relation between atmospheric humidity, as expressed by the rate of evaporation, and the moisture content of the duff and litter of the forest floor, the development of reliable forecasts of evaporation rates would be highly desirable. It is realized, of course, that evaporation is also affected greatly by the winds, so that any attempt at such a forecast would have to take into consideration the expected velocity of the air currents, their direction, and the nature of the terrain whence they come, as affecting their moisture content. Truly a complex enough problem, at first sight, but one which may well be solved—given the time and means for the proper study of its constituent factors.

On looking into the problem of forecasting the third type of fire weather—that is, winds favorable for the spreading of fires already in existence—we also find an amply complex situation. To the effects of the distribution of the centers of barometric pressure we must add the opposition to the general air movement that is afforded by the inequalities of local topography, the effects of sharp differences in temperature over contiguous areas, and the diurnal changes caused by convection during the day and the descending hill or mountain breezes at night, and, also, the intense convection caused by a widespread fire, if such be in progress. Having the weather map, however, and a thorough knowledge of the locality under consideration, the forecasting of winds should present no insurmountable difficulty.

In speaking of the use of formulæ and curves as aids to forecasting one does not wish to imply that they are by any means infallible. When properly produced, however, from reliable data, they do become of use in the delimitation of what may be expected under normal conditions. The forecaster must also take into consideration all attendant circumstances that may come or be brought to his attention, from all sources available, and then employ both his judgment and his intuition. Nor is it desired to convey the impression that completely reliable forecasts can be made from the moment that the collection of local data is begun. The number and variety of the forces that affect the weather and the difficulty in securing adequate information in advance must be considered. Time will be required for the collection of the required data and for its study and correlation.

A very general statement only of what may be attempted has been made. It would be useless and somewhat difficult to go into more specific detail. But, knowing what is required and what he must try to accomplish, and with a well-defined idea as to methods, the individual investigator will have to adapt his resources to the particular problems presented by the area to which he is assigned. And it is hoped and expected that through the cooperation of the local observer, the district forecaster, and the members of the Forest Service, the accuracy and timeliness of forecasts for fire weather may be greatly improved.

RELATION OF WEATHER FORECASTS TO THE PREDICTION OF DANGEROUS FOREST FIRE CONDITIONS.[1]

By R. H. WEIDMAN.

[Priest River Experiment Station, United States Forest Service, September 10, 1923.]

The purpose of predicting dangerous forest-fire conditions, of course, is to reduce the great cost and damage caused by forest fires. In the region of Montana and northern Idaho alone the average cost to the United States Forest Service of fire protection and suppression is over $1,000,000 a year. Although the causes of forest fires will gradually be reduced by education and law enforcement, there always will be forest fires started by lightning and other causes when conditions in the forest are dangerous. If the dangerous fire conditions, however, can be predicted a few days in advance, the fire-protection organization can be prepared to find and suppress fires when they are small and easy to control.

To predict dangerous fire conditions in the forest, it is necessary to know exactly what constitutes such conditions. The material in the forest which burns is of first interest. Taking wood as a fuel, it is clear that if wood is dry it burns readily; if it is wet it does not. The important factor in this case, therefore, is the moisture content of the materials which comprise the fuel of forest fires. Thus, if the forester knows the different degrees of inflammability of the fuel in terms of differences in its moisture content, it is possible for him to state definitely for to-morrow or the next day what influence the approaching weather will have in making it drier or wetter; in other words, more inflammable or less inflammable.

The moisture contained in duff and other débris on the forest floor is influenced, of course, by various weather elements. The materials absorb moisture chiefly from the atmosphere in the form of rain and humidity. In summer it is largely the relative humidity of the air which causes changes in the moisture content of the materials. Duff, which is the layer of matted needles on the forest floor, especially responds to the changes in relative humidity. With high relative humidity at night the duff is relatively damp; with low relative humidity in the daytime, it becomes dry. When the relative humidity is consistently low for several days in succession, the duff loses more and more of its moisture—sometimes, in the white pine forest of northern Idaho, dropping to as low as 3 per cent of its oven-dry weight.

By inflammability tests it is known that when moisture content of duff in this region is about 10 per cent the material is readily inflammable. Below this moisture content it is extremely inflammable; above it, it gradually becomes less inflammable until a moisture content of about 17 per cent is reached, when it is difficult for a camp fire to spread readily in this material. When duff has a moisture content of 25 per cent it would be difficult for large forest fires to spread.

As relative humidity is the most important factor in changing the inflammability of forest materials in summer, the question may be asked: "Why not use relative humidity as an index?" The answer is that relative humidity does not always indicate moisture content consistently, for the reason that changes in moisture content of woody materials lag behind changes in relative humidity of the air. Another disturbing element here is temperature of the air. In nature the three elements—relative humidity, temperature, and moisture content of materials—are rarely in equilibrium. Moreover, there is an infinite variation in their relations, as a result of not being in equilibrium. A few actual measurements will illustrate this better than words. The first part of the following tabulation shows the temperature, relative humidity, and existing moisture content of duff as measured at the Priest River Experiment Station; the second part shows the moisture content of wood in

[1] Presented at meeting of the American Meteorological Society at Los Angeles, Calif., September 19, 1923.

equilibrium with corresponding temperatures and relative humidities as measured under controlled conditions at the Forest Products Laboratory.

Duff.

Relative humidity.	Temperature.	Moisture content.
Per cent.	*Degrees.*	*Per cent.*
25	92	14
29	77	9
56	77	14
70	75	10

Wood.

Relative humidity.	Temperature.	Moisture content.
Per cent.	*Degrees.*	*Per cent.*
25	92	5
29	77	7
56	77	10
70	75	13

Thus it is seen that relative humidity one day may be 25 per cent and the moisture content of duff 14 per cent. The next day the relative humidity may be 29 per cent and the moisture content only 9 per cent. This sort of variation, when it occurs near the danger line of inflammability, as in this particular case, is a very important factor in predicting dangerous fire conditions.

At the Priest River Experiment Station, therefore, moisture content is used directly as an index of inflammability. As the top layer of duff is the material which carries fire through the forest, it is the one which is chiefly concerned in predicting dangerous fire conditions. This is true in the virgin forest with which the Forest Service in Idaho and Montana is mainly concerned in fire protection. In order to measure the moisture content of duff in place, a recently developed duff hygrometer is being used at the experiment station. The instrument consists of a hollow, perforated metal tube containing a strip of rattan which expands and contracts with changes in moisture content and so arranged as to register the changes on a dial attached to one end of the instrument.

Knowledge of the existing moisture content of the fuel, and therefore its existing condition of inflammability, is one of the requirements necessary for making a prediction of inflammable conditions in the forest. The other equally important requirement is a thorough weather forecast, in order to know whether the forthcoming weather will bring conditions making for greater or less moisture in the atmosphere and thus greater or less moisture in the fuel. The weather forecast, of course, should be of such a nature as to give this information—whether the changes in the moisture of the atmosphere are to be influenced by rain, temperature, cloudiness, or other elements.

Although relative humidity is the most important factor involved in the moisture content of the débris on the forest floor, it is not by any means the only factor which must be taken into consideration. Without going into the subject too deeply, some of the other factors may be mentioned. For instance, the duff moisture contents resulting from various amounts of rainfall must be determined. The rate of drying out of duff and other materials after receiving various amounts of rain must be known. The effect must also be known of a given quantity of rain occurring in one hour, for example, as compared with the same quantity occurring evenly distributed through a much longer period. What is the relative amount of rain reaching the duff through the forest canopy as compared with that falling freely to the ground in the open? What, under various conditions, is the effect of temperature, humidity, and wind velocity in the drying out of duff after a rain? What are the moisture contents of duff, twigs, branches, down logs, and such materials, under all the possible combinations of temperature and humidity commonly experienced during a fire season? And so on.

It is desired to point out, in closing, that the weather forecast and the existing condition of the fuel are both necessary in predicting dangerous forest fire conditions. Weather forecasts in themselves are not sufficient as fire warnings; nor are the records of measurable conditions on the ground alone sufficient. The Forest Service can determine the prevailing conditions of inflammability, but is dependent on the trained meteorologists of the Weather Bureau for accurate and complete forecasts of what the weather is to be. It is realized that it is exceedingly difficult to make the sort of detailed weather forecasts that are needed. In this connection, Mr. Beals stated in a recent article in the MONTHLY WEATHER REVIEW:

> The making of reliable fire weather warnings is even more difficult than the making of frost predictions; and in the latter case it has been proven that the most satisfactory method is to obtain all the information possible regarding the past weather, and then have a man on the ground capable of amplifying a general forecast to meet the conditions over a small area.

This suggests the possibility of having a meteorologist of the Weather Bureau on the ground to work side by side with the men of the Forest Service who are conducting the fundamental fire studies in several localities in the West. So far as the prediction of dangerous fire conditions is concerned, it is believed that this would be one of the most effective ways in which the Weather Bureau could help in the solution of the forest fire problem.

FOREST FIRE WEATHER IN WESTERN WASHINGTON.

GEORGE C. JOY, Chief Fire Warden.

[Washington Forest Fire Association, Seattle, Wash., September 15, 1923.]

In discussing the subject of forest fire weather in western Washington, I will take up only that phase of the weather which is the cause of crown fires in the Douglas fir region of our State.

The localities which are susceptible to such fires are the Douglas fir and white pine regions of North America. The Douglas fir region is located between the forty-third and fifty-third degree of North latitude; the summit of the Cascade Mountains on the east and the Pacific Ocean on the west. The center of this zone north and south is near latitude 47° north. The zone comprises an area approximately 650 miles long by 150 miles wide.

In the white pine region the conflagration zone is central along latitude 47° north from the foothills of the west slope of the Rocky Mountains to the Gulf of St. Lawrence.

During the past 100 years 15 great fires, of which we have more or less record, have occurred in these two regions. Six of the 15 fires referred to have occurred in the Douglas fir belt during the past 50 years. One who is