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MEASURING FIRE WEATHER AND FOREST INFLAMMABILITY

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INTRODUCTION

In the measurement of fire weather and forest inflammability, now practiced regularly at more than 90 forest stations in northern Idaho and western Montana, it is necessary to use many methods that are peculiar to this work. Some of these methods are familiar to meteorologists, but few foresters have had any appreciable training in meteorology. Others are of such recent development and so specially designed for forest protection that they are unknown to most meteorologists and are not yet taught in the schools of forestry or described in any textbooks. The information available on these methods is scattered through numerous bulletins, reports, and official letters of instruction. Much of this information is assembled in this circular for more convenient reference. It has been prepared specifically for use in the Northern Rocky Mountain Region; but much of the material presented may be of value in other regions.

The sole purpose of the weather and inflammability measurements described herein is to improve forest-fire control. Nearly every measurement described has been found by experience to contribute toward this purpose; the remainder are being tested on a large scale to determine whether or not they are worth while. Every method of the latter group has been tried experimentally over a period of years, at the Priest River, Idaho, branch of the Northern Rocky Mountain Forest and Range Experiment Station. The wood-cylinder method of measuring fuel moisture, for example, was developed and tested at Priest River over a period of 7 years before the station advocated that it be tried on a large scale in routine field practice. Field tests are essential because they often show possibilities of im-

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provement in either technique or application that cannot be discovered in more limited experimentation.

FACTORS MEASURED AND OBSERVED—INSTRUMENTS AND METHODS

The principal causes of forest-fire danger in the Northern Rocky Mountain Region, aside from human activities, are: (1) The character and volume of the common forest fuels; (2) topography, which influences the exposure of fuels and the rate of spread of fire; (3) lightning, the one weather element that causes fires; (4) wind, which often controls the rate of spread of fire; and (5) current moisture content or inflammability of the fuels, which is determined principally by precipitation, temperature, humidity, solar radiation, and soil moisture.

For any particular area, the first of these five factors is relatively constant from year to year except as it is changed by burning or by logging. The second factor changes even less. The third, fourth, and fifth vary decidedly from year to year and from day to day; consequently these three require daily measurement if the development of critical fire danger is to be anticipated and current danger estimated most dependably, if the character of each fire season is to be rated accurately, and if the efficiency of the fire-control organization is to be judged on the basis of the danger actually experienced.

For measuring weather factors, standard meteorological instruments are used by all fire-weather stations cooperating with the Weather Bureau. In most cases these are furnished by that Bureau and remain its property. The instruments used to measure inflammability are for this special purpose only, and are therefore supplied by the forest-protective agency. At each station a record of the ownership and number of each piece of equipment should be filed for ready reference. For this purpose a special form called "inspection record" is available, which appears as an appendix to this manual. In case of breakage of any instrument such a record indicates to whom application should be made for replacement. Supervising officers will find this inspection record of additional value in that it lists certain procedures which are essential to the accuracy of fire-danger measurement.

In October or November of each year all meteorological equipment should be checked over, and before April 1 all damaged instruments should be repaired or replaced. At stations where measurements are discontinued at the close of each fire season all instruments should be carefully cleaned at that time and safely stored to prevent theft or damage during the winter. Unless this is done there may be undesirable delay in beginning measurements in the spring.

Chart forms for all automatic recording instruments should always be clearly labelled to show station represented and dates included. It is best to write the date above the noon line for each day, and the station name in the blank space at one end of the chart. Proper designation of each chart record is highly important in order to prevent confusion and perhaps later loss of the data.

The officially correct hour for cooperative weather measurements in the United States is 8 o'clock, both morning and night, eastern standard time, or 7 o'clock central, 6 o'clock mountain, and 5 o'clock Pacific time. In other words, all Weather Bureau observers and all observers cooperating with the Weather Bureau, the country over, should make their measurements at the same instant. The purpose of this is to produce meteorological records showing the status of the weather at given hours on a Nation-wide basis, in order to map weather conditions for the whole Nation as of those hours. Obviously, if the various observations were not made almost simultaneously the data would not be comparable, because the weather changes continuously.

When an observer is "taking his readings" on the standard schedule, it is interesting to realize that the great majority of the 6,800 other American observers[1] are doing the same thing at the same instant.

In fire-weather work it is not always possible to schedule daily measurements for the standard Weather Bureau hours. At most forest stations in region 1 the time for making morning measurements is changed to 8 or 8:30 a. m. The hour for afternoon measurements in this region should be as close as possible to 6 p. m mountain time or 5 p. m. Pacific time. In all cases, once the time is established the daily readings should so far as possible be made regularly not more than 15 minutes before or more than 15 minutes after that time.

Fuel-moisture readings are made by Forest Service observers at the same hours as measurements and readings of weather elements, except at stations in deep canyons where the sun sets before the standard hour of measurement. At such stations the afternoon measurements of fuel moisture should be made from 15 to 30 minutes before sundown.

The "weather day" ends at the hour of the afternoon weather and fuel-moisture readings. Thus, if readings are made at 6 p. m. a rain occurring at 10 p. m. of July 15, for example, is recorded not under the actual calendar date but under the date July 16. Although this introduces some minor peculiarities into the records, some such method is necessary in order to avoid making measurements at midnight.

WEATHER

PRECIPITATION

Precipitation is the only weather element that ever obliterates forest-fire danger. High humidity or low temperature often reduces danger temporarily; but only a protracted rain can add sufficient moisture to the heavy fuels so that they become too wet to burn or to be burned.

For measuring rainfall the Forest Service uses two types of gages: The Standard Weather Bureau gage, about 30 inches high and costing about $11, and the Forest Service gage, about 10 inches high, made of cheaper materials and costing only $1.50. Both types are shown in figure 1. The small gage, if it has been accurately made according to the specifications of 1934 or later, if it is properly exposed, and if the exterior of the catching funnel has not been so

[1] Some 2,300 of these are paid from Weather Bureau funds, and about 4,500 are voluntary cooperative observers.

bent as no longer to form a perfect circle, is just as satisfactory for summer use at forest stations as the more expensive standard gage. Records obtained by use of this gage, however, are not published as

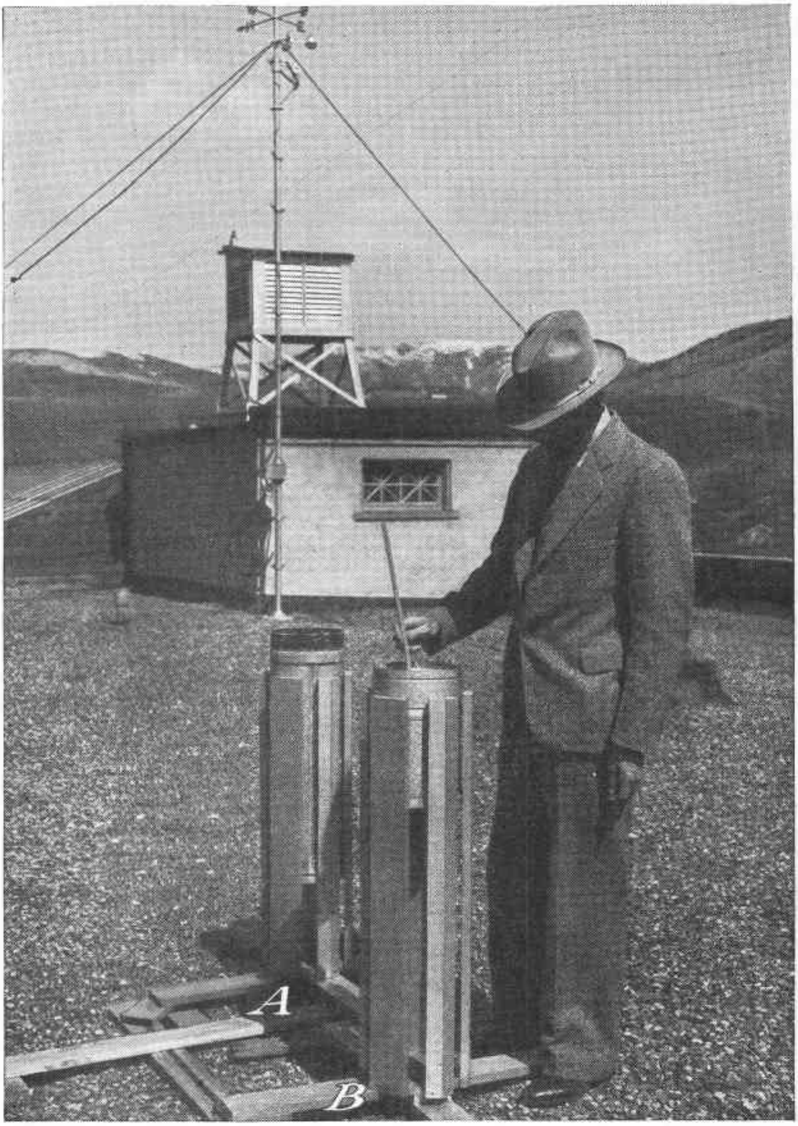

FIGURE 1.—Two types of rain gage: *A*, Standard Weather Bureau gage, 8 inches in diameter of funnel and 30 inches high; *B*, Forest Service gage, 7.64 inches in diameter of funnel and 10 inches high.

official Weather Bureau data. Comparative tests are being made to determine whether or not this gage is materially erroneous.

If the rim of the catching funnel of this gage has accidentally been bent into oval form, or so that its outline is wavy, it should be straightened, and all soldered joints loosened by the straightening process should be resoldered. The junction of the funnel and the rim should be examined periodically for weaknesses in the soldering. Leaks in this joint permit some of the rainfall to enter the outer can, instead of being concentrated in the inner tube. The inner tube itself may also develop a leak after being subjected to freezing weather.

The area inclosed by the rim of the catching funnel should be exactly 10 times the cross-sectional area of the small brass or copper tube within the gage. If the diameter inside the rim of the catching funnel is 7.64 inches and the diameter inside the brass or copper tube is 2.416 inches, the ratio of the two areas is 10 to 1. As a result of such an areal ratio between catching funnel and concentrating tube, the rain accumulating in the tube forms a column 10 times the depth of the actual rainfall. This is why, although the graduations on the rain-gage stick are in tenths of an inch, the readings signify precipitation in hundredths of an inch. The ratio should be checked for each Forest Service gage annually.

Forest Service gages that are found to have an inner-tube cross-sectional area not exactly one-tenth as great as that of the catching funnel (inside measurements in both cases) should be repaired if possible. If this cannot be done a new gage should be requisitioned and a note should be made on each report of measurements made with the faulty gage showing the cross-sectional area of both the catching funnel and the concentrating tube.

The accuracy required of a rain gage depends, of course, upon the use to be made of the measurements. When differences of 5 percent in quantity of rain are not significant or do not require different action by the organization using the data, there is little purpose in striving for 95-percent accuracy. In fire-control work, for example, the action taken on the basis of precipitation measurements is no different with a rainfall of 0.095 inches than with a rain of 0.10, and it is not different for 0.20 or 0.21 inches. Studies in New South Wales and Arizona (*9*)[2] have yielded indications that differences much greater than 5 percent may be expected in the precipitation on different parts of a small area. Many gages per acre would be required to determine true averages of precipitation.

Correct exposure of a rain gage is just as important as its accurate construction. Two features of exposure should be watched. First is the position of the gage in relation to objects such as buildings, trees, shrubs, and telephone poles. Place the gage so that these objects do not interfere with rain falling into the catching funnel, and so that the top of the gage is between 3 and 4 feet above the ground level. Such exposure helps to prevent debris from falling or blowing into the gage and thereby introducing error into the measurements. The second feature is leveling the gage so that the rim is perfectly horizontal. If the funnel is tipped toward the north, for example, it will catch more than the true rainfall when the rain comes with a wind from the north, and far less than the true rainfall when the rain comes with a wind from the south.

In measuring rainfall, insert the rain-gage stick slowly through the funnel until the end of the stick rests on the bottom of the inner tube. Then withdraw the stick and note the height at which the

[2] Italic numbers in parentheses refer to Literature Cited, p. 55.

water level came. If the stick is jammed or dropped quickly into the inner tube the water splashes and wets the stick higher than it would have otherwise.

If rain has more than filled the inner tube, measure the water in the tube, pour it outside the can, then pour what is left in the large can (the overflow) into the inner tube and measure it. The total of the two measurements represents the precipitation since last measurement. In making these repeated measurements do not use the bare hand to wipe surplus water off the stick, as oil from the skin (or from any other source) penetrates the wood and prevents the water from making a distinct level mark on the stick.

The standard rain-gage stick is 24 inches long, 0.56 inch wide, and 0.1 inch thick. It is graduated into tenths of an inch, and each graduation represents 0.01 inch of rainfall. The numerals 10, 20, 30, for example, represent 0.10, 0.20, and 0.30 inch, respectively. The decimal form is desirable in recording the data. If the quantity is less than 1 inch a zero should always be entered ahead of the decimal point. Any quantity of rain less than 0.01 inch is called a trace, and should be recorded by using the symbol "T."

Although no direct correlation has yet been established between winter snow depth and the following summer's fire danger, the reports of snow conditions called for by the Region 1 fire guide are valuable indicators.

It must be remembered that all standard snow stakes (fig. 2, *D*) show depth in inches, not in feet and tenths. The large numbers on the stakes, 1, 2, 3, 4, etc., signify 10, 20, 30, and 40 inches, etc., respectively. Such measurements show only the depth of snow existing on the date of measurement. The practice at Forest Service stations is to observe and report the snow depth on the 1st and 15th of each month whenever there is snow at the stake.

The amount of snow falling each day is measured by use of a "snow board" made of wood or tightly stretched canvas about 3 by 3 feet. This is placed level on the surface of the snow field after each snowstorm. The next snowfall then covers this board and the depth is easily measured by use of an ordinary rule, yardstick, or the rain-gage stick. The board is then cleaned, placed on top of the fresh snow at a different spot, and is ready for the next snowfall.

Stations having both snow stake and rain gage should if possible maintain, in addition to a record of depth of snowfall, a record of the water content of each day's snowfall. This may be measured by removing the funnel top and inner brass tube of the rain gage, which otherwise would quickly fill to the brim and overflow. With the funnel and inner tube removed, the outer can is used to catch snow. If this catch is believed to be typical, and it is not likely to be typical if the storm has been accompanied by much wind, the water content of the snow caught in the outer can is measured as follows: The brass inner tube of the gage is partially filled with hot water. The depth of this is measured in the regular way. This hot water is then poured over the snow in the outer can to melt it. The hot water plus snow water is poured back into the inner tube and the total depth measured. The difference between the depth of the initial hot water and the final is the water content of the snow.

If the storm has been windy so that the snow catch in the outer can has been affected by eddies around the gage another method is used to measure the moisture content of the day's snowfall. After

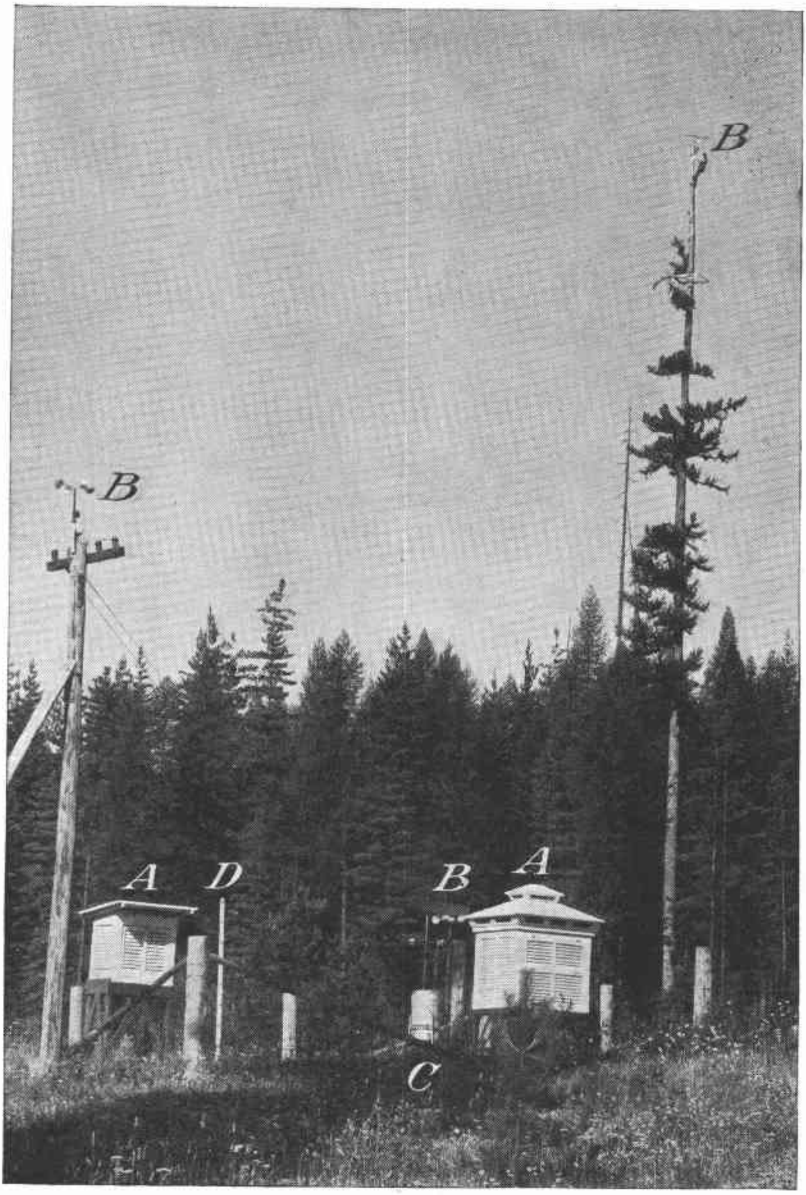

FIGURE 2.—Weather-instrument installation: *A*, Two types of instrument shelter; *B*, anemometers exposed at elevations of 9, 20, and 150 feet, respectively, above the ground; *C*, tipping-bucket rain gage; *D*, snow stake.

measuring the depth of snow on the snowboard, as described above, the outer can of the rain gage is inverted and the open end is pushed down through the layer of snow covering the board. A sheet of thin metal is then inserted across the mouth of the gage, the outer can is turned right side up, and hot water is added as described above. A second and a third sample may be collected and measured if for any reason the first measurement is not satisfactory.

Any station using a meteorograph that records measurements made by a tipping-bucket rain gage (figs. 1 *c* and 2 *c*) should have a copy of the Weather Bureau publication entitled "Measurement of Precipitation" (*17*) for reference concerning the care of the gage. Copies of this publication of the Weather Bureau, and of others mentioned later, are furnished by that Bureau to cooperating agencies without charge. Other agencies may purchase these publications from the Superintendent of Documents, Washington, D. C.

TEMPERATURE

THERMOMETERS

Measurement of maximum and minimum temperatures is described in the Weather Bureau publication Instructions for Cooperative Observers (*27*). As shown by that circular, and by experience in Region 1, the features of this work requiring special attention are as follows:

(1) Expose thermometers properly. All standard measurements of air temperature represent conditions in shade. Hence all thermometers used to measure air temperature should be exposed in such a way that the sun's rays do not strike them at any time. For this reason the door to any thermometer shelter should open always toward the north. The standard thermometer shelter has latticed sides, is well ventilated, and has a double roof and other special features. An interior view of such a shelter, with maximum and minimum thermometers and other instruments, appears in figure 3; an exterior view is shown in figure 2, *A*. A less expensive shelter has been designed for use in fire-weather measurements. Specifications for the construction of this shelter will be furnished by the Northern Rocky Mountain Forest and Range Experiment Station upon request. When no better shelter is available an ordinary wooden box may be used, nailed to a tree with the open face to the north, at such height that the thermometers are about 5 feet above ground level.

Thermometers should not be mounted directly on or even close to the outside wall, window casing, or door jamb of a building, because the building itself absorbs and radiates heat and thereby would influence the thermometer readings.

(2) Avoid haste in readings. Suppose the tip of the mercury column in the maximum thermometer, or the upper end of the rider in the minimum thermometer, is at 48°. The observer sees the figure 50, engraved on the stem, with the mercury two graduations from it. If "in a rush", he may record a temperature of 52°. This error is more common than might be supposed; to prevent it, every observer should check himself at every reading.

(3) Avoid contact of hands with bulb. Even brief contact of a warm hand with a cool thermometer bulb may introduce an error of several degrees, and mere proximity of hand to bulb may affect the measurement slightly. Care in this respect is one of the features that distinguish the expert from the novice.

(4) Lower maximum thermometer from its approximately horizontal position to a vertical position before reading it. Failure to do this often introduces serious error into a meteorological record. In the horizontal position the mercury column may have separated at the constriction in the bore and the tip of the column may be many degrees above the true reading. To obtain the correct maximum temperature, always lower the thermometer slowly to a vertical position and then note the temperature indicated by the tip of the mercury column. To obtain a true reading the eye of the observer should be on the same level with the mercury surface.

(5) Set the maximum. Since the mercury column in a maximum thermometer that is in good working order responds only to an increase in temperature, never to a decrease, at the end of each period

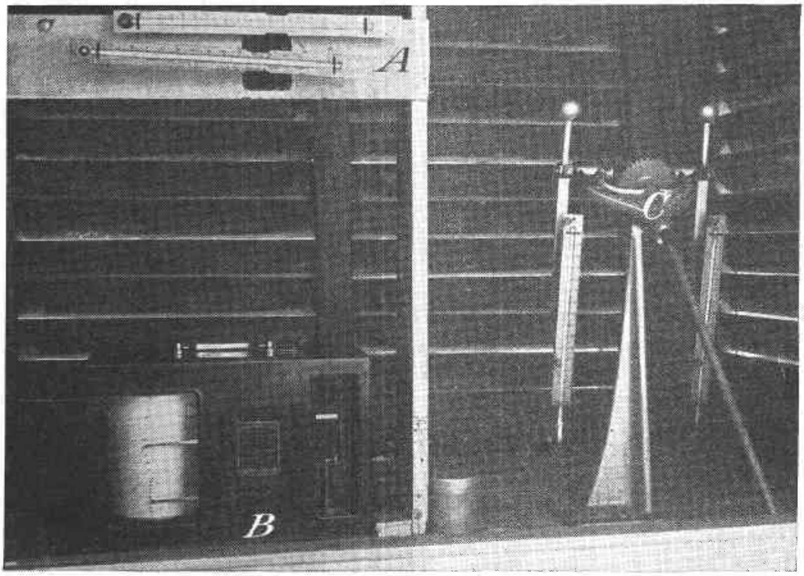

FIGURE 3—Interior view of weather-instrument shelter: *A*, Properly mounted maximum and minimum thermometers; *B*, hygrothermograph; *C*, psychrometer.

for which a reading is made it is necessary to whirl the thermometer so as to drive the mercury back into the bulb. The standard thermometer support is specially designed so that the maximum thermometer, held in the lower clamp, can be released from its horizontal position and by a gentle push with the fingers can be thrown into a rapid whirling motion. If the whirling is done properly the reading obtained immediately after the whirling, while the thermometer is in a vertical position, is the "set maximum." The set maximum temperature is the temperature existing at the instant the whirling is completed.

When the whirling is completed and the temperature is read, this reading is compared with the readings of the other indicators of current temperature, the dry-bulb thermometer of the psychrometer and the upper end of the alcohol column in the minimum thermometer. If the comparison is satisfactory, the maximum thermometer is returned to its approximately horizontal position and clamped in

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place. If the maximum thermometer reads more than 1° higher than the others the whirling should be repeated. When the thermometer is clamped in place the bulb end should be about 1 inch higher than the tip, to prevent any possibility of mercury retreating from the bore past the constriction and into the bulb as the air cools.

The temperature shown by a maximum thermometer should never be lower than the last preceding "set" temperature of that thermometer; obviously, the maximum for any period cannot be less than the maximum for a part of that period. If a maximum thermometer at any time shows a temperature lower than that recorded as the last preceding "set" temperature, an error has been made in reading the thermometer or it is a "retreater."

"Retreating" is due to insufficient constriction in the bore of the thermometer and to insufficient slope in the mounting of the thermometer. When constriction is insufficient it fails to break the mercury column, and as the temperature falls some of the mercury that has passed into the bore is drawn back into the bulb instead of staying in the bore, unless the slope of the mounting prevents this. If the maximum shown by the records for a period is always as high as the set maximum for that period, or higher, then there is no reason for suspecting that the thermometer is a retreater.

(6) Make correct reading of the minimum thermometer. The most common error in reading a minimum thermometer is failure to observe the correct end of the rider or index inside the bore. The rider is pulled down the column by the decrease in the volume of alcohol, and the upper or right-hand end of the rider finally comes to rest at the lowest point reached. The correct end of the rider to observe is the end at the observer's right hand as he faces the instrument, that is, the end farther from the bulb. The observation is made while the thermometer is still in a horizontal position.

(7) Set the minimum thermometer. After the minimum thermometer is read, it is "set" by tipping it to a vertical position with the bulb uppermost. The rider then slides until it reaches the end of the alcohol column. In this position it indicates the current temperature.

(8) Check the continuity of column of alcohol in a minimum thermometer. When the "set" temperature of the minimum thermometer is not the same as that of the maximum thermometer or as the temperature shown at the same instant by the dry-bulb thermometer of the psychrometer, the observer should immediately examine the minimum thermometer for a break in the column of alcohol. Any such break is easily detected through the presence of a section of alcohol in the upper portion of the bore, separated from the main column.

To reunite a separated section with the main column is often difficult. A detailed description of the best methods is given in a Weather Bureau publication (*27*). Briefly, the method recommended for first trial is as follows: Place several thicknesses of blotting paper on a table; then, holding the thermometer vertically, with the bulb end down, tap it lightly on the blotters. The tapping gradually jars the detached drop of alcohol down until it reunites with the main column. The fluid moves more readily when its temperature is about 100° to 110° F. The safest way to warm the alcohol is in the sun, although it may be warmed in an oven or in warm water. Trying to warm it with a match involves danger of breakage, and these thermometers cost about $3.25 each. After the column is rejoined, let the instrument stand in a vertical position in the sun for half an hour to permit any alcohol on the walls of the bore to drain down to the main column.

If efforts to rejoin the broken column fail, the extent of the error should be determined, by reference to other standard thermometers, and subsequent readings should be corrected by this amount. In the meantime a new thermometer should be requisitioned to replace the faulty one.

(9) Determine current temperature. The air temperature existing at a given moment, as has been stated, can be determined by means of the dry-bulb thermometer of a psychrometer or by means of a minimum thermometer. The upper end of the alcohol column in a minimum thermometer always indicates the current temperature. Close and careful examination is necessary to see the upper end of this column. It appears, rather faintly, as a slightly curved line.

A maximum thermometer cannot be used conveniently for determining current temperature except immediately after "setting", or when the current temperature is rising above the last previous "set."

THERMOGRAPH

In addition to maximum and minimum thermometers, use is often made of an instrument called the thermograph, which automatically makes a record showing air temperature for every minute of the day and night. One type of thermograph is illustrated in figure 4*c*. Fairly complete instructions for operating a thermograph are supplied by the maker with each instrument. The following instructions require special attention if the best possible records are desired:

(1) At every reading of the maximum and minimum thermometers, check the position of the thermograph pen for time. If it is more than 15 minutes ahead of or behind the correct time, reset it correctly. This resetting is done by turning the drum that holds the chart form. The drum can be turned, by gentle forcing, either clockwise or counterclockwise without removing it from the spindle. After the pen is reset to indicate the correct time, the drum should be tight against its gears when turned counterclockwise. Otherwise, the pen may be as much as half an hour behind correct time at the next reading, owing to play in the gears.

(2) A check of the accuracy of temperature recording should be made at the end of each week's run. On the graphic record, mark the maximum and minimum temperatures for each day of the week according to the maximum- and minimum-thermometer records. Then determine the average error of the thermograph for these 14 cases (7 maxima and 7 minima). If both the maxima and the minima shown by the thermogram (thermograph line) are higher, or if both are lower, than the corresponding readings on the thermometers, then the pen should be lowered or raised accordingly. On one type of instrument this is done by manipulating a thumbscrew; on another, by means of a key adjustment on the outside of the case. After resetting the instrument, mark the chart at the place of correc-

tion to show that the change in the record was due to resetting, and to show by how many degrees the pen was reset. For example: "Reset here. Lowered 2°." If the thermogram runs both higher than the maximum-thermometer readings and lower than the minimum-thermometer readings, and these differences total 3° F. or more,

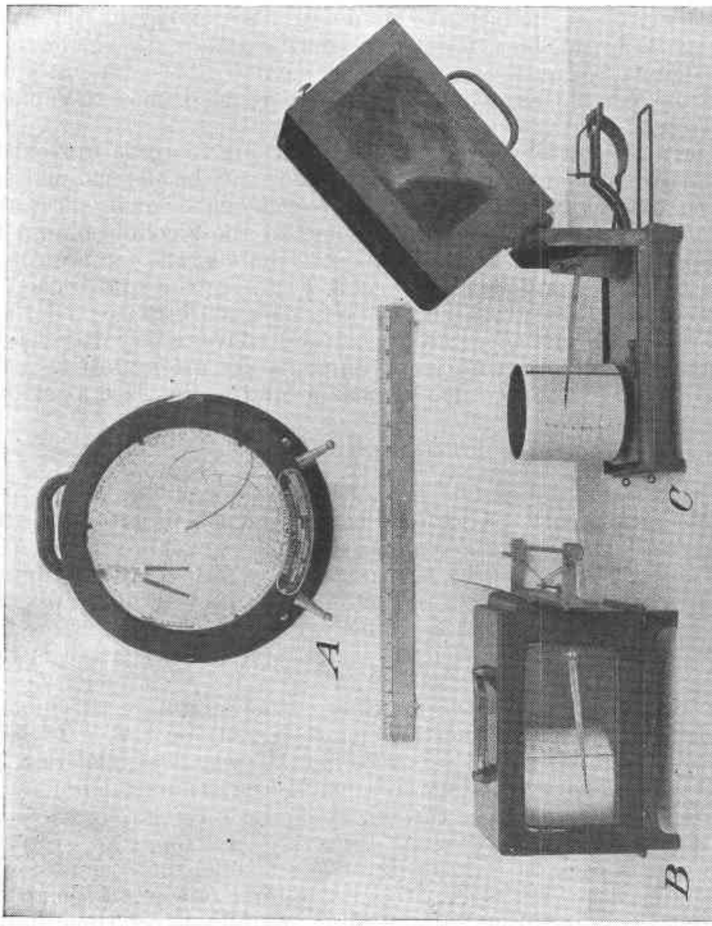

FIGURE 4.—Automatic instruments for measuring and recording temperature and humidity: *A*, One type of hygrothermograph; *B*, one type of hygrograph; *C*, one type of thermograph. The strand of hairs in the hygrograph is shown pulling against a small hook, movement of which raises or lowers a pen.

the thermograph should be sent to the regional fire-weather office of the Weather Bureau or to the experiment station for readjustment.

(3) If the thermograph clock runs consistently too fast or too slow, it should be slowed by use of the standard adjustment marked "S" or speeded by use of that marked "F." (On thermographs of French manufacture these adjustments are marked "R", for "retard", and "A" for "avance.")

(4) If the clock cannot be adjusted to turn the drum at the correct speed, or if it runs down within a week after being wound tightly, send the instrument to the regional fire-weather office of the Weather Bureau with a note requesting whatever cleaning and adjustments may be found necessary.

(5) All thermographs should be sent to the Weather Bureau for cleaning and oiling at least once every 5 years. This should be done in October or November, at the close of the season. The instruments will then be returned early the following spring.

(6) Chart forms for use on a thermograph are furnished by the Weather Bureau or by the Forest Service, whichever owns the instrument. Supplies of these forms should be requisitioned direct from the agency owning the instrument.

HUMIDITY

Humidity is one of the more important elements of fire weather, and is one of the most difficult to measure accurately.

Although it is common to speak of the "humidity of the air", as a matter of fact air—a mixture of gases—does not absorb, hold, or lose moisture. Water vapor is drawn from the ground and from other sources into the space partially occupied by the gases composing the air. This vapor acts much like any of the gases, oxygen, hydrogen, nitrogen, carbon dioxide, etc., and mixes with them in space. When the quantity of water vapor in a cubic foot of space is increased the quantity of air in that space is correspondingly lessened, if other conditions such as temperature and pressure remain constant. If the temperature of the water vapor and the gases increases, the water capacity of that space is increased. If the temperature falls, the water capacity of the space is decreased. Consequently, although air itself does not absorb or lose moisture, humidity varies with the temperature of the air.

In forest-fire weather work that measure of atmospheric water vapor called relative humidity is used; this is defined as the ratio of the quantity of moisture contained in a unit of space to the maximum quantity of moisture that could be contained in that space at the existing temperature and pressure. This ratio is expressed as a percentage. When measurements show, for example, that atmosphere moisture is one-third as great as it could possibly be at the existing air temperature, the relative-humidity reading is 33 percent.

When relative humidity is low and forest fuels are wet, moisture evaporates from the fuels rapidly. The fact that not all the fuels require the same length of time to become dry and inflammable prevents any simple correlation between humidity and fuel moisture. Even when relative humidity is as high as 99 percent the evaporation of moisture from duff, slash, snags, etc., continues if the fuels are moderately wet. It is only when fog is present, or relative humidity is 100 percent, that wet fuels cease to lose moisture. Furthermore, after the forest fuels have been dried to moisture contents of 10 percent or less the occurrence of high relative humidity does not make fire impossible. Several hours are required by even the lighter weight fuels to absorb an appreciable quantity of moisture from the air, and the total quantity that they can absorb, even during periods of very high humidity, is limited. The heavier fuels such as snags and windfalls, when they are thoroughly dried, do not change materially in moisture content unless exposed to a high relative humidity for a period ranging approximately from 12 to 24 hours. The 250,000-acre Pete King fire of 1934 made one of its most explosive runs, and added 54,000 acres to its burned area, on an afternoon when the average relative humidity at two nearby stations was 43 percent.

Relative humidity below 15 or 20 percent can always produce dangerous dryness of fuels if it prevails long enough. It has been found, for example, that if cellulosic materials such as wood or duff are exposed continuously to a relative humidity of 10 percent and an air temperature of 100° F. they lose moisture until the quantity of moisture per 100 pounds of the materials is reduced to 2 pounds. This is a moisture content of 2 percent. During our worst fire seasons some fuels that are exposed to the direct rays of the sun, and are thereby heated to temperatures well above 100°, often dry out to this dangerous condition. Low humidities are always potentially dangerous and should be watched for with great care. (The occurrence of low humidity does not necessarily produce great fire danger, however, and humidity alone is not a satisfactory index of inflammability of the coniferous forests of the northern Rocky Mountain region.)

Any relative humidity less than 10 percent is of exceptional interest and importance, and before any such figure is reported it should be verified by at least a second and preferably a third consecutive measurement, each shown specifically on the report form.

The question as to the lowest relative humidity naturally occurring is of interest among foresters. A minimum of 5 percent was accurately measured at the Priest River, Idaho, branch of the Northern Rocky Mountain Forest and Range Experiment Station in July 1931, and at Missoula, Mont., in July 1933. Neither of these readings occurred at an hour of standard measurement, however; consequently neither is included in the published records. At Spokane a relative humidity of 6 percent was measured at the regular 5 p. m. observation on July 20, 1931. These are the lowest humidity records for Region 1 based on measurements of assured accuracy. Authentic records of relative humidity as low as 2 percent were reported from California about 10 times in the period 1927–33.

The highest possible relative humidity is, of course, 100 percent. The relative humidity within a cloud or within fog—which is merely cloud close to the ground—is usually 100 percent. Measurements made during rainstorms have shown relative humidity as low as 40 percent in Region 1 and as low as 18 percent in California.

Weather Bureau instructions for measuring relative humidity are given in a bulletin entitled "Psychrometric Tables" (*16*), published in 1910. A copy of this bulletin should be included in the reference library of every forest-protective organization.

Vapor pressure, or the pressure exerted by the moisture in space, and the weight of this moisture in grains per cubic foot of space or in grams per cubic meter, are both measures of absolute humidity, or the actual—not the relative—quantity of water vapor per unit of space. Neither of these is as yet commonly used in forest fire-weather work. For information on them the reader is referred to standard textbooks by Humphreys (*10*), Gregg (*6*), and Piston (*20*).

PSYCHROMETER

The most accurate field method of measuring atmospheric moisture is use of a psychrometer. One type of this instrument is shown in figure 2; four other types are shown in figure 5. The type most commonly used is the sling psychrometer. A psychrometer has two thermometers, which should agree within one-half of 1° F. in indicating air temperatures when both are dry. Every psychrometer should be tested in this respect. If the two thermometers do not

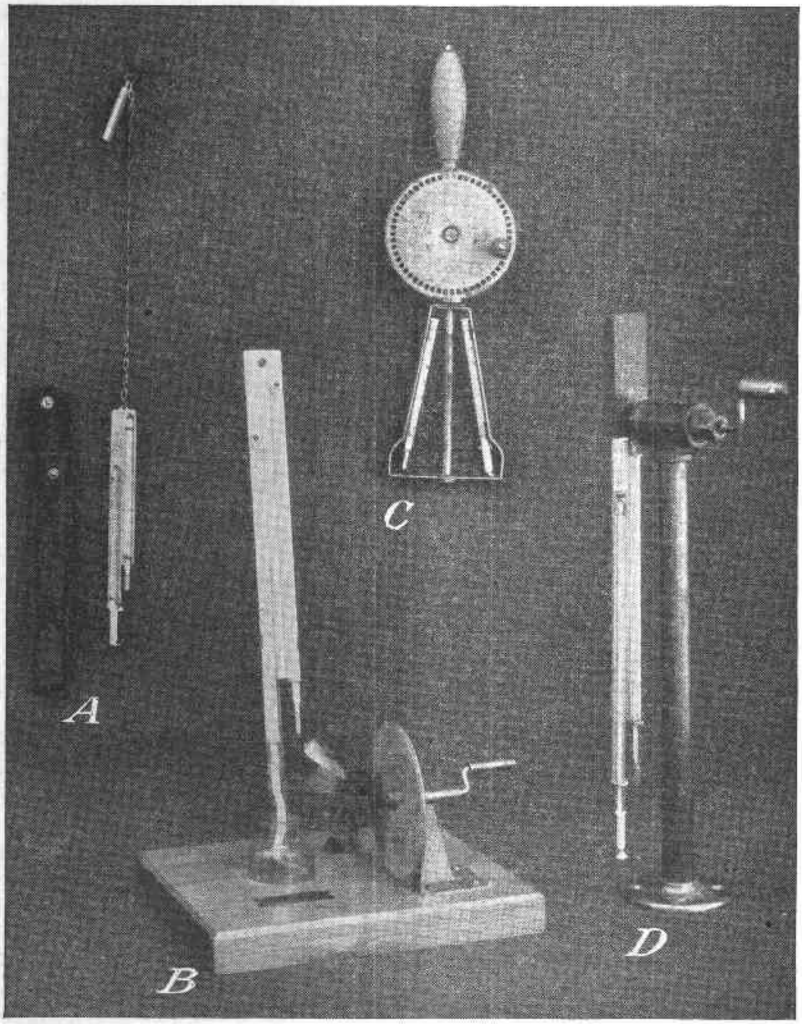

FIGURE 5.—Four types of psychrometers: *A*, Pocket size, with case; *B*, Pacific Northwest Forest Experiment Station fan type; *C*, egg-beater type; *D*, Gray whirling device.

agree within one-half of 1°, the whole instrument should be sent to the Weather Bureau or the Forest Service for testing and, if necessary, replacement of the faulty bulb. Weather Bureau standard sling psychrometers cost about $4.50 each.

The two thermometers of the sling psychrometer are mounted on a metal support attached to which is a handle that permits whirling the device. The one that projects farther beyond the support is the wet-bulb thermometer. The wet bulb should be covered with a thin layer of clean white cotton cloth. (Silk is not recommended.) A suitable covering is available in the form of a tubular wicking, which is easily applied and is tied in place both above and below the bulb with thread. This wicking can be obtained from the Weather Bureau upon request. As soon as a covering becomes soiled a new one should be applied, or the old one should be washed with soap and water and the soap thoroughly rinsed out. Unless the covering is thin and clean it is not possible to get accurate measurements of relative humidity.

To avoid soiling the wet-bulb covering, clean water only should be used to wet the bulb. Although distilled water formerly was recommended for this purpose, clean drinking water from any source is satisfactory.

For best results the temperature of the water used to moisten the wet bulb should be the same as the current temperature of the air; it should never be materially lower than air temperature. The whirling should always be done in the shade, because all air temperatures recorded are shade temperatures unless otherwise specified.

To whirl a sling psychrometer by hand, not only should the observer stand in the shade on sunny days but on rainy days he should stand under a roof or other shelter to prevent rain from striking the bulbs. Standing in the open doorway of an otherwise closed building is not good practice; the air temperature may not be the same there as outside, where air movement is unrestricted.

The psychrometer should be whirled fast enough to insure rapid evaporation of water from the wet-bulb covering, but not so fast as to endanger the instrument. A speed of about 200 revolutions per minute is satisfactory and safe.

The purpose of the whirling is to determine the temperature of evaporating water. By comparing this temperature with that of the air it is possible to compute the relative humidity. On hot, dry days, when the evaporation rate is high, the wet-bulb temperature drops rapidly with whirling and soon reaches its lowest point, which is the point to be determined. On such a day from 100 to 150 whirls may be sufficient for a first approximation. One approximation is not enough; after the instrument has been whirled 100 to 150 times, and the wet-bulb thermometer read, it should immediately be whirled again 30 or 40 times, then read again. If the two wet-bulb readings are exactly alike, probably the lowest temperature has been reached; but to be positive, it is desirable to whirl the instrument 20 or 30 times more and read the wet-bulb thermometer once again. If all three readings agree this temperature may be taken as the true measure. The dry-bulb thermometer should then be read. The two temperatures, wet-bulb and dry-bulb, constitute all the data needed for determining relative humidity by use of the proper tables.

If, as frequently happens, a rereading or each of two rereadings of the wet-bulb thermometer is lower than the reading preceding it, the whirling process is repeated until at least two and preferably three consecutive readings are exactly alike. A simple rule is to continue whirling the psychrometer until a lower wet-bulb temperature cannot be obtained, then use the lowest wet-bulb reading.

During this process the wicking should not be dipped in water again; the instrument should be kept at arm's length, so as not to be affected by body heat; and the observer's hand should never touch the thermometer bulbs. If the observer does not catch two or three consecutive readings exactly alike, he should rewet the bulb and start an entirely new measurement. Several measurements are sometimes necessary on an extremely dry day when one wetting of the cover is not sufficient to reduce the wet-bulb reading to the temperature of evaporation.

Having obtained two or three consecutive wet-bulb readings that are exactly alike, each pair separated by 20 or more whirls of the instrument, and having read the dry-bulb thermometer at the time of the last wet-bulb reading, the observer has a pair of temperature readings such as 90° F. on the dry bulb and 68° on the wet bulb. The difference, in this case 22°, is sometimes called "the depression of the wet bulb." Such "depressions" are indicated in the tables by the symbol $t—t'$. From these data the relative humidity can be determined.

For this purpose the psychrometric tables (*16*) published by the Weather Bureau are commonly used.

Unless the observer is attentive to details he may misuse these tables, not through any fault in them. In fact, systematic checking of the relative-humidity computations made at several stations over a period of years has shown that misuse of these tables has caused an average of about 10 percent of the humidity records to be in error. Two kinds of psychrometric tables are given in the Weather Bureau publication. One kind shows the "temperature of the dew point", and is so headed on each page. The other kind shows "relative humidity, percent" and is so designated. It seems inane to mention the fact that an observer should not use the dew-point table when he wants relative humidity but this error has been made by many observers. Such an error, of course, proves downright carelessness and lack of attention to the job in hand.

A second possible error is selecting the wrong table of relative humidity. The bulletin includes separate humidity tables for pressures of 23.0, 25.0, 27.0, 29.0, and 30 inches. The effect of using the wrong table is comparatively small; nevertheless, for a given station there is only one right table.

The pressures mentioned represent ranges of elevation above sea level as follows:

Pressure (inches):	*Elevation (feet)*
23.0	6,000 to 10,000
25.0	4,000 to 5,999
27.0	2,000 to 3,999
29.0	500 to 1,999
30.0	Less than 500

At nearly all forest stations, sling-psychrometer measurements of humidity are made in the morning and again in the late afternoon. At some stations additional measurements are made at other hours.

HYGROGRAPH AND HYGROTHERMOGRAPH

Relative-humidity measurements made with the psychrometer at intervals during the day serve to indicate trends, but do not show

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definitely either the lowest point reached each day or the number of hours of dangerously low humidity in each day. Data of the latter kinds are needed for efficient forest protection. Furthermore, it frequently happens that a forest officer would like to know the humidity prevailing at a given instant when he has not the time, or the inclination, to whirl a psychrometer and make a computation. These needs are met by use of an instrument called the hygrograph. This instrument measures relative humidity currently and plots a continuous record for 7 days on a properly graduated chart form. One type of hygrograph is shown in figure 4, *B*. The cost of a hygrograph ranges from $80 to $145.

An instrument called the hygrothermograph (figs. 3, *B*, and 4, *A*) continuously measures and records both humidity and temperature. The best type of hygrothermograph is that developed rather recently by the Instrument Division of the Weather Bureau and designated model B. This instrument has at one end both a bimetallic strip, which responds to temperature, and several strands of human hair, which changes length according to humidity. All instruments of this type used by the Forest Service in region 1 are the property of the Weather Bureau. Chart forms (no. 1074 B) are furnished by that Bureau upon request. Hygrothermographs of this type should be returned to the Weather Bureau at least once every 5 years for complete checking, cleaning, and repairing. A hygrothermograph costs from $95 to $165.

A third instrument called the hygrometer has a pointer that indicates the current humidity, but does not record it. A hygrometer can be obtained at a cost of $2.50 to $15. Some hygrometers are reasonably accurate, can be readjusted when they become inaccurate, and are sufficiently durable for forest-station use.

Instructions previously given for operating a simple thermograph apply also to operating the hygrograph or the hygrothermograph. In order to set the hygrograph pen, it is necessary to determine the correct humidity with a psychrometer. As relative humidity is most important when it is low—below 30 percent—the hygrograph pen should be tested and reset for accuracy preferably at such times. Furthermore the hygrograph pen should be reset only when relative humidity is comparatively constant, that is, is not fluctuating rapidly by more than 2 percent. Such fluctuation readily becomes apparent in the hygrograph line, or "trace."

In preparation for resetting the hygrograph pen, at least three consecutive measurements should be made with the psychrometer and every step of the process should be carefully checked. The observer should check his readings of both dry- and wet-bulb thermometers, should be sure to get the lowest wet-bulb reading, and should be sure to use the relative-humidity table for the pressure representing the elevation of his station. If three consecutive humidity determinations differ by no more than 3 percent the hygrograph pen should be reset to the average of these three readings, by adjusting the thumbscrew near the hairs. In doing this, extreme care should be taken not to allow one's fingers to touch the hairs. Even the slightest trace of oil or grease upon these hairs is likely to affect their sensitivity and the accuracy of their indications.

After each resetting a note should be made on the chart to show where the pen was reset and the extent of the correction.

On some instruments the hygrograph pen must be reset after nearly every rainy period. On other instruments it seems to require resetting not more than two or three times in the course of a fire season. In all cases, it is good practice to check both the hygrograph and the thermograph record every time the maximum and minimum temperatures are read and the relative humidity determined.

In general practice, it is best to reset the hygrograph pen only on the basis of a full week's record. A check for a full week, made by marking on the chart the psychrometer determinations of humidity for 5 p. m. each day, often shows that the hygrograph traces were a little high the first day, a little low the second, about right the third, a little low the next, etc., the average being within 5 percent of the average of the psychrometer determinations and thus entirely satisfactory.

If the morning humidities for the week as determined with the psychrometer are plotted on the chart, it is sometimes found that the hygrograph record for the morning averages from 5 to 15 percent higher than the actual humidities. Usually this is due to the fact that from 5 or 6 a. m. until 10 or 11 a. m., on fair days, actual humidity changes very rapidly, sometimes much more rapidly than the hairs of the hygrograph respond. It is because of this instrumental lag that a hygrograph should be reset only when the trace is approximately level, indicating that humidity is fairly constant.

WIND

Probably more large fires have been explained and "alibied" by the statement "the wind blew a gale and took the fire out of control" than in any other single way. In some cases, of course, this was true, but in others this explanation was a "good" one only because its inaccuracy was hard to prove. When wind velocity is such as to contribute to a fire's rate of spread, this fact can be determined dependably in either one of two ways. The first is careful estimate, based on recognized criteria; the second is actual measurement.

That measurements of wind velocity are essential to most efficient fire control is especially obvious when one considers how commonly a light wind one day is followed by a moderate wind the next. According to Show (*22*), "rate of spread, as governed by wind velocity, may be stated to vary as the square of the wind velocity." If one man can build fire line only a little faster than the fire makes perimeter when the wind is light, say 5 miles per hour, then nine men may be required, under otherwise similar conditions, if the wind accelerates to moderate, or 15 miles per hour. Because of its great importance, instrumental measurements of wind velocity should be made at all regularly occupied forest stations in region 1.

NORTHERN ROCKY MOUNTAIN WIND SCALE

Until 1933 the only available basis for consistent estimates of wind velocity was the so-called Beaufort scale of wind force. In recent years it has been recognized by the Forest Service in regions

1, 5, and 6, and by Canadian foresters, that use of the Beaufort-scale indicators produces ratings of wind velocity considerably higher than the actual velocities. At the Petawawa Forest Experiment Station, at Ottawa, the Beall wind scale has been produced to rectify this deficiency. At the same time the Northern Rocky Mountain Forest and Range Experiment Station has developed the northern Rocky Mountain scale of wind velocity. The latter was put to use experimentally in region 1 in 1933, in the form shown in table 1.

TABLE 1.—*Northern Rocky Mountain scale of wind velocity*

[For use in estimating wind velocities in western Montana and northern Idaho]

Effects of wind	Wind class, velocity in miles per hour	Term used in United States Weather Bureau forecasts
Smoke rises vertically; no movement of leaves of bushes or trees	Less than 1	Calm.
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.	1 to 3	Very light.
Trees of pole size in the open sway gently; wind felt distinctly on face; loose scraps of paper move; wind flutters small flag.	4 to 7	Light.
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.	8 to 12	Gentle.
Trees of pole size in the open sway violently; whole trees in dense stands sway noticeably; dust is raised in road.	13 to 18	Moderate.
Branchlets are broken from trees; inconvenience is felt in walking against wind.	19 to 24	Fresh.
Trees are severely damaged by breaking of tops and branches; progress is impeded when walking against wind; structural damage, shingles are blown off.	25 to 38	Strong.

Careful tests and statistical analysis of the resulting data by G. M. Jemison have shown that estimates based on this northern Rocky Mountain scale are less affected by personal error than estimates based on the indices usually associated with the Beaufort scale. When the northern Rocky Mountain indices are used a given man's estimates are more consistent, and there is less difference between estimates made at the same time and place by several men. A check against actual measurements of wind velocity showed that whereas the average error for estimates based on the indices usually associated with the Beaufort scale was +2.04 wind-force classes, that for estimates based on the "N. R. M." indices was −0.06 wind-force classes. When it is impossible to measure wind velocity by use of some instrument, the best substitute method now available in region 1 is careful observation of the effects of wind as classified by the "N. R. M." scale.

ANEMOMETER

The standard instrument for measuring wind velocity is the three- or four-cup anemometer, shown in three locations in figure 2, *B* and illustrated in detail in figure 6. This instrument costs about $75 and not very many have been installed in region 1. For highly accurate measurements, these standard instruments are necessary.

The standard elevation and exposure of a three- or four-cup anemometer is with the cups about 8 or 9 feet above the ground level in an open space where the sweep of the wind is not obstructed by nearby trees or buildings. This elevation is illustrated by the exposure of the lowest of the anemometers in figure 2, *B*. The record of most value is that for the afternoon, from noon to 5 or 6 p. m., when the wind is usually at its highest and the effect of wind on fire behavior is greatest. When it is impracticable to determine average velocity for this period through dial readings at noon and 6 p. m., a 1-minute measurement at 5 or 6 p. m. serves the purpose fairly well.

Detailed information concerning the construction, use, care, and maintenance of anemometers is contained in a Weather Bureau publication entitled "Instructions for the Installation and Maintenance of Wind Measuring and Recording Apparatus" (*26*). This publication is obtainable from various offices of the Weather Bureau.

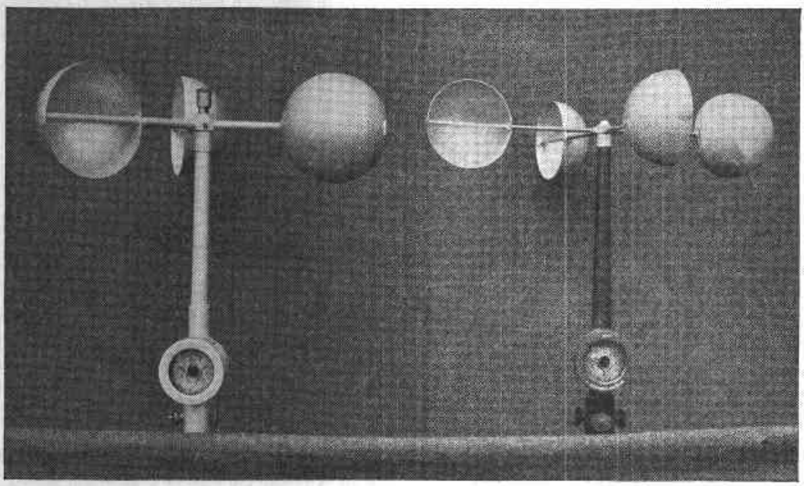

FIGURE 6.—Standard three-cup and four-cup anemometers.

Experience in region 1 has shown that the principal cause of inaccuracy in wind records based on anemometer measurements is erroneous reading of the dial. If the observer remembers that there are two places on the dial at which readings must be made, he will eliminate one common cause of error. The first indicator is a zero with a vertical line running through it and pointing to a scale on the inner dial. This indicator is shown in figure 7, *a*. The position of the vertical line against the inner dial tells how many tens of miles of wind have passed; for example, whether the last 10-mile point should be read as 10, 110, or 910. In figure 7 it indicates a point between the 440-mile and the 450-mile graduation on the inner dial.

The second index is a line on a small cogwheel in the "northwest" or "eleven o'clock" position on the dial face. It is shown in figure 7, *b*. The position of this line against the outer dial indicates what number between 441 and 449 is the present reading. An inexperienced man may have some trouble in finding this second index, because when the dial case is in place it is not visible to an observer whose eye is above the dial. By looking up into the dial, however, he can find the index and will see the vertical line pointing at some mile or tenth-of-mile mark inscribed at the rim of the outer scale. In figure 7 this index line points to the third graduation between the figures 6 and 7, or 6.3. Thus for the complete reading 6.3 miles

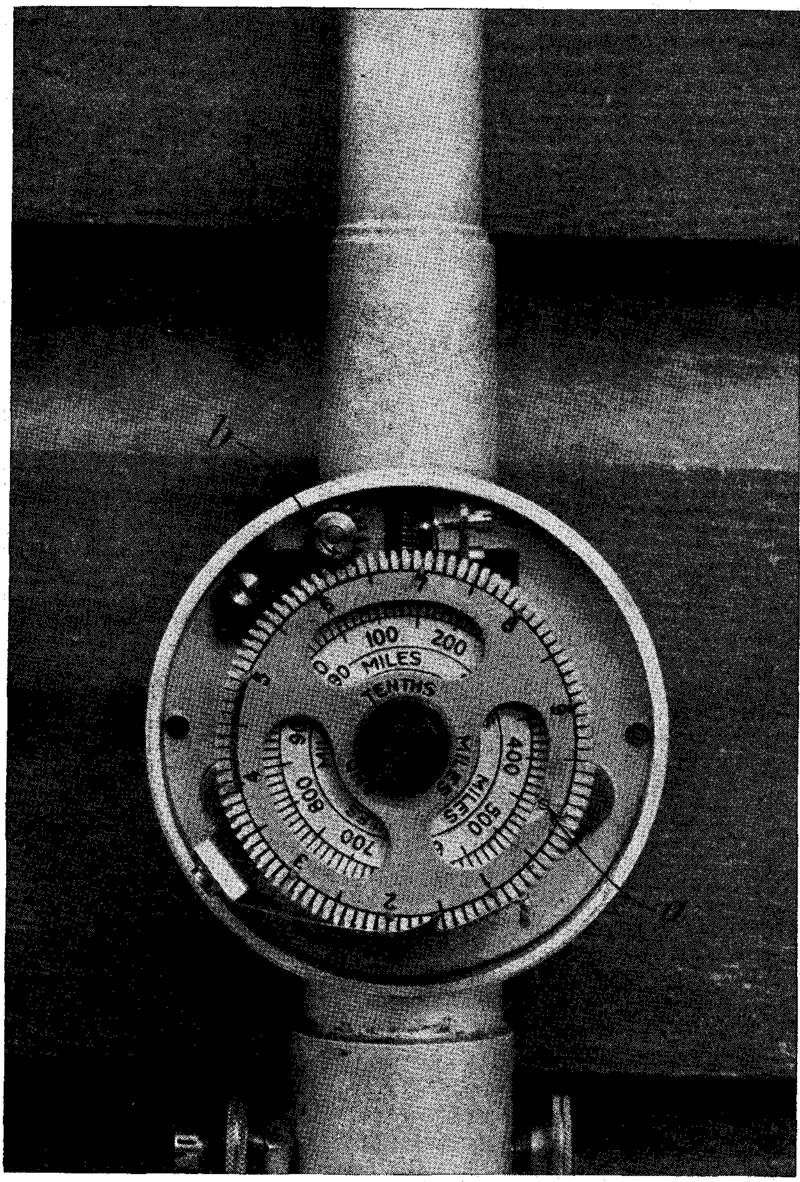

FIGURE 7.—Dial of standard three-cup or four-cup anemometer, with the protective case removed. The dial reading illustrated is 446.3 miles. *a* and *b* show the two places on the dial at which readings must be made.

(from the outer dial) is added to 440 miles (from the inner), making a total of 446.3 miles.

This reading is used exactly the same as a reading of, say, 18.4 on the trip dial of an automobile. Starting with the latter, if you drive for an hour and the dial then reads 58.4, you subtract and find that you have driven 40 miles in 1 hour. Perhaps at times you were traveling at a rate of 50 or 60 miles per hour, at other times only 20 or 30 miles; but the average was 40 miles. If the anemometer dial reads 118.4 at noon, and 168.2 at 6 p. m., then the difference, 49.8 miles, is the total wind movement during the 6-hour period. Dividing by 6 gives the average per hour, 8.2 miles.

It should be noted that the highest reading possible on the dial of a standard three- or four-cup anemometer is 990 miles. If the dial reads 980.0 at noon and reads 20.0 at 6 p. m., then 980 is subtracted from 990 and 20 is added, giving a total of 30 miles for 6 hours, or an average per hour of 5 miles.

The passing of the 990-mile point on the index is an excellent signal for oiling the anemometer. A high grade of oil should always be used. A drop or two is sufficient for each of the two places requiring oil. One of these is at the top, where the spindle emerges from the supporting shaft; the other is on the shaft behind the dial, where a small cap marked "oil" is easily removed to uncover the gears and the base of the spindle. Here the oil should be so placed on the gear that the surplus will run down and lubricate the base of the spindle.

All standard anemometers tend to show wind velocities higher than the actual during strong winds, gales, and hurricanes. In region 1, however, such winds occur rarely, and winds of more than 25 or 30 miles an hour when forest fuels are very dry mean only one thing—blow-up conditions; therefore, forest stations are not required to apply the correction factors: All official Weather Bureau stations, however, always correct their measurements of high wind velocities before publication.

Even in the lower range, for practical purposes it is not necessary to determine wind velocity more accurately than to the nearest mile per hour. Consequently, there is little value in computing and reporting a velocity such as 6.4 miles per hour; a report of 6 miles per hour serves the purpose equally well. In the lower range, differences of 1 mile per hour can be ascertained accurately and easily by anemometer measurement and often are significant, especially as showing that the wind has "picked up" say from a per-hour velocity of 4 miles an hour ago to one of 5 miles now.

INEXPENSIVE WIND GAGE

It is difficult or even impossible to recognize this important "pick-up" accurately by use of any of the wind scales based upon such indicators as dust rising or trees swaying. The practical need, therefore, seems to be for some inexpensive wind gage that will make possible determination of wind velocities to the nearest mile per hour in the lower range and to the nearest 2 miles per hour in the 20- to 25-mile range.

To meet this need, the Northern Rocky Mountain Forest and Range Experiment Station has tested a simple wind-turned device illustrated in figure 8. This device has a black square with diagonal bars in orange painted on one face. Counts of its revolutions indicate wind velocities with sufficient accuracy for use in forest-fire control. This device can be manufactured at a cost of about $3, and is sufficiently durable for several years' use. Tests have shown that by its use velocities of from 1 to 20 miles per hour can be determined to the nearest mile, and velocities of from 20 to 28 or 30 miles per hour to the nearest 2 miles. No determinations what-

FIGURE 8.—Northern Rocky Mountain wind gage.

ever can be made with this device above the 30-mile speed, because winds of more than 30 miles per hour cause the blade to revolve so rapidly that the number of revolutions cannot be counted.

Since the method of using this wind gage is to count its revolutions, it must be placed where the weather observer can see it conveniently. Revolutions are counted for ½-minute or 1-minute periods. Velocity in miles per hour can then be read from a simple tabulation or chart.

This wind gage has the advantage that at a forest station where there is only a small clearing and where the ground wind, at the standard 8- or 9-foot level, is of no significance it can be installed in the top of a tree, within easy vision distance, with no necessity for the observer's mounting the tree or using electric batteries and a buzzer to make the measurement. The device could be supplied with a counter and with a buzzer, but either of these additions would increase the cost and would influence the accuracy of calibration by introducing additional friction. As low cost is requisite for wide-spread adoption of such a device, every detail of design has been scrutinized from the standpoint of economy.

Wind gages of this type may be obtained by forest-protective agencies in region 1 from the Northern Rocky Mountain Forest and Range Experiment Station, Missoula, Mont., at a cost of about $3 per instrument plus shipping charges. A calibration chart and table are supplied with each gage.

Another inexpensive gage for use at forest stations has been designed by the Pacific Northwest Forest Experiment Station.

Records from nonstandard gages should never be released as official wind measurements. They are intended only for local use in forest-fire control.

SINGLE- AND TWO-MAGNET REGISTERS, AND METEOROGRAPH

Continuous records of wind velocity at all hours of the day and night are needed at a few stations in any forest region where great fire danger is experienced. Standard meteorological instruments for making such records are the single-magnet and two-magnet registers. The single-magnet register, illustrated in figure 9, *A*, furnishes a record of wind velocity only. It costs about $250, complete with anemometer and batteries. An excellent exposure of this instrument is shown in figure 10. The two-magnet register, used at the more important stations, makes a continuous record of wind velocity, rainfall, and sunshine. Its recording device is illustrated in figure 9, *B*. The recorder and batteries cost approximately $195. To this price the anemometer, tipping-bucket rain gage, and sunshine recorder add about $245.

The meteorograph, an electrically operated instrument that records wind velocity and direction, sunshine, and rainfall, is used at a few forest stations. For most forest stations, the cost of such equipment is prohibitive. The many details that must be watched in order to obtain dependable records by use of this instrument cannot be described here.

Each station equipped with a single-magnet register, a two-magnet register, or a meteorograph should have on file a copy of Weather Bureau publications 530 (*26*), for reference concerning the operation and care of such apparatus.

WIND DIRECTION

Wind direction is often a very important factor in fire behavior and in weather forecasting. All the report forms call for statements of wind direction at time of observation, and average direction for

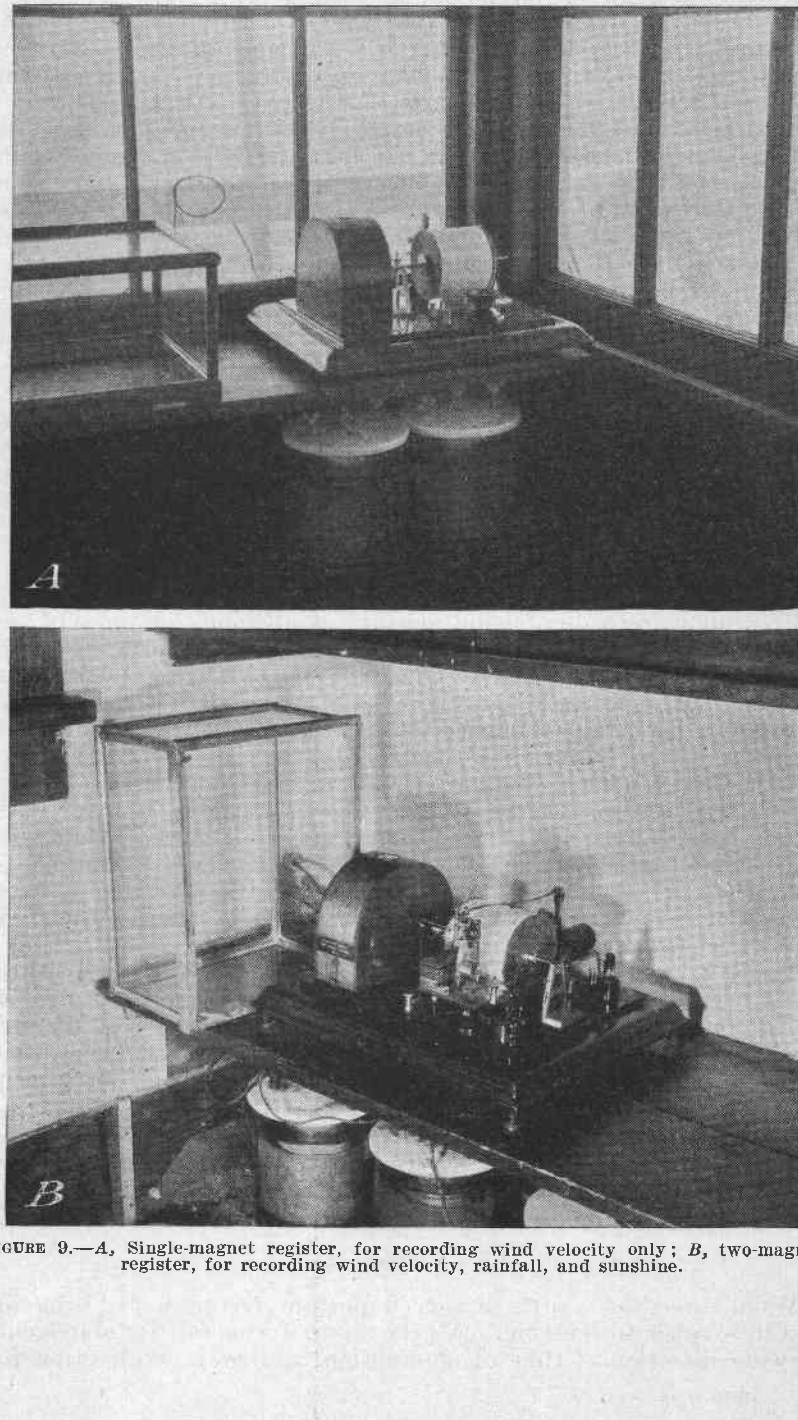

FIGURE 9.—*A*, Single-magnet register, for recording wind velocity only; *B*, two-magnet register, for recording wind velocity, rainfall, and sunshine.

FIGURE 10.—Lookout-station exposure of three-cup anemometer, on roof, and of single-magnet register, inside cabin. (Elevation of station, 5,500 feet.)

the day. The direction to be reported is the direction from which the wind is moving; for example, a southwest wind blows from the southwest toward the northeast.

LIGHTNING

With lightning causing from 2 to 18 fires per 100,000 acres per year in the various timber types of region 1, it is necessary that accurate reports and records be made of lightning-storm occurrence and characteristics. Immediate reports are necessary to proper fire-control action; and the records are basic to fire-danger comparisons between individual localities and individual seasons, without which it is impossible to determine satisfactorily the efficiency of forest-protective organizations.

Detailed reports of each lightning storm were made by most of the forest-fire lookouts in region 1 during the fire seasons of the 13-year period 1922–34. The purposes of these reports were largely fulfilled when, in 1934, an analysis was made of the data for 10 years.

It was found that the very requirement of detailed reports concerning lightning storms caused the lookouts to observe each storm more thoroughly and more critically. In fact, the opinion was frequently expressed by experienced supervisors that the study was justified on this basis alone. Consequently some forest officers may desire to continue to furnish their lookouts with the report form previously used and to require them to fill it out currently. Such action is optional with each forest supervisor.

Some sort of report on lightning storms is essential to accurate determination of the exposure of each forest unit to lightning danger. Beginning in 1935, a new form called "Record of lightning storm occurrence" is being issued in region 1. The reports called for by this form cover merely the date and hour of occurrence of each lightning storm passing over each national forest. Such reports are required of only enough lookouts on each forest to insure that every storm passing over that forest is reported.

These reports of storm occurrence are not to be confused with the Lightning Strike Report, which shows for each lightning strike the azimuth and distance from the lookout station. The strike report is intended primarily for immediate use in determining what spots should be watched most intensively for the origination of fires.

OTHER WEATHER FACTORS

In addition to precipitation, temperature, humidity, wind, and lightning, at least four features of the weather are so significant in fire-control work as to need careful observation and accurate reporting. The first three are haze, mist, and smoke. When the air is clear, lookouts may be depended upon to discover fires while they are still small at distances as great as 10 or 12 miles, if the fires are not hidden by topography; but haze, mist, or smoke sometimes prevents such discoveries at distances of only 1 or 2 miles. By noting these atmospheric conditions, weather observers provide a record that may be used to determine in which sections of a region visibility distance is most affected by these conditions.

Haze consists of fine dust and smoke particles in the air. Although haziness is often influenced by relative humidity, high humidity favoring the retention of dust particles in the air, haze is recognized by meteorologists as distinct from mist and fog, which are composed of particles of water. In aeronautical meteorology a single scale is used for rating visibility as affected by both haze and mist; but in connection with fire control it is desirable to identify haze, mist, and smoke and record them separately.

Probably the two classes of haze, mist, and smoke given by the instructions on the cover of every book of Weather Bureau form 1009–E, light and dense, are as many as need be distinguished in fire-weather observations.

The fourth feature is cloudiness, which affects visibility and also indicates impending precipitation, humidity, and wind conditions. Recent research has indicated that the visibility of a small smoke varies considerably according to whether the smoke is in direct sunshine or in the shadow of topography or of a cloud.

An instrument for measuring visibility, known as the Byram haze meter, has been devised by the Pacific Northwest Forest Experiment Station (*15*).

Cloudiness for the day is rated on a scale of 0 to 10, 0 indicating that there were no clouds at any time during the day, 1 that throughout the day an average of one-tenth of the sky was covered by clouds, and 10 that the whole sky was covered all day. The same scale is used for describing cloudiness at any instant. Two daily reports on cloudiness are usually called for; one showing the fraction of the sky covered at the time of observation, and one showing the average for the day. When less than 0.4 of the sky is covered by clouds the rating is "clear"; when 0.4 to 0.7 is covered, "partly cloudy"; and when 0.8 or more is covered, "cloudy."

A well-illustrated Weather Bureau publication entitled "Cloud Forms" (*12*) is issued by the Department of Agriculture to assist observers in distinguishing and naming cloud types. Books by McAdie (*14*), Humphreys (*10*), and Gregg (*6*), also, are well worth consulting concerning types of cloud and the significance of each. It is worth noting here that there are 10 principal types: Cirrus, cirro-stratus, cirro-cumulus, alto-stratus, alto-cumulus, strato-cumulus, cumulus, cumulo-nimbus, nimbus, and stratus. These may be grouped into four major types: Cirrus, usually occurring from 15,000 to 50,000 feet above sea level during the summer months; stratus, including (1) alto-stratus, at elevations of 8,000 to 30,000 feet, and (2) fog or stratus, close to the ground; cumulus, occurring at 1,000 to 25,000 feet elevation; and nimbus, clouds from which rain or snow is falling.

The recording of nimbus clouds offers a method of showing in the reports that even though no rain or snow has fallen in a given station's gage there has been rain or snow within sight of the station. Such information is valuable to the forecaster. It can be conveyed to him in a cloud-type report by the one word "nimbus." A record of the other cloud types is useful to the forecaster if he can rely on the observer's classification.

The direction of cloud movement, also, is important information for the skilled meteorologist, and should be observed and reported consistently at all fire-weather stations using report form 1009–E. The direction to be recorded is that from which clouds are moving.

FUEL MOISTURE

The moisture content of wood is usually described by wood technologists in terms of percentage of the material's weight when oven dry. On this basis, addition of 1 pound of water to 100 pounds of oven-dry duff gives the latter a moisture content of 1 percent. Heavy rains may raise the moisture content of dead branch wood to 80 percent or higher. Occasionally small twigs hold their own weight in water; this is a 100-percent moisture content. A compact layer of duff, fully saturated, sometimes contains three times its own weight in water; this is a 300-percent moisture content. A 4-pound sample of duff in this condition consists of 1 pound of vegetable matter and 3 pounds of water. Chemists would be likely to describe this sample as 25 percent dry matter and 75 percent moisture. The oven-dry basis of the wood technologists is used in this publication.

Although the weather controls forest-fuel moisture and hence forest inflammability, it has not been found possible to estimate fuel moisture with satisfactory exactness on the basis of weather data. Weather measurements are particularly unsatisfactory as indicators of fuel-moisture content in dense forests where the common fuels are snags, windfalls, thick duff, and other materials that, being relatively heavy, do not change quickly in moisture content with changes in weather. In more open forests where the principal carriers of fire are light fuels such as grass, dead weeds, and thin duff, the moisture content of fuels, and therefore their inflammability, changes to a greater degree with sunshine, temperature, humidity, and wind. In forests of the latter class fire danger can be roughly determined through weather measurements alone, often through measurement of relative humidity alone.

Many investigators in various parts of the United States have worked on methods for measuring fuel moisture, correlating fuel-moisture data with fire records, and using weather records alone as indices of forest inflammability. For the student interested in the development of this research, representative publications are listed (*1, 2, 3, 4, 5, 7, 11, 13, 15, 18, 19, 21, 23, 24, 25*).[3]

In region 1 the great timber losses, and the largest costs for fighting fire, occur in dense fuel types such as single burns, where heavy fuels are present in great quantities. There fire spreads rapidly and quick control is most difficult. Even there, however, so long as only lightweight fuels will burn there is no danger of explosive conflagrations. A few fires have spread through these types when the heavy fuels were wet, and some of these have even spread through the crowns of green trees when the ground beneath was covered with snow; but under such conditions the danger of great loss and expense is neither general nor acute.

Drying out of the heavier fuels calls for expansion of the forest-protective organization. Since expansion involves placing men at

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[3] Material in this field is presented also in the following mimeographed papers:
GRAY, L. G. PRELIMINARY REPORT OF FIRE HAZARD RATING STUDY. U. S. Dept. Agr., Weather Bur. 54 pp., illus. 1933.
NICHOLS, L. H. FOURTH REPORT TO THE QUEBEC FOREST INDUSTRIES ASSOCIATION, LTD. 37 pp., illus. 1931.
WRIGHT, J. G. FOREST-FIRE HAZARD RESEARCH AS DEVELOPED AND CONDUCTED AT THE PETAWAWA FOREST EXPERIMENT STATION. Canada Dept. Int., Forest-Fire Hazard Paper no. 2, 57 pp., illus. 1932.

remote lookout and smoke-chaser stations, hiring men from outside sources, etc., it is desirable that warnings of impending high danger be issued several days in advance of the event. A charted record of fuel-moisture serves to indicate impending dryness. The fuel-moisture indices used must be specific, accurate, and fully comparable for the different ranger districts comprised by a forest and for the many forests comprised by a region. Otherwise, the reports

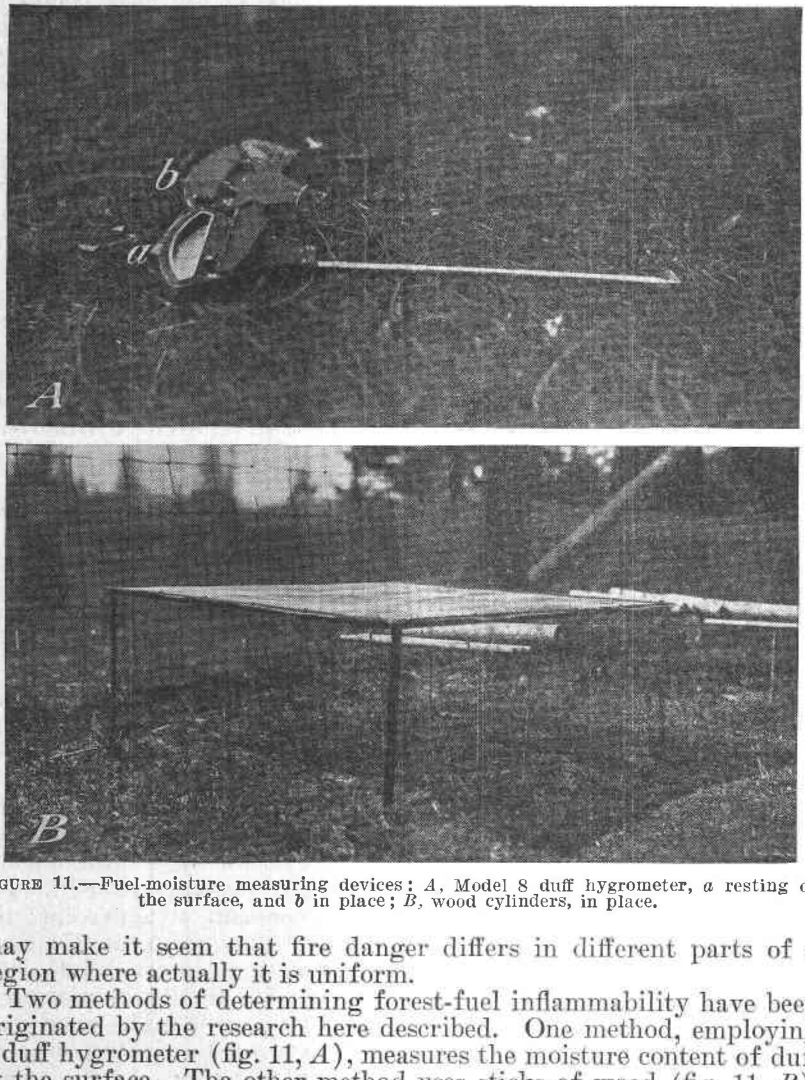

FIGURE 11.—Fuel-moisture measuring devices: *A*, Model 8 duff hygrometer, *a* resting on the surface, and *b* in place; *B*, wood cylinders, in place.

may make it seem that fire danger differs in different parts of a region where actually it is uniform.

Two methods of determining forest-fuel inflammability have been originated by the research here described. One method, employing a duff hygrometer (fig. 11, *A*), measures the moisture content of duff at the surface. The other method uses sticks of wood (fig. 11, *B*), similar to small branches to measure the wetness or dryness of branches between one-half inch and 2 inches in diameter. Both methods permit more accurate determinations of fuel moisture than are possible by estimate, even when the observer is an "old-timer" and exceptionally experienced. These methods also make it possible for the forest officer to describe and to record his observations in precise terms such as "6½ percent duff moisture" rather than in generalities such as "pretty dry duff."

DUFF

Forest duff, the mat of dead leaves and twigs and other dead vegetation that forms the forest floor,[4] is one of the most common forest fuels in the northern Rocky Mountain region. Duff is present in practically all green timber stands. When duff is dry fire easily spreads through it from log to log and from dead branch to dead branch. It is largely because of the presence of this material that trench digging is necessary in fire control.

The instrument used for measuring the moisture content and hence the inflammability of duff, the duff hygrometer, is a section of rattan about 12 inches long having one end fastened in a constant position and the other end attached to a gage that shows any change in its length.

The principle is as follows: A section of rattan that is 12 inches long when thoroughly dry may expand to 12.12 inches when wet and may be 12.06 inches long when half dry. A piece of dry rattan inserted in wet duff becomes wet, and therefore longer, and when the duff dries that rattan also dries and becomes shorter. If the length of the rattan has been determined in relation to different moisture contents of duff, then by measuring its length the moisture content of the duff at any given time can be determined.

By use of the duff hygrometer the moisture content of duff can be measured accurately from 2 to 30 percent, at which combustion is impossible. The hygrometer is capable of showing changes in duff moisture of less than 1 percent in the lower range, whereas few experienced observers are able to distinguish by observation differences of less than 7 or 8 percent. Rattan responds rather slowly, however, to increases in moisture. After a rain the duff hygrometer may take an hour or two to show the true moisture increase. When duff is losing moisture, in the fair weather following rain, the hygrometer is capable of responding as rapidly as the duff moisture changes.

The process of determining what lengths of a rattan correspond to different duff moisture contents is called calibration. This must be carried out in the laboratory each year for each instrument. Large sealed cans of duff of known moisture content are used. In can no. 1 the duff moisture may be held constant at 2 percent; in no. 2, at 7; in no. 3, at 14; in no. 4, at 20; in no. 5, at 27; and in no. 6, at 35 percent. When a hygrometer is inserted into the duff in can no. 1, the rattan loses moisture until finally its moisture content comes to equilibrium with that of the duff. The resultant length of the rattan, as shown by the gage on the instrument, is recorded as the length indicating that duff moisture. In the same way the lengths of the same rattan are determined for duff moisture

[4] This definition of "duff", making the term apply to all layers of the forest floor, differs from that approved by the Society of American Foresters. According to the latter, duff is the layer of more or less decomposed organic matter intermediate between (1) the litter, the upper, slightly decomposed portion of the forest floor, and (2) the humus, the portion of the forest floor in which decomposition is well advanced.

contents of 7, 14, 20, 27, and 35 percent, respectively.[5] These moisture contents and the corresponding rattan lengths are plotted on cross-section paper, and a smooth curve is drawn that shows the duff moisture corresponding to any length of that rattan. Such a curve constitutes the calibration chart for the instrument.

Most of the rattans increase in length very appreciably when the duff moisture rises from 4 to 20 or 25 percent. As the duff becomes wetter than this the rattan changes length less and less, until at from 30- to 35-percent duff moisture it shows no appreciable change. This indicates merely that a 30- to 35-percent moisture content in duff causes the rattan to stretch to its utmost.

It has been found by 10 years' experience with duff hygrometers that if the calibration curve is accurately determined, and if the instrument does not become jarred out of adjustment in shipping or later handling, the relation of a rattan's length to given duff-moisture percentages remains practically constant throughout one fire season. After 3 or 4 months' constant exposure of the instrument, however, the curve straightens slightly, the maximum length of a rattan 12 inches long when dry becoming greater by 0.01 or 0.02 inch. The changes that occur are not greatly important toward the close of a fire season.

When a duff hygrometer is received at a field station, after being calibrated in the laboratory, it is desirable that its accuracy be checked before it is used. If several hygrometers are available they may be used to check each other. If only one is at hand, the following method is recommended as simple and accurate:

Soak a common hand or turkish towel in water, and wring it only very slightly. Wrap this wet towel around the spike of the duff hygrometer, making sure that it covers all the holes in the spike and thus prevents any outside or drier air from reaching the rattan. Then set the wrapped instrument on a shelf or table and leave it for at least 12 hours. After such treatment the rattan should have stretched to its maximum length. Tap the dial of the instrument with your knuckle to overcome friction in the gage. The dial reading then should be that shown on the calibration chart as corresponding to the highest duff-moisture content.

If the dial reading is less than the maximum shown by the chart, or marked on the face of the instrument, it may be that the towel was not wet enough or that sufficient time has not been allowed for the rattan to stretch to its utmost. Before making any adjustments of the hygrometer, try a little more water on the towel and give the instrument a few more hours to react. Some rattans are slower than others in reaching maximum length.

If after this further test the dial reading is either more or less than the maximum shown by the chart, it is desirable to make a new curve. This is done merely by moving the original curve until its maximum point coincides with the new maximum reading. The shape of the original curve should not be changed. To relocate the curve for the new maximum, put the dial-reading scale at the base and the duff-moisture scale along the left side of a blank sheet of cross-section paper exactly like that on which the original curve

[5] In accurate calibration, allowance must be made for the phenomenon of hysteresis by determining the rattan lengths separately for increasing and for decreasing duff moistures.

was drawn. If, for example, the new maximum reading of the hygrometer is 88, place on the new chart a dot corresponding to a dial reading of 88 and a duff-moisture content of 30 percent. Then place the original chart on a window so that the light shines through it. Over this lay the new chart, with the bases of the new and old charts coinciding. Move the new chart to right or left until the dot, corresponding to 88 dial reading and 30 percent, falls at the end of the original curve. Then, holding the two charts firmly to prevent slipping, trace the original curve onto the new chart.

If, for any reason, an observer in region 1 having a hygrometer in need of recalibration cannot follow these directions, he should send the instrument to the Forest Experiment Station, Priest River, Idaho, with a request for a new one.

The spot at which a hygrometer is inserted in duff should represent an average situation as to slope, aspect, duff thickness, and soil moisture. The duff bed should not be shaded by neighboring trees, shrubs, or buildings. The only shade should be that cast by the wire screen described later in connection with exposure of wood cylinders.

When the hygrometer is inserted in duff, the spike should be covered along its entire length by a layer only a few needles thick. It is essential that this practice be uniform at all stations so that readings from various stations may be compared accurately. As the top half-inch layer of duff can carry fire at times when the lower layers are wet, the hygrometer should sample only that top half-inch layer. The sharp tip of the spike should be slightly downhill from the gage, so that heavy rains cannot fill the gage housing and rust the sensitive mechanism. When properly inserted, the hygrometer should be left in place for the remainder of the season and fenced to prevent damage by animals.

At the Priest River Branch Experiment Station the duff hygrometers, on three sites, are read twice each day, at 8:30 to 9:15 a. m. and at 4 to 4:45 p. m. At these hours, in fair weather, the duff is usually at its wettest and driest, respectively. At other stations in region 1 the instruments need not be read in the morning, if inconvenient, but should be read every afternoon, as near 5 p. m. Pacific standard time as possible.

At the close of the fire season, all duff hygrometers should be returned to the experiment station at Priest River for recalibration.

Uniformity is one of the chief merits of the use of the duff hygrometer. If one report based on estimate states that the duff is "very dry and highly inflammable", another such report, either by another man on the same day or by the same man on another day or in another year, may classify the same condition as "fairly dry and inflammable." No two men are likely to make exactly the same estimate of the same conditions or to use the same words for expressing their estimates. When a ranger or supervisor reports a duff-moisture measurement of 8 percent at a certain station, that 8 percent means the same thing year after year. Furthermore, duff-moisture measurements can be averaged to obtain comparable means or normals for 10-day periods, months, seasons, or any other periods desired. Expressions such as "dry", "very dry", and "darned dry" are hard to average.

Without measurements, it is easily possible to tell that dripping-wet duff is noninflammable and that duff dry enough to crush to powder in the hand is highly inflammable; but by estimate alone it is extremely difficult or impossible to tell just when duff becomes inflammable, and to distinguish small changes in moisture content that may cause important differences in duff inflammability. The hygrometer makes it possible to recognize these changes as they occur.

Duff-hygrometer measurements also permit specific delineation of zones of inflammability, according to the following scale of duff conditions:

Moisture content (percent):	*Inflammability*
More than 25	None.
19 to 25	Very low.
14 to 18	Low (camp fires become dangerous).
11 to 13	Medium (matches become dangerous).
8 to 10	High (matches always dangerous).
2 to 7	Extreme (all sources of ignition dangerous).

A duff-moisture content of 2 percent is about the minimum under natural conditions in region 1. This "blow-up" condition is produced only by air temperatures of 100° F. or more accompanied by relative humidities of 10 percent or less, both lasting for several hours.

An additional mode of interpreting duff-hygrometer readings is to record the daily values in the form of a chart, by which the trends are clearly visualized. Such a chart, when it shows a downward trend of daily measuremnts, may call sharply to the attention of a ranger or supervisor the fact that fire danger is rapidly increasing. By noting the existing degree of inflammability of the fuels and by studying it in relation to daily weather forecasts, later inflammability can be predicted. A certain weather forecast, independent of data on existing fuel-moisture contents, seldom means a certain degree of inflammability; but degree of inflammability can be predicted with very fair accuracy if the existing fuel moisture is known and if the general weather forecast is localized and refined to specify what local temperature, humidity, and wind are most probable.

SMALL BRANCH WOOD

In some forest types, measurements of duff-moisture content satisfactorily indicate the degree of inflammability of forest fuels in general. For use on areas where the principal carrier of fire is dead branch wood, the Northern Rocky Mountain Forest and Range Experiment Station has developed a convenient method of measuring the moisture content of slash and dead limbs.

This method consists in exposing wood sticks or cylinders representing 2-inch- and ½-inch-diameter slash, respectively, and then weighing these samples to determine their moisture content. Such wood sticks are shown in figure 11. Before supplying such samples to field stations the experiment station exposes large numbers of them side by side for several weeks, and selects those that prove closely comparable in capacity to absorb and retain moisture. This procedure is necessary because some individual samples contain more than the usual quantity of pitch or of summer wood, or have some other peculiarity that causes them to absorb or lose moisture much slower or faster than the average. These variations among specimens were found to be so great for natural samples of slash, with or without bark, crooked or straight, cracked or not cracked, knotty or clear, that determinations of the moisture contents of such samples had no comparative value. The samples now used are manufactured from selected sapwood and are perfectly straight, cylindrical, and clear. The samples are cut to a standard length of 18 inches.

Beginning in 1935, the single cylinder of ½-inch diameter has been replaced by three ½-inch cylinders held parallel with each other, about one-half inch apart, by dowels. The purposes of this change are (1) to provide a total weight sufficiently great to obviate the need of extreme precision in weighing and (2) to reduce the influence of peculiarities of individual cylinders. As the three sticks, oven dry, weigh about 80 g, by determining their total weight to an accuracy of 0.4 g their average moisture content can be determined to an accuracy of 0.5 percent.

In order to insure uniform and constant exposure of the samples, wire brackets are furnished to hold each cylinder level and about 10 or 12 inches above the ground. The cylinders are placed in a directly north-south position. So that the same side of a cylinder may be exposed to the sun day after day one end, marked with an aluminum number tag, is placed to the north, with the number right side up. Constant maintenance of this exposure is important.

It is extremely important that the sticks used at different stations in a region be uniformly exposed. One factor of exposure is degree of shade. Uniformity in this respect could be obtained by having all duff-hygrometer and wood-cylinder measurements made in full sun. But measurements made in full sun represent the most severe exposure and the extreme of danger. They would therefore indicate extreme danger more frequently than such danger actually occurs on most forest areas. Previous to 1935, duff hygrometers and wood cylinders were so placed that they were shaded by trees or brush for an hour or two each afternoon. This practice was found unsatisfactory; at no two stations could uniformity be obtained as to density of shade or as to period of day during which instruments were shaded. Beginning in 1935, therefore, each station at which fuel-moisture measurements are made has been provided with wire screens to be placed over the instruments. These screens produce a degree of shade approximately equivalent to that existing on an old-growth forest area from which three-fourths of the canopy has been removed.

The cylinders should be weighed each day—preferably between 4 and 6 p. m., when they are driest. Morning measurements may be made if the operator is curious as to how much moisture such wood samples pick up during the night. The weight of the 2-inch cylinder needs to be determined only to the nearest gram, or one-third of 1 percent; that of the three ½-inch cylinders, or "triplets", to the nearest four-tenths gram. A chart is furnished with each cylinder or set of cylinders showing moisture content in percentage of oven-dry weight.

The scales used to weigh the cylinders should frequently be checked and made to indicate 0.0 g when no weight is on the pan. Otherwise, serious errors may be introduced into the record.

If the daily measurements are plotted currently on cross-section paper, with the moisture-content scale at the left and the dates along the base line, the resulting graph will be valuable as showing trends of moisture content in branches approximately 2 inches and one-half inch in diameter.

In the course of measurements at Priest River in the years 1928–34, the lowest moisture content determined was one of 4 percent in the 2-inch cylinders. Consequently, a moisture content approaching 4 percent in the 2-inch sticks indicates great danger of "blow-up" conditions. Readings for the ½-inch cylinders may drop as low as 2 or 3 percent. If any of the sticks show less than 1½-percent moisture, they have weathered or cracked or have been chipped so that the original calibration chart is no longer accurate.

At the close of each fire season all the cylinders used in region 1 should be sent to the Priest River Branch Experiment Station for redrying. They will be returned in the following April, with new calibration charts based on the newly determined oven-dry weights.

OTHER FACTORS PROPOSED FOR OBSERVATION AND MEASUREMENT

Grass, weeds, moss, shrubs of all sizes, and small trees, from low-growing plants like kinnikinnick to willows and alders, hinder the spread of fire when they are green and moist, and increase it when they are partially dried, cured, or dead.

The 1933 fire season in the western part of region 1 afforded an excellent example of the effect of living plants other than trees in preventing the development of extreme fire danger. Probably because of the great depth to which snow accumulated during the winter of 1932–33 and of the late spring melting, which occurred so evenly that most of the moisture was absorbed by the soil, and because of the abundant rains of May and June, all vegetation grew with exceptional luxuriance and maintained its greenness throughout July and August. As a result, less than the usual number or percentage of fires showed explosive tendencies. These green materials absorbed so much heat that instead of burning freely and adding to the volume of heat generated by duff, dead wood, etc., they had to be burned.

From this it follows that soil moisture, as affected by spring rains or by the snows of the preceding winter, or by both, is another basic factor in fuel conditions that calls for measurement. The quantity and distribution of winter snows and spring rains should be recorded and correlated with July and August plant conditions so that indices of future danger may be available for use early each spring in planning for the impending fire season. It has been suggested by Elers Koch and L. F. Watts in region 1, and by H. S. Shank in region 4, that stream flow, which is likewise affected by winter snows and spring rains, may be used as an index of this factor in prospective fuel conditions.

Efforts are now being made to develop methods of correlating condition and quantity of green vegetation with rate of spread of fire, measuring soil moisture and determining its effect on plant growth, and predicting the influence of winter snows and May and June rains on subsequent fire danger.

INTEGRATION OF MEASUREMENTS

Each of the measurements of fire-danger factors previously described improves fire control by showing the status of some factor more accurately than it can be estimated. But these factors are not all of equal importance, and at times some of them are favorable while others are unfavorable. Consequently, for best use of the data the most significant factors must be selected, weights must be given to each, and a method must be evolved for stating their combined effect.

The factors thus selected in region 1 are (1) season, (2) lightning, (3) land-clearing fires, (4) visibility distance, (5) relative humidity, (6) fuel moisture, and (7) wind velocity. None of these can be omitted from any scheme of rating fire danger in region 1.

These and other factors, such as number of recreationists, berry pickers, and hunters on a forest, always have been considered by the more thorough forest executives in endeavoring to form an accurate opinion of current fire danger. But some men have occasionally failed to consider all the factors, some men have given more weight than others to certain factors, and therefore no two men could be expected to arrive at the same estimate of the fire danger of a given day. Until a few years ago there was no standard method, no numerical scale, for describing definitely the class, degree, or status of fire danger. Descriptions such as "none", "low", "high", "great", and "critical" are not sufficiently specific to serve as justification for withholding expenditures on one forest unit and releasing large sums for presuppression work on another unit. There was a distinct need for some method of integration and classification such that anyone applying it to the measurements for a given day would arrive at the same results as another applying it to the same data.

To meet this need the northern Rocky Mountain fire-danger meter was designed. This is a cardboard device about 4 by 6 inches, shown in figure 12, having two slides that are set by the operator in accordance with measurements of the seven danger factors just listed. It embodies a system of weighting and integrating measurements of these factors that was developed through tests on 13 national forests during three consecutive fire seasons. By its use current fire danger is rated on a scale of seven classes, each signifying a specific probable rate of spread of fire and each therefore warranting specific measures for preventing and suppressing fires. Class 1 on this scale signifies fire danger so slight that no men need be specially detailed to fire control. Class 7 signifies the most dangerous possible combination of factors. The intermediate classes indicate intermediate rates of fire spread and intermediate fire-control measures.[6]

This fire-danger meter is furnished without charge by the Northern Rocky Mountain Forest and Range Experiment Station both for Forest Service use and for use by cooperators. It is designed for use in the northern Rocky Mountain region only. Its use elsewhere, without modification, is not advocated unless local tests have proved that it is dependable.

RECORD-KEEPING METHODS

In taking and recording readings on weather factors and fuel moisture, determination of current fire danger is not the only purpose

[6] The seven administrative steps listed on the fire-danger meter are quoted in full on p. 51.

served. Returns from the investment of money in instruments and of effort in readings are not complete unless the data thus obtained lend themselves to analysis and serve as a basis for general conclusions regarding fire-danger factors in given regions and localities. In order that maximum benefit may be obtained from measur-

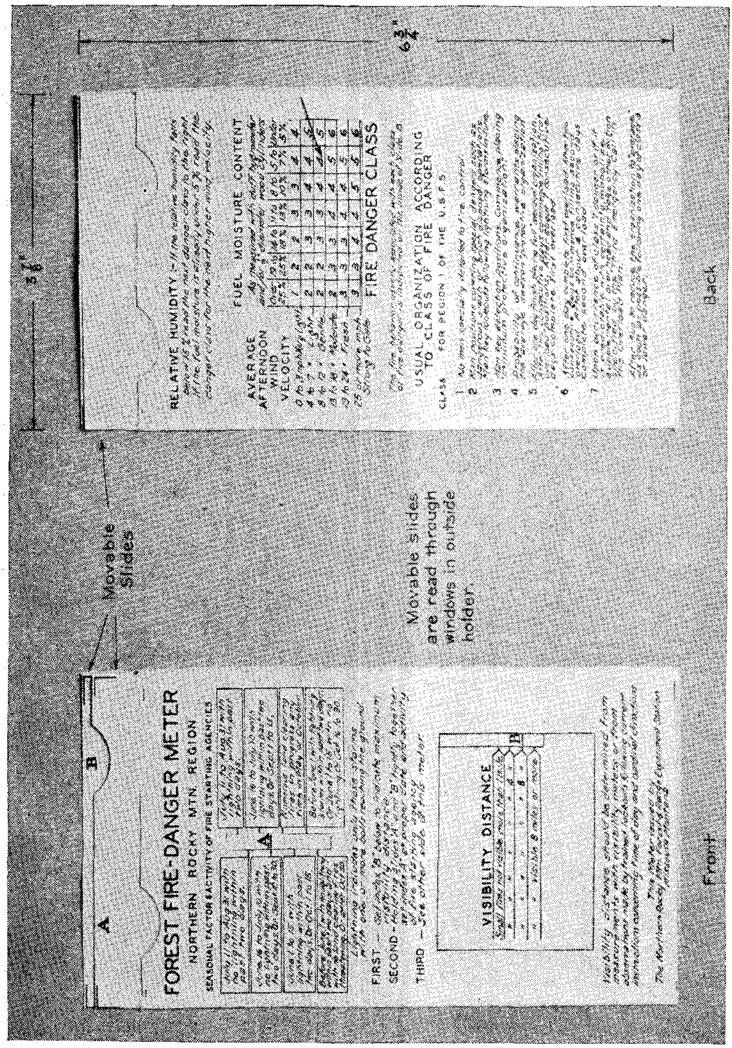

FIGURE 12.—Northern Rocky Mountain fire-danger meter. As pictured, the meter is set to show class of fire danger for any day of the period June 16–July 10, inclusive, when there have been no recent lightning storms, visibility distance is 8 miles, fuel-moisture content is 9 percent, wind velocity is 11 miles per hour, and relative humidity is 13 percent.

ing fire-danger factors, it is necessary (1) that standard record forms be used, and used correctly, and (2) that the resulting data be so charted and tabulated as to permit easy recognition of any important tendencies indicated.

CORRECT USE OF STANDARD REPORT FORMS

The fire-weather report form most commonly used in region 1 is Weather Bureau form 1009–E, 9½ by 12 inches, issued in books of 50 detachable sheets each. This form is the result of careful study by forest officers and meteorologists in several sections of the United States as to what information is most needed. Experience in region 1 has shown a need for emphasis on six features.

1. The instructions on the cover of the book are fairly complete, and if they are followed the reports are likely to be satisfactory. In many cases, however, it has appeared that the observer either lost interest in the work and thereupon became inexcusably careless, or else slowly and perhaps unconsciously substituted his own method of recording for that specified. In reporting lightning storms, some observers have habitually omitted specific statements as to "time first sighted", "direction and distance", "direction of travel", etc. If these data are omitted, opportunity for several possible uses of the records is irretrievably lost. Such a loss is distinctly discreditable to the observer.

In weather reports the movement of winds, clouds, and thunderstorms is classified according to the direction from which they move. A west wind blows from the west; for a thunderstorm moving from the southwest to the northeast the "direction of travel" to be recorded is "SW"—or, better yet, "From SW to NE" or "SW/NE."

2. In reading the instructions on the cover of a book of form 1009–E some observers have failed to understand that each sheet is intended to contain the record for a standard 10-day period, for example, July 1–10, 11–20, or 21–31. Each sheet, with the possible exception of the last sheet for the season, should end with data for the 10th, 20th, or last day of a month. If, for example, observations at some station are begun on the 6th of the month, the first sheet should carry the record only for the 6th to the 10th, inclusive, and a new sheet should be begun on the 11th. Totals and averages can then be computed for the standard 10-day periods used in reporting fires, and the fire record can readily be compared with the weather record.

3. When an observer cannot make his measurements at the prescribed time (for example, because fire-control duties interfere), if equipped with a hygrothermograph he obtains from it the temperature and humidity readings of the hour when the measurements should have been made. This, of course, can be done accurately only if the hygrothermograph was in perfect adjustment for time, for temperature, and for humidity. When data are obtained from this source, that fact should be written into the record on form 1009–E. When a departure of more than 15 minutes from the established time for daily readings is unavoidable and the measurements cannot be corrected by reference to recording instruments, the exact time at which the readings are made should be recorded against the data.

5. Records of duff moisture and wood moisture may be kept on form 1009–E by using the three blank columns under "Miscellaneous." When this is done, each column should be plainly labeled to indicate the character of the data. "Wood moisture" should be written across

the head of two of the blank columns and "½" and "2" used to distinguish the cylinders. Both the total weight and the moisture content of each cylinder should be recorded each day. The third column should be headed "Duff moisture."

6. The three criteria of weather and fuel-moisture records, in order of importance, are accuracy, completeness, and neatness. If the measurements are found by later checking to be entirely accurate, the observer can perhaps be excused if he has failed to fill out some of the station-description data at the head of the form; and an observer can be excused for an erasure here and there, or for crude writing, unless these result in illegibility of originals or carbon copies. But the observer who recognizes weather reporting as an opportunity to demonstrate his general ability endeavors to have each 10-day report form 100 percent accurate, 100 percent complete, and so neat that a first glance classifies it as a scientific record.

CHARTS AND TABULATIONS

Differences as to forms of charts and tables used to summarize fire-danger data are undesirable if they prevent comparison between forests and between seasons. The purpose of this section is not to attempt to standardize details, but to describe those types of charts and tabulations that most users in region 1 have found best adapted to presenting meteorological and inflammability data for everyday use.[7]

TEN-DAY WEATHER NORMALS

One type of compilation that has practical value for all forest officers shows the normally probable temperature, humidity, and precipitation by 10-day periods. This is exemplified by the Climatological Summary for the Priest River Forest Experiment Station, 1912–1931,[8] including both tabulations and charts. Such summaries are now in course of preparation for every forest meteorological station in region 1.

A tabulation of records for Missoula, Mont., summarizing by 10-day periods the features of weather data most important and useful in relation to fire control, appears as table 2. In this table the error inherent in averages is obviated by showing for each 10-day period not only the average but also the median quantity of rainfall. The two differ very significantly, especially for the periods May 1–10 and September 11–20. The table shows the probability of rains of various quantities according to the occurrence of such rains during the 20 years 1912–31.

[7] Other methods of charting fire-weather data have been developed by the Pacific Northwest Forest Experiment Station, making use of criteria similar to those of the methods described here. These methods, and that devised by Shank (*21*) for computing and plotting the "cumulative departure" of humidity, should be considered by anyone interested in testing different methods.

[8] JEMISON, G. M. CLIMATOLOGICAL SUMMARY FOR THE PRIEST RIVER FOREST EXPERIMENT STATION, 1912–1931. [U. S. Dept. Agr., Forest Serv.] Northern Rocky Mountain Forest and Range Expt. Sta., Missoula, Mont. 27 pp., illus. [n. d.] [Mimeographed.]

TABLE 2.—*Missoula, Mont., weather as shown by Weather Bureau and Forest Service records for 1912–31*

Period	Rainfall						Rainy days [2]			Daily maximum temperature				
	Average	Median [1]	Chances in 100 of— 0.01 inch or more	0.20 inch or more	0.40 inch or more	1.0 inch or more	Least	Greatest	Average	Average for all years	Highest average in any 1 year		Lowest average in any 1 year	
	Inch	*Inch*					*Number*	*Number*	*Number*	° *F.*	° *F.*	*Year*	° *F.*	*Year*
Apr. 1-10	0.33	0.25	90	60	35	1	0	6	3.0	54	68	1930	47	1928
11-20	.42	.33	95	70	40	5	0	6	3.4	58	73	1926	49	1927
21-30	.36	.29	95	60	40	5	0	7	2.8	61	73	1926	52	1921
May 1-10	.35	.14	85	45	30	15	0	6	2.7	63	72	1928	55	1919, 1927
11-20	.48	.45	95	70	60	5	0	7	3.6	69	82	1924	58	1913
21-31	.82	.65	95	75	55	40	0	9	4.1	68	80	1928	56	1916, 1927
June 1-10	.56	.38	90	65	50	25	0	7	3.6	73	83	1913, 1926	65	1917
11-20	.54	.52	90	65	55	15	0	8	3.8	75	89	1918	69	1915
21-30	.60	.43	85	75	55	15	0	9	3.1	78	88	1925	68	1914
July 1-10	.34	.18	85	50	30	10	0	7	2.8	83	92	1918	69	1912
11-20	.29	.17	85	45	25	5	0	6	1.9	86	94	1925	74	1915
21-31	.27	.27	80	60	25	1	0	5	1.9	88	95	1928	82	1915
Aug. 1-10	.27	.15	85	40	25	5	0	5	2.2	85	90	1915, 1930	78	1923
11-20	.54	.40	85	70	50	20	0	7	2.9	82	93	1931	70	1918
21-31	.19	.11	80	40	25	1	0	5	2.0	83	90	1913	76	1928
Sept. 1-10	.57	.47	75	70	60	20	0	7	3.0	74	84	1923	62	1912
11-20	.46	.25	85	60	40	20	0	6	2.6	71	83	1922	59	1914, 1921
21-30	.39	.29	85	70	40	5	0	7	2.6	66	73	1922, 1928	55	1926

[1] Quantity exceeded in the same number of years that it was not reached.
[2] Days with 0.01 inch or more of rainfall.

Relative-humidity data and wind data should be included in table 2, but the record of these elements for Missoula, as for most forest stations in region 1, does not yet cover a sufficient number of years to permit determination of normal probabilities. These deficiencies result from the fact that data on relative humidity and wind are not so obviously needed in agriculture and in general forecasting as in fire-weather work, and that consequently these measurements are not made at the ordinary small station cooperating with the Weather Bureau. As soon as it is decided that the records of a given station are to be used in fire-weather work, it becomes necessary to add these elements to the list to be measured.

Most of the so-called "first-order" stations of the Weather Bureau make regular measurements of humidity and obtain automatic records of wind velocity. But most first-order stations are located at points lacking forest cover and consequently lacking a typical forest climate; thus their records are not entirely satisfactory as indicating forest-fire weather. This makes it necessary that all forest agencies desiring data basic to best fire protection make complete weather measurements, in the form best adapted to their needs, over a period of years.

The danger periods indicated by table 2 are visualized more readily by means of a simple chart. A chart of rainfall probabilities for Missoula is reproduced as figure 13. This renders more striking, especially, the lower probability of moderate rains during May 1–10; the fact that the chance of rains of 1 inch or more is greatest during May 21–31; the marked danger of a dry period during August 21–31; and the generally unrecognized fact that the chances of rain are not materially better in September than during the middle third of August.

A similar form of chart is very useful in showing trends of relative humidity. Figure 14, a relative-humidity chart for the Priest River branch station, illustrates a desirable method of keep-

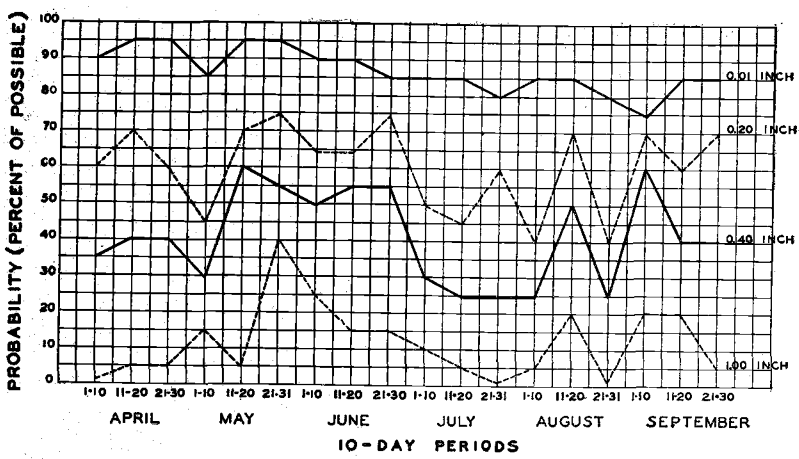

FIGURE 13.—Probability of rainfall of given quantities at Missoula, Mont., as indicated by records for 1912–31.

ing data before the forest executive's eye. Here the most useful indications are those as to averages of afternoon humidity and as to periodic minima, rather than those as to probabilities. Figure 14 supplements figure 13 by revealing the fact that relative humidities are much more favorable in September than in August.

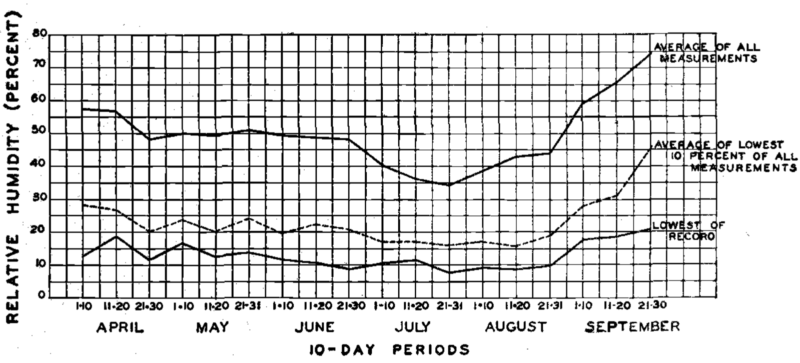

FIGURE 14.—Relative humidities at 5 p. m., Pacific time, at the Priest River Branch Station, as indicated by records for the years 1912–31.

As these data are based on 20 years' records, each point represents 200 measurements. While the general average is commonly used as a criterion and is significant, it is even more desirable to know what is the worst to be expected. For this reason the chart shows for each 10-day period the average of the lowest 10 percent of the measurements recorded for that period. In addition it shows for each 10-day period the "lowest of record", that is, the lowest humidity measured on any one of the 200 days. For these lowest humidities the probability is 1 in 200, or 0.5 percent.

It is worth noting that at the Priest River meteorological station humidities of less than 20 percent have been recorded, within a period of 20 years, in every 10-day period from April 1 to September 20. This fact reveals a striking characteristic of the climate of region 1.

RAIN MAPS

Another form for presenting important weather data for convenient use is the so-called "rain map." The need for such maps arises from the fact that no man can retain in his memory, especially during a bad fire season, the outlines of the areas wetted, respectively, by the rains that have occurred in a given vicinity within the past 6 or 8 weeks. Because he cannot do this, no man has in his mind an accurate picture of those areas that have been missed by several of these rains and are therefore in need of special protection. The kind of information presented by a rain map is illustrated by figure 15. This shows not only the localized occurrence of summer rains in region 1 but also a "missed spot" that was burned over by the Pete King fire of 1934.

The area represented by the blank spot on this map, that is, the portion of the Selway National Forest approximately bounded by the Lochsa, Pete King, O'Hara, Selway Falls, Meadow Creek, and Moose Creek ranger stations, was wetted by a rain of more than 0.20 inch on June 6, 7, and 8, 1934. By August 1 it had had no additional good rains, and the fuels on it had dried to exceptionally low moisture contents. Even without measurements of fuel moisture the rain map indicated dangerous drought. Several fires that originated within this area on August 11 spread with exceptional rapidity. The Pete King fire alone burned over 250,000 acres.

This case and several others like it in previous years indicate the desirability of using rain maps to identify dangerously dry areas needing exceptional protection from fire. In region 1 the Forest Service now requires current preparation of such maps as routine practice.

The principal instructions regarding rain maps are as follows:

(1) The classification "good rain" covers any rain of about 0.20 inch or more, regardless of duration, if the rain was not interrupted by sunshine and drying weather. Rains of less than 0.18 or 0.20 inch are not shown by hachures on the map because both experience and research have shown that their benefits are so temporary as not to warrant much consideration. They should be indicated, however, as described under (4). For the sake of simplicity, a rain that covers the entire forest is indicated not by hachures on the map but by a notation on its margin.

(2) Do not record more than four rains on one map. Even if only one rain occurs in a month, use a separate map for each month.

(3) Maps should be on a scale of one-fourth inch to the mile. Space the hachures about one-third inch apart, and use a separate direction and color of hachure for each of the rains shown on one map. Do not draw hachures directly over section or township lines.

(4) Designate each rain-gage location by a circle one-half inch in diameter. Within or beside this circle, record the exact amount of every rain of 0.01 inch or more, using the color of the hachure when this is a "good rain." (Note that all rains are recorded within or beside the circle, but only good rains are shown by hachures.)

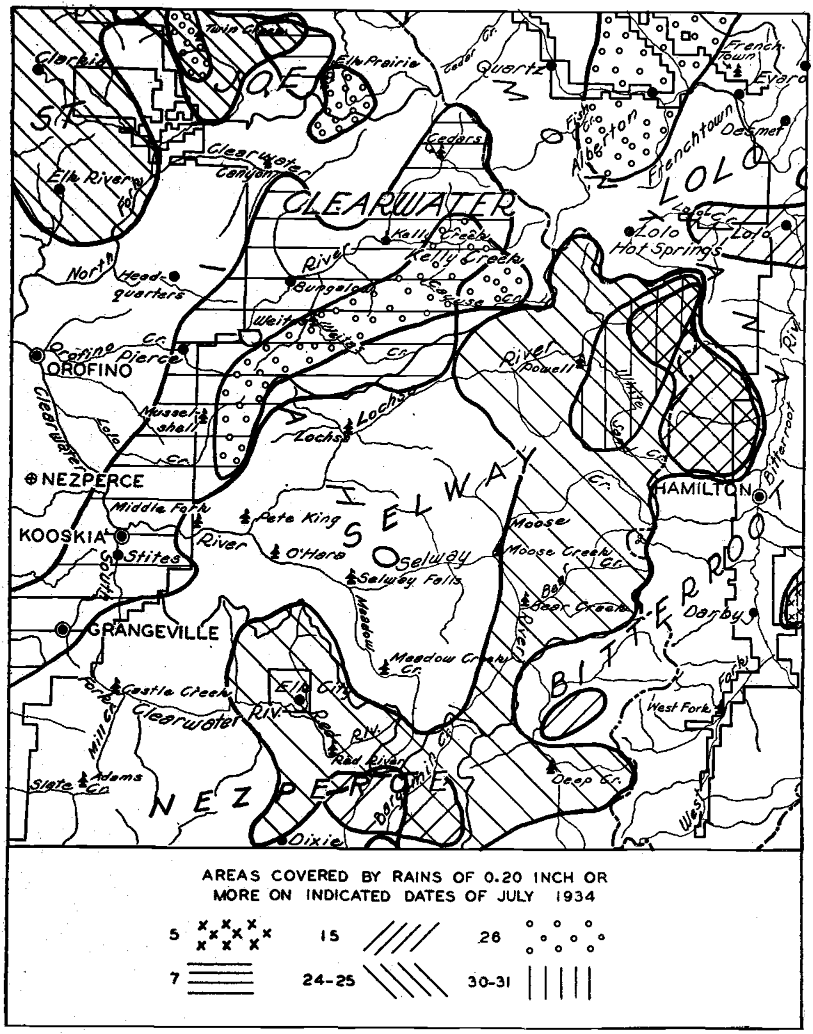

FIGURE 15.—Map of portions of southwestern Montana and eastern Idaho showing occurrence of good rains (0.20 inch or more) for July 1934.

(5) One copy of each map, with the rainfall records on which it is based, should be submitted to the regional forester by December 1.

For most dependable use, rain maps should be based on precipitation measurements from gages so distributed over the forest that there is at least one gage for each three or four townships. As the cost of standard gages distributed at this rate would be excessive, Forest Service gages, costing only $1.50 each, may be used.

Reports from all gages should be assembled each day, first at ranger headquarters, where rain maps for the ranger district should be prepared, and then at the supervisor's office, where the forest map should be kept up to date.

FIRE-DANGER CHARTS

In region 1 it has been found desirable to have each ranger and supervisor on a fire forest prepare currently a summarizing chart called a fire-danger chart. This shows the status of the most important factors of fire danger and shows the resultant status of fire danger in terms of danger-meter classes. Such charts are the best means of visualizing current danger. In addition, they provide comparable information for the use of inspection officers and for later compilation. (Their uses are discussed in full in a later section.) The region 1 standard form for fire-danger charts used in 1933, 1934, and 1935 is shown in figure 16.

The separate factors chartered currently include:

(1) Fuel-moisture content, (2) minimum or 5 p. m. humidity, (3) wind velocity, and (4) visibility distance. These factors display periodic tendencies. After a period of general safety following a heavy rain, the tendency is toward greater dryness of fuels and air, decreased visibility distance, and often increased wind velocity as a new storm center approaches. Obviously, it is of paramount importance that the forest officer recognize these tendencies, and the degree and duration of the changes.

The fire-danger graph, illustrated at the bottom of figure 16, is a single line showing class of fire danger for each day on the fire-danger meter scale of 1 to 7, 1 signifying no danger and 7 indicating the peak danger of the worst fire seasons.

In compiling charts like that shown as figure 16 the following instructions must be understood and applied:

(1) A separate chart should be compiled at each district ranger headquarters, representing conditions on that district only, and a chart representing conditions on the forest as a whole should be kept in the supervisor's office.

(2) In charting the data for a ranger district, estimates should be used only when measurements cannot be obtained. The record should be marked clearly to show which figures are estimates.

(3) Although the primary purpose of the chart is to visualize information for immediate and local use, such charts for different national-forest areas in the region must be similar in form, so that they may be compared currently and so that they may be combined for the purpose of rating fire danger for the region as a whole.

(4) Wind velocity means average velocity in miles per hour from noon to 6 p. m. Anemometers should be so located that they sample the winds in the canyon bottoms, on the lower slopes, midway to the peaks, and on the mountain tops. If all these locations cannot be sampled the charted record should represent paired measurements from high and low elevations, together with single measurements from stations that are typical in elevation and exposure. When total wind movement from noon to 6 p. m. cannot be determined, 1-minute measurements should be made at noon, 3 p. m., and 6 p. m., and the average of these measurements used. In the absence of all

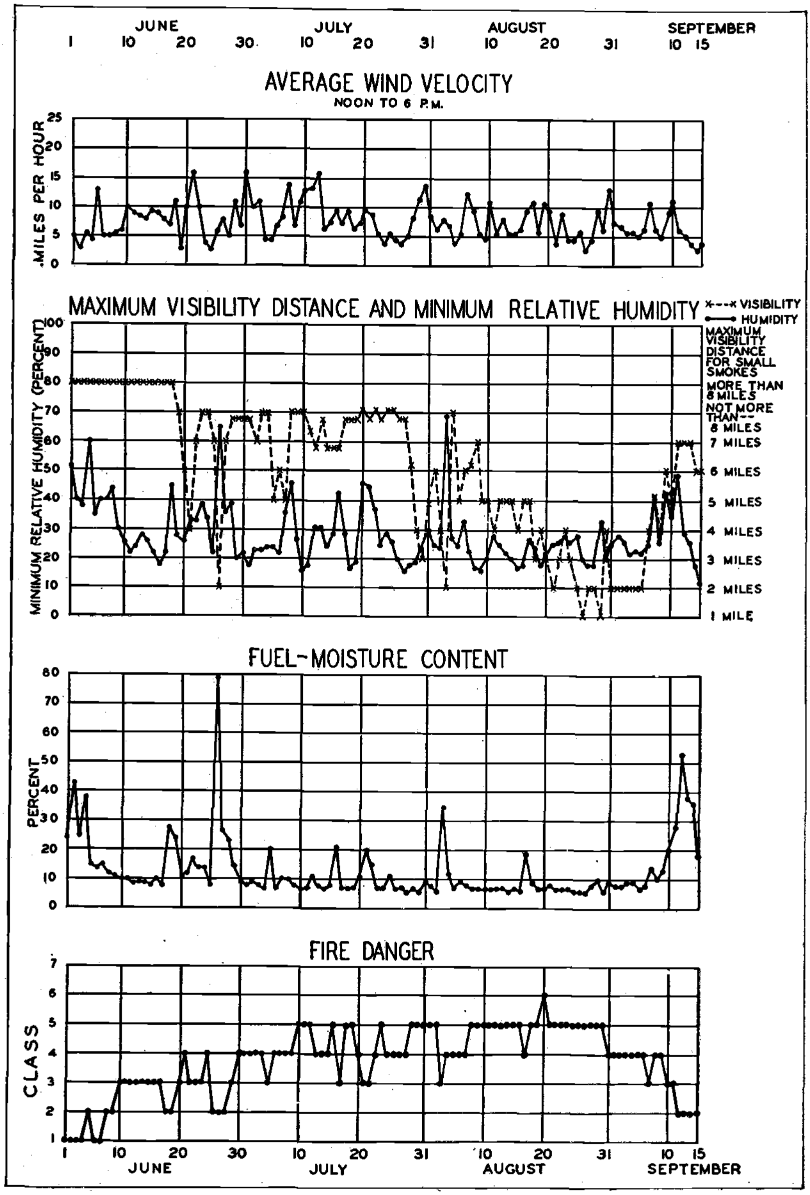

FIGURE 16.—Fire danger, Kaniksu National Forest, Idaho, 1934. Wind velocities and minimum humidities were measured at the Priest River Branch Station. Visibility average is for all lookout stations on the Kaniksu Forest. Fuel-moisture-content graph represents an average of (1) average for duff and ½-inch branch wood at 2,380 feet elevation at the Priest River station, (2) average for duff and ½-inch branch wood at 5,500 feet elevation at Priest River station, and (3) duff at Sullivan Lake.

measurements, estimates should be made at these hours on the basis of the northern Rocky Mountain wind scale, previously described. The practice of plotting wind records for several different stations is not recommended as it clutters up the chart.

(5) The visibility distance plotted should be the average of the reports made by the various lookouts. It should represent the maximum distance at which a small, single-snag fire could be discovered during the afternoon in the direction in which the visibility is poorest. It should be measured with visibility meters if these are available. Two types of visibility meters are being tested in region 1.

(6) The minimum humidity plotted should be either the lowest relative humidity recorded that day by the hygrograph or, when no hygrograph is available, the 5 or 6 p. m. psychrometer measurement. Humidity records for several stations may be charted, if desired, but the average should be made to stand out clearly.

(7) Stations having both duff hygrometers and wood cylinders should use the average moisture content of the duff and ½-inch cylinders as the index of fuel moisture. If only duff-moisture measurements are made, these are used as the index. If only wood cylinders are used, the moisture-content measurements for the ½-inch size are used.

Factors that have considerable effect on fire danger but that are not recorded graphically in region 1 are:

(1) Length of day, and duration of night coolness and humidity. (The former is greater in July and early August, the latter is greater in May and September.)

(2) Distribution of lightning storms, both as to time and as to place.

(3) Use of forests by the public, and tendency of forest visitors as to starting fires.

(4) Quantity and condition of brush and weeds on the forest—whether luxuriant, green, and fire-retardant, or sparse, dry, and fire-accelerating.

Under the present practice each forest reports its class of fire danger to the regional office each day. This is done by radio during emergencies, otherwise by telephone or telegraph.

USE OF RECORDS

Measurements described in this publication have three major uses: (1) As a basis for localizing weather forecasts, (2) as indices of current fire danger, and (3) as a basis for fire-danger comparisons.

LOCALIZING WEATHER FORECASTS

By obtaining reports twice daily from numerous stations throughout North America and from ships at sea, the United States Weather Bureau is able to prepare each day weather maps showing the location of both storm and fair-weather areas as of 8 a. m. and 8 p. m., eastern standard time. The reports are assembled and the maps prepared at stations called forecasting centers, each of which specializes in studying the weather of a specified section of the United States and in issuing daily forecasts for that section. For the Pacific States and for Idaho and Nevada, the forecasting center is

San Francisco. Denver is the center for the six States—Montana, Wyoming, Colorado, Utah, Arizona, and New Mexico.

All the weather data from all the stations regularly reporting to a given forecasting center are received at the center within 45 minutes after they are filed for transmission by telegraph or radio. As a result each district forecaster has before him, early each morning, a map showing the weather conditions as they were an hour previously, and another map showing them as they were the preceding evening. He can refer back, also, to corresponding maps for each of several preceding days.

This series of maps shows clearly how storm centers are moving and how they are changing as they move. Perhaps for 3 days a forecaster has been watching one storm center move from the Aleutian Islands southeasterly and inland, approaching northern Idaho and western Montana at a rate of about 500 miles each day. Perhaps this low-pressure center is becoming more and more pronounced as it moves inland, and is clearly going to affect region 1. In such a case, the day before this effect appears in this region the forecaster predicts it.

This brief description of the Weather Bureau's method of forecasting may serve to dispel some notions that because the general forecast for northern Idaho is prepared in San Francisco, and that for Montana prepared in Denver, the forecasts for region 1 are less accurate than they would be if prepared, for example, in Priest River, Idaho, or in Missoula, Mont. Given the necessary information and proper facilities for speedy communication, the forecaster could function equally well in Priest River, in San Francisco, or in Johannesburg, South Africa.

From this description of the method of forecasting one might conclude that reports from weather stations in northern Idaho have no influence on the forecasts for northern Idaho. This may be true in some simple cases, such as that used for illustration; but in most cases it is decidedly not true. It is least likely to be true in summer, when storm centers often pass by to the north of northern Idaho and when the quantity of moisture locally available, or the local temperature of the earth's surface, or the character of local topography may influence the local weather produced by the low-pressure center as it passes by. Under such conditions, reports from local stations are essential to accurate localized predictions of fire weather. At any season, when the disturbance is changing in character as it progresses inland, or when northern Idaho lies in the path of the edge of the disturbance—where accurate prediction is most difficult—local reports stating the character of the existing weather there are essential to a localized forecast for tonight and tomorrow.

Weather forecasts for region 1 are prepared by the Weather Bureau at from 6 to 7 o'clock, Pacific time, every morning and evening. The prediction prepared in the morning has been found of greater value and convenience in forest-fire control. This morning forecast applies to the period from 5 p. m. tonight to 5 p. m. tomorrow, Pacific time. It can be localized by the fire-weather specialist assigned to the region and distributed to forest officers usually before noon each day. Hence it is available in time for use in laying plans for tonight and tomorrow.

Localization of the regional forecast by the fire-weather specialist is essential to effective fire control. Its importance cannot be overstated. A general forecast applying to a large region such as all of northern Idaho is useful; but a forest officer in charge of the fight against a large forest fire needs to know what the weather is most likely to be in the vicinity of that specific fire. The only method by which a forecaster can learn how to localize each prediction is to determine what weather results in each drainage, according to every possible combination of local conditions, from an incoming cyclone or anticyclone. In order to cover all these possible combinations, reports of detailed and accurate measurements must be made day after day and year after year.

ESTIMATING CURRENT DANGER

Accurate identification of current fire danger is a major responsibility of every forest executive in charge of fire-control action. Experience has shown that mere observation of the several factors of fire danger is not sufficiently accurate for the fulfillment of this responsibility; measurements of each of the important factors, and uniform integration of the measurements into ratings indicating specific degrees or classes of fire danger, are essential to satisfactory accuracy.

Integration of current weather and fuel-moisture measurements to rate current fire danger, by means of the fire-danger meter, is discussed on page 38. This meter defining seven classes of fire danger, enables forest officers to rate fire danger definitely, on a numerical scale. It makes possible readily understandable statements of fire danger as the thermometer makes possible readily understandable statements of heat. Whoever uses the meter to rate fire danger arrives at the same result as anyone else working with the same data.

Ratings obtained by use of the meter serve as a dependable basis for administrative action in expanding or contracting the protective organization.

Analysis of 12,056 fire reports from 13 national forests in region 1, covering 10 consecutive fire seasons, has shown very definitely that satisfactory fire control in this region depends upon the existence and functioning of a fire-control organization large enough and with sufficient facilities to meet the peak loads occurring in the most critically dry years. Such an organization is many times as large as that needed during an average season, and perhaps 50 to 100 times as large as that needed during an easy season. Critical fire danger, although seasonal, varies greatly from year to year as to dates of beginning and ending. If fireguards, smoke chasers, and lookouts were hired and stationed according to the earliest probable occurrence of fires, the expense would be unwarranted in perhaps 7 years out of 10. If they were hired and stationed according to the average opening date of the fire season, they would be too late in some cases and too early in others. Clearly, efficient and economical forest protection requires that a skeleton force of trained men be maintained year after year and that the expensive full force be built around this skeleton force when, and only when, the class of danger definitely warrants it.

Because of the high cost of expansion and the great value of the destructible resource, expansion and contraction of fire-control forces should be timed according to current fire-danger measurements and not according to opinion or to the calendar.

For each of its seven classes of fire danger the meter indicates administrative action suitable for region 1, according to the forest-protection standards applied in 1934. Change of these standards in 1935 to include the control of all fires before 10 a. m. the day following discovery has emphasized the need of immediate action upon occurrence of the class of danger shown, and it has indicated the need of class 5 action upon the mere probability of class 5 danger. The seven administrative steps listed on the meter, representing the gamut of possible control action are:

1. No men specially detailed to fire control.
2. Man positions covering special dangers such as dangerous slash or brush-disposal operations. Man key lookout stations following lightning storms in June.
3. Man key detection positions. Commence placing "minimum" protective organization.
4. Probability of continuance warrants placing the "average season" protective organization.
5. After 1 day finish placing full "average" organization. After 2 consecutive days commence filling "first overload" positions. After about 7 consecutive days complete the first overload.
6. After 1 day complete the first overload. After 2 consecutive days commence filling second overload. After about 4 consecutive days complete second overload.
7. Upon occurrence of class 7 danger, or if it is predictable with certainty, mobilize supplemental overhead and take other action specified by "third emergency call" in overload plan.

Ratings of fire danger made by use of the fire-danger meter serve throughout the fire season, also, as a guide to the number of men that should be sent to each new fire. At least one ranger in region 1 has prepared a detailed plan of attack specifying, for each fuel type in his district, how many men should at first be sent to a fire according to the fire's prospective rate of spread as indicated by current measurements of weather and of fuel moisture. Hornby (*8*) has evolved a formula for local use in determining what combinations of speed and strength of attack are suitable for various fuel types according to prospective rate of spread of fire. This is now being tested experimentally in region 1.

Organization of a fire plan of the type just described reduces the average error of personal judgment and preserves the best judgment of the individual for the benefit of those who follow him. Such a plan may show for each spot in which a fire may originate the number of men that should be sent, according to size of fire at discovery and to prevailing fuel-moisture content and weather. Without some such plan a ranger newly assigned to a district must spend years acquiring information that was possessed by his predecessor; and in this process of acquisition by experience alone he is likely to repeat many, if not all, of the errors committed by his predecessor.

Current tendencies toward greater or less fire danger can be ascertained by the forest executive through use of a fire-danger chart, the region 1 standard form of which is discussed and illustrated on pages 46–49. By noting the trends of each of the most significant fire-danger elements for the past several days, and considering the probable trends of weather elements tomorrow as indicated by the weather forecast, the forest executive is assisted in decisions as to expanding or contracting his protective force, increasing or decreasing his strength of attack on fires, and other measures having to do with fire protection.

Records of weather measurements made in past seasons, such as those shown in table 2, are basic to fire-control plans. For a forest officer newly arrived on an area, such a record is invaluable as showing what weather to expect; for one in charge of an area with which he is familiar, such a record is more dependable than memory. In view of information given in table 2 a forest executive in charge of fire plans for an area in the vicinity of Missoula will most certainly not rely on any material assistance from nature in the way of rainfall between July 1 and August 10. Likewise, this table will call to his attention the probability of good rains in the period August 11–20 and of a marked recurrence of drought and danger during August 21–31. His fire plans may be influenced also by the record of number of rainy days, which shows that at this particular station every 10-day period from April 1 to September 30 has, 1 year or another, been absolutely rainless.

By comparing current daily maximum temperature with data on this factor in table 2, the forest executive is able to rate current danger more exactly. Suppose that in a given year daily maximum temperatures for April 21–25 average 72° F. He finds that this is 11° hotter than normal for the 10-day period and only 1° less than the heat that prevailed during that period in 1926. He remembers only too well what happened in the fire season of 1926, and with April conditions now rivaling those of that critical year he begins to "tighten up" his organization and to prepare for great danger. Without these records, the critical character of the current temperatures might easily escape attention; but with them, and with this method of using them in force at one or more stations on the forest, there should be little danger of such oversight and of consequent unpreparedness.

Weather measurements, localized weather forecasts, and data on fuel-moisture content have numerous current uses other than use in determining when to expand or contract the organization and deciding how many men to send to a fire. Many cases can be cited of control tactics on a large fire being changed when the fire chief at daybreak scanned the automatic weather records for the night and learned how conditions had changed. Tactics have been altered decidedly, and to great advantage, according to a forecast that the wind direction or velocity was about to change. The practice is growing, also, of holding smoke chasers and trail crews on the phone, sending them to emergency lookout points, and moving men from moist to dry districts when the forecast threatens lightning storms. Rain maps have been used as a basis for holding the full protective force in a rainless part of a forest intact while reducing the force on the wetted area to a skeleton.

An additional use of measurements of fire-danger factors arises in connection with fire-protective regulations. In region 1 such measurements are now used as the basis for deciding when smoking shall be forbidden within national forests, when all national-forest visitors shall be required to register and obtain permits, and when national forests shall be completely closed to entry. It is desirable that spring and fall slash burning, also, be regulated on this basis. Conditions that may result from fixing the slash-burning season by the calendar were described in one instance by an experienced member of the Forest Service as follows:

Our friend and neighbor in whom we had the utmost faith sets his slash on fire because the law says October first is the open season. Every son and his brother for miles and miles touches off his slash in the face of a 4 months' drought, a 60-mile-an-hour wind, and a 0 humidity. The result? A 100,000-acre catastrophe. A sacrifice to hell's handmaidens, selfishness, carelessness, and indifference.

MAKING FIRE-DANGER COMPARISONS

A distinctly different use of measurements of fire-danger factors lies in fire-danger comparisons between localities and seasons. Such comparisons are requisite to proper distribution of control effort, to satisfactory administration of forest-protective regulations, and to determination of the efficiency of fire-control organizations.

Comparisons of fire danger existing at different stations or on different ranger districts within a single national forest are needed by every forest supervisor, in order that protection activity may be properly distributed. One experienced officer has stated: "The failure to anticipate critical localized conditions has been our biggest stumbling block in keeping down fires." Determination of localized conditions is effected through measurement, through use of the fire-danger meter, and through current compilation of various charts, previously described.

Comparisons of various forests as to fire danger are needed by neighboring supervisors and by the regional office as a means of determining where uniformity of action is warranted and where varying action is needed. Lack of uniformity in requiring entry permits and in closure of forests to entry by the public, for example, is troublesome to people traveling from one forest to another and engenders unfavorable sentiment.

Heretofore, the usual method of rating fire-control efficiency has failed to give due credit for good work or to identify poor work. It has accepted a record showing few fires, small burned area, and low cost of suppression as evidence that on the area covered by the report the season's weather conditions favored fire control, and has accepted a record showing many fires, large area burned, and high costs as evidence that weather conditions were unfavorable. Under such a system, a forest-protective organization that educates and compels its forest users to exercise care with fire, and consequently has few fires, does not thereby gain credit for efficient presuppression action, and an organization that attacks fires promptly and practices efficient control tactics gains no more credit than one that is delinquent in these respects but is fortunate as to weather conditions. This system fails to distinguish between the two causes of fire-control results: character of weather, which determines whether or not fuels ignite easily and fire spreads fast, and efficiency of fire control, which is the quality of man's attempt to meet the first. If efficiency of fire control is to be fairly determined it is necessary that fire danger be rated and that the results obtained by the protective organization then be compared with this rating.

To form a satisfactory basis for fire-danger comparisons, measurements of weather factors and fuel moisture must have been taken at stations that fairly represent each of the forests, and must have been accurately assembled and integrated for each unit. On some forests, for example, different timber types indicate differences in climate. Each of these climatic types must be sampled by the fire-danger measurements, so that each will be represented in the single rating for the forest as a whole. If each type is represented by a number of stations proportional to the area occupied by the type, then a simple average represents the forest as a whole. If the distribution of stations fails to represent the distribution of types differing as to fire danger, the measurements for some stations must be given more weight than those for others in computing the rating for the forest as a whole.

Region 1's problems as to proper sampling and proper integration of measurements are being studied. Better timber and fuel-type maps, and several years of careful study by local forest officers, may be required for satisfactory solution of these problems.

Substantial progress has been made in comparisons of fire danger for the same station or the same forest in different years. By use of present methods it is possible to state these comparisons in percentages.

There are three steps in the process of expressing danger on a percentage basis: (1) Determination, for each station or for each forest unit, of the number of days on which each class of danger existed during the period to be studied (say July and August); (2) determination of the average class of danger for this period; and (3) determination of the maximum danger probable during the period. An example of these determinations, for the Priest River Experimental Forest, is as follows:

Class of danger:	*Number of days*
1	0
2	0
3	10
4	16
5	29
6	7
7	0
Total	62

The products of the values of column 1 multiplied by those of column 2, respectively, total 281. The average class of danger, therefore, is $\frac{281}{62}$, or 4.5.

According to the records for eight fire seasons, the worst probable average danger for July and August at the Priest River Forest is of class 5.5. With this class representing 100 percent, a rating of 4.5 is about 82 percent of the worst probable.

The selection of class 5.5 as the worst probable average danger for July and August at this station is based upon measurements that include three critical seasons, 1929, 1931, and 1934. Of these seasons 1931 was the most critical, with an average danger rating of 5.1. As certain factors, notably wind velocity, were not so dangerous during that season as during others, the class 5.5 was selected as more nearly representing worst probable danger. A similar index should be determined for every station and for every forest unit as soon as records covering an extremely bad fire year are available to guide the selection.

A determination of least probable danger, also, is needed for every national forest and for region 1 as a unit. This cannot be made, however, until another easy season is experienced comparable to that of 1923. When both greatest and least probable danger indices have been determined it will be possible to express the range of fire danger on a percentage scale between those extremes. Until then, the percentage expression includes the range from absolutely no danger to greatest probable danger.

A special need of comparable fire-danger ratings arises annually in the office of the Chief of the Forest Service. Each year the Forester is called upon to report to Congress and to the public (1) the status of fire danger during the past season and (2) how this danger was met, in terms of area burned and money spent. As the basis for such reports, each of the regions must submit fire-danger measurements or opinions of the character of the fire season. These are compared with the fire records in order to rate fire-control efficiency according to fire danger experienced, for the national forests as a whole and for the several regions. The ratings of fire danger described in this publication are being used as a criterion of fire-control efficiency in region 1. A somewhat similar method is being developed by Shank for use in region 4. A third method for Nation-wide use, based on precipitation alone, has been proposed by Loveridge (*12*).

Other Federal agencies, the Indian Service and the National Park Service, have the same annual need for accurate ratings of control efficiency on the basis of fire danger. State boards of forestry and directors of private timber-protective associations, also, must remain in doubt concerning the efficiency of fire control on their forest areas unless dependable measurements and ratings of danger are obtained. These needs can be met in the Northern Rocky Mountain Region through the technique of measurement described in this publication.

LITERATURE CITED

(1) Dunlap, M. E.
1932. The drying rate of hardwood-forest leaves. Jour. Forestry 30: 421–423, illus.

(2) Gisborne, H. T.
1928. Measuring forest-fire danger in northern Idaho. U. S. Dept. Agr. Misc. Pub. 29, 64 pp., illus.

(3) ———
1930. Forest-fire research. Sci. Monthly 31: 76–80.

(4) ———
1931. The scheme of forest-fire control. Jour. Forestry 29: 1077–1079.

(5) ———
1933. The wood cylinder method of measuring forest inflammability. Jour. Forestry 31: 673–679, illus.

(6) Gregg, W. R.
1930. Aeronautical meteorology. Ed. 2, rev. and enl., 405 pp., illus. New York.

(7) Hawley, L. F.
1926. Theoretical considerations regarding factors which influence forest fires. Jour. Forestry 24: 756–763.

(8) HORNBY, L. G.
1935. FUEL TYPE MAPPING IN REGION ONE. Jour. Forestry 33: 67–72.

(9) HUMPHREY, R. R.
1933. A DETAILED STUDY OF DESERT RAINFALL. Ecology 14: 31–34, illus.

(10) HUMPHREYS, W. J.
1929. PHYSICS OF THE AIR. Ed. 2, rev. and enl., 654 pp., illus. New York.

(11) JEMISON, G. M.
1932. METEOROLOGICAL CONDITIONS AFFECTING THE FREEMAN LAKE (IDAHO) FIRE. U. S. Monthly Weather Rev. 60: 1–2.

(12) KADEL, B. C., FRANKENFIELD, H. C., and TINGLEY, F. G.
1928. CLOUD FORMS ACCORDING TO THE INTERNATIONAL SYSTEM OF CLASSIFICATION. U. S. Dept. Agr., Weather Bur. W. B. 956, ed. 2, 22 pp., illus.

(13) LOVERIDGE, E. W.
1935. A COUNTRY-WIDE FOREST FIRE WEATHER HAZARD INDEX. Jour Forestry 33: 379–384, illus.

(14) MCADIE, A. G.
1923. A CLOUD ATLAS. 57 pp., illus. Chicago and New York.

(15) MCARDLE, R. E.
1935. A VISIBILITY METER FOR FOREST FIRE LOOKOUTS. Jour. Forestry 33: 385–388, illus.

(16) MARVIN, C. F.
1910. PSYCHROMETRIC TABLES FOR OBTAINING THE VAPOR PRESSURE, RELATIVE HUMIDITY, AND TEMPERATURE OF THE DEW-POINT FROM READINGS OF THE WET AND DRY BULB THERMOMETERS. U. S. Dept. Agr., Weather Bur. W. B. 235, 87 pp., illus.

(17) ———
1913. MEASUREMENT OF PRECIPITATION. A PAMPHLET OF INSTRUCTION FOR THE MEASUREMENT AND REGISTRATION OF PRECIPITATION BY MEANS OF THE STANDARD INSTRUMENTS OF THE U. S. WEATHER BUREAU. U. S. Dept. Agr., Weather Bur. W. B. 445, Instrument Div. Circ. E, ed. 3, 37 pp., illus.

(18) MATTHEWS, D. N.
1935. EXPERIENCE WITH HAZARD INDICATOR STICKS. Jour. Forestry 33: 392–397, illus.

(19) MUNGER, T. T.
1925. RAINFALL PROBABILITY DURING THE FIRE SEASON IN WESTERN WASHINGTON AND OREGON. U. S. Monthly Weather Rev. 53: 394–395.

(20) PISTON, D. S.
1931. METEOROLOGY. 187 pp., illus. Philadelphia.

(21) SHANK, H. M.
1935. A MEASURE OF FOREST FIRE HAZARD IN CENTRAL IDAHO. Jour. Forestry 33: 389–391, illus.

(22) SHOW, S. B.
1919. CLIMATE AND FOREST FIRES IN NORTHERN CALIFORNIA. Jour. Forestry 17: 965–979, illus.

(23) ——— and KOTOK, E. I.
1925. WEATHER CONDITIONS AND FOREST FIRES IN CALIFORNIA. U. S. Dept. Agr. Circ. 354, 24 pp., illus.

(24) SIMPSON, A. G.
1930. RELATIVE HUMIDITY AND SHORT-PERIOD FLUCTUATIONS IN THE MOISTURE CONTENT OF CERTAIN FOREST FUELS. U. S. Monthly Weather Rev. 58: 373–374.

(25) STICKEL, P. W.
1931. THE MEASUREMENT AND INTERPRETATION OF FOREST FIRE-WEATHER IN THE WESTERN ADIRONDACKS. N. Y. State Col. Forestry, Syracuse Univ., Tech. Pub. 34, 115 pp., illus.

(26) UNITED STATES DEPARTMENT OF AGRICULTURE, WEATHER BUREAU.
1914. INSTRUCTIONS FOR THE INSTALLATION AND MAINTENANCE OF WIND MEASURING AND RECORDING APPARATUS. U. S. Dept. Agr., Weather Bur. W. B. 530, Instrument Div. Circ. D, rev. 4, 77 pp., illus.

(27) ———
1924. INSTRUCTIONS FOR COOPERATIVE OBSERVERS. U. S. Dept. Agr., Weather Bur., W. B. 843, Instrument Div. Circs. B and C, ed. 7, 35 pp., illus.

APPENDIX

R-NRM
Pf,
B-52

____
Date of Inspection

____
Forest

INSPECTION RECORD

____ Inflammability Station

Location: ______________; ______________; ____________
Section Township Range

1. Instrument shelter type ______________________________________. Exposure O. K. ____________. Condition ____________________________________. Owner ______________________________.

2. Max. thermometer # ____________. Owner ____________________________.

3. Min. thermometer # ____________. Owner ____________________________.

4. Are the set temperatures alike ________. Difference __________.

5. Max. & min. support: Type _______. # ______. Owner ______________.

6. Sling psychrometer. Type ________. Owner ____________________________. Nos. ______________, ______________. Condition of wicking ______________. Extra wicking needed ______________. Do the wet and dry bulbs agree ______________. Difference ____________________. Does observer use proper care concerning wetting bulb ______________; stand in shade ______________; avoid body and hand heat ______________; keep out of rain ______________; get lowest wet bulb ______________; use tables properly ______________.

7. Hygrothermograph. Type ________. No. ______. Owner ______________. Condition ____. Chart supply sufficient for ____________ months. Ink supply sufficient for __________ months. Pens set correctly for time ____________________. Trace satisfactory during wet weather ____________________. Clock need cleaning and oiling __________________________. Last cleaned and oiled __________________. Does operator understand how to reset to record accurate maximum and minimum ____________________. Humidity reset only when trace is level and below 30% ________________. Reset only when trace is in error by more than 2% ____________________. Reset only on basis of three consecutive determinations of humidity by sling psychrometer all giving same percent humidity ______________________________________.

8. Rain gage. Type ______. No. ______. Owner __________________________ Exposure satisfactory ______________________________. Stick condition__________________________.

9. Anemometer. Type _______. No. _______. Owner ______________________. Exposure ____. Batteries # ________________________. Condition ______________________________. Need carbons and zincs __________________. Soda and oil __________________. Recorder No. ______________________. Chart supply sufficient for ______________ months. Ink supply sufficient for ____________ months. Pen set correctly for time ______________. Clock last cleaned and oiled ______________. Dial read at what hours ______________________________. Check operator's reading of dial ____________. Oil available for ____________ months. Conditions of bearings ______________________________. Does operator oil both bearings once each week on lookouts ______________________________. Once each month at other stations ______________________________.

10. Duff hygrometer No. ________. Exposure satisfactory ________. Spike slope slightly downhill __________. Spike at proper depth __________. Record indicate instrument is accurate over entire range ____________________. Not accurate between ______________________________. Have operator read dial and

determine duff moisture. Does he tap the head ____________________. Read dial properly ____________________. Use chart correctly ____________________.

11. Wood cylinders: 2″ No. ________________, ½″ No. ________________. Exposure satisfactory ____. Tagged ends point north ____________________. Tags right-side up ________________. Brackets support sticks 10″ above ground ____________________. Bracket arms not so tight that they mar sticks ____________________. Sticks seriously chipped ____________________, marred ____________________, checked ________________, dirty or greasy ____________________. Scales sheltered from wind when weighing sticks ____________. Scales balanced ____________. Off by ____________ gram. Cylinder weights converted to moisture contents ____________________. Is operator recording weights and moisture percents, or only percents__________ ____. If former, check conversion for ten scattered cases for each stick.

12. Screen: Condition of wire O. K. ____________________. Surface of wire satisfactorily level ____________________. No objectionable sags ____________. Wire 13″ above ground and 3″ above cylinders ____________________. Cylinders exposed under the north-central portion of the wire ____________________.

13. Records. What forms are used ____. Form 1009 E, one copy to Weather Bu. __________; one to Expt. sta. __________. One retained locally, or filed by supervisor ______________________________. Form properly filled out ________________. Carbons clearly legible ________________. Check data on this form against hygrothermograms and wind records for: (a) correspondence of dates ________________, (b) maximum and minimum temperature ________________, (c) afternoon humidity ________________, (d) miles of wind from noon to 6 p. m., or at time of observation ____________________. Daily reports made by wire ________________ or telephone ________________ to ________________________________, and relayed to ________________ ____________________. Charts kept at ____________________, and __________ __________, and ____________________. Items plotted at this station__________ ____.

14. Further notes and recommendations:

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