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Fire characteristics charts for fire behavior and U.S. fire danger rating

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Abstract
The fire characteristics chart is a graphical method of presenting U.S. National Fire Danger Rating indices or primary surface or crown fire behavior characteristics. A desktop computer application has been developed to produce fire characteristics charts in a format suitable for inclusion in reports and presentations. Many options include change of scales, colors, labels, and legend. The fire danger fire characteristics chart displays the relationship among SC, ERC, and BI by plotting the three values as a single point. A chart can be used to compare years, months, weather stations, and fuel models. Indices calculated by FireFamilyPlus can be imported into the fire characteristics chart program. Surface and crown fire behavior charts are separate because a different flame length model is used for each. Plotted values can be observed rate of spread and flame length or calculated values from a program such as the BehavePlus fire modeling system. The charts can aid fire model understanding by comparing, for example, the effect of a change in fuel model or wind speed on fire behavior. Other applications include fire documentation, prescribed fire plans, and briefings.

Additional keywords: Energy Release Component, Spread Component, Burning Index, rate of spread, fireline intensity, flame length, heat per unit area, computer program

Introduction

The fire characteristics chart is a graphical method for presenting either U.S. National Fire Danger Rating System (NFDRS) indices (Spread Component [SC], Energy Release Component [ERC], and Burning Index [BI]) or primary surface and crown fire behavior characteristics rate of spread (ROS), flame length (FL), and heat per unit area (HPUA).

Fire behavior fire characteristics charts are useful as a communication aid for displaying the character of a fire based on spread and intensity values that are either calculated or observed. The fire danger chart illustrates the relationship among indices that are often considered separately.

The surface fire behavior and the fire danger fire characteristics charts were presented by Andrews and Rothermel (1982). Rothermel (1991) developed a fire characteristics chart for crown fire. Those charts were designed primarily for plotting by hand. While some aspects of fire characteristics charts are available in computerized systems such as BehavePlus, FARSITE, and Nexus, a general purpose application has not been available.

A desktop computer program has been developed to produce fire characteristics charts in a format suitable for inclusion in reports and presentations. The fire behavior application is documented in (Andrews, Heinsch *et al.* 2011). A similar publication for fire danger rating will also be available. Those papers include operating instructions and example applications as well as the mathematical modeling foundation. This paper provides an overview with examples.

The fire characteristics chart program does not include calculation of fire danger indices or fire behavior values, but rather displays values obtained elsewhere. Fire danger indices produced by FireFamilyPlus can be imported directly into the fire characteristics chart program. Fire behavior values can be calculated using a program such as the BehavePlus fire modeling system (Andrews 2007), or observed fire behavior values can be plotted.

The program offers options that allow formatting to suit the application at hand. A user can, for example, change axis scales, use multiple colors, and add point labels and legends. While we use English units in these examples, metric units are available in the program.

The fire characteristics chart program and associated documentation can be found in the BehavePlus section of http://www.FireModels.org.

Fire danger fire characteristics chart

The U.S. National Fire Danger Rating System is used for pre-fire management applications such as fire prevention and suppression readiness. NFDRS is comprised of components and indices based on seasonal fire weather data. A fire danger rating fire characteristics chart can be used to compare indices from multiple years, months, weather stations, or fuel models.

The fire danger chart displays the relationship among SC, ERC, and BI by plotting the three values as a single point. The chart is possible because BI is derived from SC and ERC according to the following relationship:

$$BI = \left[\frac{ERC \times SC}{0.091}\right]^{0.461} \qquad (1)$$

SC, based on the spread rate model, is strongly impacted by wind speed, and can vary greatly from day-to-day. ERC, on the other hand, is based on the model for heat per unit area with weighting on the heavy fuels and does not include the influence of wind. ERC is driven by fuel moisture, particularly 1000-h fuel moisture (if heavy dead fuels are present in the selected fuel model), providing a seasonal look at fire danger. BI, which is derived from the flame length model, is a combination of the two components, combining the underlying seasonal trend of ERC with the daily fluctuations in SC. The fire characteristics chart can be used for comparing indices.

Among the applications of the NFDRS fire characteristics chart is communication and comparison of the level of fire danger. Andrews and Rothermel (1982), presented the example of a hypothetical briefing to describe the general fire season to an audience that included those not familiar with NFDRS. We have updated their chart as shown in Fig. 1. They wrote:

The fire danger of most of the west side of the region is low as indicated by point A, although there are a couple of districts that may cause problems (point B). Point C refers to the fire danger on the east side of the region. If we have another week of dry weather, the situation on the east side could become critical (point D).

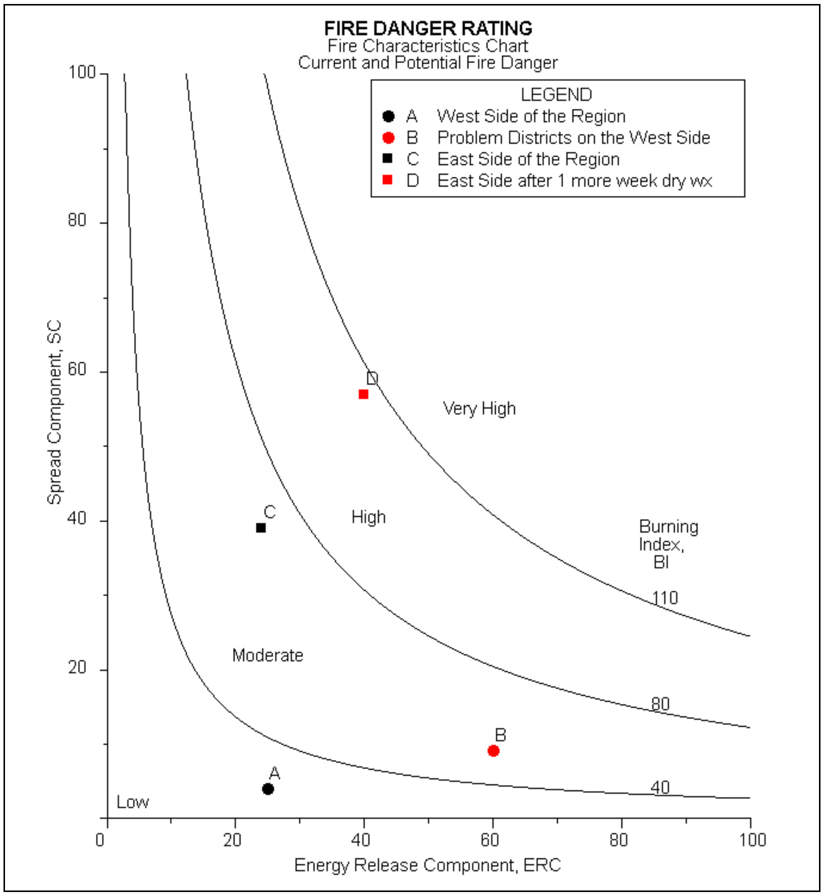

Fig. 1. An NFDRS fire characteristics chart that might accompany the hypothetical briefing outlined in the text (based on Andrews and Rothermel 1982).

The original fire characteristics concept was developed for a few points to be plotted on paper by hand. The program we describe here allows for hundreds of points to be plotted, using files imported directly from FireFamilyPlus. In the following examples, weather data for Remote Automated Weather Stations (RAWS) were obtained from the Fire and Aviation Management Web Applications website (http://fam.nwcg.gov/fam-web/). FireFamilyPlus version 4.1 was used to calculate indices. The **Weather > Season Reports > Daily Listing** function was used to export SC and ERC. BI is calculated by the fire characteristics chart application using equation 1. Relevant fire data from the U.S. Forest Service and National Park Service were also obtained from the Fire and Aviation Management Web Applications website. These data were imported into FireFamilyPlus, associated with the appropriate RAWS, and summarized.

Fire characteristics charts can be used to explore the relationship between fire activity and NFDRS indices. The indices on the discovery date of the largest nine fires (>1,000 acres) on the Nine Mile Ranger District (MT) from 1980-2009 were compared with NFDRS values from the Ninemile RAWS station for all days during that time period. The resulting graph (Fig. 2) indicates a relationship between large fires and high ERC values. Eight of the nine fires were reported on a day with ERC > 60.

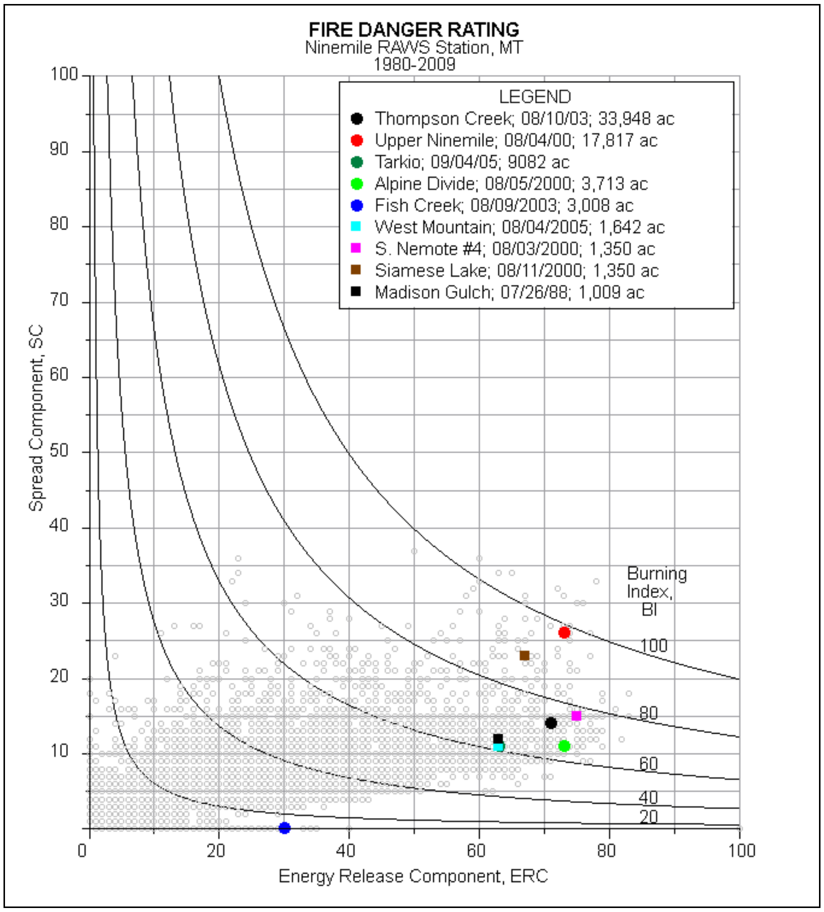

Fig. 2. Indices from the Ninemile RAWS (1980-2009) and discovery day indices for the nine largest fires on the Nine Mile District.

Seasonal plots of NFDRS indices can be supported by an associated fire characteristics chart. Fig. 3 demonstrates the fire season for the Missoula RAWS (MT) in 2000. Data from FireFamilyPlus were separated into two-month periods and imported into the chart program. Each file can be identified using a specific icon/color combination in the Fire Characteristics Chart program. Seasonal traces of SC, ERC, and BI were generated using other software to use corresponding colors. During 2000 the highest ERC values were found during July and August, months that are often the height of the fire season for the area. High values of SC in March and April are associated with the higher winds that typically occur during that time.

Fuel model selection has a great impact on fire danger indices. As described by Heinsch and others (2009) fuel models G and H are quite similar in the way that they reflect the fire season, although the magnitude of index values is quite different. Fuel model L, on the other hand, is comprised solely of fine fuel, resulting in indices that behave quite differently. In Fig. 4 NFDRS indices for Conroe, TX, were calculated for Fuel models G, H, and L, all using the same weather data. Fuel model G provides much more information about fire danger at Conroe as demonstrated in the wider range of values. Overlap between models G and H demonstrates their similarity. Fuel model L shows the high SC and low ERC values typical of grass fuel models.

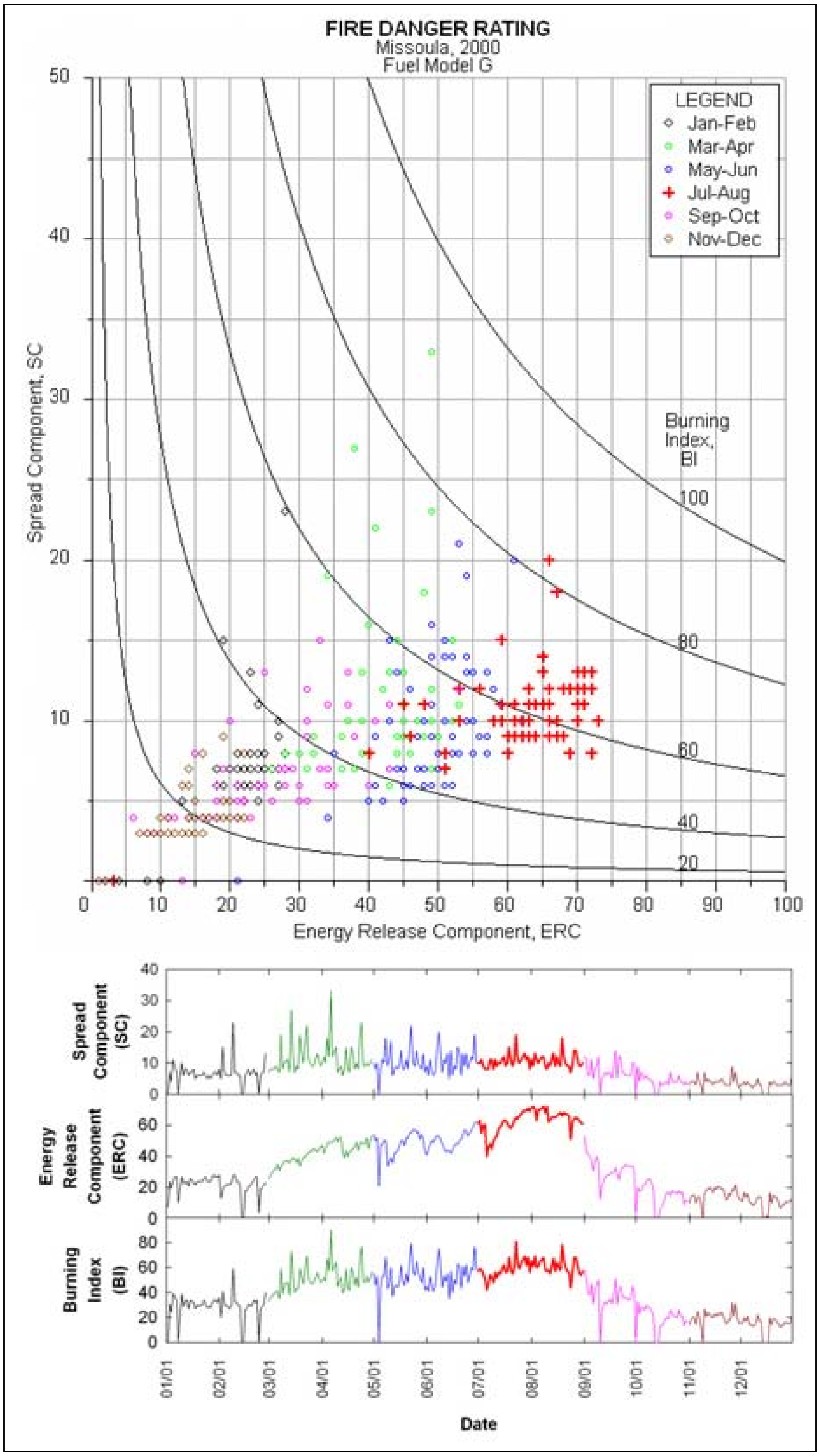

Fig. 3. Fire characteristics chart and corresponding seasonal traces for Missoula, MT, 2000.

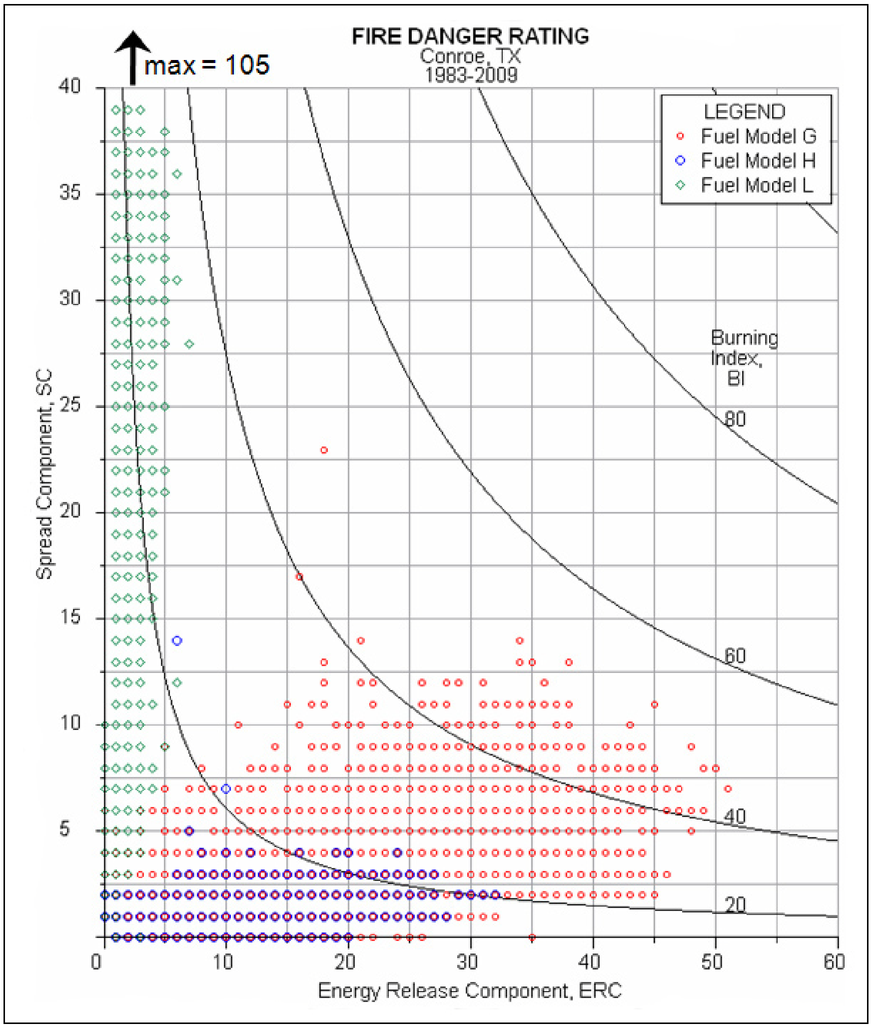

Fig. 4. Comparison of indices for fuel models G, H, and L calculated for the Conroe, TX, RAWS.

Comparison of interannual variability is an important application of fire danger rating. At the Mammoth, WY, RAWS in Yellowstone National Park (Fig. 5), data for July through August, 1988 (a very dry year; red) and 1991 (a relatively wet year; blue) are compared. Similar data from 1965-2009 (grey) are also plotted. The difference in fire danger for the two years becomes apparent through the difference in ERC. The large fires of 1988 were associated with higher values of ERC on the day they were reported (ERC > 80).

Proper use of fire danger rating indices is based on a climatological analysis. The fire characteristics chart can supplement the seasonal plots, percentile analysis, and relationship to fire activity available in FireFamilyPlus.

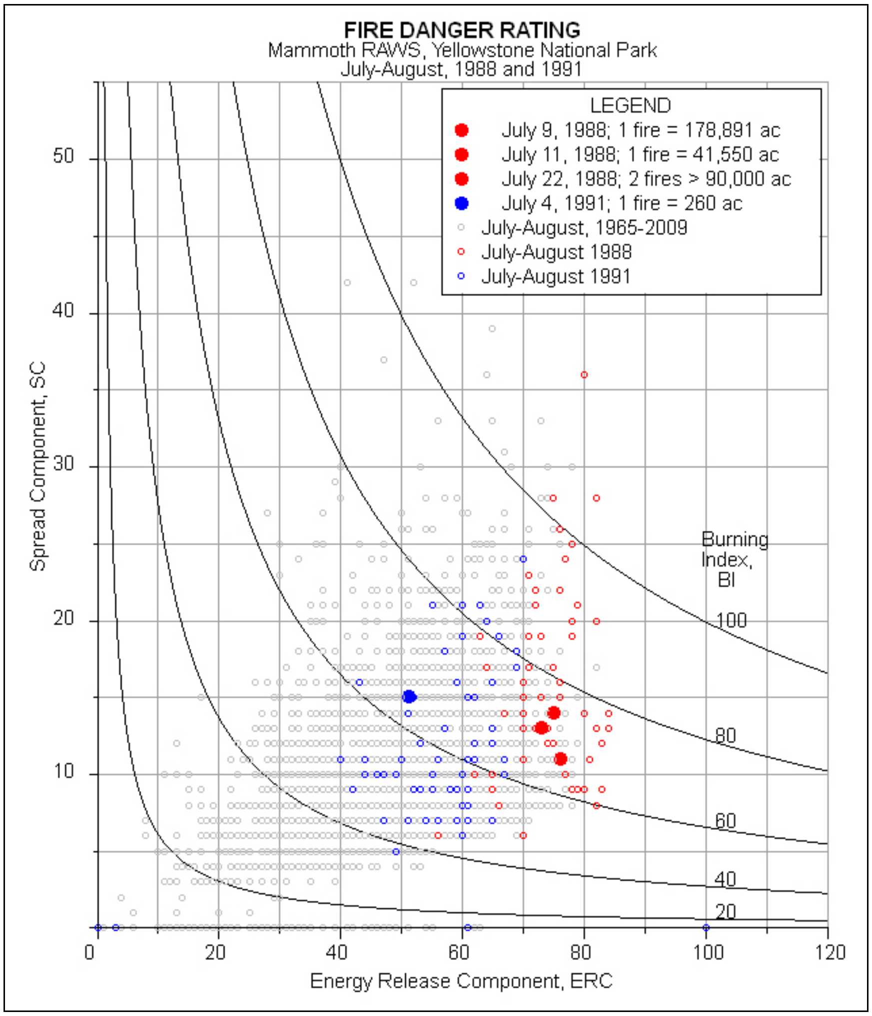

Fig. 5. Interannual variability is demonstrated at Mammoth, WY, for a very dry year (1988) and a fairly wet year (1991) compared to 1965-2009 indices.

Fire behavior fire characteristics charts

Fire behavior fire characteristics charts illustrate the relationship among primary fire behavior values—rate of spread (ROS), flame length (FL), and heat per unit area (HPUA). Two values, one of which must be ROS, are entered. The user can then input either FL or HPUA—the program will calculate the third value. These values can be either observed values or calculated using other software. For observed fire behavior a user will often input ROS and FL; HPUA will be calculated. Calculated fire behavior values were generated for the following examples using BehavePlus version 5.0. The following examples (and others) are given in more detail in Andrews and others (in press).

A fire characteristics chart can aid fire model understanding by comparing, for example, the effect of a change in fuel model or wind speed on fire behavior. Other applications include fire documentation, prescribed fire plans, and briefings.

Byram's (1959) fireline intensity model forms the basis of the fire behavior charts. Separate charts are used for surface and crown fire behavior charts because a different flame length model is used for each. Byram's (1959) flame length equation, based on fireline intensity, is used for the surface fire chart.

$$F_B = 0.45\, I_B{}^{0.46} \qquad (2)$$

where F_B is Byram's flame length (ft) and I_B is Byram's fireline intensity (Btu/ft/s).

The crown fire chart uses Thomas' (1963) flame length model.

$$F_T = 0.2\, I_B{}^{2/3} \qquad (3)$$

where F_T is Thomas' flame length (ft) and I_B is Byram's fireline intensity (Btu/ft/s).

The difference between the two flame length models is significant as shown in Fig. 6. Fireline intensity of 4000 Btu/ft/s is associated with surface fire flame length of 20 ft and crown fire flame length of 50 ft. For simplification, the curves on the fire behavior charts are labeled with flame length, not fireline intensity.

Flame length and fireline intensity are related to the heat felt by a person standing next to the flames. Table 1 is an interpretation in terms of suppression capabilities (National Wildfire Coordinating Group 2006; Rothermel 1983). Icons are available for the surface fire behavior chart and can be removed from the chart when the flame length curves no longer reflect the specific values for which they apply. Because crown fire exceeds all suppression activities, there are no icons on the crown fire behavior chart.

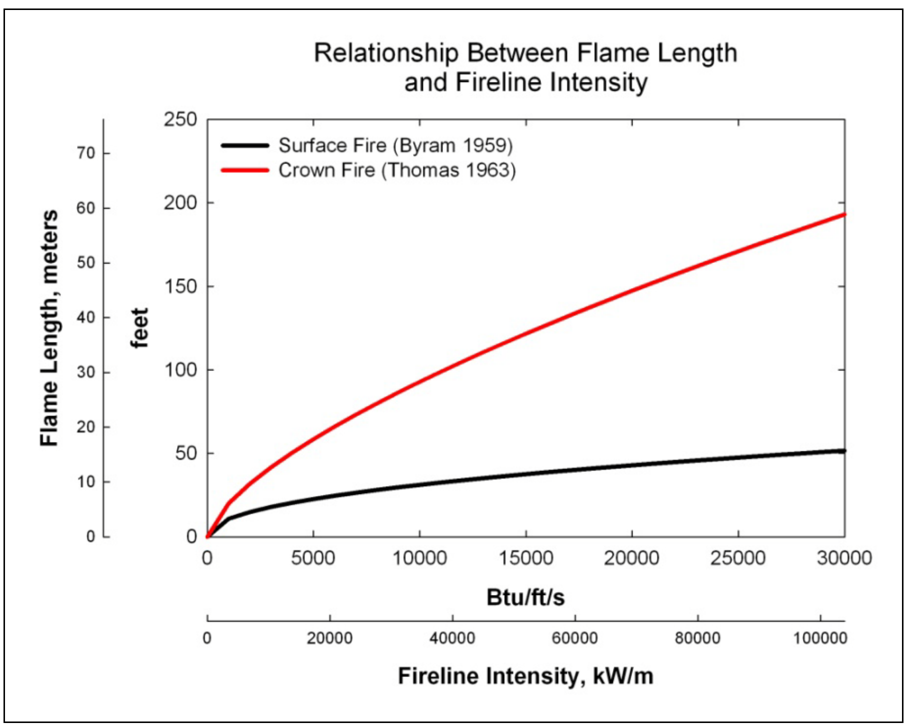

Fig. 6. Differences between Byram's and Thomas' flame length models are apparent as fireline intensity increases.

Table 1--Relationship of surface fire flame length and fireline intensity to suppression interpretations (Rothermel 1983).

Flame Length		Fireline Intensity			Interpretation
ft	m	Btu/ft/s	kJ/m/s		
< 4	< 1.2	< 100	<350		• Fires can generally be attacked at the head or flanks by persons using hand tools. • Hand line should hold the fire.
4 – 8	1.2 – 2.4	100 – 500	350 - 1700		• Fires are too intense for direct attack on the head by persons using hand tools. • Hand line cannot be relied on to hold the fire. • Equipment such as dozers, pumpers, and retardant aircraft can be effective.
8 – 11	2.4 – 3.4	500 – 1000	1700 - 3500		• Fires may present serious control problems -- torching out, crowning, and spotting. • Control efforts at the fire head will probably be ineffective
> 11	> 3.4	> 1000	> 3500		• Crowning, spotting, and major fire runs are probable. • Control efforts at head of fire are ineffective.

As an example of the value of the surface fire characteristics chart in displaying relationships, consider the effect of fuel model on calculated fire behavior. Fig. 7 demonstrates the differences for four fuel models (1, 4, 8, 10; Anderson 1982) with other conditions held constant: dead fuel moisture 5%, live fuel moisture 100%, midflame wind speed 7 mi/h, and slope 10%.

While the flame length is roughly the same for fuel models 1 and 10, the character of the two fires is very different. The fire in fuel model 1 (short grass) is fast spreading with a low heat per unit area, while the fire in fuel model 10 (timber litter and understory) is slow spreading with a high heat per unit area. A fire in fuel model 8 (short needle litter) has both a low spread rate and low heat per unit area. At the other extreme, fire in fuel model 4 (chaparral) is very fast spreading with high intensity.

Plotted points are circled for emphasis (added to our chart using other software) and might also serve as a reminder of the inherent variability of wildland fire and the limitations of fire modeling, including the fire models, fuel description, and/or model inputs.

Rothermel's (1972) surface fire spread model is based on the assumption that the fire is steady-state and burning under uniform conditions. While this might be appropriate for modeling the behavior of potential spot fires outside the unit, fire behavior on prescribed burns is often controlled by ignition pattern (Wade and Lunsford 1989). Such behavior can be illustrated on fire characteristics charts as described by Rothermel (1984). The chart can be included in prescribed fire burn plans to show the relationship between model results based on ambient weather and planned fire behavior affected by ignition pattern.

Fig. 8 shows calculated steady-state behavior based on the forecast zero wind speed as well as behavior that would result from 8 to 10 mi/h winds. The planned range of fire behavior, with induced winds of 8 to 10 mi/h is indicated on the chart by the large red oval. Flame length curves were changed from the default values on Table 1 and icons were removed from the chart.

In the final example application, observed crown fire behavior from the Sundance Fire (northern Idaho, 1967) is plotted on a crown fire behavior characteristics chart (Fig.9). Observed rates of spread and calculated fireline intensity were taken from Anderson (1968). Flame length values were calculated using Thomas' (1963) flame length model. This fire burned through mixed conifers, driven by winds of up to 45 mi/h, reaching spread rates of 6 mi/h. A prolonged dry spell, persistent high temperatures, sustained winds, and an uncontrolled 4-mi fire front led to a sustained major crown fire run on September 1, 1967 from 1400 to 2300 hours. During that 9 hour period, the fire traveled 16 miles, burning more than 50,000 acres. The sharp increase in ROS between 1900 and 2000 hours and the rapid decline by 2100 show the diurnal variability in fire behavior, even during a sustained major run.

Summary

The Fire Characteristics Chart program is useful for interpretation of fire behavior values or fire danger rating indices. Charts can effectively be used for communication in briefings, presentations, and reports. While features of the program may eventually be integrated into comprehensive systems, it is now a supplement to BehavePlus and FireFamilyPlus.

Dead fuel mois 5%, Live mois 100%, Midflame wind 7 mi/h, Slope 10%

Fuel Model	ROS (max) ch/h	Heat per Unit Area Btu/ft2	Fireline Intensity Btu/ft/s	Flame Length ft
1	196.6	92	333	6.5
10	14.1	1330	344	6.6
8	3.5	200	13	1.5
4	125.9	2712	6262	25.1

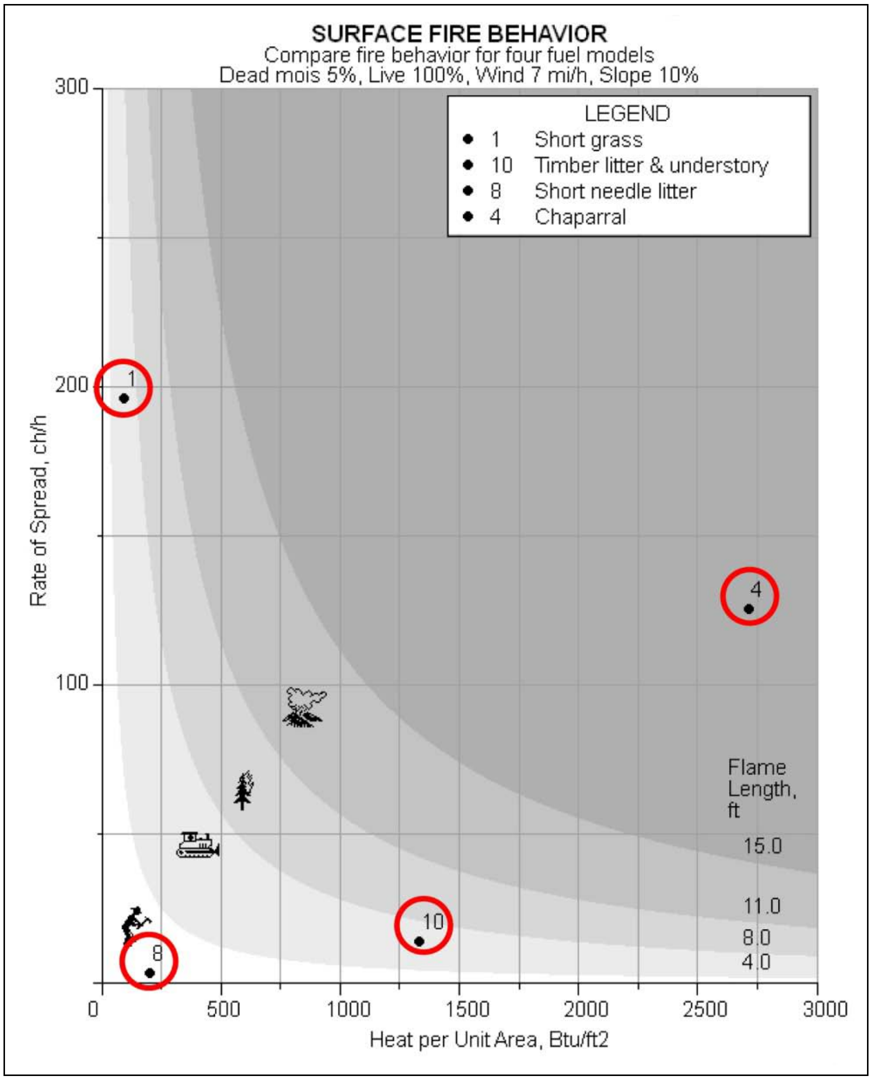

Fig. 7. Outputs from BehavePlus are plotted on the fire characteristics chart to illustrate the effect of fuel model.

Fuel model 5, Dead mois 6%, Live mois 90%, Zero slope

Midflame Wind Speed mi/h	ROS (max) ch/h	Heat per Unit Area Btu/ft2	Fireline Intensity Btu/ft/s	Flame Length ft
0	1.2	656	15	1.6
8	50.1	656	602	8.5
10	67.9	656	816	9.8

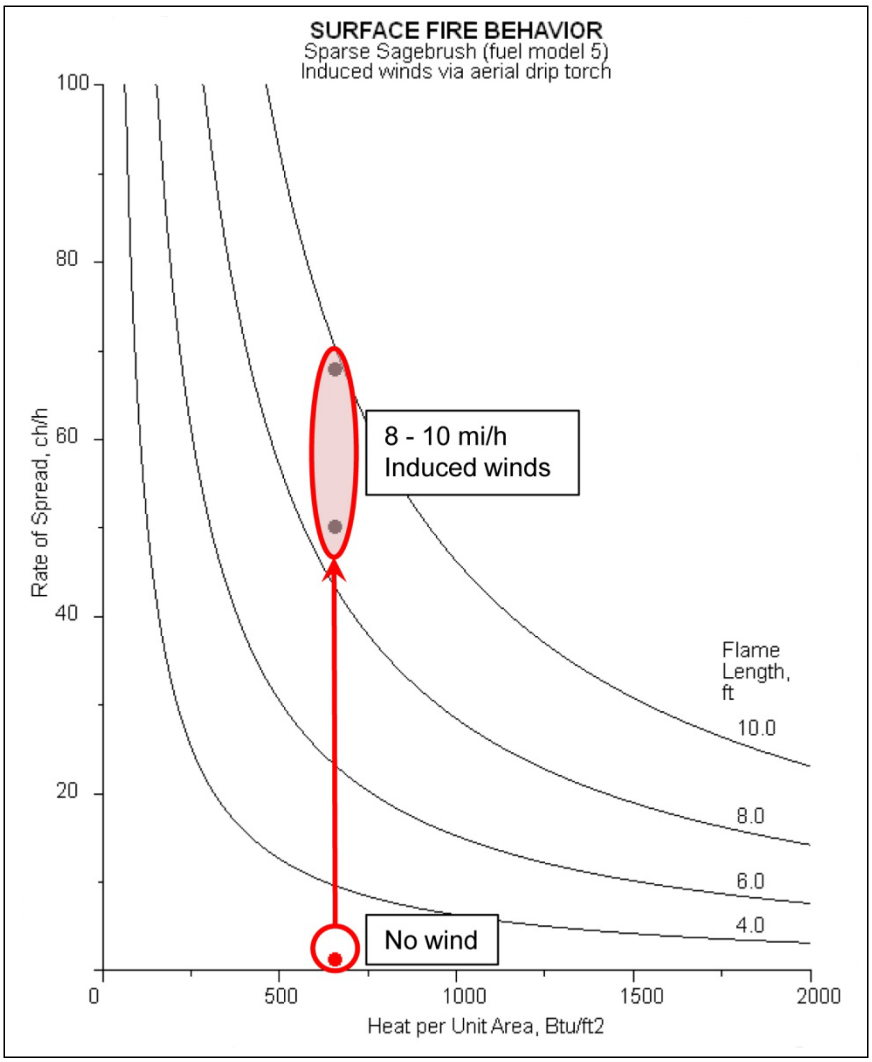

Fig. 8. Effect of induced wind on sagebrush fire characteristics (based on Rothermel 1984).

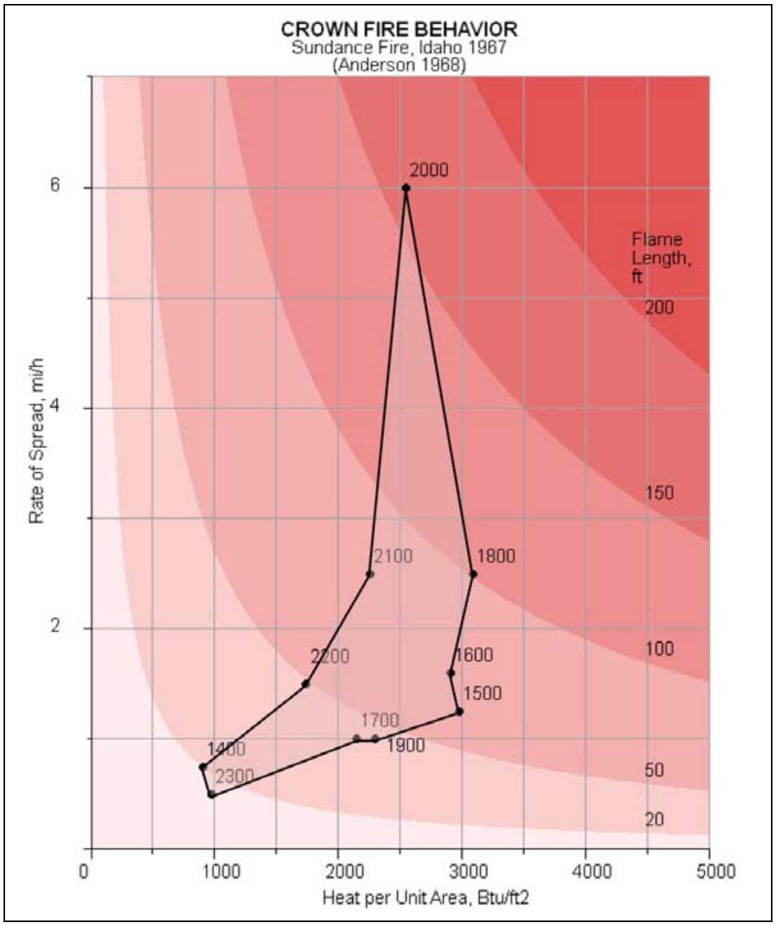

Fig. 9. Envelope of observed behavior for the Sundance Fire by time of day for September 1, 1967.

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