# THE PRINCIPLES OF MEASURING FOREST FIRE DANGER

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**The current adjustment of fire control action to the prevailing status of fire danger is basic to efficient forest fire control. Unless this is done, expenses will be too high in some years and losses will be unnecessarily great in others. It is therefore essential that the prevailing status of fire danger be determined accurately and with as great refinement as is warranted by the flexibility of the fire control organization. The article describes the technique of applying the device known as a fire danger meter to obtain a numerical rating of fire risk.**

RESEARCH in fire danger measurement was commenced in 1922 at the Northern Rocky Mountain Forest and Range Experiment Station of the U. S. Forest Service, with headquarters at Missoula, Mont. Since then investigations have been made concerning (1) what to measure, (2) how to measure, and (3) field use of these measurements. In all cases the laboratory or restricted field experiments have been followed by several years of extensive application and test on the 10 fire forests of northern Idaho and western Montana, comprising an area of some 17,000,000 acres.

From this work three basic principles have become evident. They are:

1. All the significant daily variables of fire danger must be measured or dependably estimated.
2. These measurements must thoroughly sample the forest property.
3. The net effect of the several variables must be determined by some method so that, whoever applies it to the measurements for a certain day and area, the same rating of danger will be arrived at.

These principles do not demand that certain factors be measured in all forest types, that a certain number of stations be used per unit of area, or that the use of experienced judgment be eliminated. The research and field tests have shown, however, that unless all the significant factors are considered, unless each fire and climatic type is properly represented, and unless the applications of personal judgment and estimate are standardized, the resultant ratings of fire danger will not be as accurate or refined as they can be made by adherence to these principles.

## Factors That Affect Fire Danger

Studies of going fires and the analysis of fire reports have shown for the Northern Rocky Mountain Region that at least five factors affect the fire danger, which varies from day to day and season to season.[1] These variable factors are: (1) date, or season, (2) fuel moisture, or inflammability of specific materials, (3) wind, (4) visibility range, and (5) activity of fire-starting agencies. Some of these factors include two or more sub-factors, but each of the five listed is of major significance in this region.

*Date, or Season.*—Even though temperature, humidity, wind, and fuel moisture may be the same in mid-June as in mid-July, or even mid-August, the green vegetation such as grass, weeds, and brush is maturing, curing, and becoming less a fire retardent and more a fire accelerator as the season progresses. Hence danger increases with date, up to

[1]Topography and fuel type (3) are factors of fire danger which vary from forest to forest.

a certain point. An allowance is made for this variation in the Northern Rocky Mountain scheme. Even more consistent with calendar date is the number of hours of dangerous burning weather, according to hours of sunshine each day.

On September 15, for example, there are at Missoula, Mont., 3.3 fewer hours of sunshine and 3.3 more hours of cool, calm, humid weather favorable for fire control than there are on June 15. This shortening of the fire day opposes and finally offsets the effect of maturing vegetation. Both the vegetative factor and the hours-of-sunshine factor are, at present, brought into the rating according to calendar date.[2]

*Fuel Moisture.*—This variable, which determines forest inflammability, is the second most important one considered by the Northern Rocky Mountain method. The top layer of duff and half-inch-diameter dead branchwood are the two fuels measured. The drier these fuels, the greater the danger, and in determining current danger it does not matter whether this dryness is controlled by precipitation alone, humidity alone, or any combination of precipitation, temperature, humidity, wind, and sunshine. Fire research in this region has shown (1) that if surface duff or litter moistures and the moistures of small dead branchwood (2) are measured, the inflammability of a majority of the dead fuels is accounted for. A statistical analysis (4) of the influence of weather factors on the moisture content of these fuels has shown that even very complete weather measurements cannot be used dependably every day for this purpose.

Some of the finer fuels such as tree moss, dead grass, and weeds also contribute appreciably to fire danger when they are extremely dry. As the moisture contents of these fuels change faster than duff or twigs and lag only a few hours behind relative humidity, the Northern Rocky Mountain method provides a higher rating of danger whenever the humidity drops below 15 per cent.

*Wind.*—Many experienced men believe that wind is one of the most important variables of fire danger. Cases can be cited of crown fires occurring with snow on the ground, and of blow-ups during high humidity. In all such cases a high wind is usually the cause, and when the fuels are dry and the humidity low, even a small increase in wind velocity immediately accelerates the rate of spread of fire. Wind velocity, therefore, cannot be omitted from any complete scheme of rating fire danger. In the Northern Rocky Mountain scheme wind is given almost as much weight as fuel moisture.

*Visibility Range.*—The distance at which small smokes may be detected is a factor in fire danger. Visibility conditions may be such as to permit seeing small smokes 20 miles or more from a lookout, or the atmosphere may be so hazy that new fires can occur within 1 mile of a lookout, yet not be seen. When visibility is restricted there is greater danger of fires becoming large, more lookout stations must be manned, and in dry weather more men must be sent to every fire that escapes quick detection. In the early spring, before the average season fire control organization is warranted, the only action needed may be the placement of a few observers at their stations, their distribution depending primarily upon atmospheric visibility range.

*Fire-Starting Agencies.*—Fire danger and fire control are, of course, affected by the activity of any fire-starting agency. Lightning, which causes about 72 per cent of the fires in Region One, is there-

[2]The fact is recognized that vegetation starts growth earlier and stays green and is a fire retardent much later in some years than in others. A research project is being carried on in an attempt to determine more accurate vegetative criteria (5).

fore brought into the Northern Rocky Mountain scheme.

The fire records show that man does not produce peak loads of fires in Region One. Consequently this scheme does not rate danger higher on week-ends and holidays even though there are more people in the forests at such times. An allowance is made, however, for increased danger whenever numerous land-clearing fires, permitted by law, are occurring adjacent to the forest property being protected.

These five factors, date, fuel moisture, wind, visibility, and certain fire-starting agencies, have therefore been selected as the principal variable controls of fire danger in Region One. On any midsummer day only one of these may contribute to fire danger, while the four others subtract from it. Or any two factors may contribute, while three subtract.

In fact, if we distinguish merely between two classes, those favorable to high danger and those favorable to low fire danger, without any regard for the degree of favoritism, 120 combinations of these five factors are possible. Hence it is not surprising that forest managers have in the past failed to agree when, for instance, date and duff or wood moisture have been conducive to high fire danger while humidity, wind, lightning, and visibility were favorable to easy forest protection.

## Classes of Fire Danger

With five factors combining their effects or counteracting each other, the integration cannot be left to personal opinion or judgment. This is especially true if large expenditures of funds are to be based on the resultant opinion, or if the daily opinions are to be combined at the end of a fire season into a seasonal rating to be used in determining efficiency of fire control. To rate fire danger some method must be used, such as Koppen's system of classifying climates, so that whoever applies the system will arrive at the same result as another using the same basic data. The more numerous the factors, the more essential such a system becomes.

Each significant degree or class of danger must then be designated in such a manner that all danger reports are consistent and comparable. There is little consistency and less comparability in designations such as "none, easy, average, bad, and very bad" when applied by numerous men of different temperament and varying observational experience.

The Northern Rocky Mountain scheme divides the total range of danger into seven classes. This number was chosen because in this region there are at present seven rather definite stages or steps in fire control organization. These are as follows:

Class 1. No men need be specially detailed to fire control.

Class 2. Fire control stations covering heavy slash or active brush-disposal operations should be manned. A few key lookouts also may be manned following lightning storms early in the season.

Class 3. All key detection stations should be manned and the limited number of guards and smokechasers included in the "minimum protective organization" should be sent to their stations.

Class 4. The "average season protective organization" should be placed.

Class 5. The "first overload" positions should be filled.

Class 6. The "second overload" positions should be filled.

Class 7. Every economically justifiable step should be taken, including the mobilization of supplemental overhead, stationing crews of firefighters at strategic points, and other action specified by the Region One fire-control plan for meeting the most extreme fire danger.

Actually there is no sharp division

between one class of danger and another, and in actual practice the fire control organization is not expanded suddenly from one stage to the next. Perhaps 100 gradations could be set up, but for all practical purposes the present distinction of seven classes of danger and seven stages of organization are as refined as is needed at present.

In addition to the advantage of correlating fire control action with degree of danger, the numerical scale of one to seven serves another very practical purpose. Previous to the adoption of this scale forest managers had no standard terminology whatever for describing fire danger. Usually, the more expletives used, the greater the danger, but when expletives had to be eliminated the reporting officer often had difficulty in specifying extreme and critical conditions. The provision of a definite scale was immediately recognized by field men as an aid in describing the status of fire danger consistently and understandably. It was a material factor in the substitution of fire-danger measurements for fire-danger "guesstimates" on the National Forests in Region One.

## Fire Danger Meter Designed

The integration of effects of the five outstanding factors of fire danger so that all of the 120 combinations can be expressed on a scale of 1 to 7 requires the use of some sort of nomograph, alinement chart, or slide rule. A simple device, called the Harvey exposure meter, has long been used for a similar purpose in photography, and this idea was used in designing a fire danger meter, illustrated in Figure 1.

This pocket-size cardboard device is easily adjusted to register the status of each of the six factors of fire danger. The resultant class of danger is then indicated on the scale of 1 to 7. Although this device is complex at first glance, its manipulation is not difficult after a few minutes' practice. It has been readily adopted in Region One.

For best daily and seasonal use a record should be kept to show for each day the status of each factor of fire danger and the resultant class of danger. Figure 2 shows the type of chart used in Region One for this purpose during 1933, 1934, and 1935. The values plotted on this chart are the 1935 daily averages for all the stations used in this region. An improved chart has been designed for use in 1936.

With a record of this kind available for a ranger district, a National Forest, or an entire Region, the forest manager is aware, during the season, of the existing status and the current trend of each element of danger. The meter then shows the fire control organization warranted or justified.

On the 10 fire forests of Region One, the measurements of factors are made in early May at less than a dozen stations. These are at the lower elevations. By early July or after the lookouts have been placed, as many as 180 lookout, smokechaser, and ranger stations measure one or more elements of fire danger. Approximately 70 stations serve as the major network for the 17 million acres included in these 10 Forests. This represents an average of one complete weather and inflammability station per 240,000 acres. During the past three fire seasons this distribution has appeared to be sufficient to reveal nearly all local differences in danger warranting different fire control action.

At the close of each fire season the daily record of fire danger may be used to rate the character of any part of the season, or of the season as a whole. As shown by Figure 2, in July and August, 1935, there were 0 days of Class 1 danger, 2 days of Class 2, 10 days of Class 3, 22 days of Class 4, 27 days of Class 5, 1 day of Class 6, and 0 days of Class 7. Multiplying the number of days by its class value gives a total of 263, which divided by the total number of days, 62, gives an average danger class of 4.24 for this period.

Other records indicate that the rating for the easiest probable July and August would be about 2.8, while that for the worst probable would be 5.5. Class 2.8, therefore, represents zero danger and 5.5 represents 100 per cent for this period. On this scale, the 1935 average of 4.24 represents 53 per cent of worst probable danger.

This method, therefore, makes it possible to express the character of fire danger on a percentage basis which is readily understood by boards of directors, state legislators, and congressmen who are not familiar with, and perhaps not interested in, the detailed technique of danger measurement. Rating on a percentage scale also permits ready comparisons of successive seasons on a Forest, or comparisons between Forests for a particular season. For example, July and August rated as 46 per cent of worst probable in 1933, 71 per cent in 1934, and 53 per cent in 1935. The individual National Forests could be likewise compared.

In comparing one year with another, we need to consider length of fire sea-

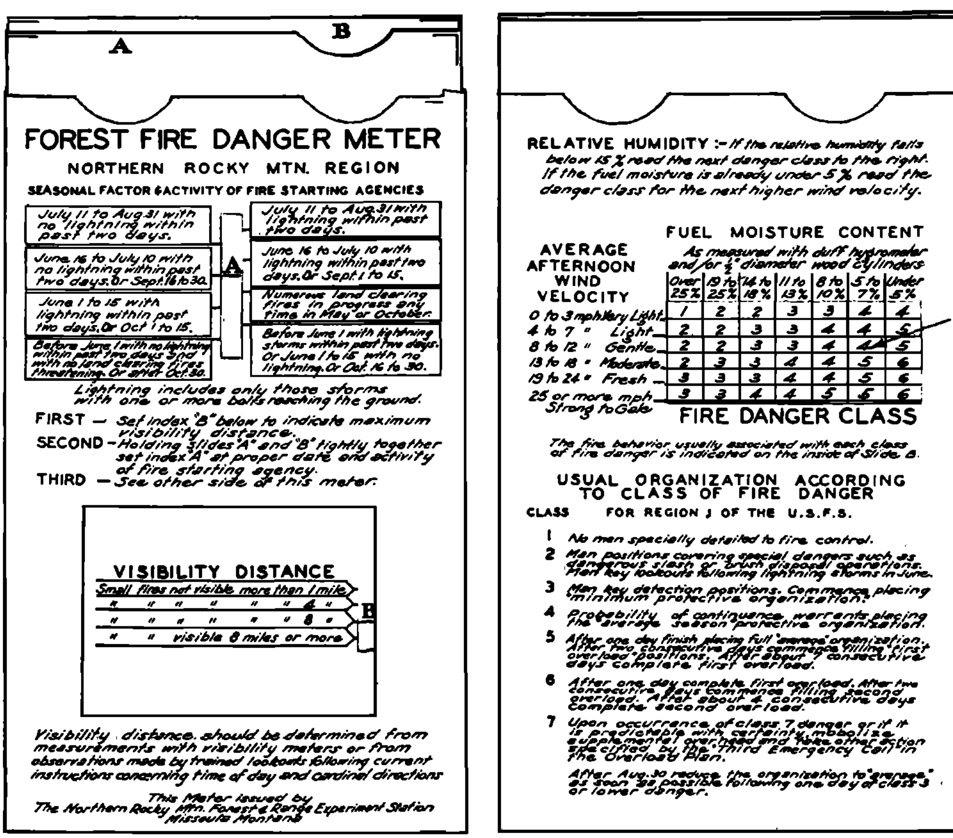


Fig. 1.—The forest fire danger meter.

Left: front view. At the top are two slides, marked A and B. These slides are movable and are read through windows in the outside of the holder.

Right: back view. The dimensions of the folder are 3⅞ inches by 6¾ inches.

son as well as intensity, because a four-month season rating, say, 50 per cent of worst probable may justify greater organization costs than a two-month season rating 65 or 70 per cent. The records for Region One do not, however, as yet include a sufficient variety of seasons to indicate the best method of incorporating the length-of-season factor.

## Rating Fire Control Efficiency

As an indication of the use of seasonal ratings to determine efficiency of fire control, Table 1 shows several relationships that are sometimes overlooked.

First is the fact that even during the most favorable fire seasons some minimum, $250,000 assumed in this case, must

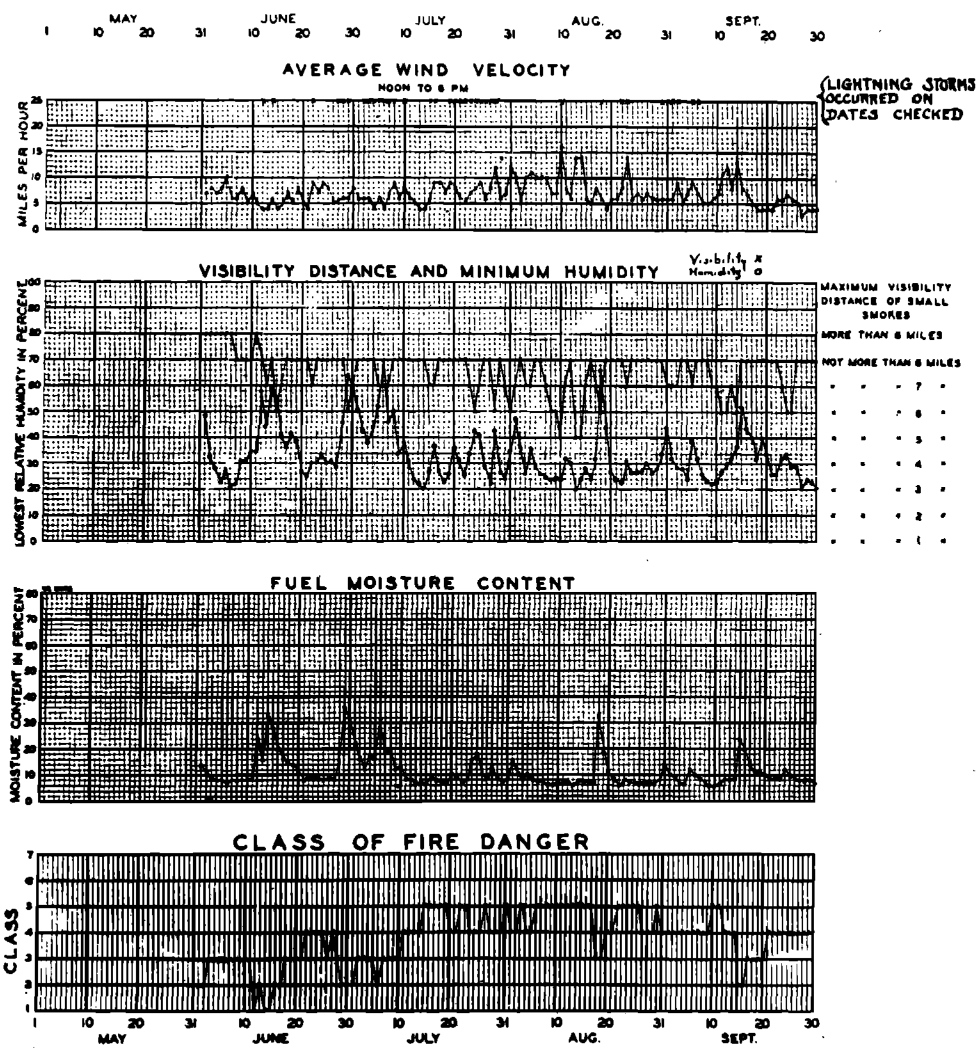


Fig. 2.—Type of chart used to record fire danger in ten National Forests in Region One during 1935.

be expended for the maintenance of fire-control facilities and a skeleton fire-control force of men.

Second, as the character of the fire season becomes more dangerous the control force must be increased proportionately, or the property will be unduly exposed to damage.

Third, the ultimate objective of efficient fire control is to follow the very narrow path between acceptable expenditures and too risky exposure of the property.

Fourth, as danger increases more leeway should be allowed to compensate for those unfavorable catastrophes that so often characterize critical seasons. In Table 1, a 91 to 100 per cent season allows a leeway of $1,000,000 in total costs plus damage, while a 31 to 40 per cent season restricts efficient work to a range of only $250,000. The bare minimum of maintenance costs is acceptable, with no allowance for damage, if the character of season rates as less than 10 per cent of worst probable.

Fifth, such a scheme definitely specifies the maximum total cost plus damage that will be accepted as efficient for each specific class of season.

Without some such system of comparing cost plus loss with character of fire danger, efficiency ratings can be at best only impartial and thoroughly experienced judgments. If the judge has incomplete information concerning the character of season, if he is unfamiliar with fire behavior and fire-control practices in the region in question, if he is a personal friend or a personal enemy of the fire-control manager being judged, or if the judge's health happens to be below par at the time, his rating of efficiency of the work is not likely to be as just and impartial as it would be if the criteria of efficiency were deliberately specified.

By measuring fire danger and by testing the relationship of cost-plus-loss to character of season, it should be possible to produce experience tables similar to Table 1 which will permit the rating of

TABLE 1

EFFICIENCY OF FIRE CONTROL[1]

| Total costs plus damage | Character of season — Per cent of worst probable: 10 or less | 11 to 20 | 21 to 30 | 31 to 40 | 41 to 50 | 51 to 60 | 61 to 70 | 71 to 80 | 81 to 90 | 91 to 100 |
|---|---|---|---|---|---|---|---|---|---|---|
| | Efficiency A = Acceptable. E = Excellent | | | | | | | | | |
| Dollars | | | | | | | | | | |
| 250,000 | A | A | E | E | | | | | | |
| 315,000 | | A | A | E | E | | | | | |
| 400,000 | | | A | A | E | E | | | Too risky | |
| 500,000 | | | | A | A | E | E | | | |
| 630,000 | | Too costly | | | A | A | E | E | | |
| 800,000 | | | | | | A | A | E | E | |
| 1,000,000 | | | | | | | A | A | E | E |
| 1,260,000 | | | | | | | | A | A | E |
| 1,600,000 | | | | | | | | | A | A |
| 2,000,000 | | | | | | | | | | A |

[1]These relationships might apply on a forest area of 25 to 30 million acres requiring fire control facilities of a type and quantity necessary in a region of fire behavior similar to that in Region One.

fire control efficiency by the same principle that life and fire insurance companies use in judging a human or property risk. These companies could not operate for long if they let each of their many agents judge each risk on the basis of the agent's limited and very personal experience. Such judgment and rating should be a procedure inherent in the business, not a personal ability of the employees.

By the methods described here it is possible to determine the prevailing status of fire danger far more accurately than it can be estimated, and on this basis to adjust the size of the fire control organization so that unjustifiable expenses and unnecessary losses may be reduced. Later it may be possible to rate efficiency of fire control much more precisely than is possible by personal judgment alone.

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