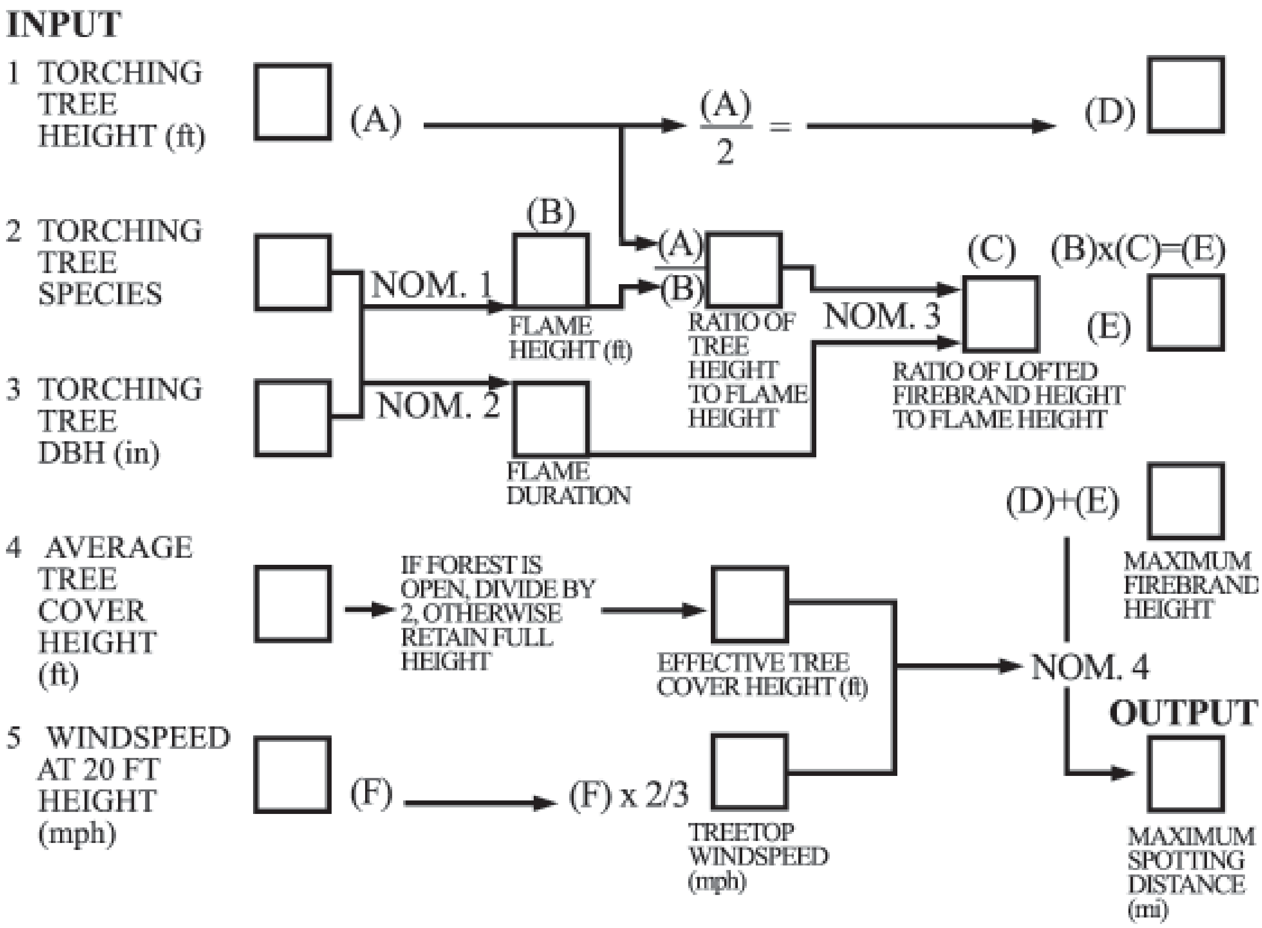


Input 2
Ponderosa Pine, Lodgepole Pine, Engelmann Spruce
Subalpine Fir, Douglas Fir, Grand Fir, Balsam Fir , White Pine
Western Hemlock
FLAME DURATION
DBH (in)—Input 3
10
8
6
4
2
0
5
10
15
20
25
30
35
40

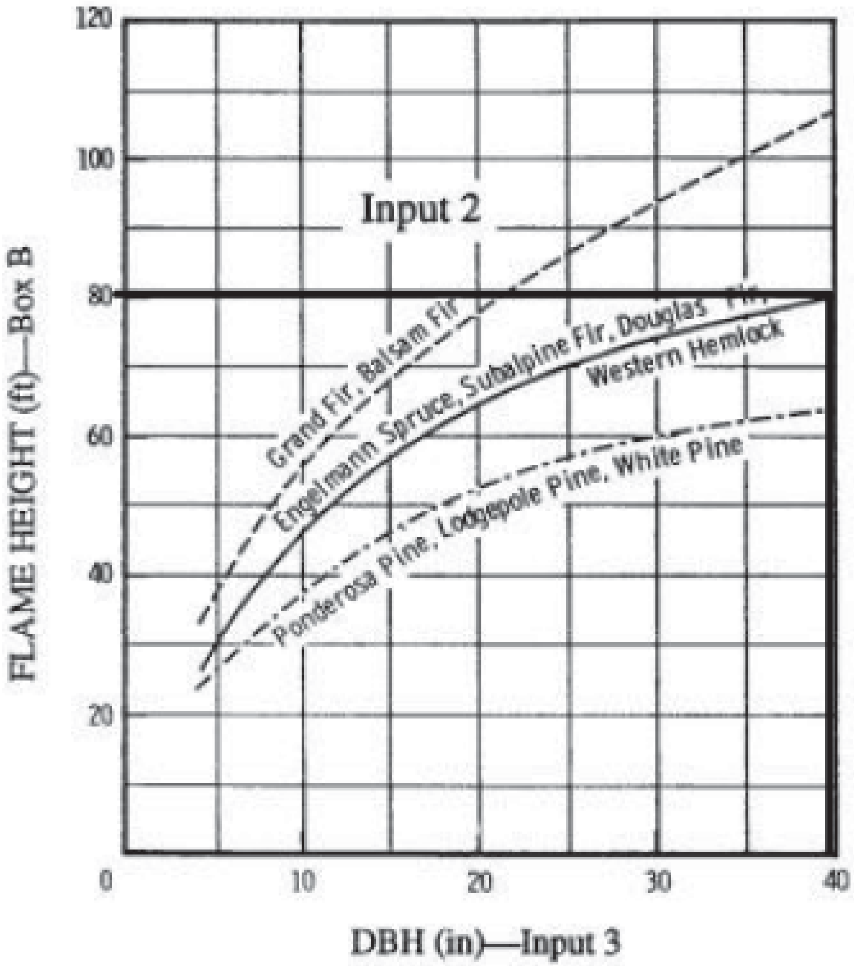

RATIO OF LOFTED FIREBRAND HEIGHT TO FLAME HEIGHT—Box C
RATIO OF BURNING TREE HEIGHT TO FLAME HEIGHT
1.0 to 1.5
More than 1.5
0.5 to 1.0
Less than 0.5
FLAME DURATION

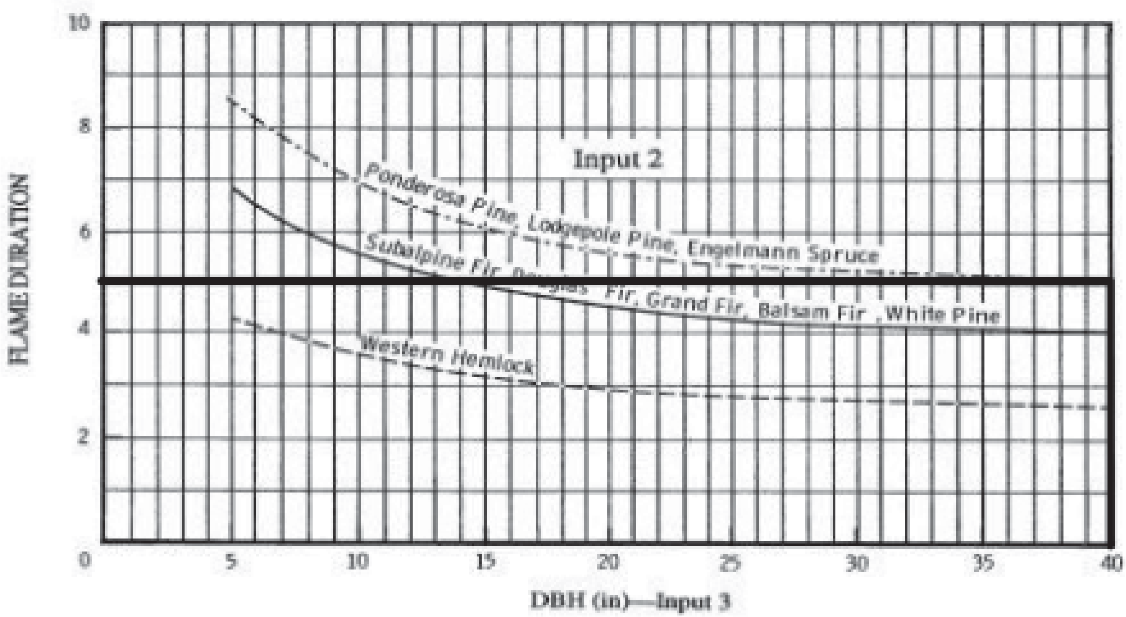

EFFECTIVE TREE COVER HEIGHT (ft)
25
50
100
200
40
30
20
10
TREETOP WINDSPEED (mi/h)
Step 2
Step 1
MAXIMUM SPOTTING DISTANCE (mi)
MAXIMUM FIREBRAND HEIGHT (ft)

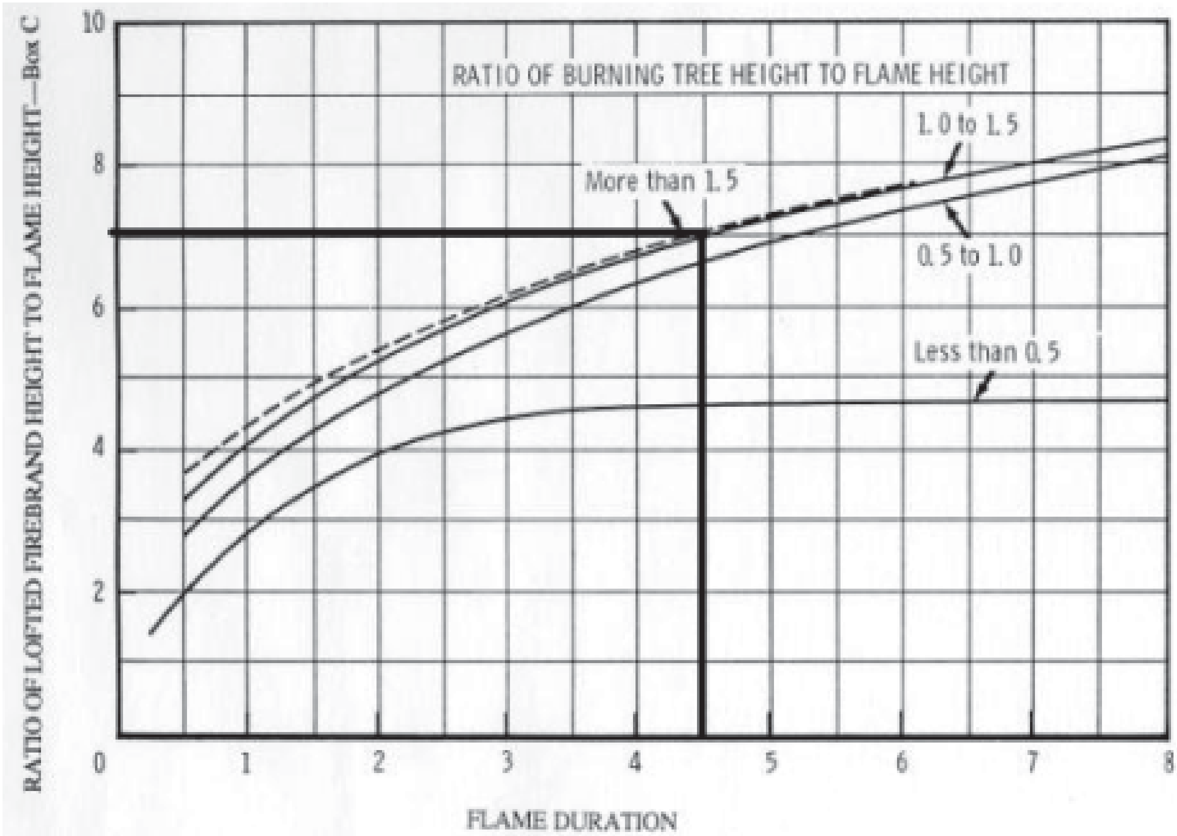
PROBLEM 1

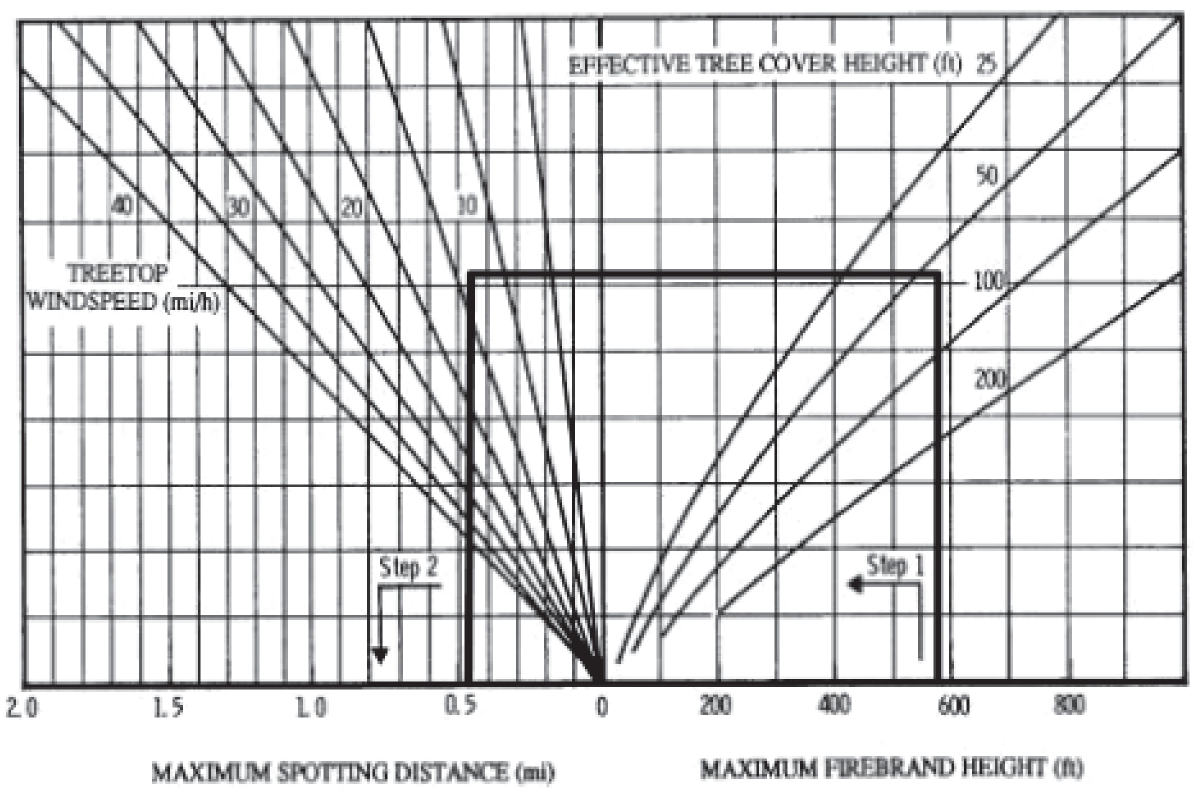


INPUT
1 TORCHING TREE HEIGHT (ft)
(A)
(A)/2 =
(D)
2 TORCHING TREE SPECIES
(B)
NOM. 1
FLAME HEIGHT (ft)
(A)/(B)
RATIO OF TREE HEIGHT TO FLAME HEIGHT
NOM. 3
(C)
(B)x(C)=(E)
(E)
RATIO OF LOFTED FIREBRAND HEIGHT TO FLAME HEIGHT
3 TORCHING TREE DBH (in)
NOM. 2
FLAME DURATION
(D)+(E)
MAXIMUM FIREBRAND HEIGHT
4 AVERAGE TREE COVER HEIGHT (ft)
IF FOREST IS OPEN, DIVIDE BY 2, OTHERWISE RETAIN FULL HEIGHT
EFFECTIVE TREE COVER HEIGHT (ft)
NOM. 4
OUTPUT
5 WINDSPEED AT 20 FT HEIGHT (mph)
(F)
(F) x 2/3
TREETOP WINDSPEED (mph)
MAXIMUM SPOTTING DISTANCE (mi)

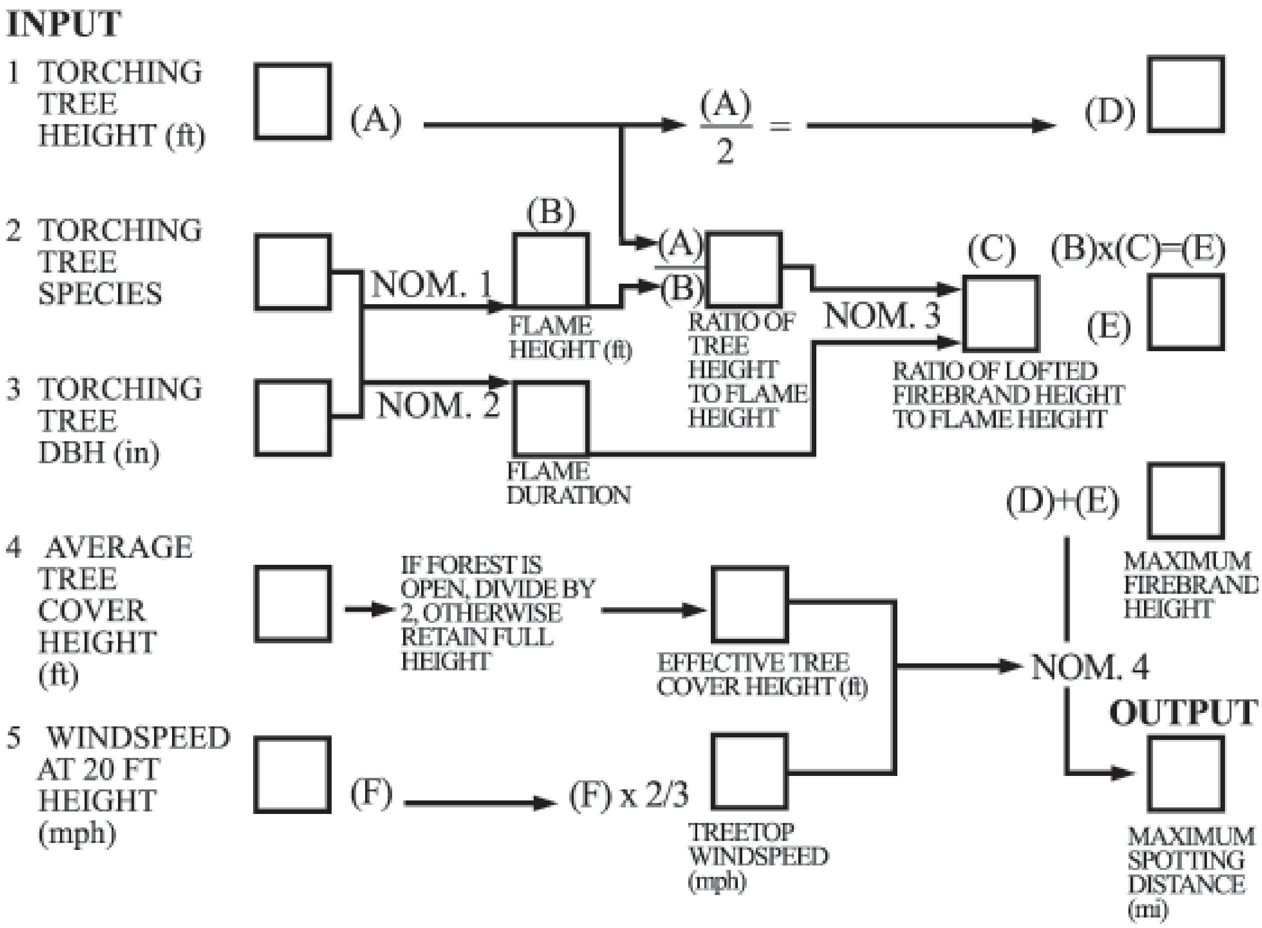

Input 2
FLAME HEIGHT (ft)—Box B
DBH (in)—Input 3
Grand Fir, Balsam Fir
Engelmann Spruce, Subalpine Fir, Douglas Fir, Western Hemlock
Ponderosa Pine, Lodgepole Pine, White Pine


Input 2
FLAME DURATION
DBH (in)—Input 3
Ponderosa Pine, Lodgepole Pine, Engelmann Spruce
Subalpine Fir, Douglas Fir, Grand Fir, Balsam Fir , White Pine
Western Hemlock

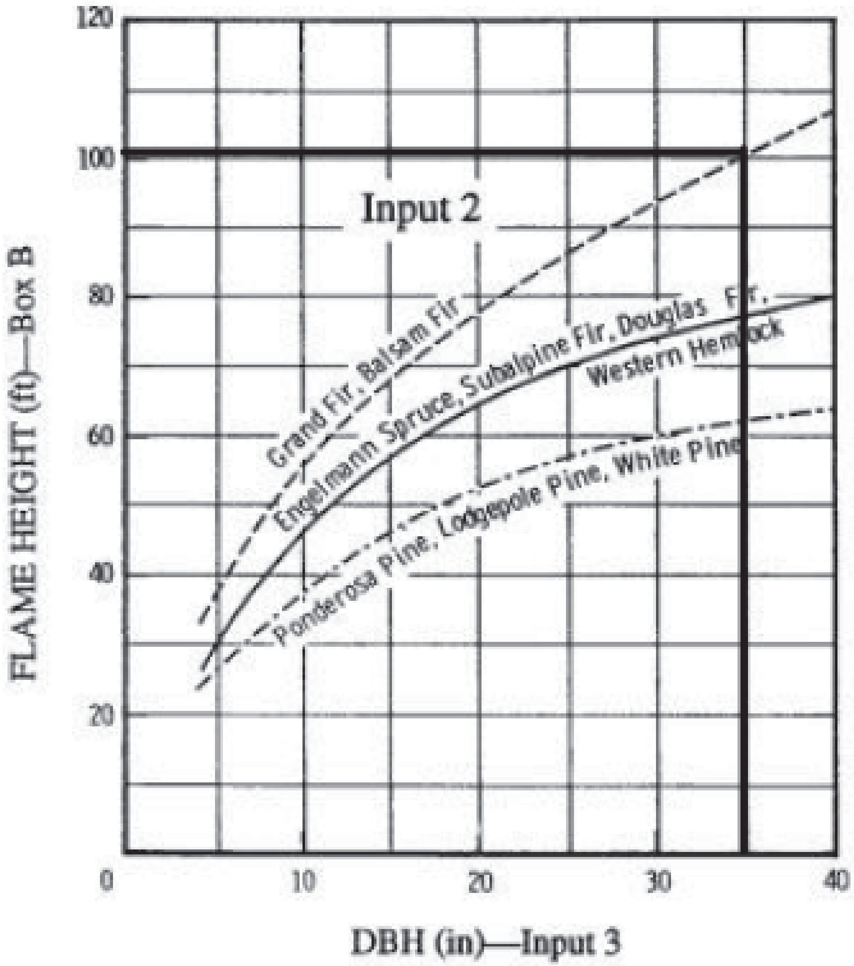

RATIO OF BURNING TREE HEIGHT TO FLAME HEIGHT
1.0 to 1.5
More than 1.5
0.5 to 1.0
Less than 0.5
RATIO OF LOFTED FIREBRAND HEIGHT TO FLAME HEIGHT—Box C
FLAME DURATION
0
1
2
3
4
5
6
7
8
10
8
6
4
2


EFFECTIVE TREE COVER HEIGHT (ft) 25
50
100
200
40
30
20
10
TREETOP
WINDSPEED (mi/h)
Step 2
Step 1
2.0
1.5
1.0
0.5
0
200
400
600
800
MAXIMUM SPOTTING DISTANCE (mi)
MAXIMUM FIREBRAND HEIGHT (ft)

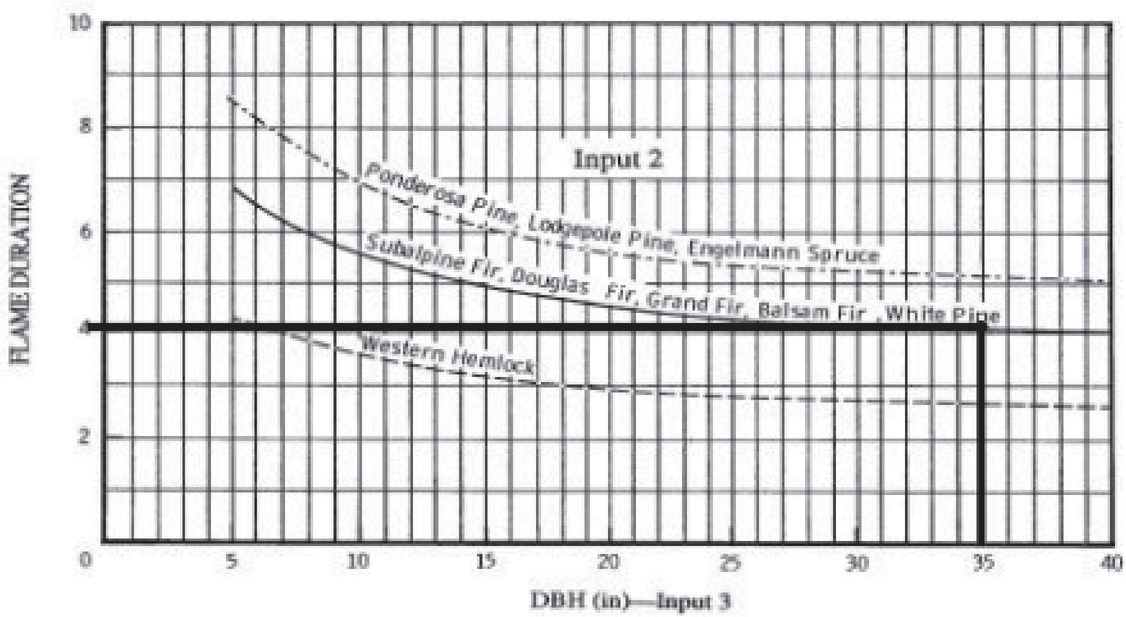
PROBLEM 2



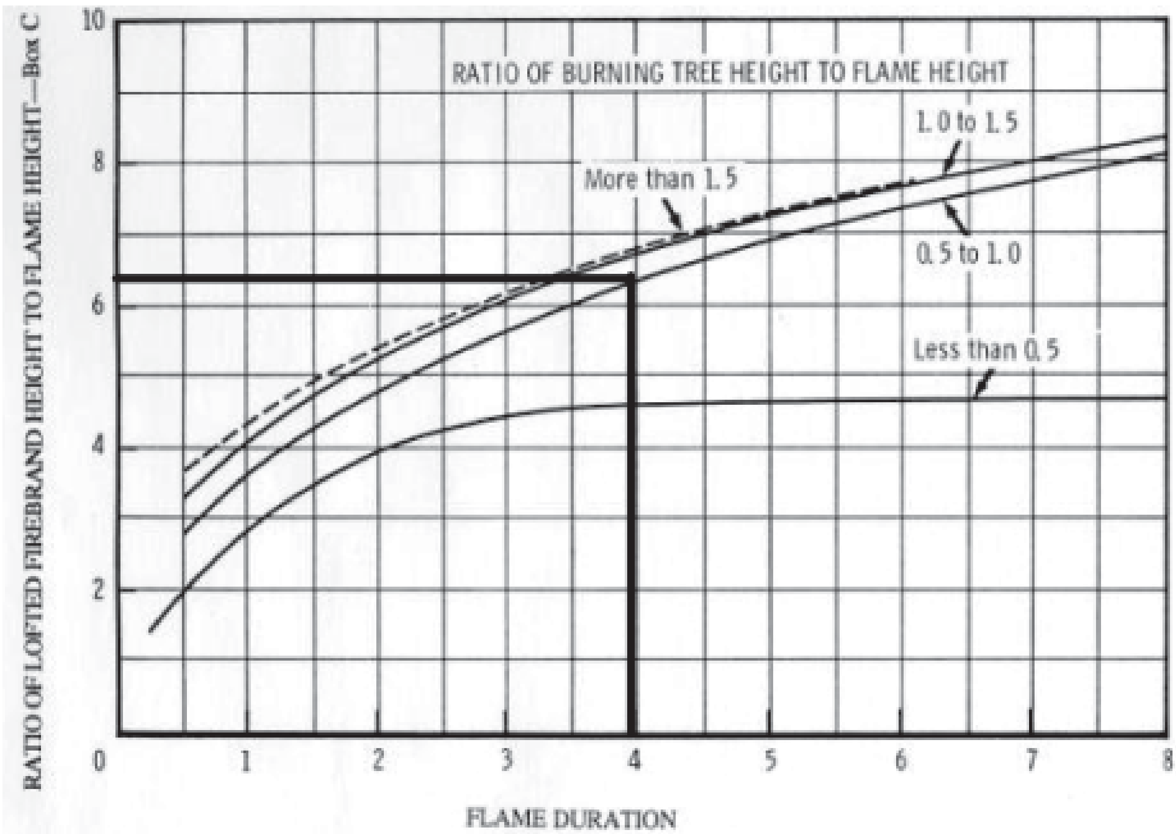
INPUT
1 TORCHING TREE HEIGHT (ft)
(A)
(A)/2 =
(D)
2 TORCHING TREE SPECIES
NOM. 1
(B)
FLAME HEIGHT (ft)
(A)/(B)
RATIO OF TREE HEIGHT TO FLAME HEIGHT
NOM. 3
(C)
(B)x(C)=(E)
(E)
RATIO OF LOFTED FIREBRAND HEIGHT TO FLAME HEIGHT
3 TORCHING TREE DBH (in)
NOM. 2
FLAME DURATION
(D)+(E)
MAXIMUM FIREBRAND HEIGHT
4 AVERAGE TREE COVER HEIGHT (ft)
IF FOREST IS OPEN, DIVIDE BY 2, OTHERWISE RETAIN FULL HEIGHT
EFFECTIVE TREE COVER HEIGHT (ft)
NOM. 4
OUTPUT
5 WINDSPEED AT 20 FT HEIGHT (mph)
(F)
(F) x 2/3
TREETOP WINDSPEED (mph)
MAXIMUM SPOTTING DISTANCE (mi)

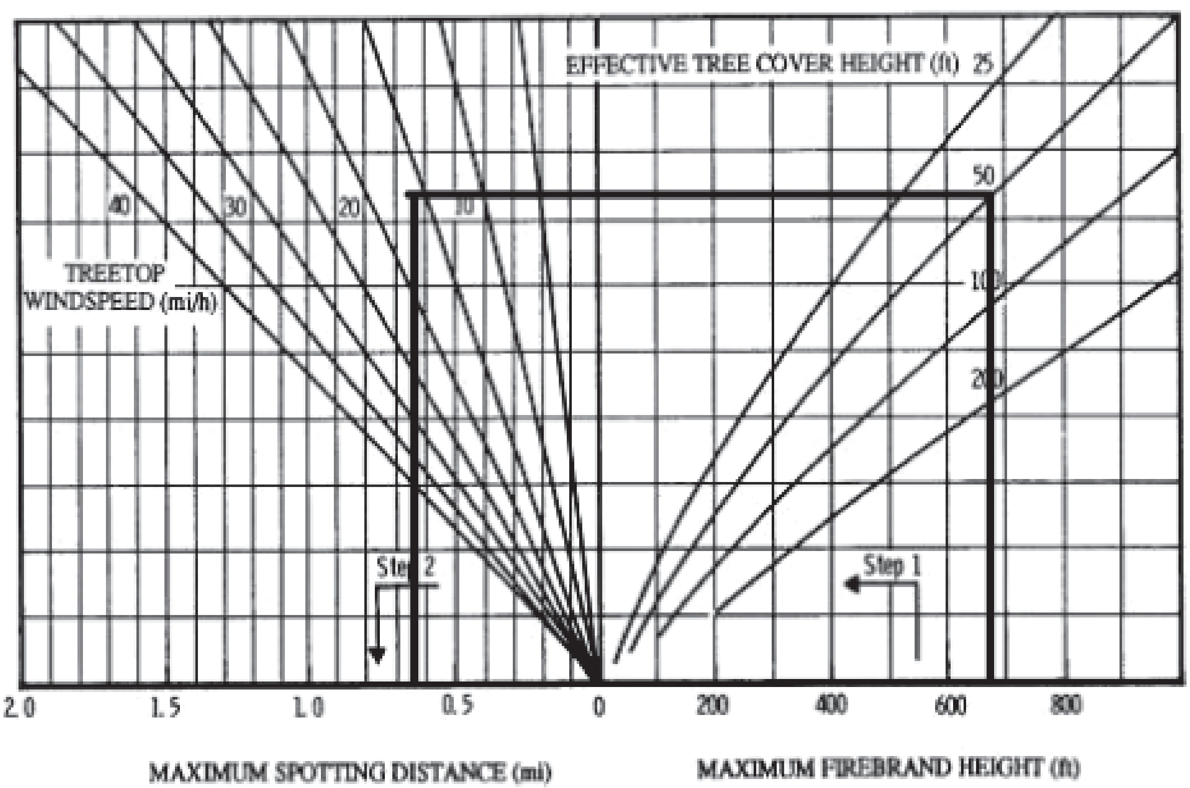


120
100
80
60
40
20
0
10
20
30
40
FLAME HEIGHT (ft)—Box B
DBH (in)—Input 3
Input 2
Grand Fir, Balsam Fir
Engelmann Spruce, Subalpine Fir, Douglas Fir,
Western Hemlock
Ponderosa Pine, Lodgepole Pine, White Pine

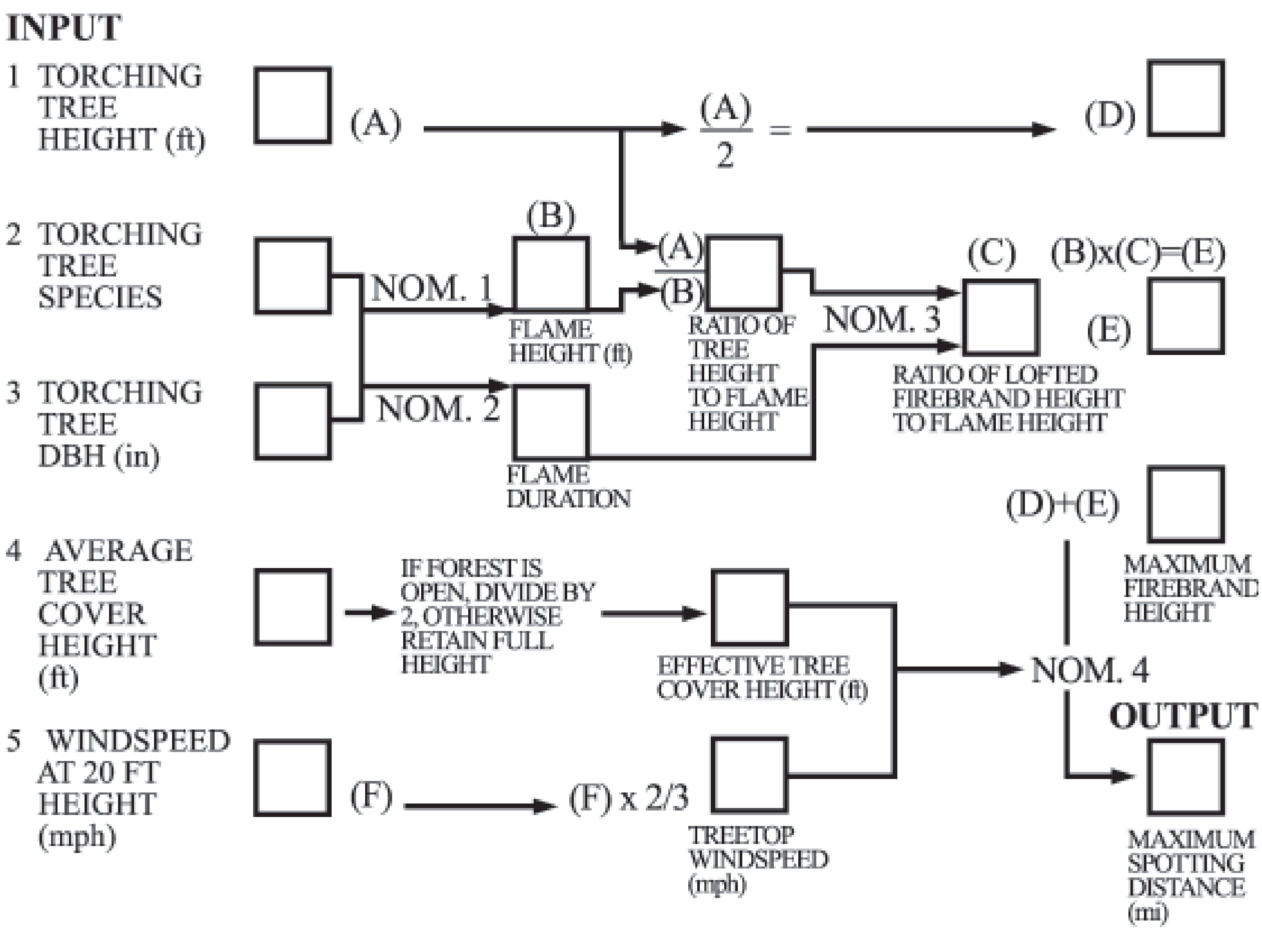


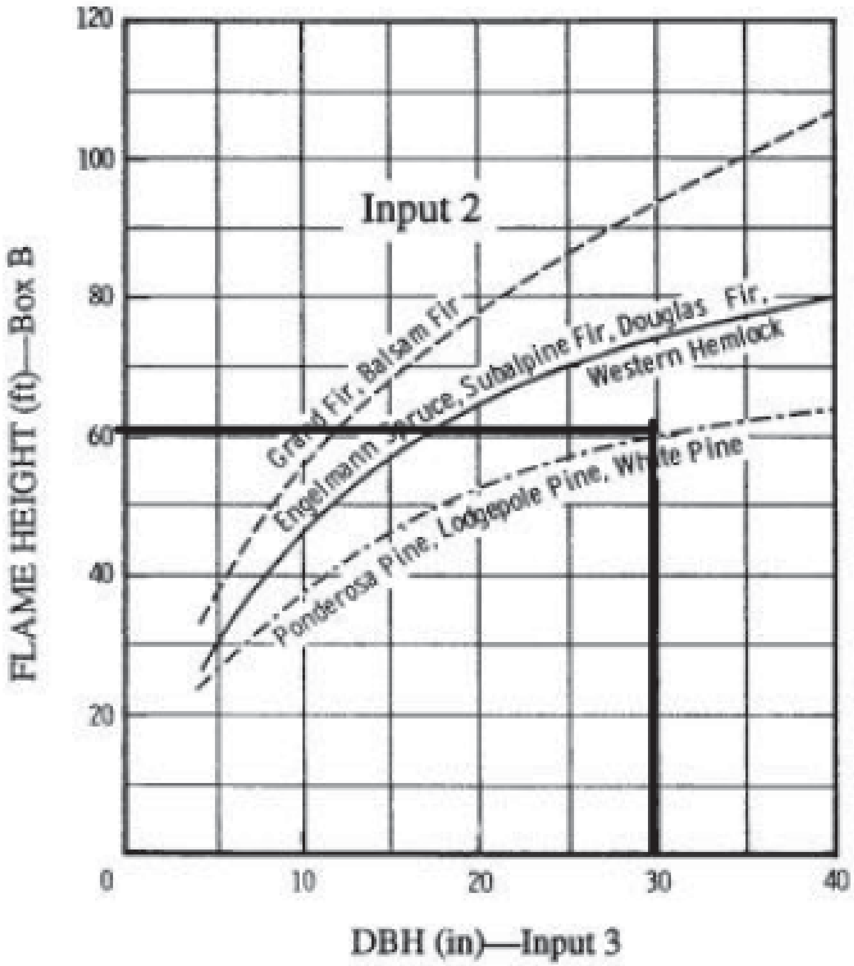
10
8
6
4
2
0
5
10
15
20
25
30
35
40
FLAME DURATION
DBH (in)—Input 3
Input 2
Ponderosa Pine, Lodgepole Pine, Engelmann Spruce
Subalpine Fir, Douglas Fir, Grand Fir, Balsam Fir, White Pine
Western Hemlock


RATIO OF BURNING TREE HEIGHT TO FLAME HEIGHT
1.0 to 1.5
More than 1.5
0.5 to 1.0
Less than 0.5
RATIO OF LOFTED FIREBRAND HEIGHT TO FLAME HEIGHT—Box C
FLAME DURATION

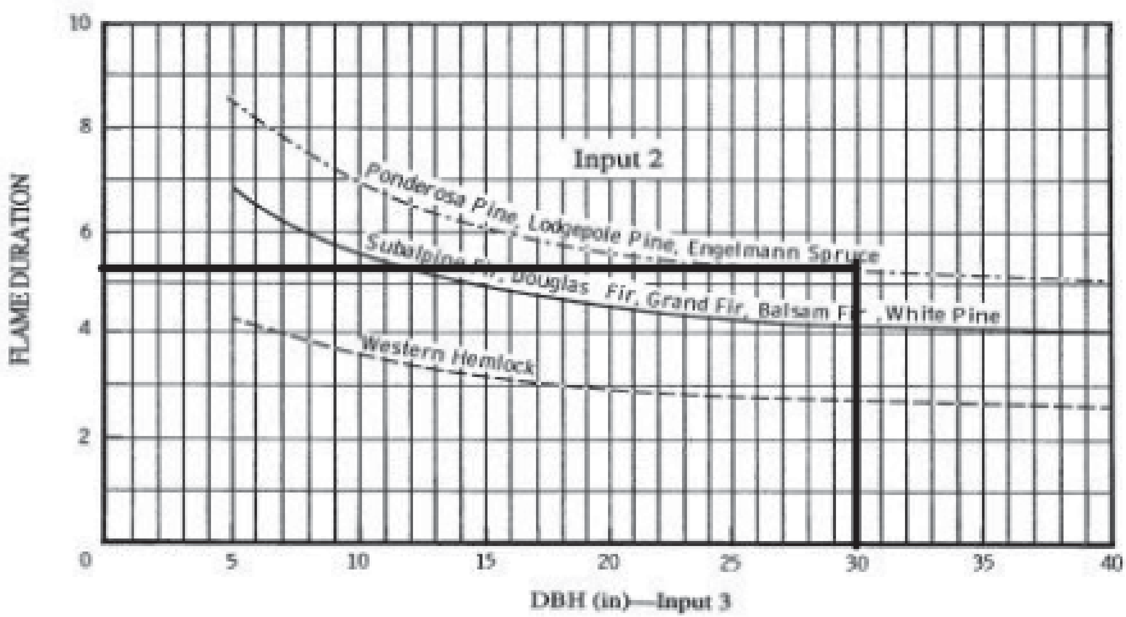

EFFECTIVE TREE COVER HEIGHT (ft) 25
50
100
200
40
30
20
10
TREETOP
WINDSPEED (mi/h)
Step 2
Step 1
MAXIMUM SPOTTING DISTANCE (mi)
MAXIMUM FIREBRAND HEIGHT (ft)

PROBLEM 3

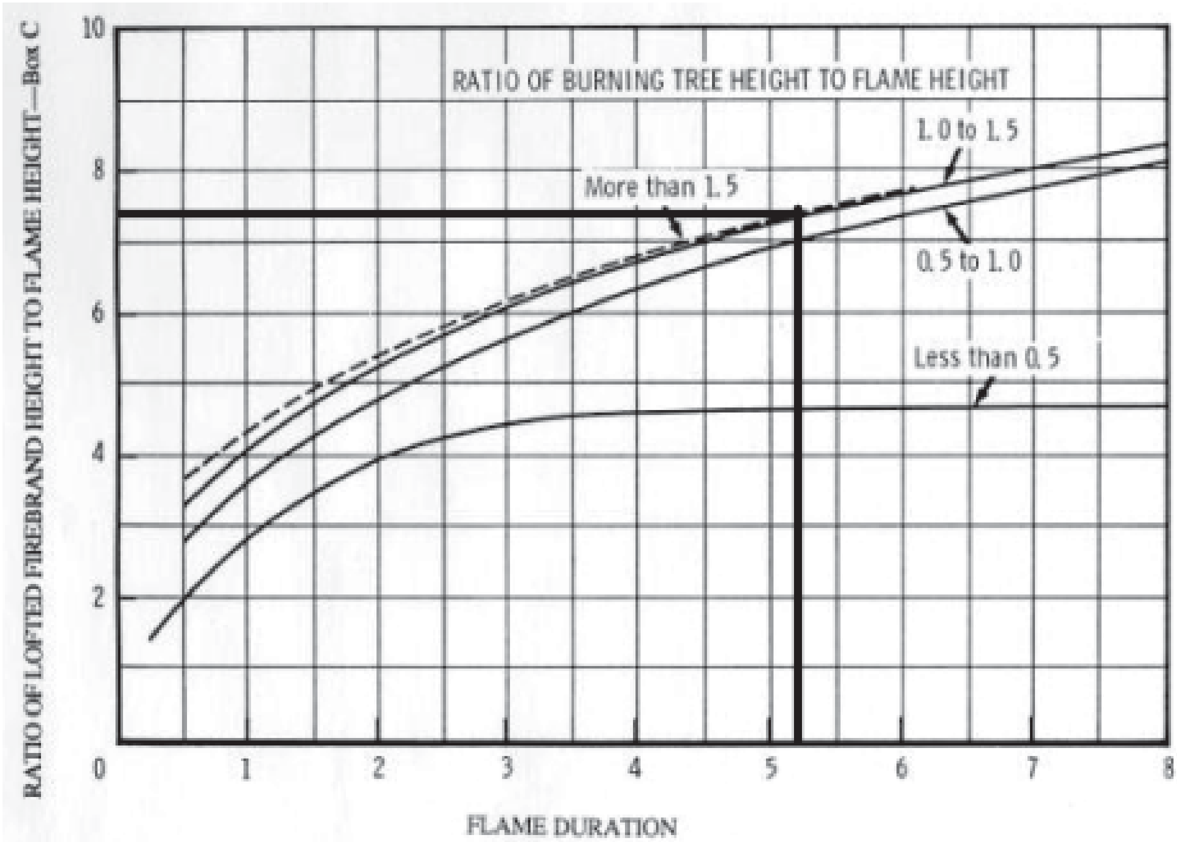

INPUT
1 TORCHING TREE HEIGHT (ft)
(A)
(A)/2 =
(D)
2 TORCHING TREE SPECIES
3 TORCHING TREE DBH (in)
NOM. 1
NOM. 2
(B)
FLAME HEIGHT (ft)
FLAME DURATION
(A)/(B)
RATIO OF TREE HEIGHT TO FLAME HEIGHT
NOM. 3
(C)
RATIO OF LOFTED FIREBRAND HEIGHT TO FLAME HEIGHT
(B)x(C)=(E)
(E)
(D)+(E)
MAXIMUM FIREBRAND HEIGHT
4 AVERAGE TREE COVER HEIGHT (ft)
IF FOREST IS OPEN, DIVIDE BY 2, OTHERWISE RETAIN FULL HEIGHT
EFFECTIVE TREE COVER HEIGHT (ft)
5 WINDSPEED AT 20 FT HEIGHT (mph)
(F)
(F) x 2/3
TREETOP WINDSPEED (mph)
NOM. 4
OUTPUT
MAXIMUM SPOTTING DISTANCE (mi)

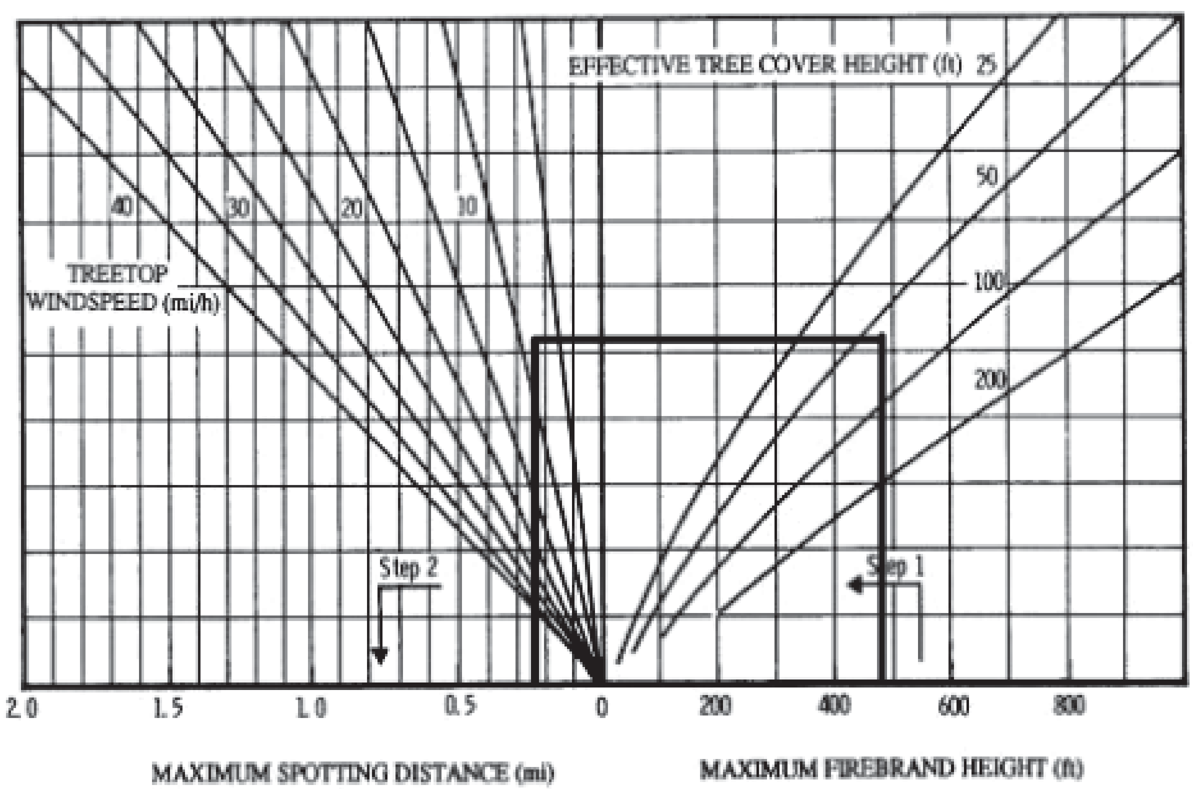


120
100
80
60
40
20
0
10
20
30
40
FLAME HEIGHT (ft)—Box B
DBH (in)—Input 3
Input 2
Grand Fir, Balsam Fir
Engelmann Spruce, Subalpine Fir, Douglas Fir, Western Hemlock
Ponderosa Pine, Lodgepole Pine, White Pine

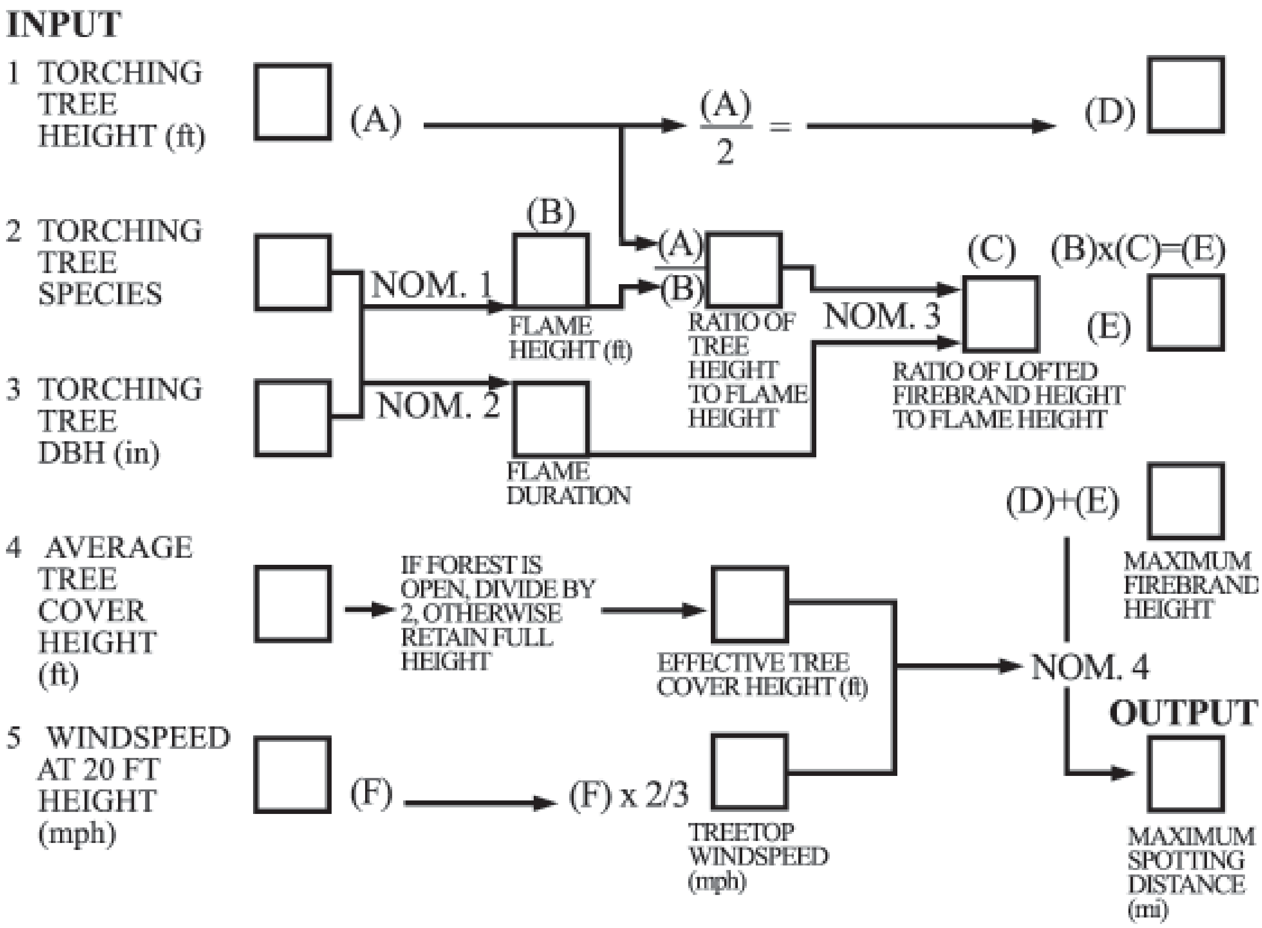


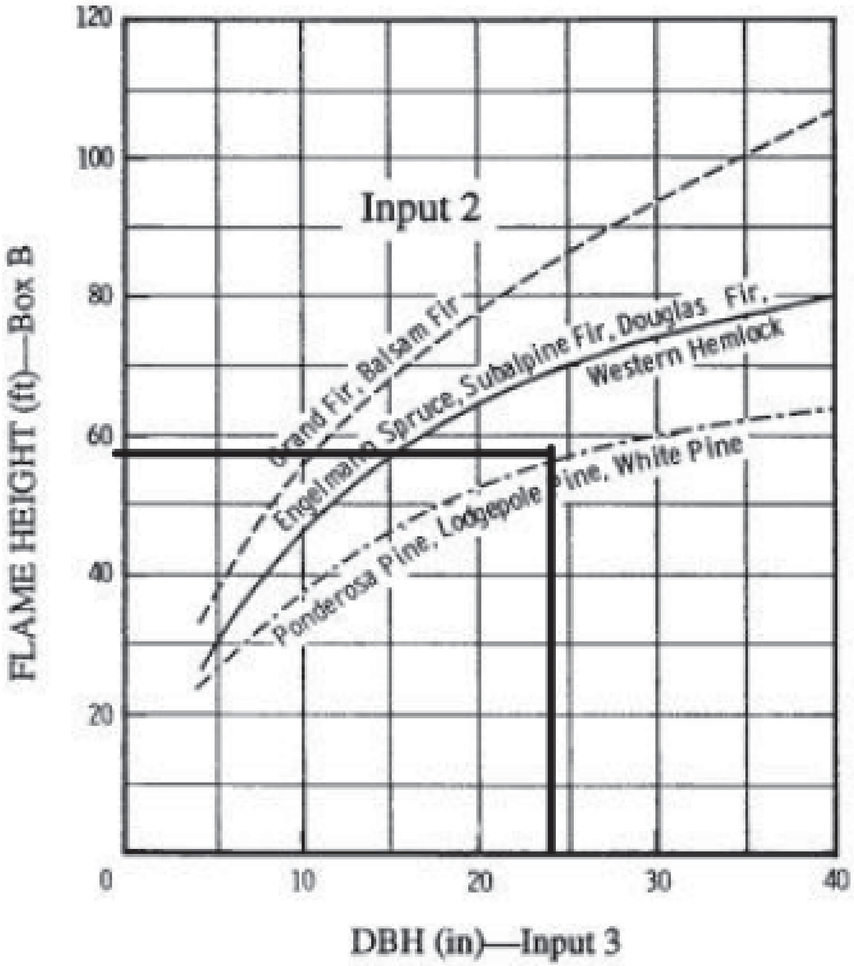
10
8
6
4
2
0
5
10
15
20
25
30
35
40
FLAME DURATION
DBH (in)—Input 3
Input 2
Ponderosa Pine, Lodgepole Pine, Engelmann Spruce
Subalpine Fir, Douglas Fir, Grand Fir, Balsam Fir, White Pine
Western Hemlock


RATIO OF BURNING TREE HEIGHT TO FLAME HEIGHT
1.0 to 1.5
More than 1.5
0.5 to 1.0
Less than 0.5
RATIO OF LOFTED FIREBRAND HEIGHT TO FLAME HEIGHT—Box C
FLAME DURATION
0
1
2
3
4
5
6
7
8
2
4
6
8
10

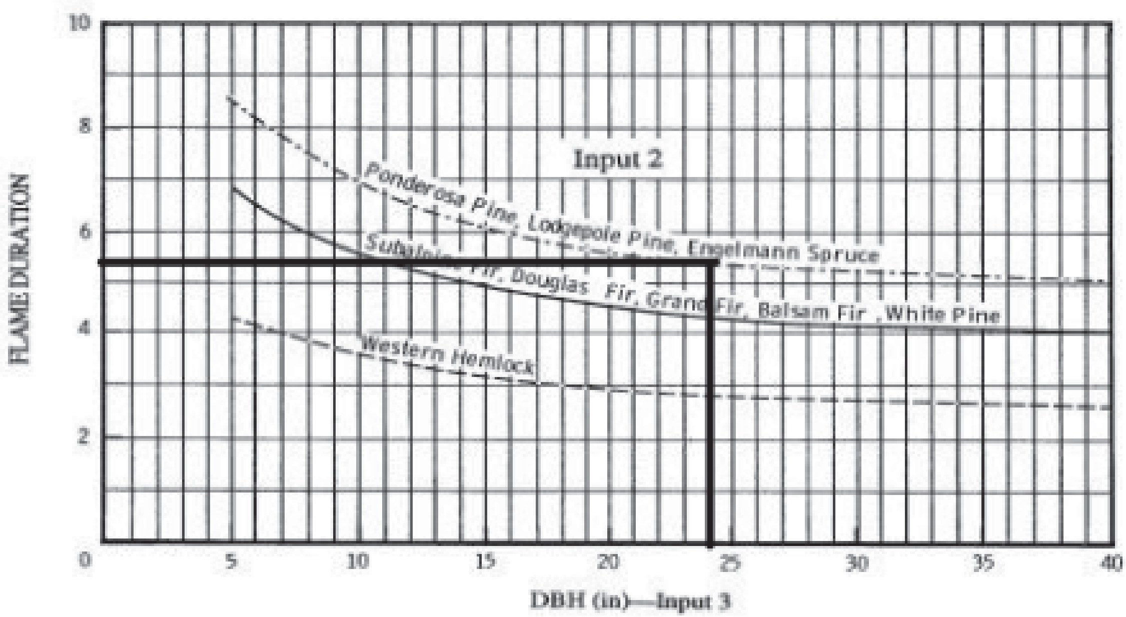

EFFECTIVE TREE COVER HEIGHT (ft) 25
50
100
200
40
30
20
10
TREETOP
WINDSPEED (mi/h)
Step 2
Step 1
2.0
1.5
1.0
0.5
0
200
400
600
800
MAXIMUM SPOTTING DISTANCE (mi)
MAXIMUM FIREBRAND HEIGHT (ft)

PROBLEM 4

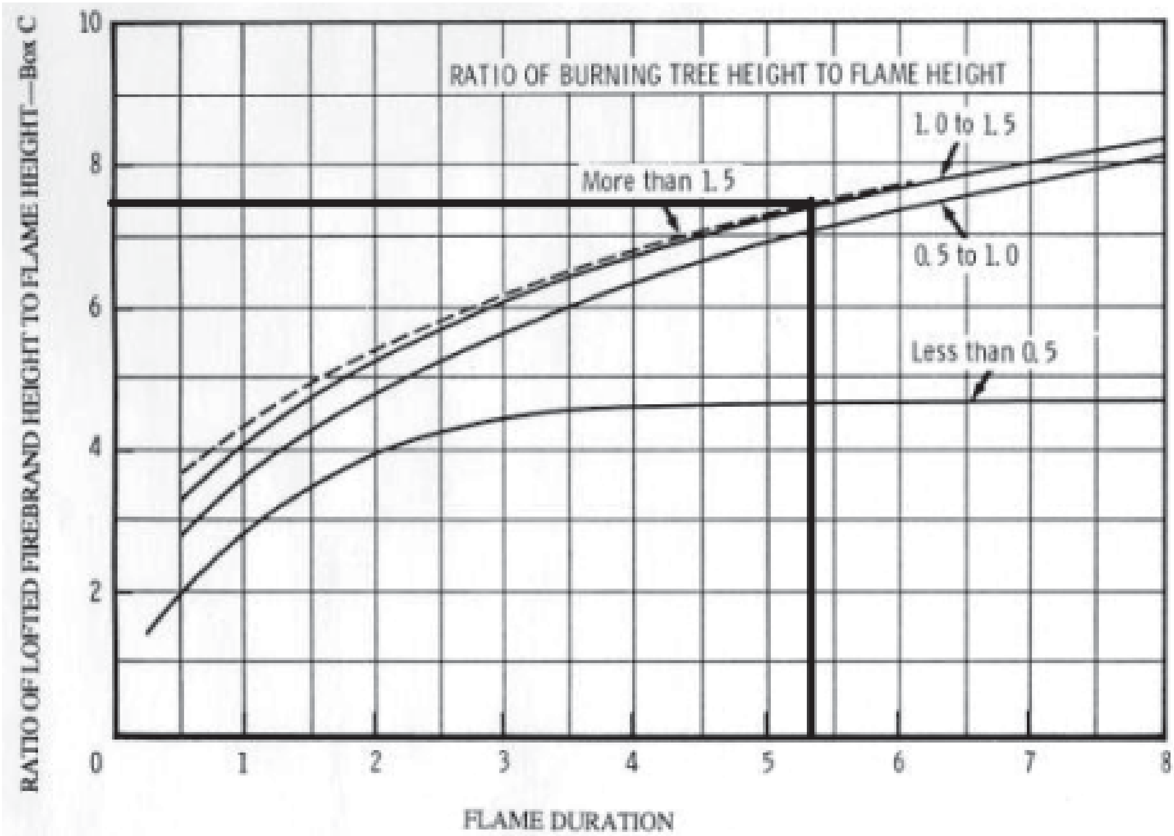

INPUT
1 TORCHING TREE HEIGHT (ft)
(A)
(A)/2 =
(D)
2 TORCHING TREE SPECIES
(B)
NOM. 1
FLAME HEIGHT (ft)
(A)/(B)
RATIO OF TREE HEIGHT TO FLAME HEIGHT
NOM. 3
(C)
(B)x(C)=(E)
(E)
RATIO OF LOFTED FIREBRAND HEIGHT TO FLAME HEIGHT
3 TORCHING TREE DBH (in)
NOM. 2
FLAME DURATION
(D)+(E)
MAXIMUM FIREBRAND HEIGHT
4 AVERAGE TREE COVER HEIGHT (ft)
IF FOREST IS OPEN, DIVIDE BY 2, OTHERWISE RETAIN FULL HEIGHT
EFFECTIVE TREE COVER HEIGHT (ft)
NOM. 4
OUTPUT
5 WINDSPEED AT 20 FT HEIGHT (mph)
(F)
(F) x 2/3
TREETOP WINDSPEED (mph)
MAXIMUM SPOTTING DISTANCE (mi)

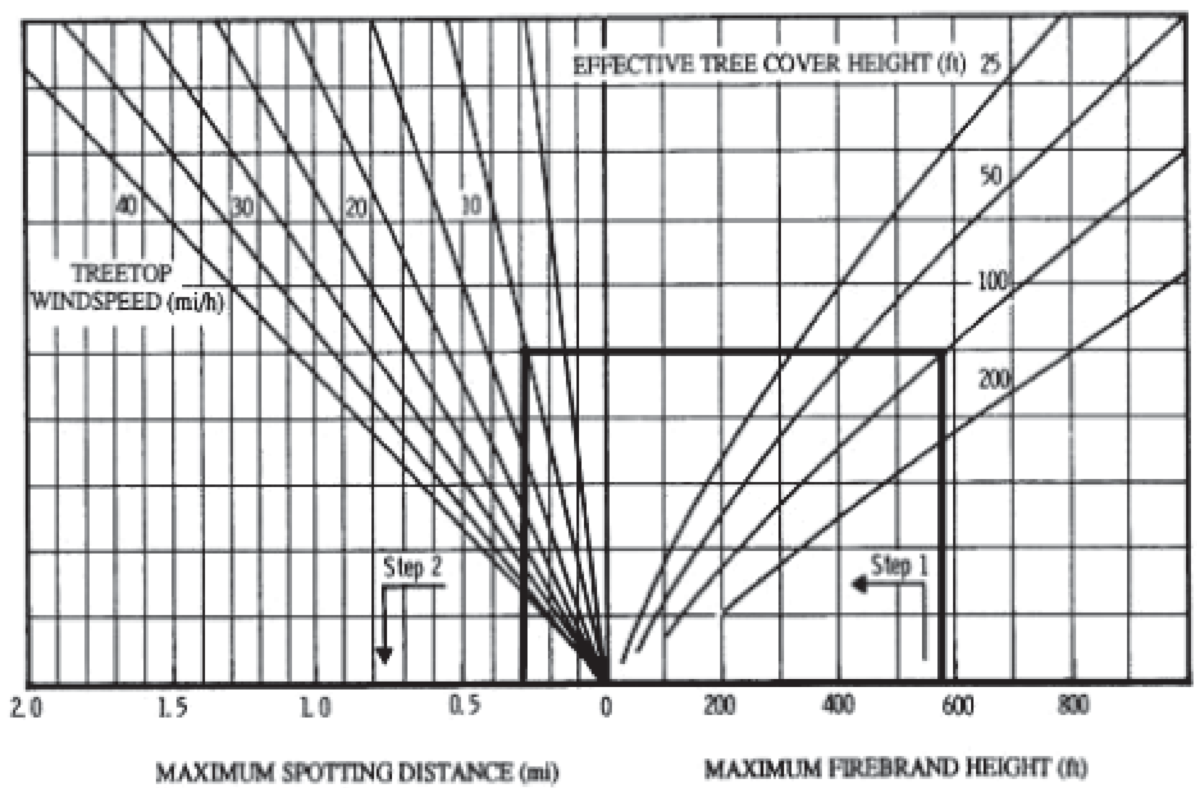


Input 2
FLAME HEIGHT (ft)—Box B
DBH (in)—Input 3
Grand Fir, Balsam Fir
Engelmann Spruce, Subalpine Fir, Douglas Fir, Western Hemlock
Ponderosa Pine, Lodgepole Pine, White Pine



Input 2
FLAME DURATION
DBH (in)—Input 3
Ponderosa Pine, Lodgepole Pine, Engelmann Spruce
Subalpine Fir, Douglas Fir, Grand Fir, Balsam Fir , White Pine
Western Hemlock


RATIO OF LOFTED FIREBRAND HEIGHT TO FLAME HEIGHT—Box C
RATIO OF BURNING TREE HEIGHT TO FLAME HEIGHT
1.0 to 1.5
More than 1.5
0.5 to 1.0
Less than 0.5
10
8
6
4
2
0
1
2
3
4
5
6
7
8
FLAME DURATION


EFFECTIVE TREE COVER HEIGHT (ft) 25
50
100
200
40
30
20
10
TREETOP WINDSPEED (mi/h)
Step 2
Step 1
2.0
1.5
1.0
0.5
0
200
400
600
800
MAXIMUM SPOTTING DISTANCE (mi)
MAXIMUM FIREBRAND HEIGHT (ft)

Introduction to Wildland Fire Behavior Calculations, S-390

Unit 5 – Fire Behavior Models

Lesson C – Safety Zone Calculations

OBJECTIVES:

Upon completion of this lesson, students will be able to:

1. Describe the difference between a safety zone and a deployment zone.

2. Define and describe a safety zone by:

    a. Identifying inputs needed for safety zone calculations.

    b. Listing assumptions used in safety zone calculation.

3. Identify issues with safety zones on slopes.

4. Examine safety zones in fire entrapments.

5. Determine separation distance and safety zone size.

I. INTRODUCTION

Safety zones are an integral part of fireline safety. Their size varies greatly depending fire behavior.

The size of safety zones needed under differing conditions can and should impact fireline tactics.

The purpose of this unit is to give the student the tools to be able to determine the size of safety zones for their use in the field based on fire behavior.

This unit will not explore the flame physics and other experimental data that were used in developing safety zone size criteria.

It will only cover the operational details of determining an appropriate safety zone size.

II. DEFINITIONS

A. Safety Zone

A safety zone is an area that firefighters can retreat to and not have to deploy fire shelters to remain safe.

B. NWCG Glossary of Wildland Fire Terminology definition:

"An area cleared of flammable materials used for escape in the event the line is outflanked or in the case a spot fire causes fuels outside of the control line to render the line unsafe. In firing operations, crews progress so as to maintain a safety zone close at hand allowing fuels inside the control line to be consumed before going ahead. Safety zones may also be constructed as integral parts of fuel breaks; they are greatly enlarged areas which can be used with relative safety by firefighters and their equipment in the event of blowup in the vicinity."

C. Deployment Zone

"…used when fire conditions are such that escape routes and safety zones have been compromised. Deployment zones are the last ditch areas where fire shelters must be deployed to ensure firefighter survival due to the available space and/or fire behavior conditions at the deployment zone location."

III. SAFETY ZONE CALCULATION

A. Two Inputs Needed for Safety Zone Calculation

1. Flame height (flame length).

2. Number and type of resources using the safety zone.

B. Assumptions

1. Safety zone size calculations are done on the "worst case scenario" that the fire will burn around the safety zone on all sides. Each side of the safety zone will receive the same amount of heat.

2. Flame Length = Flame Height

3. Safe separation is a straight line from the heat source to the firefighter.

C. Safety Zone Calculation

1. Separation distance is everything.

a. Minimum Separation Distance = 4 x flame height

b. Total Separation Distance = 4 x flame height + additional distances for crews and equipment

2. 4 x the flame height rule:

   a. Very rough – Minimum Separation Distance.

   b. Does not consider personnel or equipment needs.

   c. Considers only radiant heat.

   d. Convection heat not considered:

      - Strong Wind
      - Chimneys
      - Slopes

3. Two methods for acquiring the additional distance necessary to find total separation distance:

   - The simplified equation – crew and equipment additional separation distance:

     4 x flame height + 20 + (4 x # of crews) + (# of pieces of equipment) = Total Separation Distance.

   - The following table:

Table 1—Additional separation distance radius needed for crews and equipment*

		Number of pieces of equipment**			
		0	**1**	**5**	**10**
Number of 20-person crews***	**1**	18	20	27	34
	5	41	42	46	50
	10	57	58	61	65

*total separation distance is 4 x flame height (in feet) + added factor from table (in feet)
**250 ft^2 per item
***50ft^2 per firefighter

4. Circle safety zone example:

Total separation distance = the radius of the circle.

a. Flame height = 20 feet

b. 202 x 4 = 802 radius

c. 1 crew + 3 vehicles = 27 feet

d. Total separation distance = 107 feet

e. Diameter of circle = 107 X 2 = 214 foot diameter

Butler's research is based on radii of circles. In real life, circles and radii are not used on the fireline. Traditionally, a square/parallelogram is used for defining safety zones and clearings.

The square used in the following examples is an adaptation of Butler's work to meet the field user dimensional descriptions. A conversion to acres is also included.

Remember: Picture a football field; this is a close approximation to an acre.

5. Square safety zone square example:

Total separation distance x 2 = 1 side of the square.

a. Flame height = 20 feet

b. Total separation distance = 80 + 27 for personnel and equipment = 107 feet

c. 107 X 2 = 214 feet

d. Acres = 1

6. How to figure acres from the dimensions of a square:

   a. Side x side = square feet / 43,560 (sq feet in an acre) = acres in that safety zone.

   b. For this example it is:

      214 x 214 = 45,796 square feet

      45,796/43,560 = 1 acre

7. Total separation distance = the side of the square.

   Things not considered in the formula:

   a. Heavy slash accumulations built up from safety zone clearing operations

   b. If you change the fuel loading by adding slash around a safety zone, you change fire behavior and flame height.

IV. ISSUES WITH SAFETY ZONES ON SLOPES

A. Safety Zones on Slopes

Consider the following situations:

1. A safety zone midslope above upslope spreading fire.

   Intuitively it is expected that when safety zones are located above upward spreading fires that occupants may be exposed to convective energy transfer from the fire.

   Recent experimental measurements in large scale crown fires and analytical calculations suggest that convective energy transfer rates can be on the order of the radiant energy transfer.

Thus, when safety zones are located above upslope spreading fires (case 1 and 3), radiant energy transfer may be reduced but the additional contribution due to convective heating will probably more than compensate for the decreased radiant transfer.

2. A safety zone midslope with fire moving down the slope above the safety zone.

   In all cases other than very strong downslope winds, a minimum separation distance of at least 4 times the flame height should be sufficient.

3. A safety zone at the top of the ridge with fire below.

   This situation is similar to case 1 and carries the same assumptions regarding upslope convective energy transfer.

   The convective energy transfer may be reduced in case 3 if the safety zone is located on the lee side of the ridge.

   However, if the fire cannot be visually monitored from the safety zone, provision should be made for communication with lookouts that can monitor weather conditions, fire intensity, flame heights and fire location.

4. A safety zone at the base of the slope below the downslope spreading fire.

   This situation assumes:

   - Fire stops at edge of safety zone
   - No strong downslope winds

   4 x flame height applies unless there are strong downslope winds.

B. Summary

1. Upslope convection biggest unknown.

2. 4 x flame height works in most cases.

3. Lesson from 30 Mile — maximize distance from fuels.

4. Allow extra travel time for uphill escape routes.

V. EXAMINATION OF SAFETY ZONES IN FIRE ENTRAPMENTS

Approximate safety zone/deployment area sizes come from the investigations of these accidents:

A. Mann Gulch

This fire resulted in 10-40 foot flame lengths. The fire lit by Wag Dodge resulted in a safety zone that may have provided a separation distance as great as 130 feet, although some estimates put it much smaller.

The comparison above indicates that the safety zone rule of thumb generally suggests that Dodge was on the "line" as far as burn injury.

The fact that he survived with little or no burn injury lends some credibility to the model.

B. Battlement Creek

Three firefighter fatalities and one serious burn injury on this fire.

Comparing against the safety zone model indicates that the model predicts severe injury or fatalities. Again this lends some credibility to the model.

The crew involved was the Mormon Lake IHC. Although the crew had fire shelters they were not carried on the line that day. At that time, fire shelters were still an optional use item.

Firing out was done by another crew from below the Mormon Lake crew.

Communications were also an issue. Basically, the people found a wide space in the line to lay down.

C. Butte Fire

Flames reached 200-300 feet in height. Firefighters were required to deploy their fire shelters to prevent injury. This agrees with the model.

The crews were in their shelters for up to two hours. They crawled from side to side of the clear-cut they were deployed in to avoid heat as the fire burned around them.

Several hotshot crews refused to go into the area and bailed out to a larger area when the fire started blowup. DIVS and Ops were telling crews to go into the area.

D. South Canyon

Firefighters died while attempting to deploy in fire shelters on a fireline surrounded by flames that were 50-90 feet tall.

Others survived while in fire shelters more than 400 feet from crown fires. These data suggest that the safety zone model is qualitatively accurate.

VI. EXAMINATION OF REASONS WHY FIREFIGHTERS CAN BE CLOSER AND UNINJURED

- Use difference in heat output 7.4 vs. 4.8. Refer back to Butte fire where crews crawled around to avoid heat as each side burned.
- Real FL/FH's are hard to estimate accurately, especially when adrenaline is flowing and the fire is running.
- Fast moving fire/ little residence time, smaller FH.
- Baggy clothing is good – creates an air space between clothing and body to help dissipate.
- Low emissionability of heat transfer from short flames.

A. Reality Checks

1. Reality check # 1

   a. Good safety zones are often recognized not built (meadows).

   b. Distance to safety zones needs to reflect the ROS of the fire.

   c. Situational Awareness – size of safety zones and length of escape routes change dependent on conditions; continual re-evaluation is a must.

2. Reality check # 2

   a. Is the size of the safety zone too large for resource objectives?

   b. Is the safety zone being used for a parking area / fuel storage / equipment?

   c. Is construction of a large safety zone feasible within time constraints?

   d. If the safety zone is large do we need to put people in that area?

   e. What are other tactical options?

B. Where Do We put Safety Zones?

1. Meadows
2. Large open areas below the fire.
3. On the lee side of ridges outside of eddy effect when windy.
4. Cross slope from the head of the fire.
5. Areas with good access for personnel.
6. Broad open ridgelines (if windy see #3).
7. In previously burnt areas if it is hard black.

C. Where Not to Put Safety Zones

1. Saddles
2. Chimneys
3. Heavy fuels concentrations.
4. Areas with poor access.
5. Razor back ridges.
6. Windward side of ridge above the fire.
7. Midslope above the fire.
8. Above the fire.

SAFETY ZONE EXERCISES.

You will be given three different flame heights, numbers of crews, and equipment. Determine the total separation distance for:

1. Safety zone as a circle.

2. Safety zone as a square.

3. Acres needed for a safety zone.

Wildland Firefighter Safety Zones

B.W. Butler and J. Forthofer, USDA Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory, Missoula, MT. Tel: 406-329-4801 or 4874, e-mail: bwbutler@fs.fed.us.

In 1998, a simple rule-of-thumb was proposed as a definition of minimum separation distance between firefighters and flames to prevent burn injury. The rule stated that the safety zone must be large enough to allow the firefighter to be at least 4 flame heights in distance from the fire front.

Since then, safety zone research efforts have focused on obtaining measurements of energy emitted by "real" fires. These measurements are needed to evaluate the accuracy of the theoretical safety zone model. Unfortunately, such measurements are difficult to make in wildland fires.

To date, measurements have been collected in fires burning through high elevation sage brush in Montana; manzanita, juniper and pinyon pine in northern Arizona; tall grass prairies in Kansas; crown fires in the boreal forest of Northern Canada; and lodge pole pine forests in eastern Oregon.

The Flame Model

Technically speaking, wildland fires are composed of turbulent diffusion flames, meaning that the temperature of the flame and the energy released by the flame is a function of the rate that oxygen in the air can mix with the combustible gases released by heating of the woody fuels. This also explains why wind is the dominant environmental factor affecting fire behavior. Any firefighter who has worked on a fire has observed the strong influence that wind can play on fire intensity and size.

The effect occurs in two ways: 1) increased wind causes increased mixing of the air and combustible fuels—leading to faster burning and higher temperatures; and 2) wind causes the flames to tilt forward closer to the vegetation ahead of the fire front—leading to increased energy transfer to those fuels and thus faster heating and ignition.

If the temperature of the flame increases then the radiant energy emitted by the flame also increases. In fact, the radiant energy is proportional to the flame temperature raised to the power of four! For example: a change in flame temperature from 1000°F (the typical temperature of the flame tip) to 1500°F will increase the radiant energy emitted by the flame nearly **four times**!

The original safety zone research study assumed that the flame was essentially a flat plate of steel 66 feet wide with a constant temperature of 1832°F (figure 1).

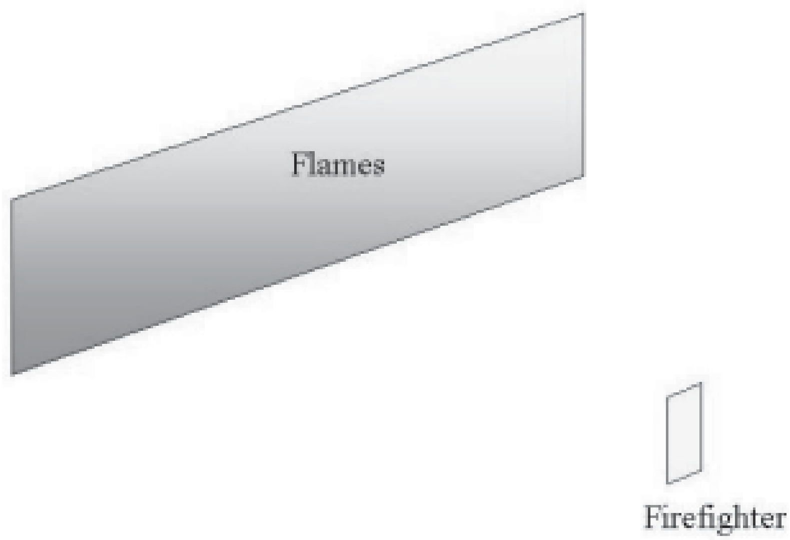


Figure 1—Flat plate fire front.

This geometry was selected primarily because the mathematics for even this simple shape were relatively complex and presented a computer programming challenge. However, in reality, temperatures vary greatly in flames with the highest temperatures (as high as 2500°F) usually occurring in the lower third of the flame and the tip of the flame being roughly 1000°F.

We now use a commercial software package designed specifically to model radiant energy exchange. This new tool permits us to model the flames with varying temperatures throughout (figure 2).

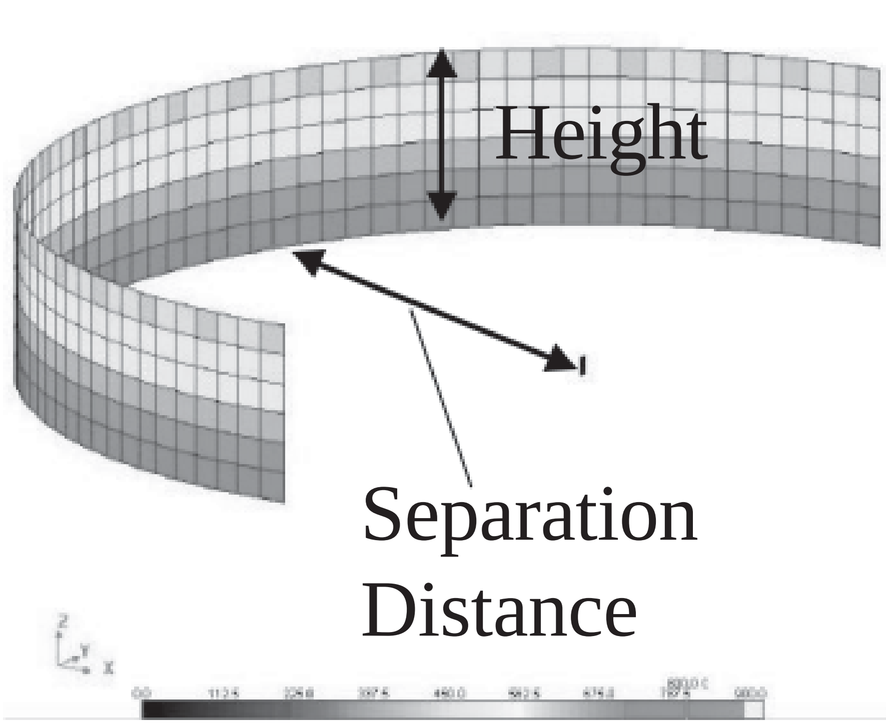


Figure 2—Semicircular flame model with vertically varying temperature.

Wind affects firefighter safety zones in two ways, it can increase the maximum flame temperature leading to longer and taller flames and it tilts the flames forward increasing the amount of radiant heating ahead of the flames. For example, if we calculate the minimum safe distance from a vertical flame front to a firefighter at its center as shown in figure 2, the minimum safe separation distance is between 3 and 3.5 times the flame height.

If that flame is now tilted towards the firefighter as would occur if the wind were driving the flame (figure 3) then the minimum safe separation distance increases to between 3.5 and 4-times-the-flame-height.

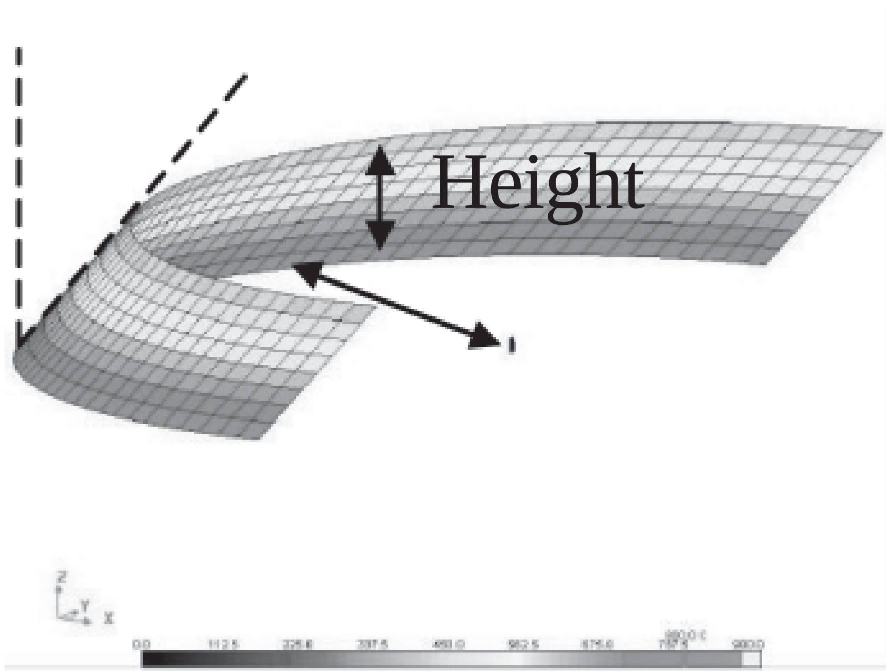


Figure 3—Semicircular tilted flame front with vertically decreasing temperature.

The tilted semicircular configuration is chosen for the firefighter safety zone calculations because it represents the "worst case" scenario in terms of heat impact on the firefighter.

Burn Injury Limits

The effect to the skin is the same regardless of whether the heating occurs by radiation from the fire, conduction from contact with a hot source, or convection from hot air or flames. The heating levels that cause burn injury are not easily defined; burn injury severity depends on exposure time and heating magnitude.

In other words, exposure to a low level heating source like the sun for a long time would result in the same effect as exposure to a higher energy source like a fire for a short time. The type, thickness, number of layers, fit of clothing and even the rate at which the person wearing the clothing perspires also are important.

The Society of Fire Protection Engineering Handbook indicates that exposure of bare skin to any type of heating greater than 0.23 Btu/ft^2-s (2.5kW/m^2) for a long period will result in burn injury. As a point of comparison, the maximum energy that a person could receive by exposure to the sun is less than 0.09 Btu/ft^2-s (1kW/m^2). Exposure of unprotected skin to heating levels greater than 4.5 Btu/ft^2-s (50kW/m^2) will result in severe burn in less than 15 seconds, and if the area of exposure is large enough, fatality in 40 seconds.

In the original safety zone study, 0.6 Btu/ft^2-s (7kW/m^2) for 90 seconds was selected as the level at which a firefighter wearing Nomex clothing would receive second degree burn injury. The 0.6 Btu/ft^2-s limit is based on an experiment where Nomex cloth was located ½ inch away from the burn sensor. If the cloth is touching the skin then the time to burn injury drops to about 35 seconds.

The bottom line is that severe burn injury to skin covered with one layer of Nomex from radiant heating occurs when energy flux levels exceed 0.45 to 0.72 Btu/ft^2-s (5 to 8 kW/m^2) for a minute or two. At this time, there is no clear reason to change the burn injury limit (0.6 Btu/ft^2-s after exposure of 80 to 90 seconds) that is being used to define the firefighter safety zone size.

As a point of comparison, while working on the Monument Fire in eastern Oregon this summer we stood about 40 feet away from flames that were 15 feet wide and 50 feet tall. We were receiving enough heat that it was very uncomfortable and even painful forcing us and the firefighters around us to shield our faces. Calculations assuming a rectangular flame with temperatures similar to those used for the safety zone model suggest that we were receiving about 0.3 Btu/ft^2-s (3 kW/m^2); a rate about one half that selected as the burn injury limit for safety zones.

Given the increased heating for tilted flames and the uncertainty associated with estimating burn injury limits, flame heights, and fire intensity we recommend that the 4-times-the-flame-height rule be retained as the **minimum** separation distance model. **We emphasize minimum.** At this separation distance, under conditions where the flames are uniformly radiating from two or more sides of the safety zone, firefighters will probably be subjected to heating levels that require shielding all exposed skin, breathing thick smoke, and likely experience ember showers.

The math
For purposes of calculating firefighter safety zone size, we propose the following geometrical configuration (figure 4) where the safety zone is a circle. The radius of the circle or total separation distance is a combination of 4-times-the-flame-height and the additional area needed for people and equipment. In other words, the person closest to the fire must be 4-times-the-flame-height away.

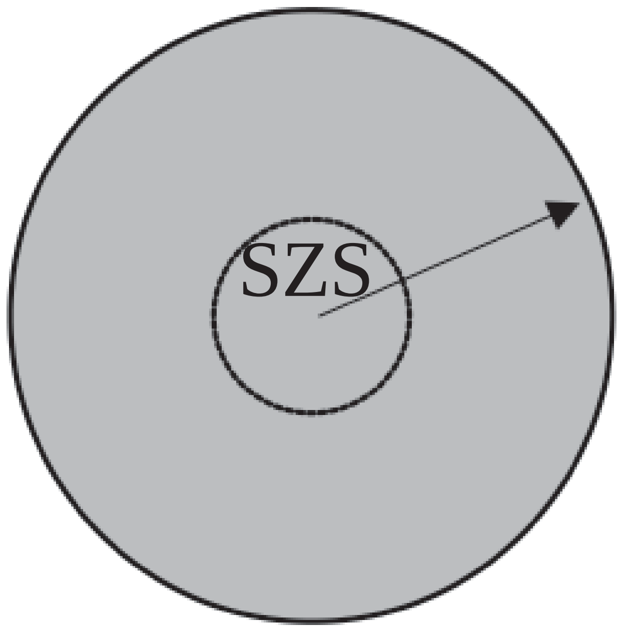


Figure 4—Safety zone configuration. SDR is the radius of the safety zone and is determined by the flame height or length and the number of firefighters and equipment that will be using the area.

The **S**afety **Z**one **S**ize (SZS) can be calculated using equation 1.

$$SZS = 4F_H + \left[\frac{A_{FF}N_{FF} + A_E N_E}{3}\right]^{\frac{1}{2}}$$

SZS is total separation distance for a circular safety zone the radius of the circle. F_H is flame height or alternatively flame length. A_{FF} is area needed for each firefighter (we suggest 50 ft^2 — the space needed to deploy a fire shelter). N_{FF} is the number of personnel that will be using the safety zone. A_E is the area needed by each item of heavy equipment (a crewcab pickup would require about 200 ft^2, a D6 Caterpillar with blade and ripper attachments requires about 280 ft^2, a D8 with attachments requires about 360 ft^2). N_E is the number of pieces of heavy equipment that are expected to use the safety zone. The dividing factor of three is an approximation to the numerical constant *pi* (actual value 3.14159). This equation is difficult to apply while working on a fire.

Table 1 presents the solution to equation 1 for a range of numbers of firefighter crews and number of vehicles. The number obtained from the table should be added to 4-times-the-flame-height to get total minimum separation distance or safety zone radius.

Table 1—Additional separation distance radius needed for crews and equipment*

		Number of pieces of equipment**			
		0	**1**	**5**	**10**
Number of 20-person crews***	**1**	18	20	27	34
	5	41	42	46	50
	10	57	58	61	65

*total separation distance is 4 x flame height (in feet) + added factor from table (in feet)
**250 ft^2 per item
***50ft^2 per firefighter

Finally, a third option is to use the following approximation to equation 1:

> **The additional distance needed above the four times flame height for people and equipment (in feet) = 20 + 4 x (the number of 20 person crews) + (the number of pieces of equipment)**.

This will give an approximation to the solution of equation 1.

A fourth method is to use the 4-times-the-flame-height rule and simply estimate the area needed for people and equipment.

> **The 4-times-flame-height rule represents a very rough approximation based only on radiant heating and should be taken as a minimum. It does not account for convective heating such as may occur under strong winds, in steep narrow canyons, or on slopes.**

What about short flames?
There is some evidence that the 4-times-flame-height rule does not hold true for short flames (less than 5 feet in height). The primary reason for this relates to the depth or thickness of the flames. Shorter flames are less efficient radiators than taller flames and thus they give off less energy. However, limited measurements in actual wildland fires indicate that as height or length of the flames increases the flames radiate more energy per unit area.

Another factor is that the model is based on a uniform and continuous flame front oriented in a semicircle around the front of the firefighter (figure 5). Very seldom is this actually the case for short flames; they usually are less uniform and continuous, and do not encircle the firefighter. For these basic reasons, we have not modified the 4-times-flame-height rule for short flames.

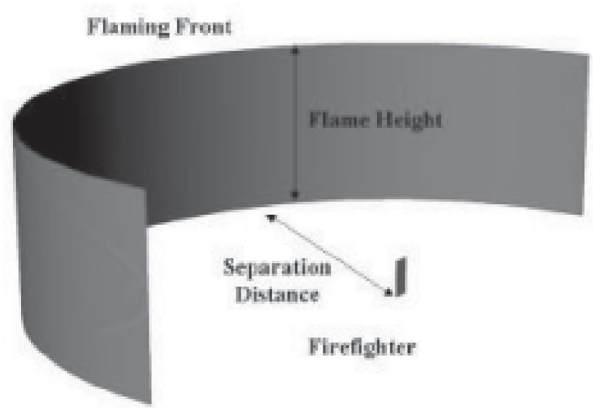


Figure 5—Semicircular fire front.

What about using water bodies as a safety zone?
There are historical accounts of firefighters and others successfully using water as a safety zone. Two different cases can be distinguished. The first case is when firefighters are *on* the water, for example in a boat. For this case, the standard 4-times-the-flame-height minimum separation distance rule applies. Common sense dictates that all personnel on the water should have a personal floatation device.

The second case is when firefighters are *in* the water (swimming, floating, wading, etc.). For this case the separation distance model we have developed does not apply. The reason is because the water (assuming typical stream and lake temperatures) cools the skin more effectively than air does.

This suggests that the firefighter could be closer than 4 times the flame height and not be burned from radiant heat. However, there are other factors that should be considered in this case such as the risk of drowning and hypothermia. Also, being closer to the flames could expose the firefighter to convective heating which could lead to burning of the airways.

In general, water should not be considered as a safety zone except as a last resort, when escape routes have been cut off and a deployment situation is imminent. Such action should include use of the fire shelter as a heat shield while in the water.

Conclusion
In conclusion, further modeling and field measurements support the 4-times-flame-height rule of thumb for minimum safety zone size. It is important to realize that this should be considered a minimum—meaning that in all cases larger is better.

It is also important to remember that the rule of thumb is based on radiant heating and firefighters should always be cognizant of situations that may lead to convective heating.

Future work will focus on characterizing the parameters that influence convective heating. Up-to-date summaries of firefighter safety zone information can be found at www.firelab.org/fbp/reshome.htm.

Example calculation of safety zone size:

Situation:
You are a member of a crew of 20 firefighters that has just arrived at a fire burning south of Ely, Nevada. You arrived the previous night. The morning briefing is scheduled for 20 minutes from now and your crew boss asks you to provide him with some estimates of minimum safety zone sizes that will be needed for the morning and afternoon. He expects that you will be assigned to build and maintain fireline on the southeast flank of the fire. You may have one D4 dozer assigned to work with you.

Solution:
Information needed is:

1) F_h—flame height or length for both the morning and afternoon.
2) N_{ff}—number of persons that will be using the safety zone.
3) N_E—number of vehicles and/or heavy equipment that may need to use the safety zone.

Procedure:
You are unfamiliar with the area and fire behavior, so you go to the fire behavior analyst (FBAN) and ask for estimates of flame lengths given expected weather and fuels in the area you will be working. He says that flames have been 15 to 20 ft in the mornings and 20 to 25 ft in the afternoon. But today a dry cold front is expected to pass through about 1430, it will result in higher westerly winds then previous days.

The FBAN is predicting flame lengths of 28 to 35 ft during the cold front passage. The FBAN predictions correspond with observations from the previous day's burning (during initial attack, an FBAN may not be available, but in most cases, other firefighters that have observed fire in similar fuels and under similar conditions can provide estimates of flame height). With this information you now can calculate the minimum safety zone size assuming a circular safety zone.

F_h = 20 in the morning and 35 in the afternoon
N_{ff} = 20 plus 2 (crew plus dozer operator and dozer boss)
N_E = 4 (2 crew rigs, a dozer boss rig and a D4 dozer)

Using Equation 1:

Safety zone radius = 4 x flame height + [(N_{ff} x 50 + N_E x 200)/3]$^{1/2}$

Safety zone radius = 4 x 20 + [(22 x 50 + 4 x 200)/3]$^{1/2}$
= 80 + [(1100 + 800)/3]$^{1/2}$
= 80 + [633]$^{1/2}$
= 80 + 25
= 105 ft for the morning period and (140+25 due to the expected taller flames) or 165 ft in the afternoon.

Using Table 1:

Safety zone radius = 4 x flame height + (# from table for 1 crew and 4 pieces of equipment)

Safety zone radius = 4 x 20 + 24
= 80 + 24
= 104
= 104 ft for the morning period and (140+24 due to the expected taller flames) or 164 ft in the afternoon.

Using the simplified equation:

Safety zone radius = 4 x flame height + 20 + 4 x (# crews) + (# of pieces of equipment)

Safety zone radius = 4 x 20 +20 + 4 x 1 + 4
= 80 + 20 + 4 + 4
= 108 ft for the morning and 168 ft (140 + 28) during the afternoon.

You can now tell your crew boss that the safety zones need to be big enough to allow the firefighters to be more than 100 feet from the flames in the morning and more than 160 feet from the flames in the afternoon. For a circular safety zone, these distances would be the circle's radius.

Introduction to Wildland Fire Behavior Calculations, S-390

Unit 6 – Fire Growth

Lesson A – Plotting Fire Size and Shape

OBJECTIVE:

Upon completion of this lesson, students will be able to:

- Given an active wildland fire situation, plot on a map the predicted perimeter, shape, and area of a fire originating from a point source.

I. PLOTTING FIRE SIZE AND SHAPE

A. Area and Perimeter Predictions and Shape Patterns

Fire perimeter, area, and shape may be calculated from a point source using effective wind speed and spread distance.

1. What information is needed for fire perimeter and area calculation?

   a. Effective mid-flame wind speed and spread distance.

   b. Effective mid-flame wind speed is derived from combining the effects that slope and mid-flame wind have on the fire front.

2. Where do you get the effective mid-flame with speed?

   In the lower left quadrant of the surface fire nomogram, or the following guideline for effective wind speed calculation:

   - Mid-flame wind speed (in mph) plus 1 mph per 20% increase in slope.

3. Spread distance – this is the product of ROS multiplied by the projection time.

B. Solving for Fire Area and Perimeter

1. Appendix B of the Fireline Handbook.

2. Follow the matrix – effective wind speed across the top and spread distance down the left column.

EXERCISE 1:

A test fire is started at 1400 hrs. The ROS is estimated at 8 ch/hr with an effective MFWS of 5 mph.

Solve:
Fire perimeter and area at 1430 and 1500.

EXERCISE 2:

A 900-acre size wildland burn is desired in fuel model 3 in a flat riparian marsh. Normally, the relative humidity rises to a level by 1900 in August so that the fire's spread will halt. Average afternoon conditions are: 20-foot wind speed is 7 mph, relative humidity is 25 to 29%, and dry bulb temperature is 80 to 90°. Assume 1600 for fuel moisture calculations.

Solve: Use nomograms and/or tables to determine the time that the fire should be lit to allow for a 900-acre fire at 1900 allowing free burning to occur.

C. Fire Shapes

1. Calculate the effective wind speed for the fire.

2. Appendix B of the Fireline Handbook - find the appropriate shape of the fire using the effective wind speed.

D. Plot the Ellipse on a Map

1. Mark the point of origin on the map.

2. Draw a line indicating the direction of the slope.

3. Measure the spread distance on the map and mark the furthest point from the point of origin.

4. Using Appendix B of the Fireline Handbook, find the appropriate shape of the fire using the effective wind speed.

5. Draw the shape of the fire on the map.

EXERCISE 3 – FIRE SHAPE

Use the information below and the map on the next page to complete the exercise.

Inputs:

ROS = 15 ch/hr
PT = 2 hrs
EWS = 8 mi/hr

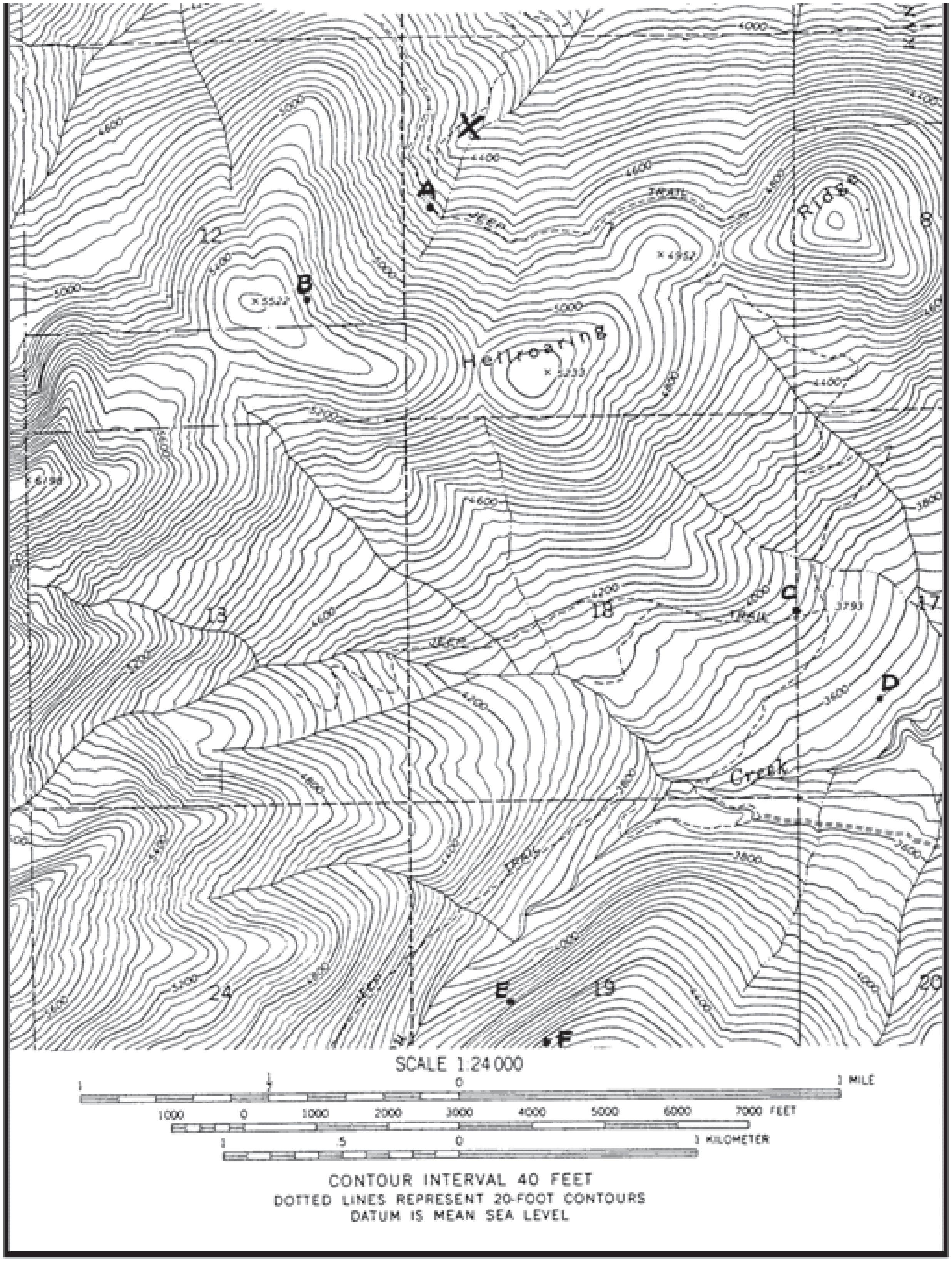
MAP SPREAD WORKSHEET

<u>INPUT</u>

0	Projection Point	______	______	______
1	Rate of Spread, ch/hr	______	______	______
2	Projection Time, hr	______	______	______
3	Spread Distance, ch (line 1 x line 2)	______	______	______
4	Spread Distance, ft (line 3 x line 66 ft/ch)	______	______	______
5	Map Scale	______	______	______
6	Conversion Factor, ft/in (see map scale conversion)	______	______	______

<u>OUTPUT</u>

1	Map Spread Distance, in (line 4 divided by line 6)	______	______	______


X
A
B
C
D
E
F
12
13
17
18
19
20
24
Hellroaring
Ridge
Creek
TRAIL
JEEP
SCALE 1:24 000
1 MILE
7000 FEET
1 KILOMETER
CONTOUR INTERVAL 40 FEET
DOTTED LINES REPRESENT 20-FOOT CONTOURS
DATUM IS MEAN SEA LEVEL

Introduction to Wildland Fire Behavior Calculations, S-390

Unit 6 – Fire Growth

Lesson B – Point Source

OBJECTIVES:

Upon completion of this lesson, students will be able to:

1. List the situations where basic fire behavior and point source projections are appropriate.

2. Identify concepts, limitations, and assumptions for Point Source.

I. SITUATIONS WHERE BASIC FIRE BEHAVIOR AND POINT SOURCE PROJECTIONS ARE APPROPRIATE

Point source refers to a fire that is very small at origin in relation to its size at the end of the burning time.

The fire spread occurs from a "point" or "spot" as opposed to a line of fire, such as:

- Lighting strike
- Spot fire
- Prescribed fire ignition points

The fire spreads in a relatively constant fire environment where:

- Fuel and fuel moistures are constant
- Weather conditions are constant
- Topography is constant

II. CONCEPTS, LIMITATIONS, AND ASSUMPTIONS FOR POINT SOURCE

A. Basic Assumption

Point source can only be used when:

1. The fire is originating from a point source and burning on flat ground or straight upslope.
2. The wind is blowing in the direction of maximum slope plus or minus 30°.
3. The period of burning time is usually short, up to 1 hour, but could be longer.

4. Calculations of fire area and perimeter with effective mid flame wind speeds less than 2.5 mph are generally too low.

   Better predictions result with wind speeds greater than 2.5 mph because the shape of the fire will probably be more uniformly controlled by the stronger wind speed.

5. Fire perimeter and shapes are based on smooth ellipses. The actual perimeter of the fire edge would likely be a greater length and follow topographic relief.

6. All the assumptions made in fuel models, the fire behavior model, and the application of the fire behavior model, are made in this procedure.

B. Uses of Point Source Predictions

Keeping in mind the assumptions and limitations of the models, tables, charts, and other tools used in calculating point source predictions, the following could be useful in fire behavior outputs, perimeter, area, and shape predictions.

- Crew locations
- Equipment locations
- Helispot locations
- Fuel break locations
- Development of the Wildland Fire Situation Analysis (WFSA)

1. Pre-suppression planning

    a. Personnel requirements.

    b. Need for retardant before the fire can be staffed.

    c. Attach priorities in multiple-fire situations.

2. Prescribed burning

    a. Distance between point ignitions to accomplish the objective.

    b. Calculating timing of ignition to take advantage of diurnal weather patterns (humidity recovery).

    c. Managing wilderness fires.

    d. Development of the escaped fire contingency plan.

POWERPOINT EXERCISE 1:

Given: A prescribed burn escapes at 1200 hours in fuel model 5.

Inputs:

- Fine fuel moisture is 5%
- Mid flame wind speed 4 mph
- Slope 35%
- Live fuel moisture is 100%
- A patrol with hand tools will arrive by 1230.
- A dozer can be on the fire by 1300.

Use nomograms and/or tables to solve.

What will rate of spread, flame length, fire perimeter and area be when:

- The patrol arrives:

- The dozer arrives:

POWERPOINT EXERCISE 2:

Given: A wildfire starts on September 1 at 1200. The ignition point is shown on the map.

Inputs:

- Fuels – model 2
- Live fuel moisture 150%
- Temperature 89°
- RH 30%
- Dead fuel moisture – use table. Assume the readings were taken at your location.
- 20 foot winds SW at 12 mph

Use nomograms and/or tables to solve.

Calculate area and perimeter of the fire by 1300.

Sketch approximate shape of the fire at 1300.

Plot fire behavior outputs on a fire characteristics chart.

Introduction to Wildland Fire Behavior Calculations, S-390

Unit 7 – Extreme Fire Behavior

OBJECTIVES:

Upon completion of this unit, students will be able to:

1. Describe environmental conditions and key indicators under which crown fires are likely to occur.

2. Describe the characteristics of plume dominated fires.

3. Describe the reverse wind profile and effects on fires.

4. Describe pyrocumulus cloud development.

5. Describe the warning signs and the potential hazards of a collapsing column.

I. ENVIRONMENTAL CONDITIONS AND KEY INDICATORS UNDER WHICH CROWN FIRES ARE LIKELY TO OCCUR

A. Crown Fire

Crown fire is a critical element of overall fire behavior. Increased fire intensity is typically experienced after the transition.

B. Favorable Conditions for Crown Fire

- Dry fuels
- Low humidity, high temperatures
- Heavy accumulations of dead and down fuels.
- Ladder fuels such as conifer reproduction and brush.
- Steep slopes
- Strong winds
- Instability in the atmosphere.
- High percentage canopy cover and continuous forest cover.

These conditions will vary over time and space.

Their interaction can cause an increase in intensity of the surface fire where the flames will reach the crowns and the foliage will ignite.

This will create torching and spotting. As this activity increases the stage is set for an active crown fire.

Crown fires can be either wind driven or plume dominated.

C. Canopy Bulk Density and Crown Fire

- Canopy bulk density is an important factor affecting crown fire occurrence.

- Canopy bulk density is the amount of needles and small twigs per unit of volume.

- Canopy bulk density is analogous to fuel load in surface fuels.

D. Crown Fire Initiation

C. E. Van Wagner's research into crown fire in Canada shows that crown fire initiation can be boiled down to essentially three major components.

1. Crown fire is a function of:

   - Canopy base height
   - Surface fire intensity
   - Foliar moisture content

2. Van Wagner's Crown Fire Initiation Model

   Foliar Moisture Content (FMC) has only a small effect on crown fire initiation relative to Canopy Base Height (CBH) and Fireline Intensity (flame length).

   For most purposes, assume a FMC of 100% is good.

   The flame height = base height is included to show how the flame heights above 6 feet do not need to be actually touching the crowns to ignite them. This is a function of the heat output of the fire.

E. Types of Crown Fire

- Passive – individual trees torching.
- Active crown fire – is actively burning and advancing with the surface fire.
- Independent – very rare; crown fire burns independently of the surface fire.

F. Crown Fire Cessation

Occurs when the spread rate through crowns falls below critical thresholds due to the following factors:

- Reduced windspeed
- Lower canopy bulk density
- Reduction in slope
- Increase in fuel moisture
- Increase in canopy base height
- Reduced surface fuels

II. CHARACTERISTICS OF PLUME DOMINATED FIRES

A. Description of Plume Domination

Plume domination occurs when the energy release of the fire is great enough to overpower its environment.

- It is associated with relatively low windspeeds. The 20 foot windspeeds are usually less than 20 mph.

- Atmospheric conditions such as reverse wind profile can make the atmosphere conducive to plume domination.

- A fire can change from wind driven to plume dominated and back again dependent on environmental conditions.

- Although plume domination is often mentioned, it is a very rare event.

B. Characteristics of Plume Dominated Fires

- Strong convection column towering directly over the fire – not leaning over before the wind.

- Pyrocumulus cloud development over the fire – with no downwind drift of the cloud.

- Very high intensity fire.

C. How Plume Dominated Fires Spread

There are at least two mechanisms for movement:

1. Momentum from the column – the column keeps building on itself, increasing intensity and spreading outwards.

2. Downburst of winds blowing outward near the ground from the bottom of a convection cell (pyrocumulus).

The spread of both of these can be extremely dangerous, fast moving, and erratic in direction.

III. REVERSE WIND PROFILE

The reverse wind profile is the occurrence of winds decreasing in speed in the atmosphere as the altitude increases.

"A reverse wind profile allows a strong vertical column to develop directly over the fire without being sheared away by winds aloft."
– Richard C. Rothermel, 1991.

For the purpose of this class, reverse wind profile will be defined as:

Any weather pattern that results in the surface winds (or jet point winds) being higher than the winds aloft.

A. Necessary Wind Conditions

- Surface winds of approximately 10-24 mph.

- Jet point winds within 1,000 to 2,500 feet of the surface of 18-28 mph.

- Lower wind speeds in the layers above these.

This can happen at various times. Some examples are:

- Pre or post cold front passage.
- In late afternoon or evening when winds start stabilizing from the surface up.
- When thermal surface troughs develop.

1. Daytime
   - Daytime – jet point within 100 feet of ground or missing (most dangerous, least common).
   - This is the most dangerous, but the least common.
2. Late afternoon and night
   - Jet point within 1,000 to 2,500 feet of fire.
   - Second most dangerous, more frequent.

B. Reverse Wind Profile

Rare but potentially lethal.

- 1976 survey of 62 fires only showed this happening in 8% of the fires.
- Butte Fire – 73 shelter deployments.
- Mack Lake Fire – one fatality.
- 2002 in Colorado – this weather pattern was a frequent occurrence that coincided with their largest fire season in history.

IV. PYROCUMULUS CLOUD DEVELOPMENT

Pyrocumulus is a cloud development over a fire that closely resembles the development of a thunder cell. The differentiation is the method of lifting.

A. Pyrocumulus

1. The heat of the fire produces the lifting for pyrocumulus development.

   Normal cumulus development is caused by three processes:

   - Orographic (terrain)
   - Frontal (cold front moving under a warmer layer)
   - Thermal (heat from the surface of the earth)

2. Any intense wildland fire can produce a pyrocumulus cloud.

3. Pyrocumulus development does not necessarily mean plume domination.

4. Intense wind driven fires also produce pyrocumulus clouds

5. Wind driven pyrocumulus drift downwind of the fire.

B. Incipient Phase

Phase where heat from fire is building enough to produce a convective column and the beginning of a cloud is forming.

C. Pyrocumulus Building Thunder Cell (the mature stage)

More heat, larger convective column, continues inflow from bottoms and sides of the cloud/column.

D. Pyrocumulus / Thunder Cell Dissipation / Downdrafts

Downbursts from the mature and dissipating stages of a pyrocumulus cloud can be extremely dangerous.

Downbursts come from outflow from the bottom of the convection cell and can have very strong winds. Winds such as these occurred on the Dude Fire in 1990 when six firefighters were killed.

E. Pyrocumulus Dissipation

- Most intense wildland fires produce a pyrocumulus cloud.

- Most pyrocumulus clouds move with the wind away from the fire – wind driven.

- Most pyrocumulus clouds dissipate without the outflow affecting the fire.

- For those that stay over the fire (plume dominated) then the dissipation can become a convection column collapse. This is a very dangerous event.

V. COLLAPSING CONVECTION COLUMN

One of the major hazards with a plume dominated fire is the collapse of the convection column and its associated pyrocumulus cloud. Warning signs of a potential convection column collapse:

- Rapid development of a strong convection column.
- Anvil head forming on the pyrocumulus.
- Virga or any precipitation.
- Calm created when inflow winds have subsided – outfow winds may soon begin.

A. Column Collapse (extremely hazardous)

- Outflow of winds from dissipating column and pyrocumulus cell.
- The winds can be greater than 60 mph, and spread horizontally at ground level – up and down hill.
- Topography can funnel these winds changing direction and increasing the windspeed.
- Can cause unanticipated spotting of the fire.
- Contributed to six fatalities on the Dude fire in 1990.

B. Plume Reading

What do we see? What does it mean on the ground?

What to look for:

1. Smoke color

   - Light = dead dry or light fuels
   - Dark = live fuels

2. Smoke volume

   - Light = low intensity
   - Dense = high intensity

3. Drift smoke

   - None = initial run, unstable air
   - Vertical angle = wind driven, direction of spread

4. Column height

   - High = high intensity, possible plume domination, pyrocumulus
   - Moderate = new run, moderate intensity
   - Low = low intensity, light fuels

Identify what the smoke plumes are telling you.

PLUME READING EXERCISE.

Record the plume description for each photo.

PLUME #1 DESCRIPTION:

Division fire in 1996 from 25-30 miles away in Jackpot, Nevada. Shows both the wind driven convection column and the building pyrocumulus at higher altitude. This is about one hour prior to it becoming plume dominated. Fuels burning were pinyon-juniper and sagebrush.

Smoke Color:

Smoke Volume:

Drift Smoke:

Column Height:

Pyrocumulus:

PLUME #2 DESCRIPTION:

Picture from West Yellowstone during 1988, showing the pyrocumulus buildup during a wind driven event.

Smoke Color:

Smoke Volume:

Drift Smoke:

Column Height:

Pyrocumulus:

PLUME #3 DESCRIPTION:

From the angle of the sunlight and shaded ridge, it is late afternoon; just when the atmosphere starts to stabilize and winds aloft start dying down. Also, the three prominent puffs of cumulus are normal parts of any strong convection column. The frequency of their puffing is predictable and part of the fluid dynamics of the cloud.

Smoke Color:

Smoke Volume:

Drift Smoke:

Column Height:

Pyrocumulus:

PLUME #4 DESCRIPTION:

Sagebrush and grass on the lower slopes transitioning to pinyon-juniper on the upper slopes.

Smoke Color:

Smoke Volume:

Drift Smoke:

Column Height:

Pyrocumulus:

PLUME #5 DESCRIPTION:

From the angle (too close to the fire) cannot tell if it is plume dominated or not, it has the potential. It looks like updrafts are causing the interesting smoke. The part of the column towards the top and sides of the image are curling back into the strong updraft in the center. This is a normal fluid dynamics feature of fires with a strong convection column.

Smoke Color:

Smoke Volume:

Drift Smoke:

Column Height:

Pyrocumulus:

PLUME #6 DESCRIPTION:

Cerro Grande fire in 2000. A good illustration of the high winds that effected fire growth.

Smoke Color:

Smoke Volume:

Drift Smoke:

Column Height:

Pyrocumulus:

PLUME #7 DESCRIPTION:

Clear Creek Complex in Montana in 2000.

Smoke Color:

Smoke Volume:

Drift Smoke:

Column Height:

Pyrocumulus:

PLUME #8 DESCRIPTION:

South Cricket Complex in Nevada in 2000. Fire activity is just picking up as the inversion is starting to break up. Smoke column is building a couple of thousand feet then hitting the remaining inversion layer and rolling back down. The atmosphere is still stable.

Smoke Color:

Smoke Volume:

Drift Smoke:

Column Height:

Pyrocumulus:

Introduction to Wildland Fire Behavior Calculations, S-390

Unit 8 – Documentation, Briefings, and Monitoring for Fireline Safety

OBJECTIVES:

Upon completion of this unit, students will be able to:

1. Identify weather, fire behavior, and fuels information requiring documentation.

2. Identify critical environmental and fire factors for monitoring.

3. Identify fireline briefing needs.

I. INTRODUCTION

Accurately recording fire behavior and fire weather are critical factors in formulating safe and effective operation plans on wildland fire incidents.

Fireline briefings must include these critical factors to be effective and to provide for firefighter safety.

There are four Fire Orders based on this critical information:

- Keep informed on fire weather conditions and forecasts.
- Know what the fire is doing at all times.
- Base all actions on current and expected behavior of the fire.
- Identify escape routes and safety zones, and make them known.

II. CRITICAL OBSERVATIONS

A. Critical Weather Observations

- Temperature – wet and dry bulb
- Relative humidity
- Dew point
- Wind speed and direction
- Cloud type and cloud cover

B. Critical Fire Behavior/Fuels Observations

- Flame length
- Rate of Spread
- Current fuel model
- Fuel model in areas of concern
- Continuity of fuels
- Freezekill and insect/disease areas

C. Critical Topographic Observations

- Aspect
- Slope
- Special features such as:
  - Chimneys
  - Chutes
  - Saddles

D. Documentation Forms

- Fire Weather Observer's Record
- Spot Weather Forecast

E. Fire Behavior/Topographic Documentation

- Use your notepad, map, and Unit Log.
- Make sure your observations are written down.

F. Fire Behavior Calculation Documentation

Use your Fire Behavior worksheet to document the expected:

- Rate of Spread
- Direction of Spread
- Flame Length
- Probability of Ignition
- Spotting Distance

III. FIRELINE MONITORING NEEDS

Specifics will vary from region to region and between fuel types. The basics are:

- Fire Weather – take the weather hourly or as it changes.
- Fire Behavior – record what the fire is doing through the day – when does it change?

Why monitor?

- Changes in weather often occur before the fire behavior changes.
- Changes in fire behavior often necessitate changes in tactics.
- Re-evaluate and reassess strategies and tactics based on these changes.
- Firefighter safety requires constant monitoring of environmental and fire behavior factors.

IV. FIRELINE BRIEFING NEEDS

A. Spot Weather Forecast

Fire Order #1 – Keep informed of fire weather conditions and forecasts.

B. Safety Zone Calculations

Fire Order #4 – Identify escape routes and safety zones and make them known.

C. Basic Fire Behavior Calculations

1. Flame length

2. Rate of spread

3. Probability of ignition

4. Spotting distances

Fire Order # 2 – Know what your fire is doing at all times.

Fire Order # 3 – Base all actions on current and expected behavior of the fire.

V. ELEMENTS OF A FIRELINE BRIEFING

- Current and expected weather
- Fuels and terrain
- Observed fire behavior
- Predicted fire behavior
  - Rate of spread
  - Flame length
  - Probability of ignition
  - Spotting distance
- Areas of highest concern
- Safety concerns
  - Safety zones
  - Fire behavior driven tactics

Introduction to Wildland Fire Behavior Calculations, S-390

Unit 9 – Final Group Exercise

OBJECTIVES:

Upon completion of this unit, students will be able to:

1. Prepare basic fire behavior calculations given basic information.

2. Give a basic fireline briefing.

Final Group Exercise

<u>Instructions:</u>

Refer to the Fireline Briefing Checklist on page 9.5. Everyone will present a briefing based on this checklist.

There will be four groups. Each group is responsible for completing the worksheets and presenting a briefing to the class and instructors on each part of their assigned exercise.

The elements of the briefing will include:

- Current and Expected Weather
- Fuels and Terrain
- Observed Fire Behavior
- Predicted Fire Behavior which includes:
  - Rate of Spread
  - Direction of Spread
  - Flame Length
  - Probability of Ignition
  - Spotting Distance
- Areas of Highest Concern
- Safety Concerns which includes:
  - Safety Zones includes Safety Zone size
  - Fire Behavior Driven Tactics
- Map showing point source projections and safety zones

Grading/Points:

Each student must participate in the briefing for the group to receive all possible points.

- 3 points for a completed documentation package:
  - Current and expected fire behavior (½ point)
  - Current and expected weather conditions (½ point)
  - Safety issues (½ point)
  - Strategy and tactics (½ point)
  - Your point source prediction plotted correctly on the map (1 point)

- 2 points for the presentation:
  - If all the basic information is covered, you receive 2 points. Everyone in the group needs to participate. The entire group will lose 1 point for each person not participating in either Part 1 or Part 2 Briefing.

Part 1

After receiving Part 1, you will have approximately 40 minutes to complete your documentation package. You will then have 5 minutes to "Brief" the resources on scene.

Part 2

After receiving Part 2, you will have approximately 40 minutes to complete your documentation package. You will then have 5 minutes to "Brief" the resources on scene.

Each group needs to fill out a "Spot Weather Forecast Request." As soon as it is turned in to the mentoring instructor or the meteorologist, you will receive the actual spot weather forecast.

Fireline Briefing Checklist

- Fire behavior forecast or notes
- Fire weather forecast or notes
- IAP if available
- Map of the area(s) to be discussed (if available)
  - * Big enough for your audience to read

1. Don't read directly off the forecasts, discuss only the highlights.
2. Be brief but concise.
3. Emphasize any areas of concern:
   - * Fireline safety
   - * Fire behavior
   - * Weather conditions
   - * Topographic influences
4. Use the map to correlate discussion points.
5. Be ready to answer questions or discuss concerns.
6. Don't guess! If you don't know just say so!