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HELP IN MAKING FUEL MANAGEMENT DECISIONS

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and
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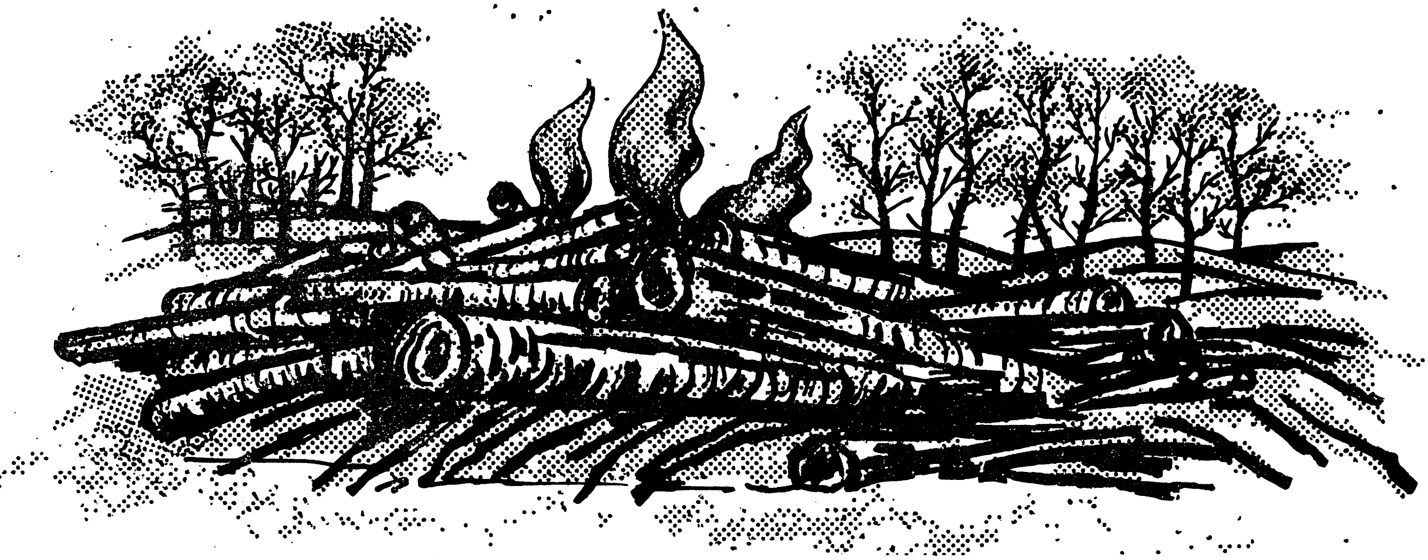

NORTH CENTRAL FOREST EXPERIMENT STATION
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HELP IN MAKING FUEL MANAGEMENT DECISIONS

Peter J. Roussopoulos and Von J. Johnson

Forest management activities such as cutting or thinning of timber for harvest, constructing roads, or clearing rights-of-way, generally leave large amounts of foliage and woody debris on or near the ground. Besides being unsightly and possibly jeopardizing various forest resources, this debris becomes potential fuel for forest fires. Fires in these surface fuel accumulations are generally difficult to control and can quickly spread into surrounding stands of valuable timber. When large amounts of debris are created by forest operations, it is often desirable to treat or remove it to protect forest and human resources from damage by fire. Whether treatment is actually needed, what to do, and when to do it, however, are decisions frequently made on a subjective or arbitrary basis.

To be more realistic and effective, such decisions should be based upon answers to these four questions:

1. What level of fuel hazard is the fire control organization prepared to handle?

2. What is the post-cutting slash hazard?

3. If the slash hazard exceeds what the control organization is prepared for, what can be done to reduce it to an acceptable level?

4. How should priorities for treatment be ordered when more than one area requires treatment?

Fuel hazard is an expression of the flammability of forest fuels.

To effectively manage fuel, then, decision-makers must be able to predict fuel flammability from what is known about the fuels themselves and local weather regimes. We have devised a method for making these predictions, thereby providing approximate answers to the four questions listed above. It permits comparing man-created fuel hazards with one of several fuel hazard "standards" used for fire control planning.

THE APPROACH

Anderson (1971) suggested using the Rothermel (1972) fire model to predict potential fire behavior for evaluating planned management practices in terms of fuel hazard, before the fact. The National Fire Danger Rating System (Deeming *et al.* 1972) is based on fire behavior predictions made by this model. Moreover, Rothermel and Philpot (1973) used the model to predict the flammability of chaparral, permitting land management consequences to be analyzed in terms of future fuel hazard. In slash fuels, Rothermel's predictions are reasonably accurate (Brown 1972), and they seem suitable for rating slash fuel hazard. Our system for managing North Central and Northeastern logging slash involves using Rothermel's model to construct a series of graphs that display fuel hazard for seven species of slash (figs. 1-7). They relate hazard to slash loading, depth, condition of foliage and local "average bad" weather conditions.

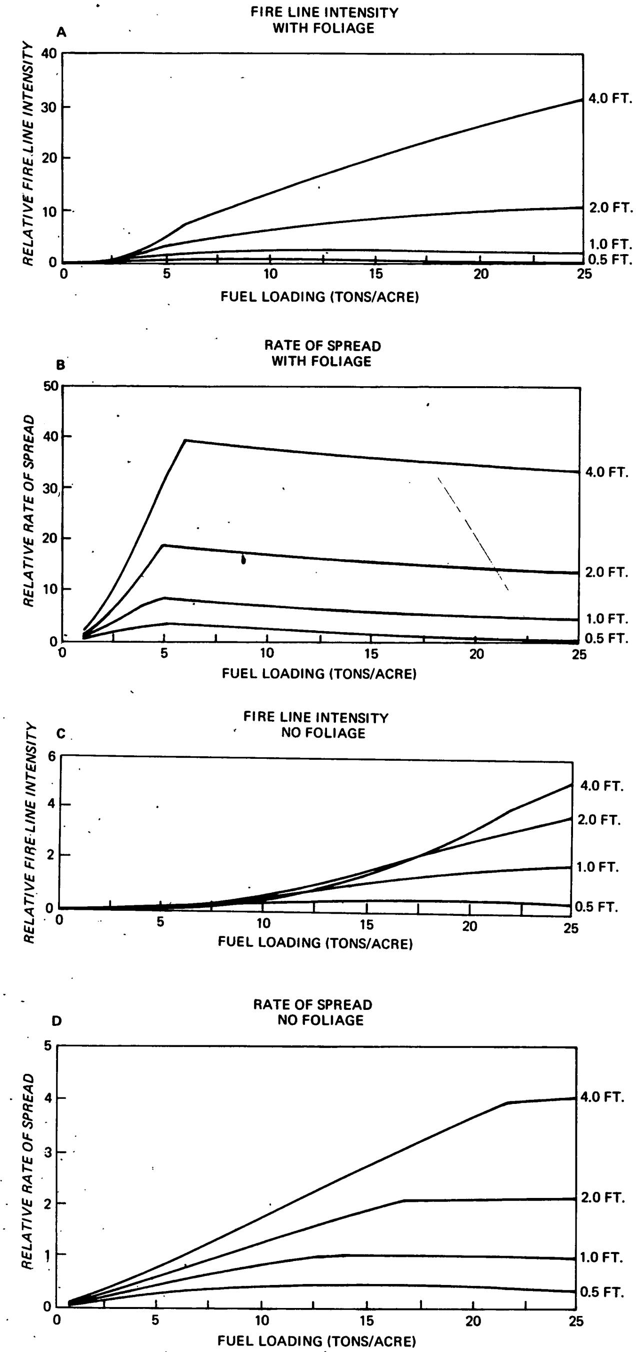


Figure 1.--*Relative fire line intensities and rates of spread for jack pine slash: wind = 14 mi/h; moisture content = 6 percent.*

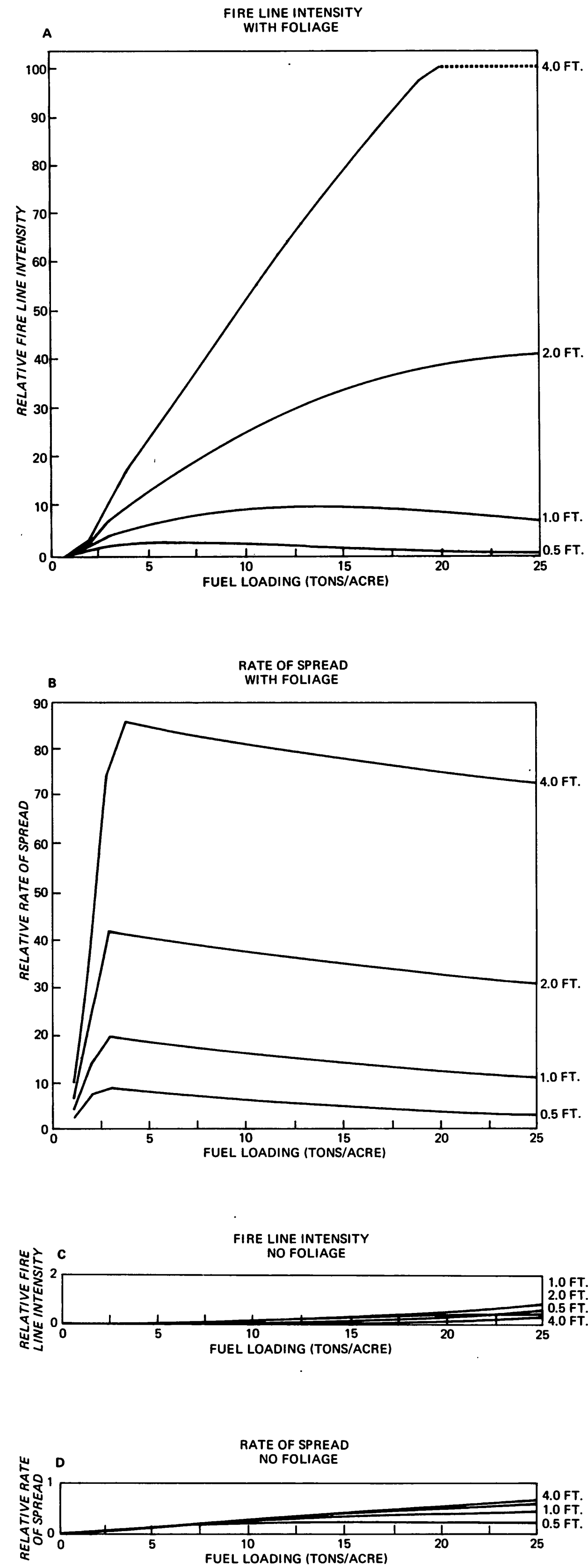
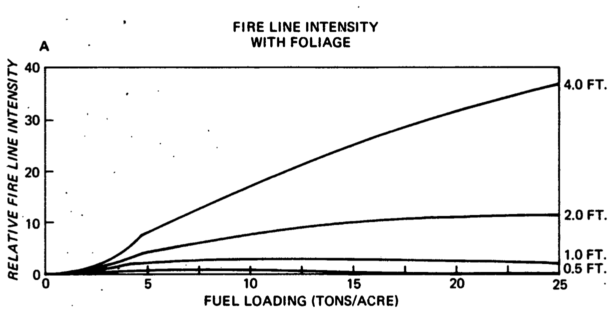


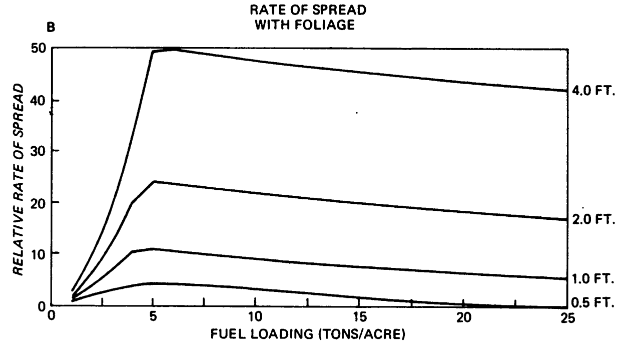
Figure 2.--*Relative fire line intensities and rates of spread for red pine slash: wind = 14 mi/h; moisture content = 6 percent.* →

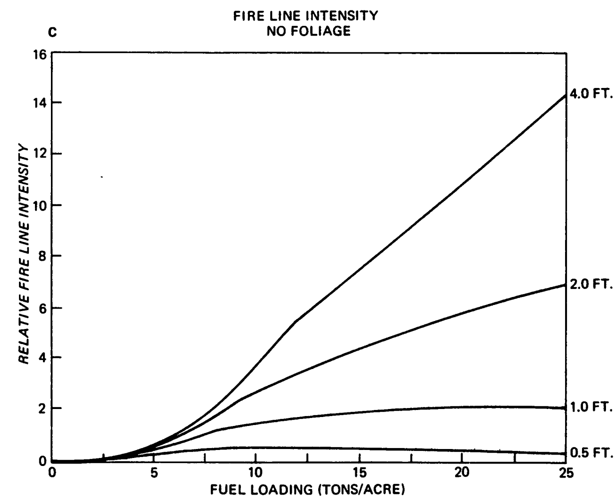
Table 1 lists the inputs needed to plot these graphs with the Rothermel fire model. Initially, the fuel inputs were sought for seven species and four particle size classes: (1) foliage; (2) fine twigs (0-1/4 inch); (3) coarse twigs (1/4-1 inch); (4) branches and tops (1-3 inches). The input values used for each slash species (by particle size class) were obtained from a variety of sources. Where available, published values were used. Otherwise, field measurements and laboratory determinations were made.

The Rothermel model predicts the forward rate of spread (ft./min.) and the intensity of the combustion reaction (BTU/ft.^{2}/min.) of "quasi-steady-state" fires burning under conditions described by the input variables. These fire behavior predictions are for conditions that would be expected at the flaming front of a fire only. Spotting and erratic flame movement are not considered. The model's predictions are most appropriate for uniformly spaced surface fuels such as grass, dense shrubs, forest litter, and well distributed logging slash.

Traditionally, Byram's (1959) expression of fire intensity (BTU/ft./sec.), often called "fire line intensity", has been used to describe the rate of energy release on wildland fires. It is the amount of energy or heat released per unit time per unit width of the fire front. Because this value represents the total energy flowing over each foot of the fire line more accurately than Rothermel's reaction intensity, fire line intensity appears more meaningful to the practicing fuel manager. So, relative fire line intensity was graphed, along with relative forward rate of spread, to represent potential fuel hazard in northeastern







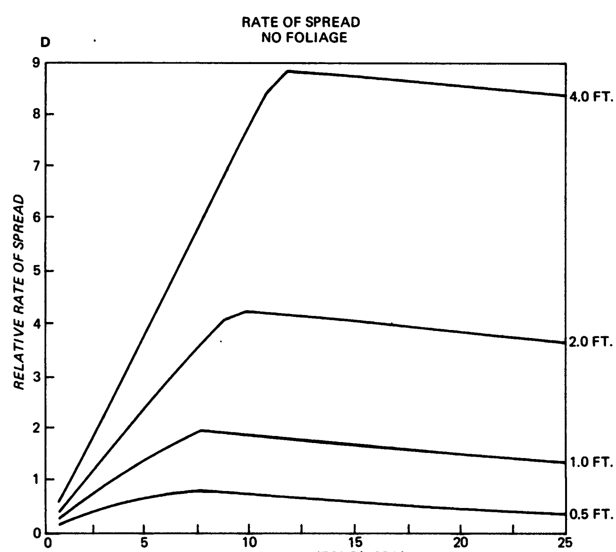
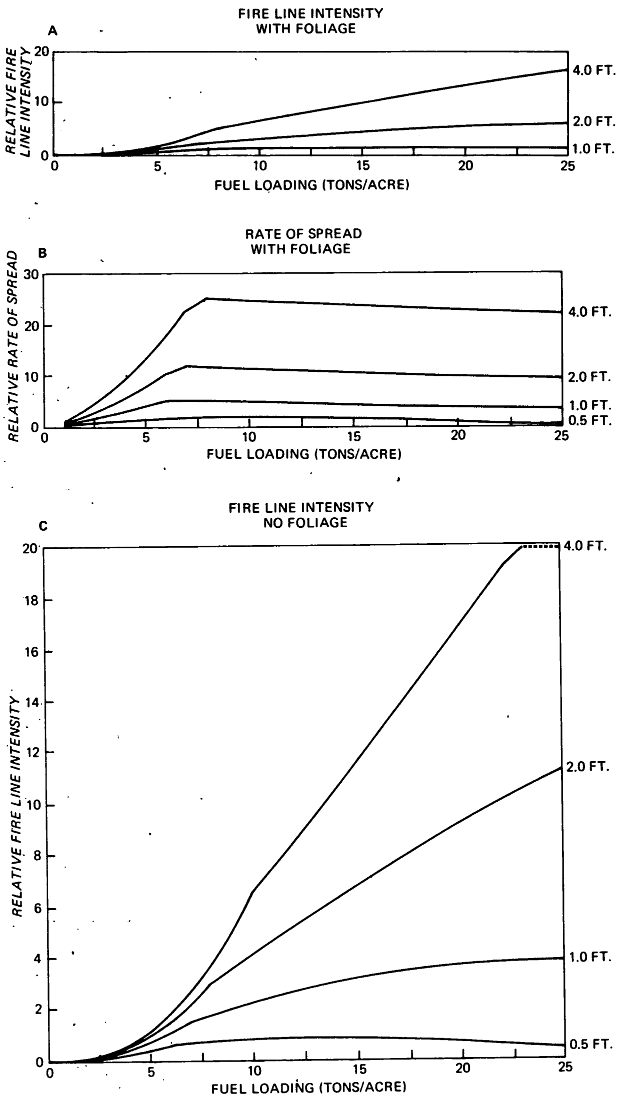


Figure 3.--*Relative fire line intensities and rates of spread for balsam fir slash: wind = 14 mi/h; moisture content = 6 percent.*

logging slash. Fire line intensity was determined using outputs of the Rothermel model by:

$$I = \frac{R \, I_R \, \tau}{60}$$

where: I = fire line intensity (BTU/ft./sec.)
R = Rothermel's forward rate of spread prediction (ft./min.)
I_R = Rothermel's reaction intensity prediction (BTU/ft.^{2}/min.)
τ = combustion residence time (min.)[1]



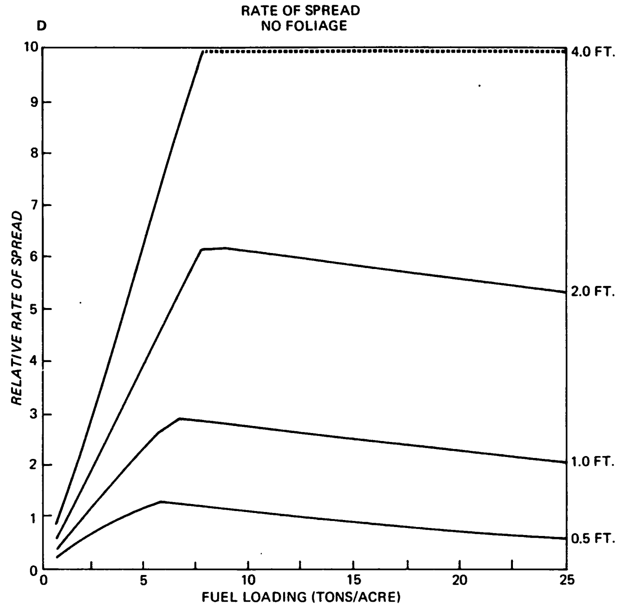


Figure 4.--*Relative fire line intensities and rates of spread for black spruce slash: wind = 14 mi/h; moisture content = 6 percent.*

The graphs represent fuel hazard, then, by the rate of spread and fire line intensity that the fuel would be expected to support under "average bad" weather conditions. Local weather conditions corresponding to the "very high" fire planning level were chosen to represent average bad burning conditions for any geographic locality. A series of graphs was constructed for each of the 13 different combinations of wind speed and fuel moisture content defining the very high fire planning levels on 15 National Forests comprising the Eastern Region (table 2).

To obtain open-ended, dimensionless index scales for relative hazard rating, the rate of spread and fire line intensity predictions were normalized against 5.5 ft./min. and 166.7 BTU/ft./sec., respectively. That is, the absolute predictions of rate of spread and fire intensity were divided by these values. These values were chosen so that a relative scale from 0 to 100 would encompass at least 90 percent of all realistic fire behavior situations. By eliminating actual units of measure, the

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[1] *The residence time was derived using the relationship given by Anderson (1969). Residence time in minutes is equal to eight times the particle diameter in inches.*

potential confusion associated with unfamiliar measurement units has been circumvented, possibly making the fuel hazard graphs more useful.

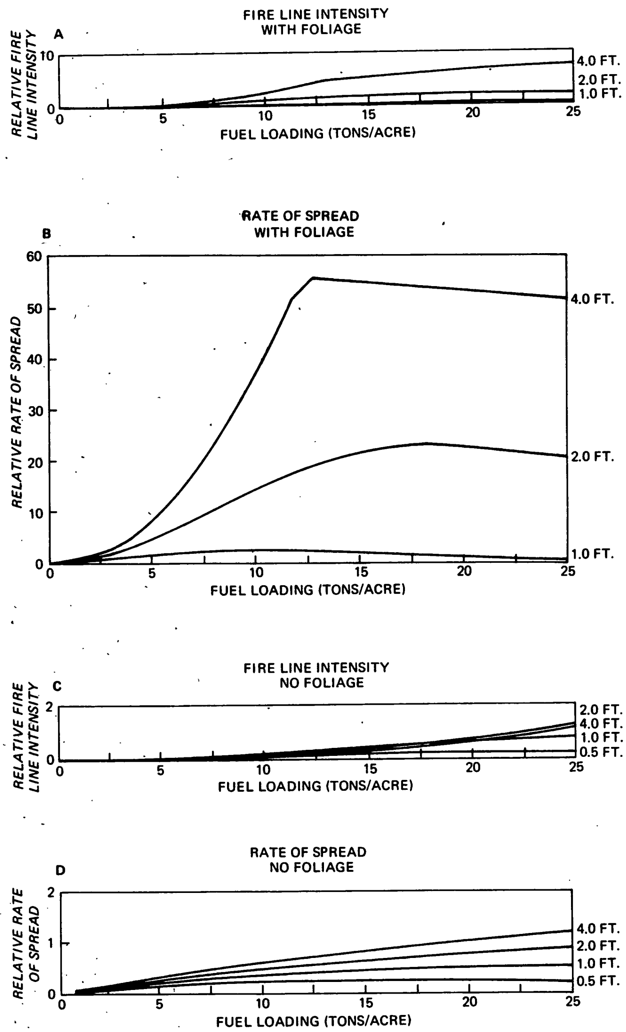


Figure 5.--*Relative fire line intensities and rates of spread for aspen slash: wind = 14 mi/h; moisture content = 6 percent.*

WHAT THE GRAPHS SHOW

Four graphs were plotted for each combination of species, wind speed, and fuel moisture content. They depict: (A) *relative* fire line intensity for slash retaining all its foliage; (B) *relative* forward rate of spread for slash retaining foliage; (C) *relative* fire line intensity for slash that has lost its foliage; and (D) *relative* forward rate of spread for slash that has lost its foliage (figs. 1-7). In all, 364 graphs were produced representing a wide variety of slash conditions and weather regimes in the northeastern United States. Of these, 28 are presented, representing 7 species of slash at only one combination of wind speed and fuel moisture content.

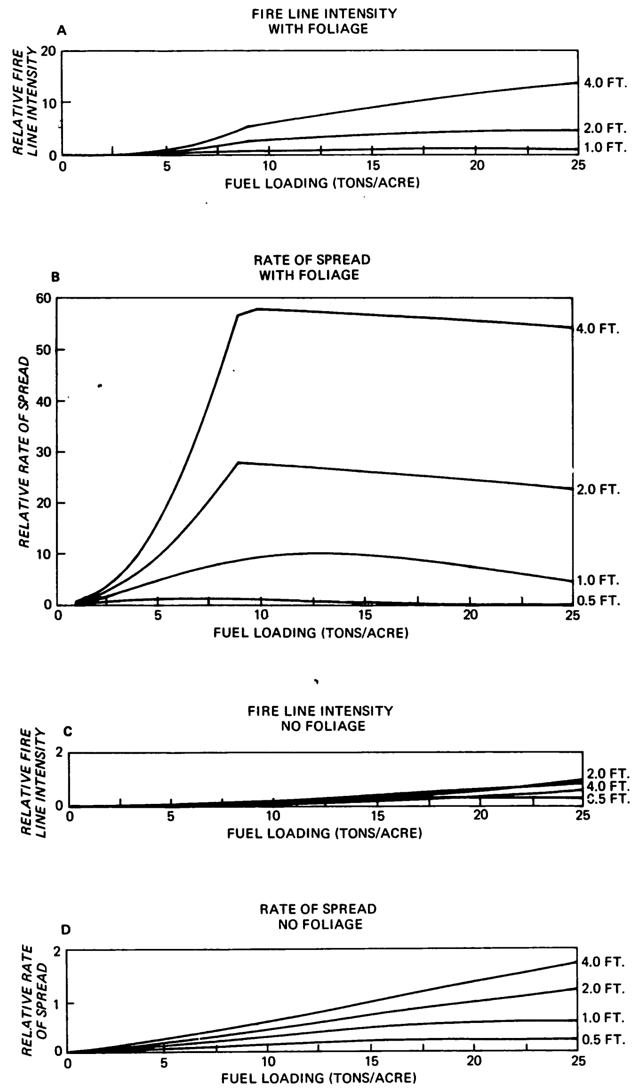


Figure 6.--*Relative fire line intensities and rates of spread for paper birch slash: wind = 14 mi/h; moisture content = 6 percent.*

The species are jack pine (*Pinus banksiana* Lamb.), red pine (*Pinus resinosa* Ait.), balsam fir (*Abies balsamea* (L.) Mill.), black spruce (*Picea mariana* (Mill.) B.S.P.), quaking aspen (*Populus tremuloides* Michx.), paper birch (*Betula papyrifera* Marsh.), and mixed oaks (*Quercus* spp.). The 14 mile-per-hour wind and 6 percent fuel moisture content define the very high planning level for portions of the Allegheny, Huron-Manistee, Superior, and Wayne-Hoosier National Forests. Graphs for other combinations of wind speed and fuel moisture content can be obtained from the authors.

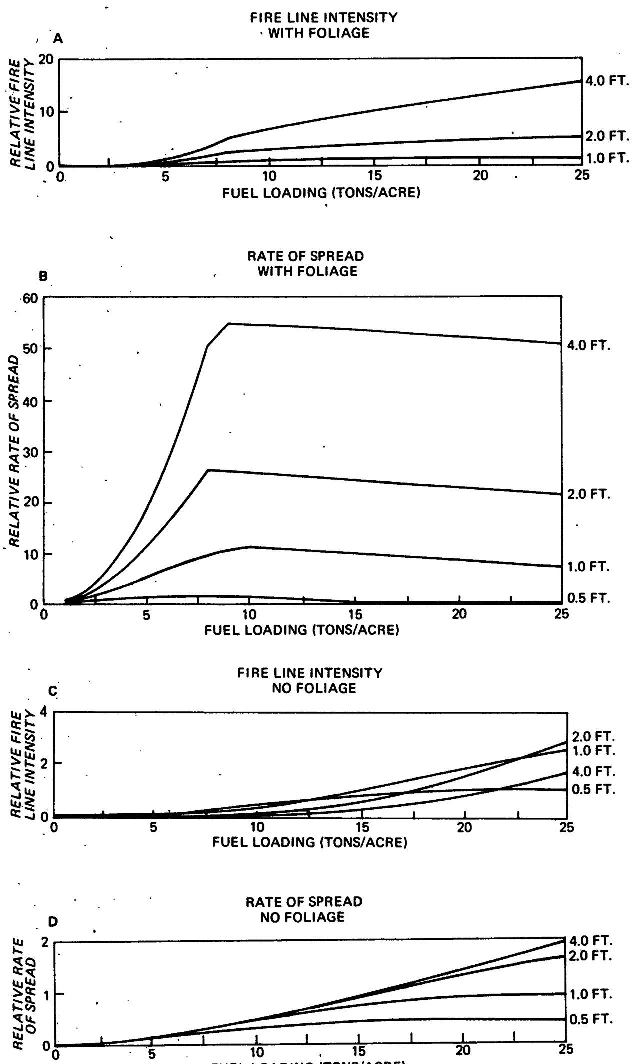


Figure 7.--*Relative fire line intensities and rates of spread for oak slash: wind = 14 mi/h; moisture content = 6 percent.*

Figure 1, showing relative fire line intensity and rate of spread for jack pine slash, both with and without foliage, exemplifies a single set of four fuel hazard graphs. Loadings range from 0 to 25 tons per acre, and depths of 1/2, 1, 2, and 4 feet are represented.

In figure 1A, relative fire line intensity (vertical axis) is graphed for jack pine slash, foliage attached. The horizontal axis is the loading, in tons per acre, of slash material less than 3 inches in diameter (including foliage). Material larger than 3 inches in diameter is ignored because, except for reducing maneuverability and physically supporting the finer fuels, it contributes little to fuel hazard. The vertical axis is a relative intensity scale. It relates to the amount of heat energy flowing over the fire line, and hence to the difficulty of direct attack. Also, it is open-ended; there is no upper limit to its possible values. Fires having relative intensities over 100 are infrequent, however, so extension of the axis beyond this would not be justifiable. Table 3 attempts to make these dimensionless numbers meaningful in terms of the behavior of real fires, while figure 8 shows the appearance of several experimental fires, conducted in jack pine slash by Stocks and Walker (1972), to relative fire line intensities.

Each of the four curves (the bottom one is partially obscured by the fuel loading axis) indicates relative intensity for slash, at various loadings, piled to the average depth shown at its extreme right end. Moving from left to right, each of these lines shows how fire intensity changes as more slash is packed into the same space (fixed depth). The 4-foot curve, for example, shows that fire line intensity will constantly increase as slash fuel is added to the 4-foot fuel bed. It increases from 0 at about 1 ton per acre, where fuel particles are too loosely packed to burn, to a value of 31 at 25 tons per acre. The 2-foot curve, representing slash packed twice as tightly, has a similar shape. It rises rapidly from 0 at about 1 ton per acre and begins to level off as the loading approaches 25 tons per acre. Here the relative fire line intensity is about 10.

Table 1.--*Input variables for the Rothermel fire model*

Input	Dimensions	Sources of Values Used
Total loading of slash material under 3" in diameter	Tons/ac.	This input is used as a continuous independent variable ranging from 0 to 25 tons per acre
Average slash depth	feet	This input is a discrete independent variable having values of .5, 1, 2, and 4 feet
Proportion of the fuel loading in each size class	dimensionless	Determined through actual data collection in Minnesota and Michigan
The ratio of fuel surface area to fuel volume by size class	$ft.^{-1}$	Brown (1970), supplementary data collection
Low heat of combustion for each size class	BTU/LB	Gorham and Sanger 1967 Hough 1969 Hughes 1971 Reiners and Reiners 1970
Oven dry fuel particle density by size class	$lbs/ft.^3$	Byram *et al.* 1952, Wood Handbook 1955, supplementary data collection
Silica free mineral content by fuel size class	percent by weight	Hough 1969, supplementary data collection
Total mineral content by fuel size class	percent by weight	Hough 1969, supplementary data collection
Moisture content of extinction	percent by weight	Rothermel 1972
Fuel particle moisture content	percent by weight	Average "very high" planning level values for Eastern Region National Forests[1]
Wind speed	ft./min.	Average "very high" planning level values for Eastern Region National Forests[1]
Slope	percent	Fixed at zero

[1]From FIRDAT (Furman and Helfman 1973).

Table 2.--*Fuel moisture (FFM) and wind speeds (WDS) for high, very high, and extreme fire planning levels in the Eastern Region*[1]

Forest and Station	High FFM	High WDS	Very High FFM	Very High WDS	Extreme FFM	Extreme WDS	Fuel Model[2]
Allegheny	8	14	6	14	4	14	H
Marienville							
Chequamegon	7	11	6	12	4	14	H
Clam Lake	7	11	6	12	4	14	C
Chippewa	7	15	6	17	7	25	C
Cass Lake							
Clark							
Salem	6	14	5	16	4	20	E
Green Mountain	8	8	6	9	5	11	H
Mt. Tabor							
Hiawatha	7	11	10	13	7	17	H
Town Lake & Moran	10	12	8	14	7	18	C
Huron-Manistee	9	12	6	14	6	18	C
Mio & Baldwin							
Mark Twain	5	12	5	16	4	20	E
Ava							
Monongahela	8	9	7	14	6	21	H
Marlington							
Nicolet	7	14	5	15	5	18	H
Laona	7	14	5	15	5	18	C
Ottawa	7	13	7	15	5	19	H
Watersmeet							
Shawnee	8	12	7	18	7	22	E
Vienna							
Superior	8	14	5	14	5	16	H
Ely S.C.	7	14	6	14	5	16	C
	8	12	6	14	6	16	I
Wayne-Hoosier	8	10	6	14	4	17	E
Athens							
White Mountain	5	8	4	10	2	13	H
Conway							

[1]As determined by FIRDAT (Furman and Helfman 1973).

[2]As described by Deeming *et al.* (1972).

The curves representing 1/2-foot and 1-foot slash depths may, at first glance, seem a bit bewildering. The 1-foot curve rises to a maximum fire line intensity just under 3 at 12-1/2 tons per acre, than begins to decline slightly as additional slash is packed into the 1-foot fuel bed. How can additional fuel result in reduced combustion intensity? Adding more fuel, when depth is held constant, creates a more tightly packed fuel complex, reducing the availability of oxygen to fuel surfaces and altering the efficiency of heat transfer. It must be emphasized, however, that this condition seldom occurs in unmodified slash fuels and therefore the fire behavior model has not been thoroughly tested in such fuel beds. The addition of fuel will usually increase a fuel bed's depth as well as its loading.

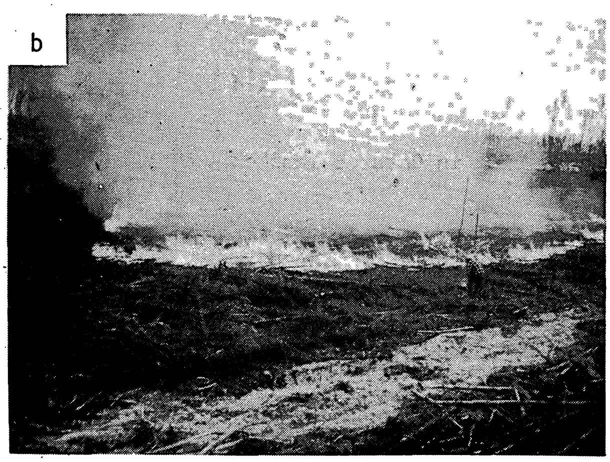
Table 3.--*Relation of relative fire line intensity to actual fire behavior*

Relative intensity	BTU/Ft./Sec.	Fire description
.01-.02	2-3	Few forest fires have intensities this low (Byram 1959).
.1-.3	19-58	Most prescribed fires burning against the wind. Depth of the flaming zone (front to back) would be less than 1 foot and the flame length about 2 feet. Could easily step over the fire without fear of injury (Byram 1959).
.6-6	100-1,000	The section of prescribed and wild fires burning with the wind in surface fuels. At the upper end of this range, where "the roar of flames would be accompanied by occasional explosive and whistling sounds," the fire might be described as "fairly hot" (Byram 1959). Flame length would be about 9 feet and observers 30 to 40 feet from the fire would be uncomfortably warm.
12-39	2,000-6,500	Crown fires in standing pine measured by Van Wagner (1968).
63	10,500	1971 Thackary Fire in Ontario (Walker and Stocks 1972).
81	13,500	1971 Whistle Lake Fire in Ontario (Walker and Stocks 1972).
135	22,500	1967 Sundance Fire (Anderson 1968).
2-103	357-17,090	Range of observations for 24 experimental fires in jack pine slash (Stocks and Walker 1972).

Figure 9 plots fuel depth against loading of material under 3 inches for a number of slash areas measured by the author and by Muraro (1968, 1971), and shows, by dashed lines, the general range of depths that should normally be expected at various slash loadings. On this basis, the loading for unmodified slash averaging 1 foot in depth would seldom exceed 11 or 12 tons per acre. Of course, by treating slash mechanically, it is possible to artificially create conditions beyond these limits.

Figure 1B is similar to figure 1A. The fuel loading axes (horizontal) are identical, and the 4 curves represent the same fuel depths. The vertical axis, representing relative forward rate of fire spread, again has no units of measurement.

The sharp change in the rate-of-spread curves at a fuel loading of about 5 tons per acre is where the wind becomes fully effective in driving the fire. At loadings below this point, the effect of wind on fire spread is limited by the intensity of the fire. The fact that the spread rate drops off at loadings above this point doesn't necessarily indicate that more fuel results in slower spread. This contradicts experience. Remember, each of the curves shows the effect of packing more fuel into the *same space*. Additional fuel can reduce the rate of spread by obstructing convective and radiant transfer of heat. Again, however, higher fuel loadings are generally accompanied by deeper fuel beds--with the overall effect of increased rate of spread.



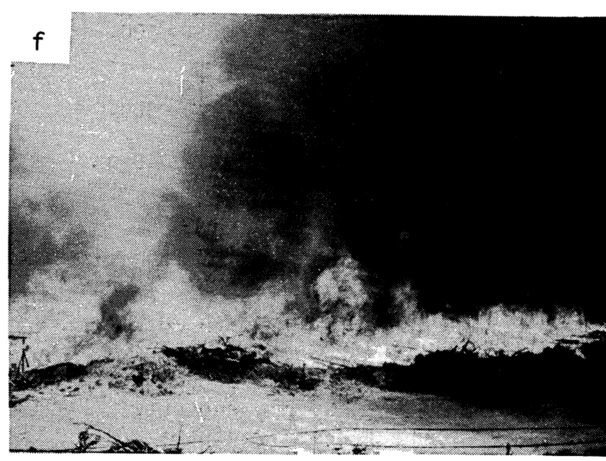


Figure 8.--*Visual appearance of experimental fires in jack pine slash. Measured relative fire line intensities were (a) 2, (b) 5, (c) 8, (d) 25, (e) 57, and (f) 103. Photographs and intensity measurements were provided by Brian Stocks and John Walker (Stocks and Walker 1972).*

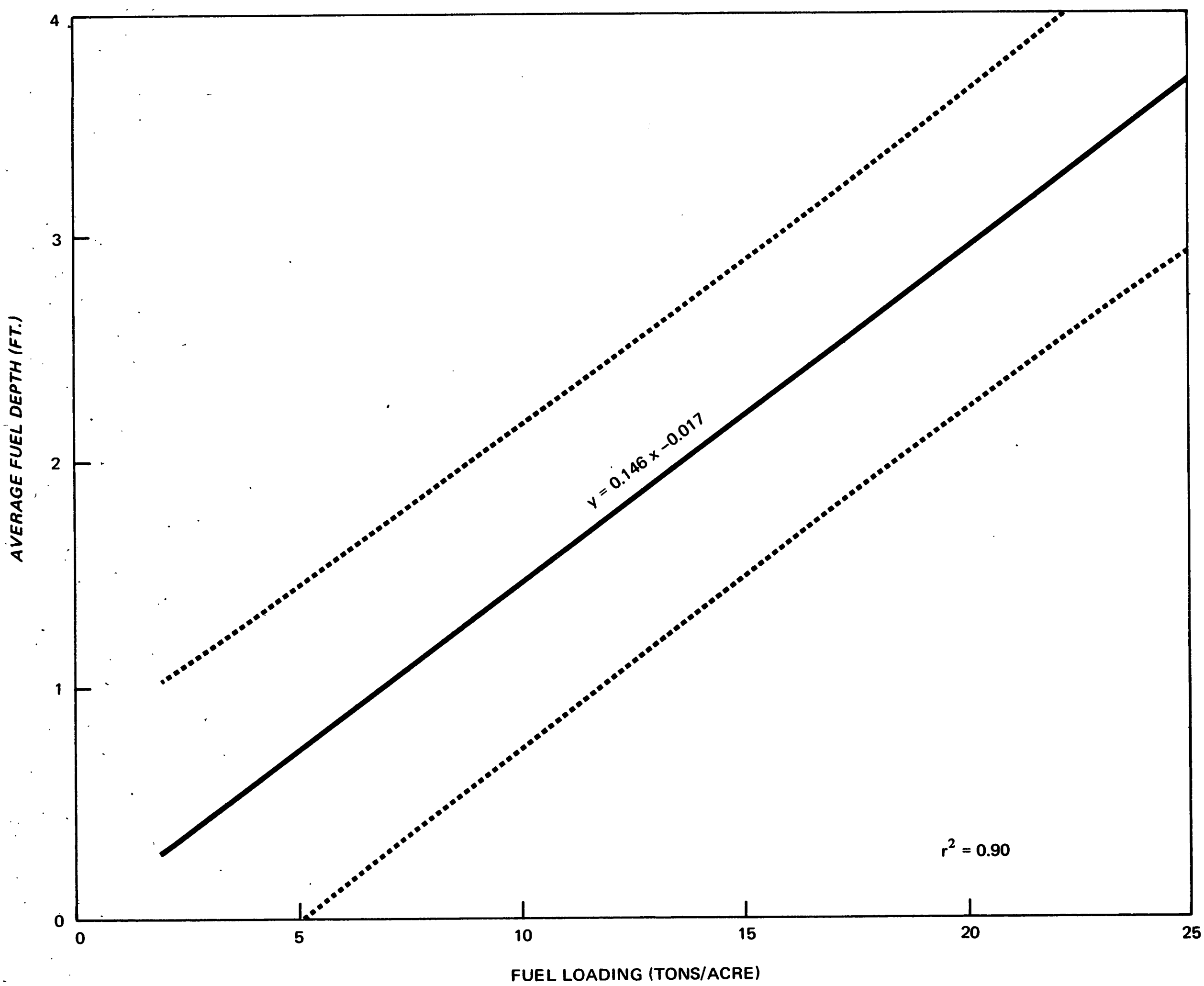


Figure 9.--*Regression of fuel depth on loading for unmodified slash material under 3 inches in diameter. The regression involves two data sources: 1) field measurements in a tornado blowdown near Virginia, Minnesota, and 2) published data extracted from Muraro (1968, 1971). The dashed lines depict the 95% confidence interval for a single prediction by the equation.*

In figures 1C and 1D, relative fire line intensity and rate of spread are graphed for jack pine slash after all foliage had dropped. Note that the scales of the vertical axes are different than those in figures 1A and 1B. The vast reduction in fuel hazard when foliage falls makes the scale change necessary to allow visual separation of the curves. Without this modification, the lines would be difficult to distinguish from one another. Scale should be closely observed when making comparisons of fuel hazard for slash with and without foliage.

HOW TO USE THE GRAPHS

The greatest potential for this system is that slash hazard can be predicted before cutting begins, as well as after its completion. To estimate fuel hazard for logging slash, all that is needed is knowledge of the condition of foliage, loading of slash material less than 3 inches in diameter in tons per acre, average slash depth in feet, and the wind speed and fuel moisture content representing the local "very high" fire planning level.

Visual determination of the condition of foliage and average slash depth should be adequate. Because the fuel hazard prediction is sensitive to changes in depth, average slash depth should be estimated conscientiously. Depending on the accuracy desired, slash loading can either be estimated or measured in the field. If the slash has already been created, and time is available to take some measurements, Roussopoulos and Johnson (1973) explain a field sampling procedure that can be done in northeastern slash with little time and effort. Fahnestock (1960) developed a way to estimate the weight of slash before logging for nine western species. A similar method can be used in the east. To predict slash loading (in tons per acre), multiply the basal area to be harvested from each D.B.H. class by the corresponding value from table 4[2] and sum these products for all classes in the harvest.

After the condition of foliage, slash depth, and slash loading has been determined or predicted, the fire-intensity and rate-of-spread graphs can be used to estimate fuel hazard. An example may help illustrate the use of these graphs in fuel management decisionmaking. Assume that the local "very high" planning level corresponds to the wind speed and fuel moisture content in figures 1-7. Also, assume that a jack pine stand has been clear cut producing about 10 tons per acre of slash material less than 3 inches in diameter, uniformly distributed at an average depth of about 2 feet. Figure 1 can be helpful in deciding how this slash should be managed by providing answers to the questions asked in the Introduction.

What fuel hazard can be handled adequately through normal fire control operations? This can be expressed as the relative intensity and rate of spread for the National Fire Danger Rating System (Deeming *et al.* 1972) fuel model used for fire control planning in any forest protection unit. Because fire control efforts are based on the expected behavior of fires burning in a chosen fuel model, this model can reasonably be used as a standard of fuel hazard against which fuel hazard on specific sites can be compared. Table 5 shows the relative rates of spread and fire line intensities for the nine fuel models when the wind speed is 14 miles per hour and fuel moisture content is 6 percent. For example, if fuel model H has been chosen for the protection unit in which the jack pine stand was harvested, the planning level fuel hazard can be represented by a *relative* fire line intensity of 0.6 (97 BTU/ft./sec.) and a *relative* rate of spread of 4.3 (24 ch./hr.). Either slash treatment or increased protection should be considered then, if the ratings for the post-cutting slash exceed these values.

What is the post-cutting hazard? Assuming that the foliage is retained on the slash, the post-cutting hazard attributable to the slash can be determined from figures 1A and 1B. In figure 1A, at a slash loading of 10 tons per acre, a horizontal line drawn from the 2-foot depth curve cuts the fire-line-intensity axis at about 7, far above the 0.6 determined for fuel model H. The relative rate of spread, from figure 1B, is about 18, again much larger than 4.3 for fuel model H. Both post-cutting hazard components clearly exceed those for the "standard" planning level hazard, calling for some form of slash treatment or increased protection.

What treatment alternatives are feasible? Because the Rothermel model can be applied only to uniformly distributed fuels, the graphs cannot be used to evaluate efforts to interrupt fuel continuity, such as creating fuel breaks and windrows. They may be helpful, on the other hand, in deciding among alternative broadcast treatment methods such as lopping and scattering, prescribed burning, and crushing or chopping. One alternative is simply to increase protection of the slash area until, through natural breakdown, the fuel hazard is reduced to a tolerable level. The hazard of jack pine slash, of course, is highest when the needles are still attached. As needles dry and fall, a process taking up to 4 years (Williams 1955), hazard slowly diminishes. Figures 1C and 1D, the pair

[2] *Loomis, Robert M. 1973. Unpublished secondary analysis of published data. (On file at North Central Forest Experiment Station, East Lansing, Michigan.)*

of graphs for jack pine slash without foliage, make this evident. For the above example, figure 1C indicates a relative intensity of 0.5, while the relative rate of spread in figure 1D is about 1.2. Both are below the planning level values, so increased protection until the foliage drops seems a feasible approach. In this case, the overall fuel hazard is underestimated because the fire would be spreading mainly in the litter, rather than in the slash itself. The graphs indicate fire behavior *in the slash*. Nevertheless, the values from the graphs

Table 4.--*Tree crown weights by species and d.b.h. per square foot of basal area in tons*[1]

D.B.H. (inches)	Shortleaf pine	Red pine (white pine)[2]	Jack pine	White spruce (black spruce)	Balsam fir (white cedar, hemlock)	Aspen (larch)	Yellow-poplar (other "soft" hardwoods)	"Hardwoods" (all "hard" hardwoods)
1	0.16	1.01	0.15	0.13	0.13	0.20 (.19)	0.26 (.25)	0.32 (.29)
2	.20	.35	.16	.17	.18	.15 (.14)	.34 (.33)	.42 (.40)
3	.16	.18	.15	.17	.16	.11 (.10)	.37 (.36)	.35 (.33)
4	.11	.13	.14	.14	.12	.09 (.08)	.23 (.22)	.25 (.23)
5	.09	.11	.15	.13	.12	.08 (.07)	.17 (.16)	.22 (.20)
6	.07	.10	.15	.14	.12	.07 (.06)	.13 (.12)	.20 (.18)
7	.09	.10	.15	.15	.14	.07 (.06)	.11 (.10)	.19 (.17)
8	.09	.10	.15	.16	.15	.06 (.05)	.10 (.09)	.18 (.16)
9	.09	.10	.15	.17	.17	.06 (.05)	.09 (.08)	.18 (.16)
10	.09	.11	.15	.18	.19	.06 (.05)	.08 (.07)	.18 (.16)
11	.09	.12	.15	.19	.20	.05 (.04)	.07 (.06)	.17 (.16)
12	.10	.14	.15	.20	.22	.05 (.04)	.07 (.06)	.17 (.16)
13	.10	.16	.15	.22	.25	.05 (.04)	.06 (.05)	.17 (.16)
14	.11	.18	.15	.23	.26	.05 (.04)	.06 (.05)	.17 (.16)
15	.11	.22	.15	.24	.28	.05 (.04)	.06 (.05)	.17 (.16)
16							.06 (.05)	.17 (.16)
17							.06 (.05)	.17 (.16)
18							.06 (.05)	.17 (.16)
19							.05 (.04)	.18 (.17)
20							.05 (.04)	.18 (.17)
21							.05 (.04)	.18 (.17)
22							.05 (.04)	.18 (.17)
23							.05 (.04)	.19 (.18)
24							.05 (.04)	.19 (.18)

[1]Tree crown weight includes stemwood less than 3 inches in diameter, branchwood, and foliage; numbers in parentheses do not include foliage.

[2]Species in parentheses are additional species to which table may be applied.

NOTE: The larger hardwoods include branchwood larger than 3.0 inches in diameter. All branchwood included. Dead branchwood included for jack pine, white spruce, and balsam fir.

indicate the relative significance of the slash itself, in terms of fire behavior, even when superimposed on a litter substrate.

Table 5.--*Relative rates of spread and fire line intensities for the NFDRS fuel models with a wind velocity of 14 miles per hour and fuel moisture content of 6 percent*

NFDRS Fuel Model	Relative Rate of Spread	Relative Fire Line Intensity
A	79.3	8.4
B	48.8	27.6
C	47.8	7.1
D	23.2	5.5
E	10.6	1.5
F	9.2	2.1
G	9.0	4.7
H	4.3	0.6
I	20.1	15.9

If 3 or 4 years of increased protection are not logistically or economically desirable, some means of fuel treatment should be considered. One alternative is prescribed fire. Even the most modest fire will at least remove the foliage, which would reduce the hazard to an acceptable level in the example situation.

The effectiveness of depth reduction, another alternative, can be clearly seen in figures 1A and 1B. If, by lopping and scattering, roller-chopping, or some mechicanical means of crushing, the average slash depth could be reduced to 1/2 foot, the relative intensity would drop to about 0.6 and the relative rate of spread to about 3, both acceptable.

The above procedures are summarized in Figure 10. In choosing among feasible alternatives, of course, silvicultural and environmental implications should be considered as well as hazard reduction effectiveness. What, for example, is the possible influence of slash compaction on regeneration success? On these matters there is no substitute for professional expertise.

How should priorities be established for different areas? In addition to the severity of the fuel hazard itself, the priorities should be based on local risk, surrounding resource values, silvicultural significance, accessibility, juxtaposition of natural barriers, environmental impact, and logistics. When these other factors are nearly equal, however, as is often the case, hazard ratings can help order priorities for the areas needing treatment. The relative fire line intensity and rate of spread can be used to establish priorities. Then areas can be treated in order of decreasing hazard until time, funding, or other limiting resources are exhausted.

CONCLUSION

The procedure presented and discussed here can reduce the need for managerial guesswork. The graphs were constructed using a mathematical model based strictly on laboratory experiments, and a number of addition assumptions and simplifications were incorporated into the graphic displays. It is assumed that only uniformly distributed slash is burning, that the fire has reached an equilibrium state, that is, it is not an accelerating fire, and that fuels of all sizes have identical moisture contents. These assumptions are somewhat less than realistic, but not overly restrictive. Even more important, users must realize that fuel management is only one aspect of land management. Costs and benefits of alternative fuel management strategies should be weighed, not only in terms of resulting fuel hazards, but also relative to overall land management objectives. Still, if used properly, with regard for inherent limitations, these hazard rating graphs can be valuable decisionmaking tools. If nothing else, they can provide concrete justification for projects already underway. Beyond this, they quantify fuel hazard in a way meaningful to any manager, regardless of his level of experience. Alternative fuel management practices can be evaluated and compared objectively before they are actually attempted. Fuel hazard potentially resulting from planned forest management projects can be anticipated, and operations that cannot economically provide adequate fuel treatment to meet protection standards can be aborted before resource values are jeopardized.

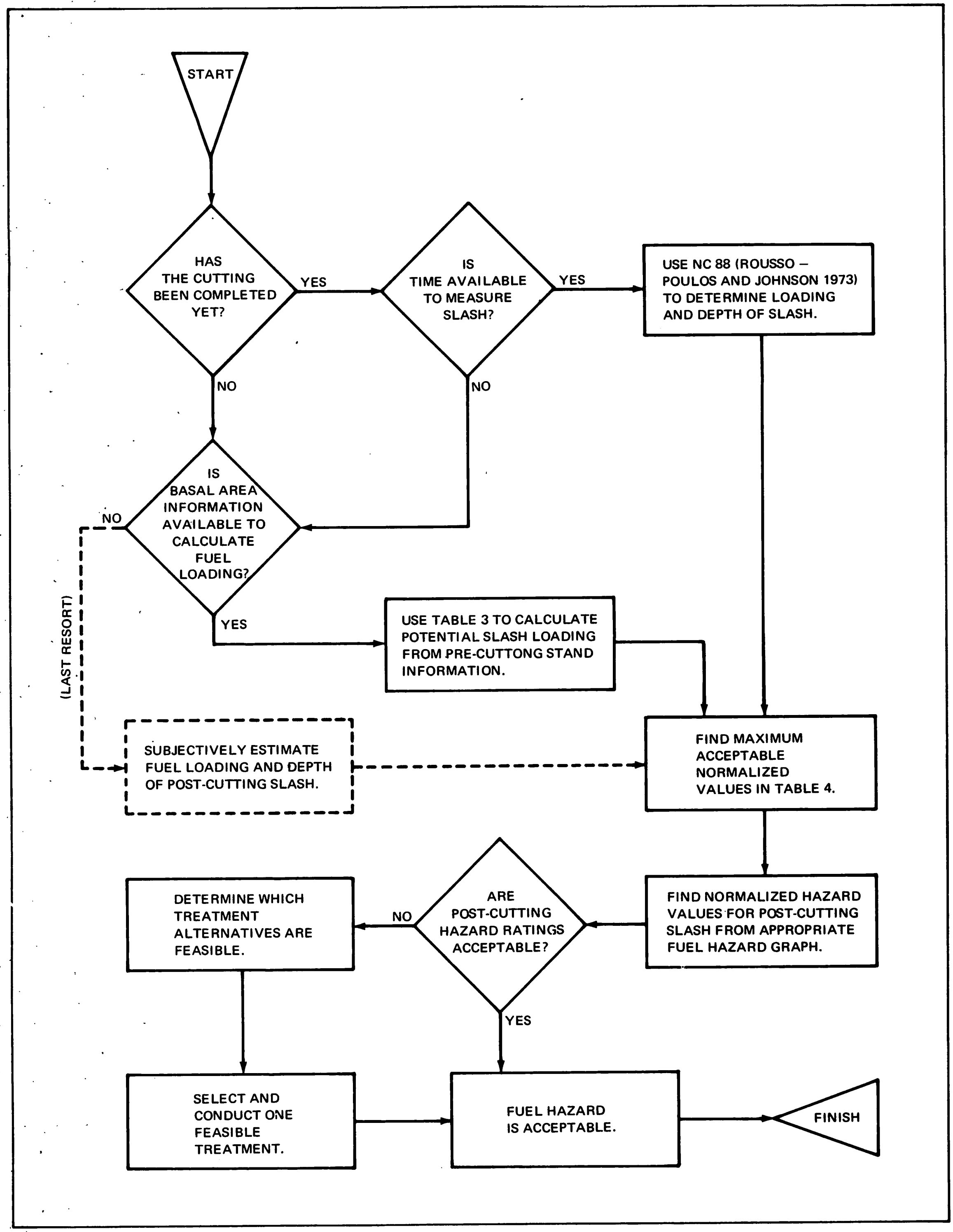


Figure 10.--*Flow chart illustrating the use of fuel hazard graphs in slash management decision making.*

As the technology of forest fire management steadily becomes more sophisticated and effective, the human or managerial aspects must keep pace. Advance planning and objective decision-making will be the key to successful management. The approach suggested here is a step in that direction.

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