PART 2A. MANUAL WEATHER STATIONS: MEASUREMENTS; INSTRUMENTS

This portion of the handbook focuses on manual weather station instruments and their operational features. The individual chapters first define and describe the weather elements or parameters that are measured at fire-weather and other stations.

Observers with a basic understanding of weather instruments, and what the measurements represent, are better prepared toward obtaining accurate weather data. They will be better able to recognize an erroneous reading or defective instrument. Similarly, persons assigned the task will be more likely to properly install and maintain the instruments.

In addition, an increased understanding of the instruments may bring greater satisfaction to what might otherwise become a routine, mechanical task. An understanding of the weather elements and processes may further stimulate interest. The text by Schroeder and Buck (1970) is particularly recommended.

The instrument description in the various chapters begins with the standard, recommended equipment in present use (prefixed by the word "standard"), except where a standard design or model has not been adopted. It also includes commonly used or recommended alternatives, as explained in the Introduction.

A brief, advance listing of the standard or recommended equipment is given in chapter 6.

CHAPTER 6. STANDARD EQUIPMENT LIST

6.1 Manual Fire-Weather Station

A standard manual fire-weather station contains the following equipment:

1. Cotton region instrument shelter, with support legs.
2. Liquid-in-glass maximum and minimum thermometers, having scales graduated in 1-°F increments, and Townsend support. Two separate thermometers are used; the maximum is mercury-in-glass and the minimum is alcohol-in-glass.
3. Electric (battery-operated) fan psychrometer, consisting of dry bulb and wet bulb thermometers graduated in 1-°F increments.
4. Anemometer, either contacting type with 1/60-mile contacts or a suitable generator type, and mounting pole or mast. No particular model has been adopted as the standard.

Contacting anemometers are the most widely used type at present but are becoming more difficult to obtain. Of the three most popular makes or models—the Forester anemometer (several models), the Stewart aluminum cup anemometer, and the Bendix-Friez small Airways type anemometer—the latter two are no longer manufactured. Recent generator models, available from Natural Power Inc. and NRG Systems, have been recommended as a possible replacement.

5. Mechanical wind counter equipped with a timer (Forester 10-Minute Wind Counter), or other suitable readout device, such as the Forester (Haytronics) Totalizing Wind Counter. The counter enables measurement of average windspeed in miles per hour. The generator anemometers mentioned above have an electronic accumulator or odometer that can give a digital readout of 10-minute average windspeed.
6. Wind direction system—including wind vane and remote readout device. Again, no particular model has been adopted as the standard.
7. Nonrecording ("stick") rain gauge, with support; gauge has 8-inch diameter and may be either large capacity type or Forest Service type. Measuring stick gives rainfall in hundredths of an inch.
8. Fuel moisture stick (1/2-inch ponderosa pine dowels) and supporting rack.
9. Fuel moisture scale (Forester model), mounted in a scale shelter such as the recommended Appalachian scale shelter.

Additional recommended items are: (1) a hygrothermograph, Belfort or Bendix-Friez type, and (2) recording precipitation gauge, Universal weighing type.

6.2 Evaporation Station

A standard evaporation station, operated for hydrological or agricultural/forestry applications, contains the following equipment:

1. Class "A" evaporation pan, on wooden ground support; also a water supply tank.
2. Micrometer hook gauge and stilling well; or a fixed-point gauge, stilling well, and measuring tube.
3. Totalizing anemometer and display-stand support. Widely used models, with self-contained mechanical counters, include the Belfort Totalizing Anemometer and the Weathertronics Totalizing Anemometer.
4. Six's type (U-tube) maximum-minimum water thermometer, with submerged mount or float mount. Graduations are etched on the glass tube in 1-°F increments.
5. Cotton region instrument shelter, with support legs.
6. Liquid-in-glass maximum and minimum thermometers and Townsend support, as described for fire-weather station.
7. Nonrecording ("stick") rain gauge, 8-inch diameter large capacity type.

Additional, optional items are (1) a hygrothermograph, (2) weighing precipitation gauge, (3) psychrometer, electric-fan or sling type, and (4) mercury-in-steel or electrical soil thermometers, with head shelter.

6.3 Climatological Station

A basic climatological station of the National Weather Service (NWS) type, measuring only temperature and precipitation (including snowfall), consists of evaporation station items 5, 6, and 7. Evaporation stations and fire-weather stations may thus also serve as climatological stations. In recent years, a digital thermometer inside a small radiation shield has replaced items 5 and 6 at many of the NWS stations. A more complete climatological station will include observations of wind, humidity, and sunshine (or solar radiation).

CHAPTER 7. TEMPERATURE AND HUMIDITY

7.1 Temperature

Simply stated, temperature is a measure of the degree of hotness or coldness—in the present context, hotness or coldness of the air. Temperature measurements routinely taken at fire-weather stations are: dry bulb, wet bulb, maximum, and minimum. Dry-bulb temperature represents the air temperature at observation time.

Dry- and wet-bulb temperature measurements are taken to calculate relative humidity and dewpoint and are discussed further in section 7.2. Recorded maximum and minimum temperatures are the highest and lowest values occurring during a specified period of time, such as 24 hours. At fire-weather stations, this period covers the 24 hours preceding the basic afternoon observation time. Maximum and minimum temperatures are arithmetically averaged to obtain a generally good approximation of the 24-hour average temperature.

For fire-weather and climatological purposes in this country, temperatures are obtained from thermometers calibrated in degrees Fahrenheit (°F). The air temperatures are normally measured about 5 ft above the ground; this height may be altered at locations experiencing deep snow cover.

Available thermometers (sections 7.4, 7.5, and 7.7) are of several types, differing both in design and in operating principle. Liquid-in-glass thermometers, Bourdon thermometers, and bimetal thermometers are commonly used. A newer, electronic type has a digital readout.

7.2 Relative Humidity and Dewpoint

Relative humidity (RH) is the percentage ratio of (1) the actual amount of water vapor in the air to (2) the amount of water vapor required for saturation at the existing temperature. These amounts are often expressed in terms of vapor pressures (Countryman 1971; Schaefer and Day 1981; Schroeder and Buck 1970). The saturation vapor pressure increases with temperature. Thus, RH is largely dependent upon temperature, with an inverse relationship. It tends to be lowest during the afternoon, when the temperature is near its daily maximum, and highest near dawn, when the temperature is near its minimum.

Dewpoint (DP) is the temperature at which the air, if cooled, would reach saturation. At this temperature, dew (or frost) will start to form on an exposed surface. In standard calculations, both DP and RH are based on saturation with respect to water even at temperatures below freezing. This convention gives lower DP and RH values than those with respect to ice, because of differences between saturation vapor pressures over ice

Table 7.1—Selection of psychrometric tables according to elevation above sea level[1]

Elevation above sea level		Psychrometric table
Alaska	**All other States**	**Pressure**
Feet		*Inches of mercury*
0 - 300	0 - 500	30
301 - 1,700	501 - 1,900	29
1,701 - 3,600	1,901 - 3,900	27
3,601 - 5,700	3,901 - 6,100	25
5,701 - 7,900	6,101 - 8,500	23

[1]At higher elevations, to about 10,000 ft, table for 23 inches may be used; obtained values will be slightly low.

and (supercooled) water at similar temperatures (Schaefer and Day 1981). Thus, at saturation, the calculated RH will be 100 percent at temperatures above freezing but will be only 94 percent at 20 °F and 84 percent at 0 °F. Above freezing, the dewpoint and dry- and wet-bulb temperature values will all be equal at 100 percent relative humidity.

Relative humidity is the primary humidity variable used in standard fire-weather observations, although dewpoint is also important (Countryman 1971). As mentioned previously, the current RH and DP are calculated from dry- and wet-bulb temperatures. These temperatures are measured with a psychrometer (section 7.6). Daily maximum and minimum relative humidity, for the 24 hours preceding the basic observation time, are usually obtained from a hygrothermograph (section 7.7). In fire-weather observations, these two humidity values are used to estimate a 24-hour average.

USE OF PSYCHROMETRIC TABLES

Relative humidity and dewpoint are determined from dry- and wet-bulb temperatures by use of NWS "Relative Humidity and Dewpoint Tables," also known as "psychrometric" tables. Separate tables are provided for each of five levels of atmospheric pressure and corresponding ranges of elevation above sea level (see table 7.1). These tables are available in appendix 2.

Another type of table is based on the dry-bulb temperature and the wet-bulb depression. The wet-bulb depression is simply the difference between the dry- and wet-bulb readings. Special slide-rule calculators may also be used; again, these are valid only for their specific pressure or elevational range.

7.3 Instrument Shelters

Temperature and humidity instruments (sections 7.4 through 7.7) are typically exposed inside a specially designed, white-painted enclosure or shelter. This instrument shelter, also termed a thermometer shelter or screen, serves to shield the instruments from precipitation and sunshine, while allowing adequate ventilation. Shelters have traditionally been constructed from wood, but aluminimum and plastic materials have also been used. The standard "cotton region" shelter (described below) provides space for a complement of several instruments and is generally effective in representing conditions of the surrounding outside air.

COTTON REGION SHELTER

The cotton region type of instrument shelter (fig. 7.1) has been standard at National Weather Service climatological stations and is recommended for use at all manual stations employing both temperature and humidity equipment. This is a medium-size shelter constructed of wood and painted white both inside and outside. The white, reflective outside coating minimizes absorption of solar radiation, which otherwise could cause excessively high daytime temperatures inside the shelter. Radiation errors may, nevertheless, sometimes reach 2 or 3 °F, given calm wind conditions combined with strong sunshine. Conversely, temperature readings on clear, calm nights can be 1 or 2 °F too low, due to cooling of the shelter by outgoing (longwave) radiation.

The cotton region shelter has a double roof, louvered sides, and slotted openings in the floor. Interior dimensions are 30 inches wide, 32 inches high, and 20 inches deep. The interior contains a crossboard for mounting thermometers. The shelter door, usually hinged at the bottom so that it opens downward, faces north when the shelter is properly oriented. Except when the instruments are read, this door should be kept closed at all times to keep out indirect or reflected solar radiation. The shelter is mounted on an open wooden or aluminum stand that is firmly anchored to the ground.

A variety of homemade instrument shelters of different design have been used at many fire-weather stations in the past. The use of such shelters is now discouraged as they lessen the comparability of data between stations.

Figure 7.1—Cotton region instrument shelter; the standard design in use at manual fire-weather, climatological, and evaporation stations.

Figure 7.2—Gill multiplate solar radiation shield (R.M. Young Company); naturally ventilated type made of plastic, used with electrical or electronic temperature and humidity sensors. (Photo courtesy of Sierra-Misco, Inc.)

SOLAR RADIATION SHIELDS

Small radiation shields constructed of metal (anodized or white-painted aluminum) or white plastic are used in conjunction with sensors of remote-reading, electronic thermometers; the shields are similar to those used at automatic weather stations (Part 3). Two of these shields are shown in figures 7.2 and 7.3. In common with the cotton region shelter, these shields allow natural ventilation while reflecting solar radiation and keeping out precipitation. A shield of the cylindrical, stacked-plate type (fig. 7.2) is used by the National Weather Service in its new maximum-minimum temperature (MMT) system at cooperative climatological stations. The MMT system has replaced the cotton region shelter and liquid-in-glass thermometers (section 7.4) at many locations. This particular system is not available to other agencies, and it is not as yet (as of 1989) problem-free.

These radiation shields would not be adequate for manual stations where fan psychrometers and hygrothermographs are employed in addition to maximum-minimum thermometers. Such instrumentation requires the housing afforded by a cotton region type shelter.

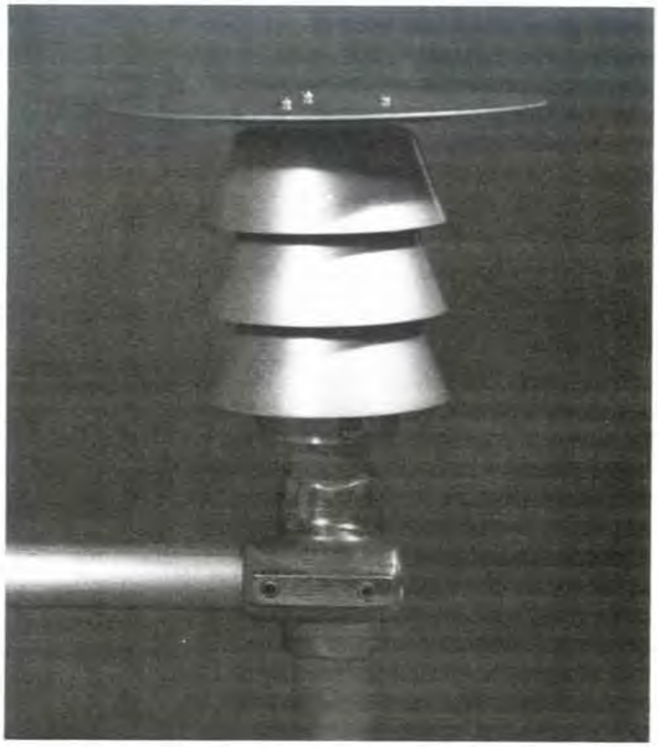


Figure 7.3—"Pagoda" type solar radiation shield; naturally ventilated type made of anodized aluminum. (Photo courtesy of Qualimetrics, Inc.)

PORTABLE SHELTERS

Various portable instrument shelters can be used for fire-weather and other purposes. Some are small wooden shelters; others are aluminum or plastic shelters. All should be painted white. The adequacy of these shelters depends to a large extent on shelter design, the instruments used, and the required accuracy of the data to be collected. They are not meant for use at permanent stations but rather serve as alternatives to the cotton region shelter at temporary field locations.

Aluminum Shelter—A field installation of a portable aluminum instrument shelter is shown in figure 7.4. This shelter can be collapsed to a compact size (fig. 7.5) for relatively easy portability. With 2-ft-square louvered side panels, it has the advantage of being generally comparable in size and similar in design to the cotton region shelter. When compared with the cotton region type (USDA FS 1964a; Finklin 1979), aluminum shelters tend to produce larger radiation errors; the test results indicate temperature corrections that may be applied.

Orchard-Type Shelter—This white plastic shelter (fig. 7.6), commercially labeled "ThermoShelter," offers an inexpensive means of exposing a minimum thermometer or compatible Six's maximum-minimum thermometer. More properly categorized as a shield, it may be particularly suited where numerous measurement points are required. The curve-shaped construction provides an

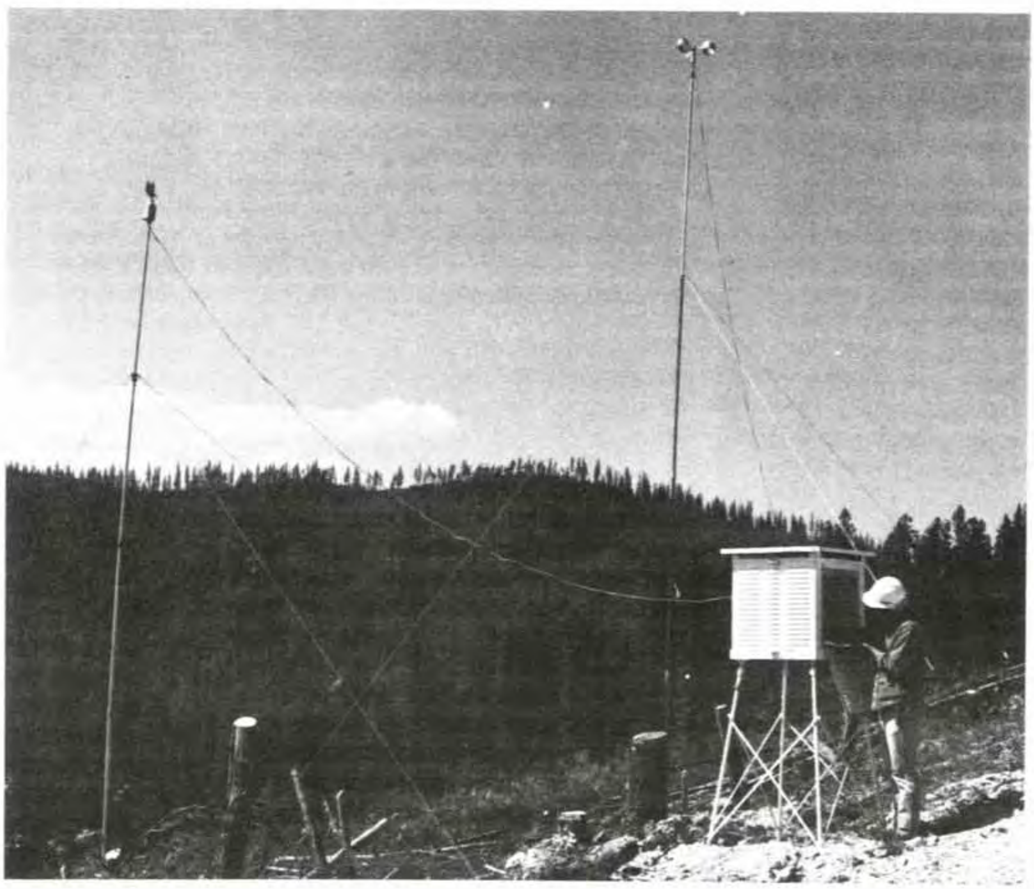


Figure 7.4—A portable aluminum instrument shelter installed at a temporary field station.

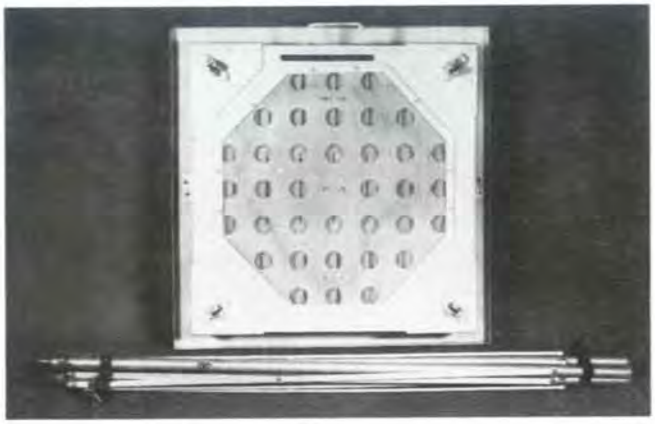


Figure 7.5—Portable aluminum instrument shelter, knocked down for easy transport.

Figure 7.6—Orchard type shelter, made of molded plastic. (With mounted Six's type maximum-minimum thermometer.)

7.4 Liquid-in-Glass Thermometers

Liquid-in-glass thermometers indicate temperature by the difference in expansion between the liquid (mercury or alcohol) and the glass bore in which the liquid is enclosed. The bulb at the bottom of the glass bore acts as a reservoir for the liquid, which rises or falls as the temperature changes.

Mercury-filled thermometers are designed to measure temperatures above –38 °F (the freezing point of mercury). Alcohol- or spirit-filled thermometers can measure much lower temperatures, well below –100 °F.

Liquid-in-glass thermometers vary in length of stem and shape of bulb. As a general rule, long-stemmed thermometers can be read more precisely than those with short stems. Everything else being equal, a thermometer with a relatively narrow, cylindrical bulb (fig. 7.7C) will indicate changes in air temperature faster (will have less time lag) than one with a spherical bulb (fig. 7.7A).

STANDARD MAXIMUM AND MINIMUM THERMOMETERS

The standard, recommended maximum and minimum thermometers are two separate thermometers mounted (in a near-horizontal position) in a special device called a Townsend support (fig. 7.8). Accuracy of new thermometers, as specified in some instrument catalogues, should be within 0.3 to 0.5 °F at temperatures above 0 °F.

Maximum Thermometer—The standard maximum thermometer is mercury-filled and has a small constriction in the capillary (the fine bore of the tube) just above the bulb (fig. 7.7A). As the mercury in the bulb expands with increasing temperature, some of it is forced past this constriction and upward through the bore. When the temperature falls, the mercury normally cannot recede through the constriction. Hence, when the bulb end of the

overhang but leaves the thermometer (mounted horizontally) unshielded in forward, sideward, and downward directions. The shelter should be mounted on a post or tree, with the thermometer facing slightly east of north.

When exposed in full sunshine, this shelter is less efficient than the standard cotton region shelter in curtailing radiation errors; the errors are often 1 to 3 °F greater. Nighttime errors resulting from radiational cooling may also be greater, by about 1 °F.

With this shelter, the sun's rays can fall on a north-facing thermometer early and late in the day during spring and summer. Shelter orientation somewhat east of north will reduce this sunshine intrusion late in the day, when it would more likely affect maximum temperature readings. Natural or artificial shading may also be helpful during these times of day. Shelter placement should avoid nearby light-colored, reflective ground (soil or rock) surfaces, which can reflect solar radiation upward to the shelter interior and thermometer bulb, raising temperature readings by more than a few degrees (see MacHattie 1965). Likewise, the shelter is not suitable for use during months of snow cover, which presents a highly reflective surface.

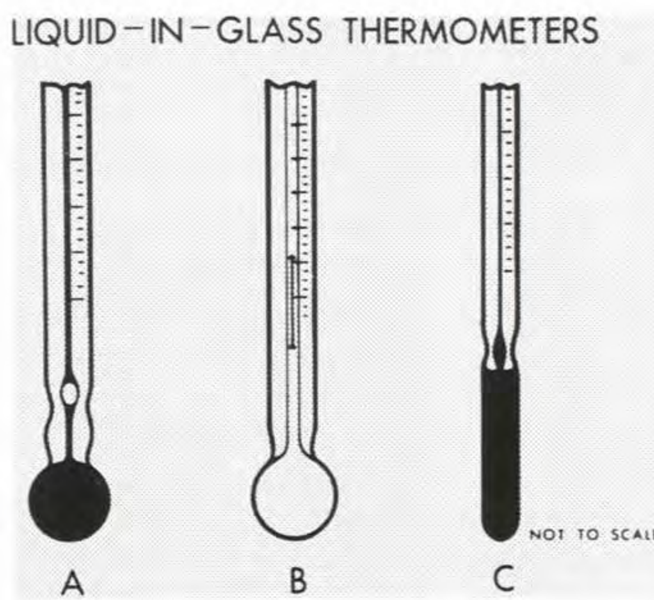


Figure 7.7—Liquid-in-glass thermometers: A, mercury-filled maximum thermometer; B, alcohol-filled minimum thermometer; C, standard mercury dry-bulb thermometer.

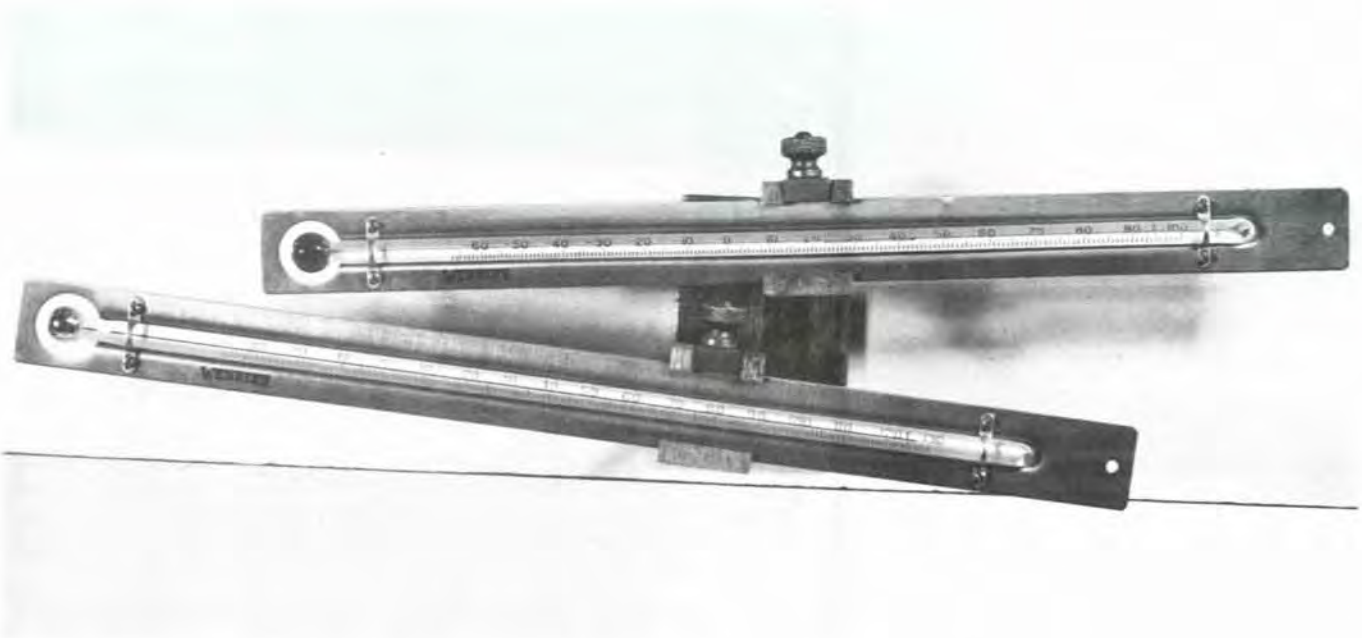


Figure 7.8—Standard maximum and minimum thermometers mounted in a Townsend support; in the lower and upper clamps, respectively.

thermometer is lowered to a reading position, the top of the mercury column indicates the highest temperature attained.

After the maximum temperature is read, the thermometer is reset by spinning it, fastened in its mounting clamp. This forces the mercury downward through the constriction and back into the bulb.

Minimum Thermometer—The standard minimum thermometer is alcohol-filled and has a small glass index rod immersed in the alcohol (fig. 7.7B); this index can move freely through the bore. When the temperature falls, the retreating alcohol column drags the index with it by means of surface tension at the top of the column. When the temperature again rises, the alcohol column moves past the index, which remains at its lowest temperature position.

The thermometer is reset by inverting it, fastened in its mounting clamp, until the index returns to rest against the top of the alcohol column.

Townsend Support—The Townsend support, with its spinning and rotating clamps, facilitates reading and setting of the maximum and minimum thermometers. This support is designed for mounting on the crossboard inside an instrument shelter.

SIX'S (COMBINED) MAXIMUM-MINIMUM THERMOMETER

The Six's, or combined maximum-minimum thermometer is distinguished by its U-shaped tube. This is a spirit-filled (creosote) thermometer employing an imbedded mercury column as an indicator. It is a less expensive, but generally less accurate, alternative to the standard maximum and minimum thermometers. It may serve (with calibration checks) in temporary field use or in other applications where great precision is not essential. A special model is employed to obtain maximum and minimum water temperatures at evaporation stations (chapter 12).

A metal, dumbbell-shaped index rod is enclosed above the mercury column in each arm of the U-tube (fig. 7.9). When reset, the indexes rest against the ends (or tops) of the mercury columns. The scale along the right arm of the U-tube indicates maximum temperature; the left scale, which is inverted, indicates minimum temperature. The top of the mercury column in either arm always indicates the current temperature.

The index rods are pushed upward in the tube by the mercury column, which rises up the right or left arm as the temperature rises or falls. The rods remain in place at their extreme positions when the mercury column retreats. The rods do not slide downward even though the Six's thermometer is normally exposed in a vertical position.

The maximum and minimum temperature values are read at the **lower ends** of the respective index rods. After each observation, the thermometer is reset with a small magnet, drawing the metal index rods down to the tops of the mercury columns. In some models, the index rods are reset with a push-button device.

The Six's maximum-minimum thermometer most commonly has temperature scales marked only on its backing, with 2-°F graduations, but higher priced models have the scales etched on the glass. The model used for water temperatures at evaporation stations has 1-°F graduations on the glass. Six's thermometers should be periodically checked against a standard dry bulb thermometer (section 7.6). Where errors are not due to column separations (section 30.2), corrections may be applied. Alternatively, the thermometer's scale plates may be shifted

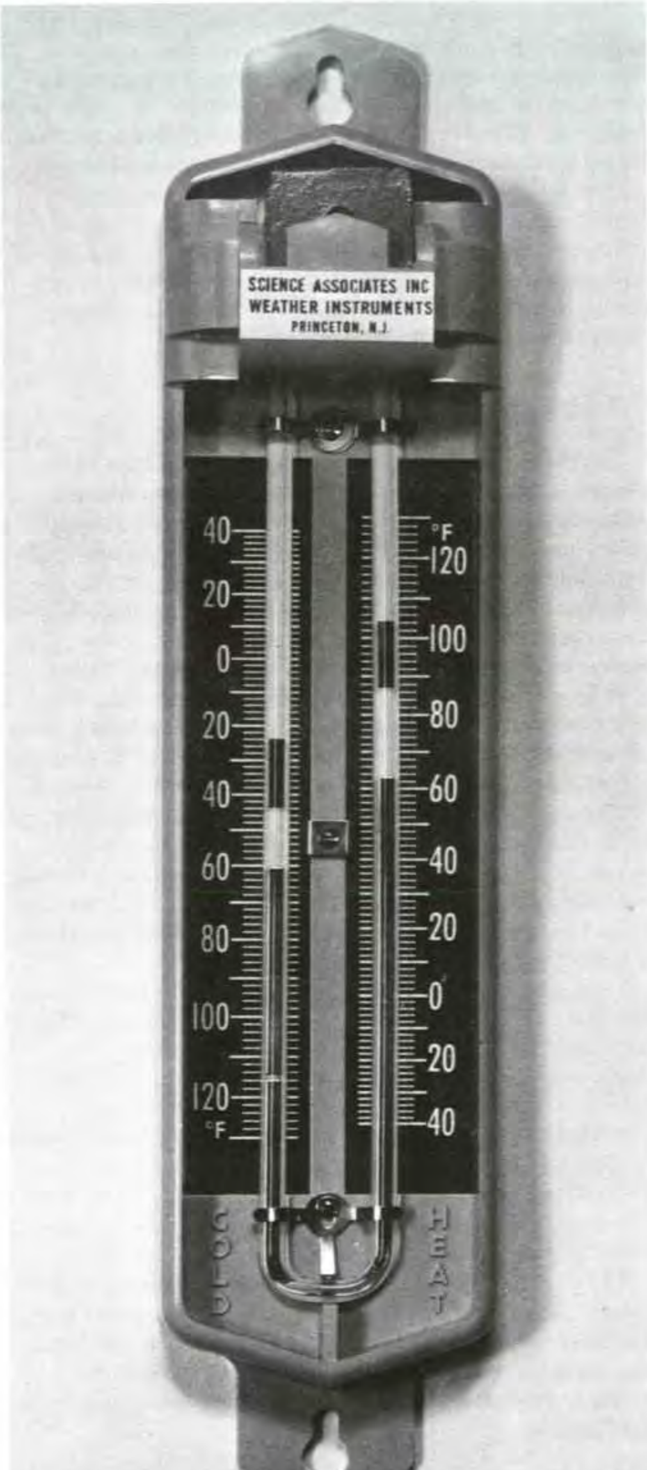


Figure 7.9—Six's type maximum-minimum thermometer. Maximum temperature is read on the right; minimum temperature, on the left. (Also see thermometer included in fig. 7.6.)

where this is possible, as in a Taylor model. For air temperature measurements, the thermometer should be exposed in adequate shade and free-moving air (preferably inside an instrument shelter).

Figure 7.10—Dial type maximum-minimum thermometer, employing a mercury-in-steel sensing element with direct-drive Bourdon spring. (Photo courtesy of Palmer Instruments, Inc.)

7.5 Other Thermometers

BOURDON AND BIMETAL THERMOMETERS

Because they are designed to change form with corresponding changes in temperature, Bourdon and bimetal thermometers are often referred to collectively as "deformation" thermometers. Deformation thermometers are used as temperature-sensing elements in dial thermometers and thermographs (and hygrothermographs), discussed later.

Dial Maximum-Minimum Thermometer—A good-quality dial maximum-minimum thermometer can provide a satisfactory substitute for the standard liquid-in-glass type. And it has the advantage of being less prone to breakage. The dial type usually has three separate pointers for the current, maximum, and minimum temperatures. The scales are graduated in 1- or 2-°F increments. The sensing element is typically a bimetal strip wound into a continuous multiple helix, which is contained in a sealed tube extending to the rear of the dial. A more expensive, improved design (fig. 7.10) has a mercury-actuated sensing bulb together with a direct-drive Bourdon spring. Dial thermometers can be mounted on the crossboard inside a cotton region instrument shelter.

ELECTRICAL/ELECTRONIC THERMOMETERS

Remote-Reading Digital Thermometer—Modern electrical thermometers suitable for use at basically manual type weather stations operate in conjunction with a microprocessor to produce a digital, remote readout. The sensor is usually a resistance thermometer, thermistor, thermocouple, or diode junction (Fritschen and Gay 1979; Sceicz 1975), enclosed within a metal probe that is typically exposed in a solar radiation shield. The probe can also be exposed in a standard cotton region shelter, particularly when the shelter is required for additional instruments. The readout unit and its enclosed electronics can be located in an office up to 100 ft or more distant.

The most accurate (and expensive) resistance thermometers utilize platinum wire, but those using nickel wire are quite satisfactory. The electrical resistance of the wire is proportional to ambient temperature. Thermistors, which are small beads of a semiconductor, also measure temperature through its effect on resistance. Thermocouples, in principle, consist of two junctions of dissimilar metals (usually copper and constantan) that generate a voltage proportional to the temperature difference between the junctions, one of which is a reference junction kept at a constant, known temperature (typically 32 °F, in an ice bath). Modern thermocouples utilize electrical compensation instead of the reference junction. Diode junctions measure temperature through its effect on voltage drop across a junction. Whatever type of sensor is used, the resulting electrical current or voltage that reaches the microprocessor is converted to a temperature in digital display.

Figure 7.11—Digital maximum-minimum thermometer, Computemp 5 model. (Photo courtesy of Rodco Products Company, Inc.)

Instruments such as the Rodco Computemp (fig. 7.11) and the more expensive Sensor Nimbus have a memory that stores the maximum and minimum temperatures, which can be retrieved by pressing a button (or membrane covering). (The Nimbus also stores hourly temperatures, for up to 35 days.) The standard Computemp automatically resets at midnight and thus will erase maximum temperatures that may occur after an afternoon observation time. As an option, the instrument can be ordered with a manual reset. Specified accuracy of these instruments is within 1 °F over most of the operating range; calibration can be adjusted where necessary.

7.6 Psychrometers

The psychrometer is the most widely used type of instrument for current relative humidity measurements at manual weather stations. Another type of humidity instrument is the hair hygrometer, which finds use in the hygrothermograph (section 7.7). The psychrometer consists basically of two matched, mercury-in-glass thermometers mounted side-by-side on a common frame. The bulb of one thermometer, termed the "wet bulb," is covered by a thin, closely woven cotton (muslin) wick, which is wetted with water when measurements are taken. The other thermometer, not covered, is termed the "dry bulb."

During an observation, evaporation from the wet bulb will cause its temperature to fall below that of the dry bulb. The amount of evaporational cooling, at a given temperature (and atmospheric pressure), varies inversely with the relative humidity of the air. Thus, the lower the relative humidity, the greater is the spread between the dry-bulb and wet-bulb temperatures.

From the dry- and wet-bulb readings, both relative humidity and dewpoint are easily determined from standard psychrometric tables. These tables assume that there is adequate ventilation of the wet bulb. For this reason, artificially ventilated (force-ventilated) psychrometers are generally more reliable than those that depend on natural air movement. The dry and wet bulb thermometers are normally read to the nearest 1 °F for fire-weather observations, but where desirable and possible they may be read to the nearest 0.5 or 0.1 °F.

The electric fan psychrometer, described below, is the standard instrument recommended at permanent manual fire-weather stations. Other psychrometers, employed at some stations or for temporary field use, are also described. Most are designed to cool the wet bulb by forced ventilation.

STANDARD ELECTRIC FAN PSYCHROMETER

An electric (battery-operated) fan psychrometer is shown in figure 7.12. When mounted inside a suitable instrument shelter, this psychrometer can provide consistently accurate dry- and wet-bulb measurements. Its primary advantage is that effective ventilation is easily obtained. Since tiresome hand-cranking or slinging is eliminated, observers are more likely to continue ventilation until the wet bulb cools to its lowest reading. The two thermometers are 9½ inches long and normally have a range from –20 to +120 °F, in 1-°F increments.

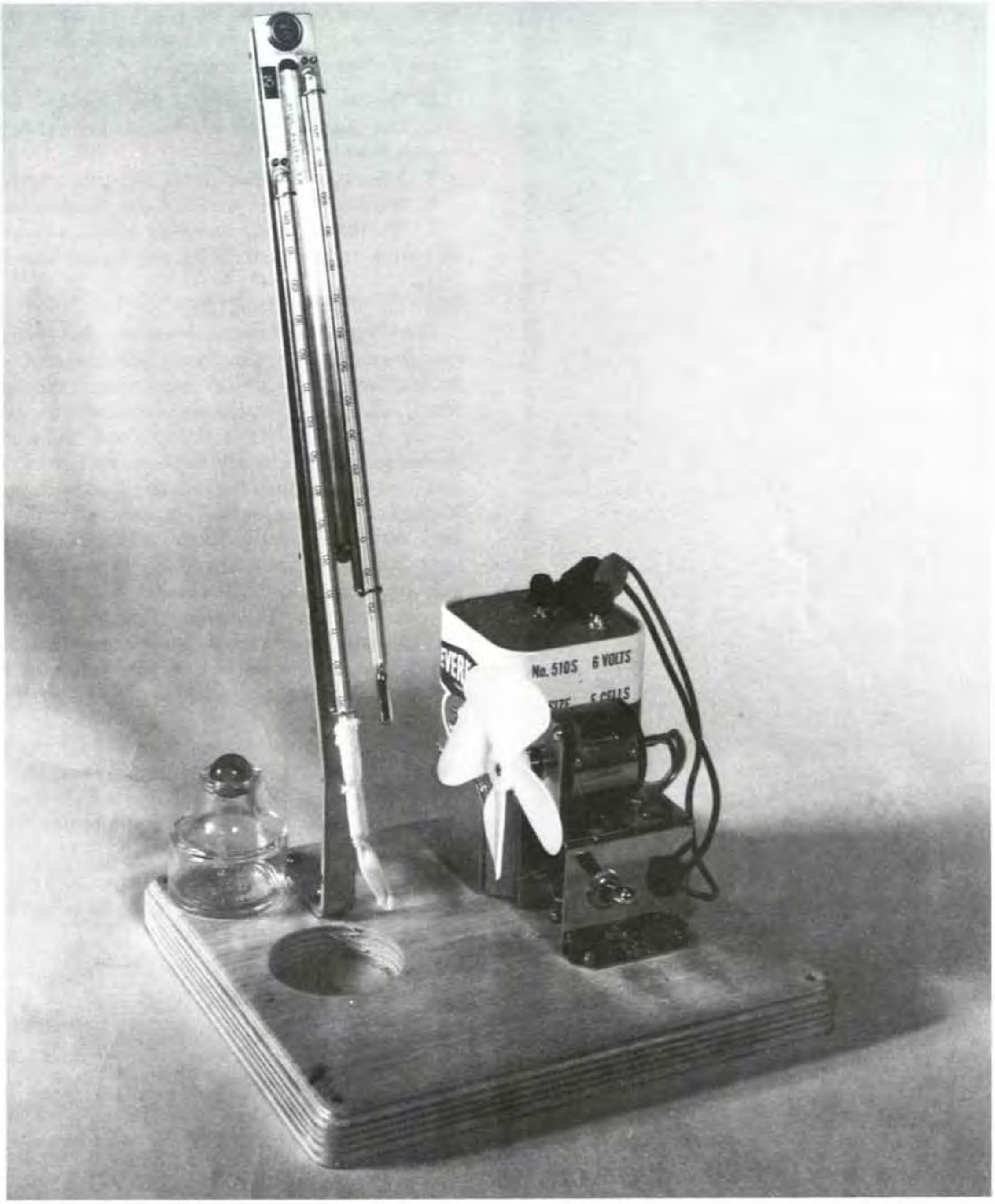


Figure 7.12—Electric fan psychrometer, Forest Service type; recommended for use at permanent manual type fire-weather stations.

HAND FAN PSYCHROMETER

Except for the method of fan operation, the hand fan psychrometer (fig. 7.13) is identical to the electric fan psychrometer. It, likewise, is designed for use in an instrument shelter. Ventilation of the thermometers is accomplished by rapidly cranking the fan. Cranking must continue without interruption until the lowest wet-bulb reading is obtained.

PORTABLE ELECTRIC FAN PSYCHROMETER

A recommended portable, battery-operated fan psychrometer is shown in figure 7.14. This type of instrument is particularly suited for spot measurements in tight spaces that do not provide clearance for a sling psychrometer (described below). Like the standard fan psychrometer, the thermometers can be read continuously during an observation. This instrument is usually supplied with a metal or plastic carrying case containing a

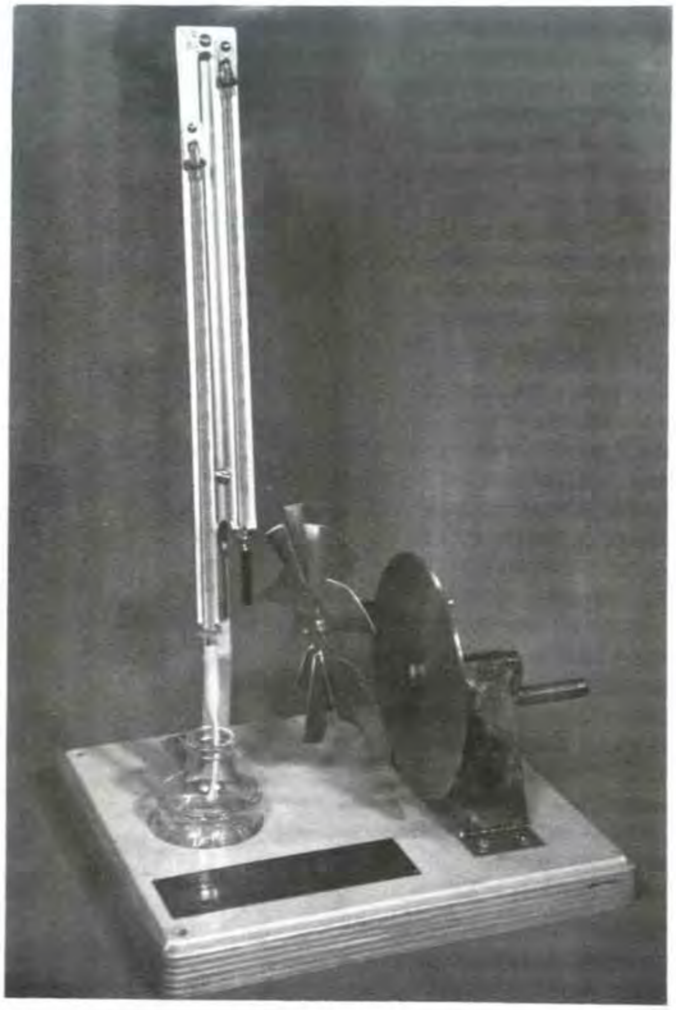


Figure 7.13—Hand fan psychrometer, Forest Service type.

foam-padded section for the psychrometer and a separate compartment for accessories and spare parts. Other features include the following:

1. The fan is powered by D-size flashlight batteries.
2. The thermometers are recessed and shock mounted with rubber fittings.
3. A built-in light facilitates nighttime readings.
4. A water bottle is stored in the psychrometer housing.
5. The thermometer assembly can be removed and used as a sling psychrometer if battery failure should occur.

SLING PSYCHROMETER

The sling psychrometer, recommended primarily for spot observations or temporary field stations, is ventilated by whirling it in a vertical circle around the observer's hand. Sling psychrometers are available in various models (fig. 7.15), differing in the size and precision of their thermometers and also in the construction of their handle and sling assembly. Most are supplied with protective storage or carrying cases. The standard model most often used at manual weather stations has $9^{1}/_{2}$-inch thermometers with 1-°F graduations from –20 to +120 °F; the thermometers are identical to those in the standard electric fan psychrometer. It has a comfortable, easily gripped wooden handle. Another standard model has 9-inch, somewhat more protected thermometers with 1.0-°F graduations over a range +20 to 120 °F, together with a smaller handle.

The easily portable pocket type usually has $5^{1}/_{2}$-inch thermometers with 1-°F graduations from +30 to 110 °F. This psychrometer is provided in the "belt weather kit" (USDA FS 1959); see section 8.4, under heading of Dwyer hand-held wind meter.

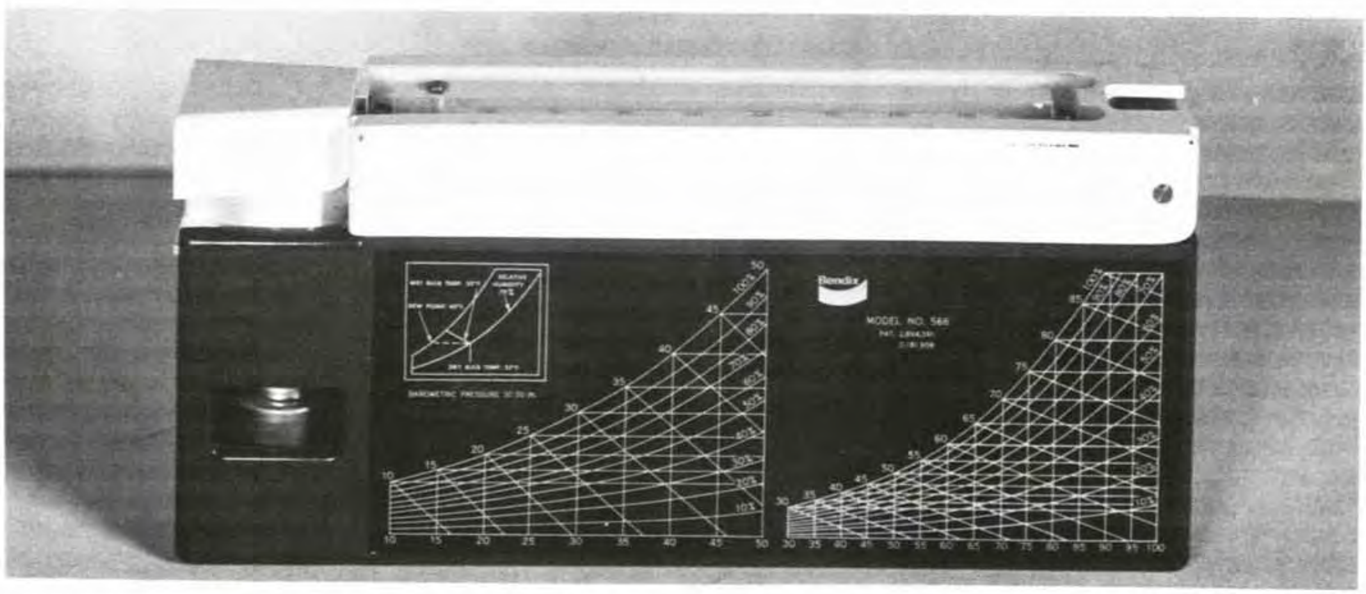


Figure 7.14—Bendix (Belfort) "Psychron" portable electric fan psychrometer. This instrument enables accurate measurement of relative humidity in both open and cramped field locations.

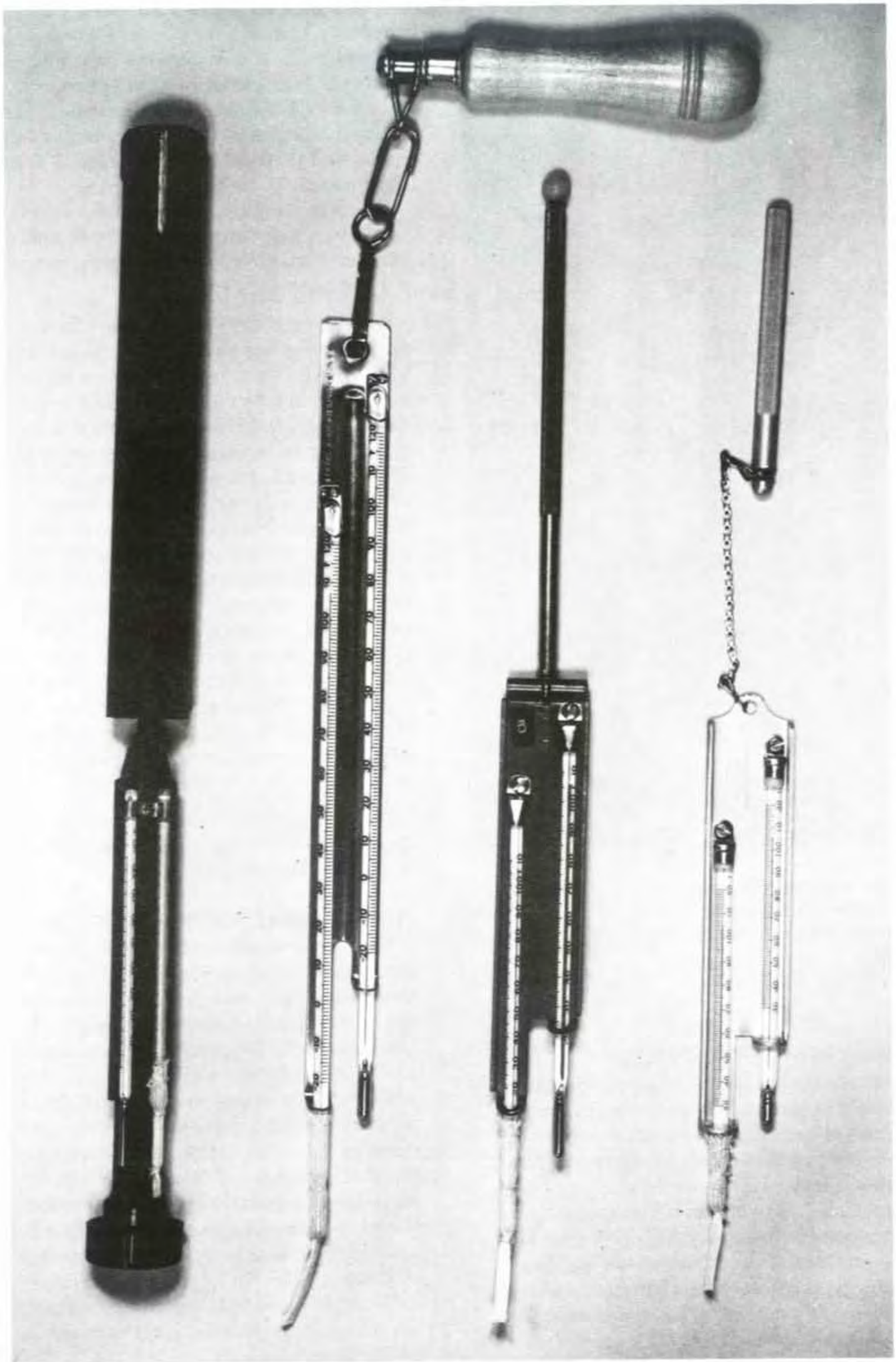


Figure 7.15—Sling psychrometers. The standard $9^1/_2$-inch psychrometer (second from left) is often used for calibration checks of other temperature and humidity instruments.

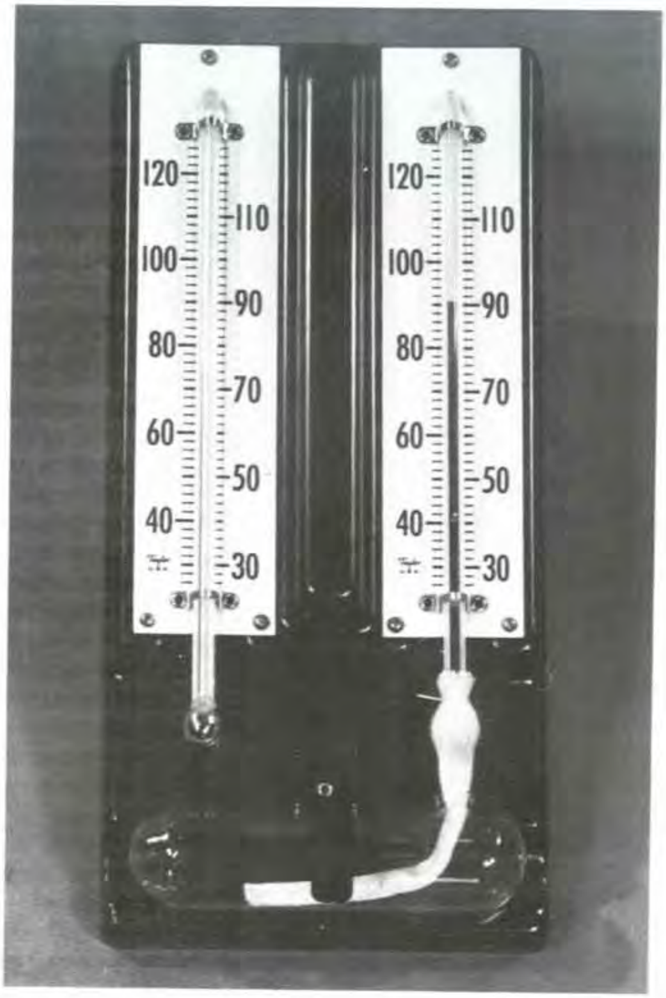


Figure 7.16—Mason hygrometer; a stationary, naturally ventilated type of psychrometer. Tail of wet bulb wick is continuously immersed in reservoir filled with water.

MASON (OR MASON'S) HYGROMETER

The Mason hygrometer (or Mason's hygrometer), actually a psychrometer, is designed for use in an instrument shelter. Unlike the preceding psychrometers, however, ventilation depends upon natural air movement or fanning with a piece of cardboard.

The instrument (fig. 7.16) consists of two easily readable mercury thermometers, usually with 2-°F graduations; these are marked on the thermometer backing rather than on the glass tubes. In the illustration, the thermometers have spherical bulbs, but thermometers with more desirable cylindrical bulbs are provided in some currently produced instruments such as those by Taylor. The wet bulb is covered by a long wick that extends into a water container, where it remains while the instrument is in service; the container must be refilled at regular intervals. The Mason hygrometer is not suited for use in below-freezing temperatures.

The model in figure 7.16 has a built-in plastic water reservoir, but another utilizes a glass jar placed beneath the wet bulb. A thin plastic oilcan with the spout cut short has been recommended as the most desirable water container (Williams 1964), because (1) the water level can be seen at a glance, (2) evaporation is reduced to a minimum, and (3) there is little chance of bursting during a light freeze.

Relative humidity and dewpoint values obtained with the Mason hygrometer generally do not have the accuracy of those from other psychrometers, because of the following reasons:

1. Thermometers with 2-°F graduations, marked on the backing, may not have a full-scale accuracy better than ±2 °F. Some thermometers will be better than others, as was found in a test of a recent Taylor unit; the uncovered thermometer bulbs were immersed in water at different temperatures. Over the range from +32 to 120 °F, error of the wet bulb thermometer varied between 0 and –0.7 °F, while the dry bulb error ranged from –1.6 to +1.6 °F. Agreement between the two thermometers was within ±1.0 °F from about +40 to 105 °F.
2. Thermometers with spherical bulbs are relatively sluggish in response to temperature changes. As previously noted, however, the thermometers in some current instruments have cylindrical bulbs.
3. Natural ventilation of the thermometers may be inadequate. This shortcoming becomes particularly important with the ambient wind less than 5 mi/h, when the affected wet bulb readings can give relative humidity values more than 5 percent too high.

During light wind conditions, to achieve greater accuracy, the thermometers should be fanned with a piece of cardboard (section 23.4).

MORTARBOARD PSYCHROMETER

The mortarboard psychrometer (fig. 7.17) was developed at the Southern Forest Fire Laboratory to provide a simple, accurate, and yet inexpensive means of obtaining dry- and wet-bulb temperature readings (Taylor 1963). Used mainly in Georgia, it consists of an upper and lower radiation shield, naturally ventilated thermometers, and supports. The radiation shields consist of three sheets of polished aluminum, supported horizontally. The two inner surfaces facing the thermometers are painted flat black to reduce possible internal reflections. The thermometers are mounted in a fixed horizontal position. Water is continuously supplied to the wet bulb by a wick running from a capped plastic cup mounted on the lower radiation shield. In light winds, the thermometers are ordinarily fanned with a piece of cardboard (as advised for the Mason hygrometer). Alternatively, an electric fan can be installed.

Figure 7.17—The mortarboard psychrometer, with self-contained aluminum radiation shield; used in southeastern area of United States.

Figure 7.18—Hygrothermograph, Bendix model, as normally exposed with case closed. The upper pen records temperature; the lower pen, relative humidity. Calibration adjustment screws are at right.

7.7 Hygrothermographs

The hygrothermograph (fig. 7.18) provides a continuous chart record of both temperature and relative humidity. Several models are in common use at fire-weather and other stations. (Separate recorders for temperature and relative humidity—thermographs and hygrographs, respectively—are also available but are less convenient where both measurements are required.) Although details of design vary according to manufacturer, general operating principles are similar. All hygrothermographs consist of four major working parts: (1) temperature element, (2) relative humidity element, (3) pen arm assemblies, and (4) chart drive mechanism.

The chart drive mechanism, which turns a cylinder (a "drum") holding the chart, most commonly employs a spring-wound or battery-operated clock movement. Newer mechanisms are now available (in Belfort instruments) that employ a stepper motor governed by a battery-operated quartz crystal oscillator. The clock is either located inside the drum (turning with it) or fixed to the base of the instrument. In the latter design, the drum revolves around the clock; the motor-type chart drive also uses this arrangement.

The pen arm assemblies are the link between the chart and the temperature and humidity elements. The pens are of two main types: (1) the barrel-type (with the two horizontal nibs extending from a small, open-sided cylindrical reservoir), furnished with Belfort and formerly manufactured Bendix-Friez hygrothermographs, and (2) the open-top V-point type, found on WeatherMeasure hygrothermographs. Cartridge-type pens are also available.

THE TEMPERATURE ELEMENT

Hygrothermographs normally used at weather stations employ a deformation-type sensing element (thermometer) for measuring temperature. This sensing element consists of either a curved Bourdon tube or a curved or coiled bimetal strip.

The Bourdon tube, slightly elliptical in cross section, is filled to capacity with an organic liquid. One end of the tube is fixed to the hygrothermograph base and the other to the temperature pen arm linkage. As the temperature of the surrounding air varies, the liquid expands or contracts and, accordingly, causes changes in the Bourdon tube curvature. These changes are transmitted to the chart through the pen arm linkage (fig. 7.19).

The bimetal strip is constructed by a welding of two different metals that have differing rates of expansion (or contraction) in response to increasing (or decreasing) temperature. As the temperature changes, this differential expansion or contraction causes the strip to change in curvature. These changes are, again, transmitted to the chart through the pen arm linkage (fig. 7.20).

THE RELATIVE HUMIDITY ELEMENT

Most hygrothermographs employ a human-hair element to measure relative humidity. This element is usually in the form of either a "banjo spread" (fig. 7.19) or a "bundle" of hairs (fig. 7.20). Whatever the arrangement may be, high humidity causes a lengthening of the hairs while low humidity causes a shortening. These hair responses are transmitted to the chart through the pen arm linkage.

Hair elements indicate the relative humidity with respect to water even at temperatures below freezing (World Meteorological Organization 1983) (see section 7.2).

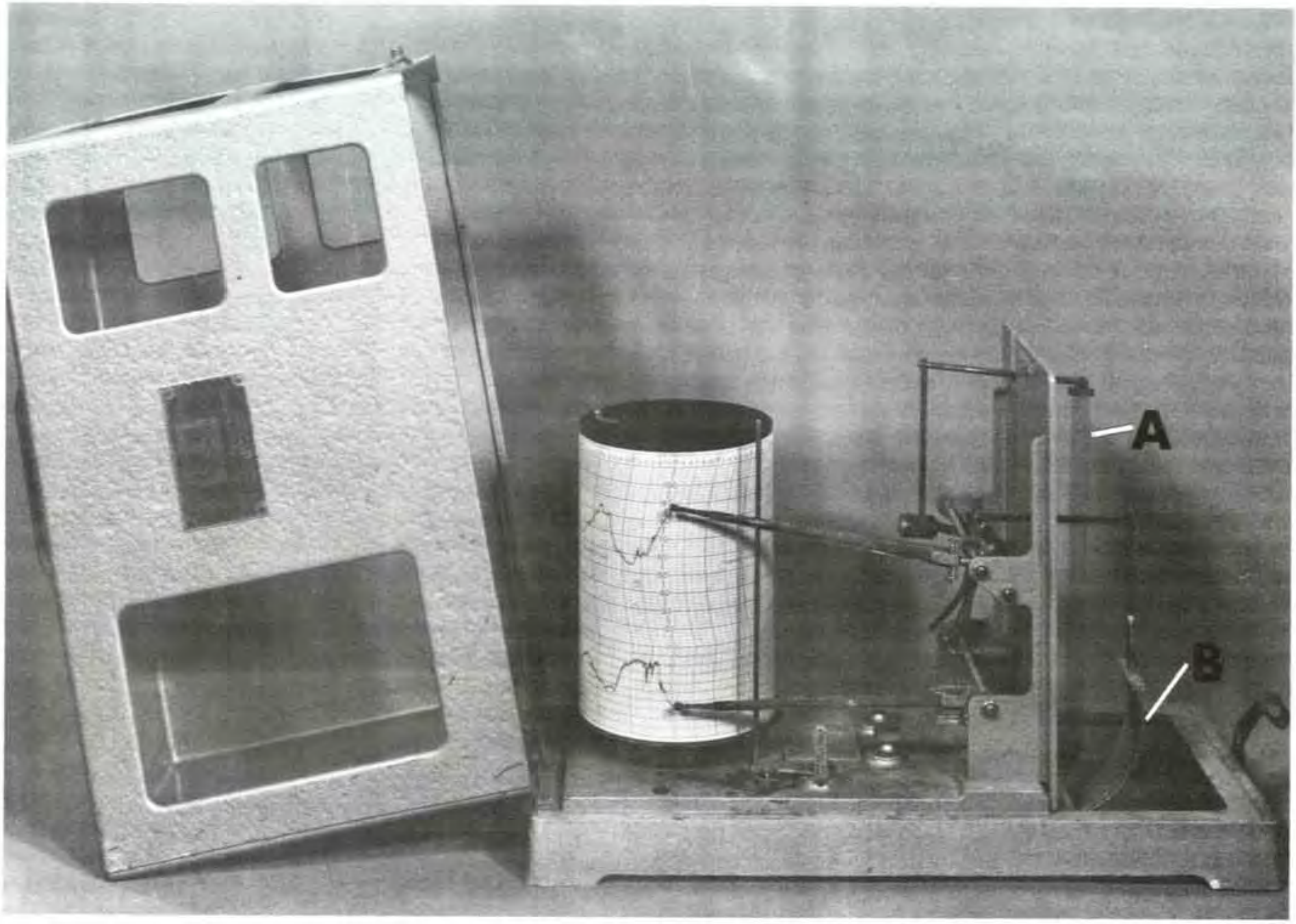


Figure 7.19—Open view of hygrothermograph, Belfort model, employing (A) banjo-spread hair element for relative humidity and (B) Bourdon tube for temperature. Calibration adjustment screws are on the base plate.

THE CHART RECORD

The temperature pen traces a record on the upper portion of the chart, while the humidity pen traces on the lower portion (fig. 7.21). Several temperature ranges are available. For Belfort and Bendix-Friez hygrothermographs (fig. 7.19), charts with the Fahrenheit scale have ranges from +10 to 110 °F for ordinary summer use; from –30 to +70 °F for winter use. WeatherMeasure (Weathertronics) instruments (fig. 7.20) use charts with a slightly larger range (from +10 to 120 °F for ordinary summer use). The relative humidity scales of all of these models cover the full range from 0 to 100 percent.

Daily, weekly, and monthly charts are available. Whatever chart is used, its time scale must be compatible with the gear ratio or drum rotation of the instrument. The gear ratio can easily be changed, as desired, by changing the gears on both the drum and base (or base-mounted clock). Weekly charts are most often used at fire-weather stations. To obtain a monthly record, instruments equipped with a spring-wound clock will require a special chart drive mechanism, in addition to the required set of gears. The long-running battery-operated chart drives have an advantage here; they can be used for either weekly or monthly charts.

Hygrothermograph charts have either square or tapered ends. Only the tapered-end charts can be used on drums that have a vertical slot in the cylinder wall. The ends of the chart are inserted into this slot and held in place by a metal retainer that presses the ends against the inside of the drum.

Both square- and tapered-end charts can be used on nonslotted drums, which are the drums usually supplied. Both types of chart are retained by a metal clip that presses the chart ends against the drum surface. The square-end charts are most commonly used, but the tapered-end charts may be advantageous, having a fold-over tab that covers the retaining clip. This feature prevents loss of data (at the clip) when the drum is allowed to go beyond one complete revolution before a chart is changed. The pen traces will read slightly high, however, when the pens ride over the resulting bulge in the chart near the covered clip.

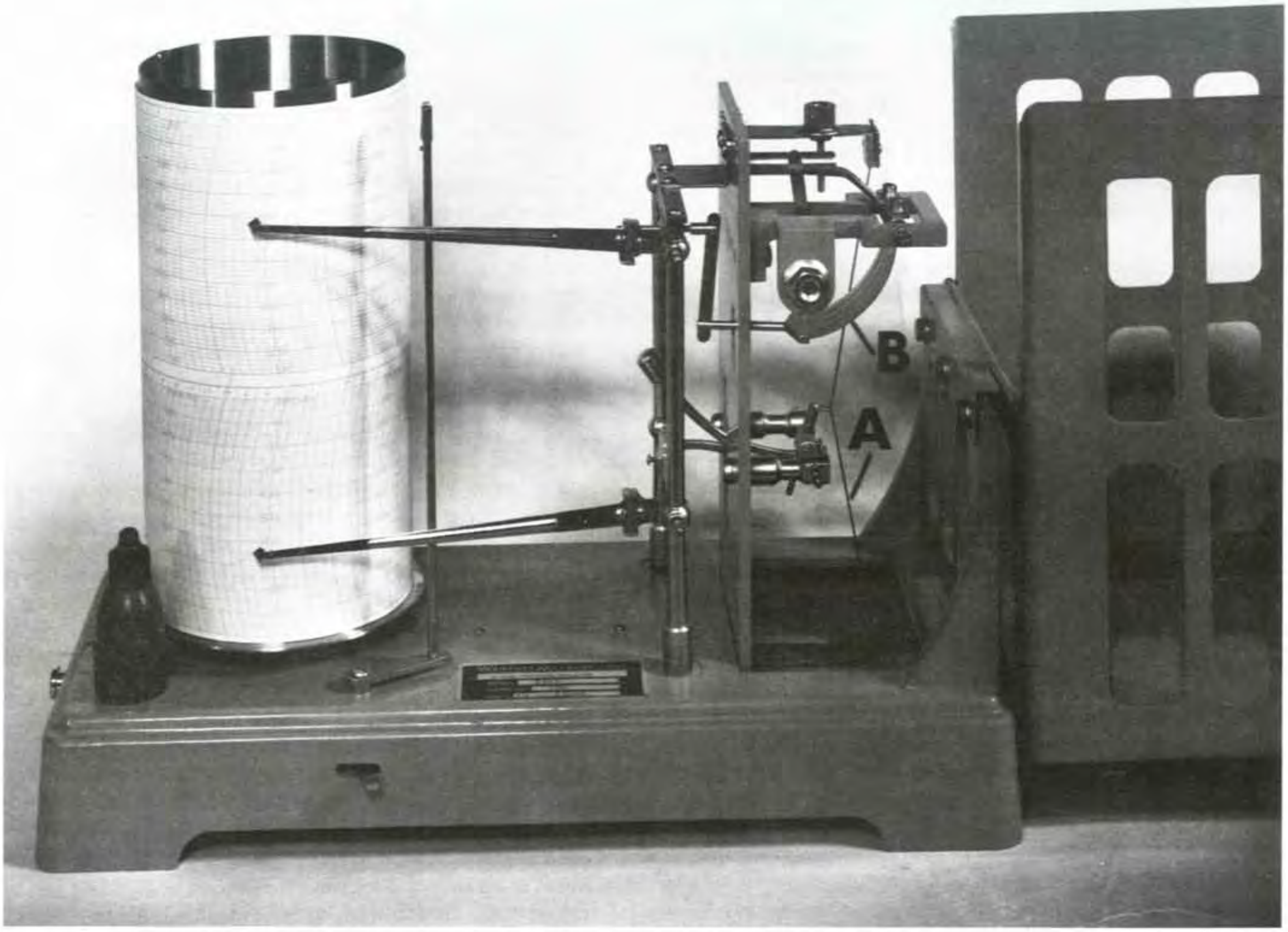


Figure 7.20—Hygrothermograph, WeatherMeasure model, employing (A) hair bundle humidity element and (B) curved bimetal strip.

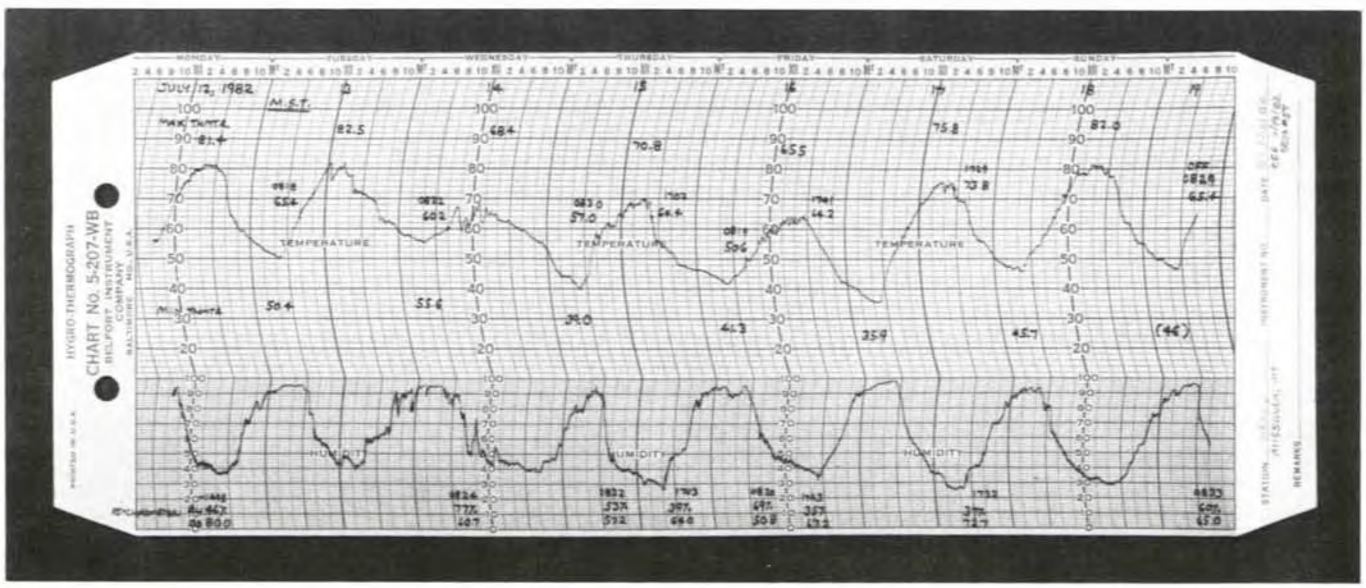


Figure 7.21—Weekly chart record from a hygrothermograph. Temperature trace is on upper portion of chart; relative humidity trace, on lower portion.

RELIABILITY

The reliability of hygrothermograph data depends greatly on the instrument's calibration and maintenance. With careful calibration and proper maintenance, an acceptable level of accuracy (within plus or minus 3 to 5 percent relative humidity and 1 °F temperature) can generally be maintained. This is particularly true for temperature data. Relative humidity readings tend to be less reliable because of calibration difficulties and certain inherent characteristics of human hair.

A test by Meeks (1968) with carefully calibrated hygrothermographs showed that characteristic "hysteresis" errors occurred. The errors varied, depending on whether the relative humidity was increasing or decreasing. The recorded values were typically too high at low relative humidities and too low at higher relative humidities.

Often the greatest loss in reliability of data occurs with calibration shifts (or "zero shifts") accompanying marked weather changes. Shifts of 10 to 15 pecent relative humidity have been observed (Hayes 1942; MacHattie 1958). Persistent dry weather causes an upward shift in calibration. Subsequent storms and saturation then bring a downward shift to near the original calibration position. If the humidity pen has been reset during the dry weather, the trace will later read too low.

CHAPTER 8. WIND

Wind is air in motion. This motion, or velocity, has two components: windspeed and wind direction.

Windspeed refers to the rate at which air passes a given point. Fire-weather measurements of windspeed are expressed in statute miles per hour (mi/h). This differs from the measurements at airport stations, which use knots (nautical miles per hour); one knot equals 1.15 statute mi/h.

Wind direction refers to the direction **from** which the air is moving. This is recorded, often in coded form, as a compass point (N, NE, E, SE, etc.); or, as at airport stations, in azimuth degrees from true north (0° to 360°).

8.1 Windspeed Instruments

Measurements of windspeed are most often obtained from cup anemometers. At standard weather stations in this country, the anemometers are exposed at a height of 20 ft above open, level ground (fig. 8.1). Particularly at fire-weather stations, it is often necessary to adjust this height to compensate for the height of ground cover, surface irregularities, and nearby obstructions (section 17.1).

Cup anemometers are calibrated to rotate at a rate proportional to the actual windspeed. Most commonly, this rotation is transferred by the main shaft to either a contacting mechanism or a generator, depending on the type of anemometer. The windspeed reading is, thus, provided by either the number of contacts made or the voltage generated. The readout device, wired to the anemometer, can be located either at the weather station or in a nearby office.

Contacting anemometers are the most widely used type at fire-weather stations, enabling easy calculation of a standard average windspeed. Generator anemometers are commonly used where instantaneous reading or continuous chart recording of windspeed is desired. Generator models that electronically accumulate the passage of wind have recently been developed and also enable an easy determination of average windspeed. Such models may find increased use, as some of the contacting models are no longer available (section 6.1).

8.2 Contacting Anemometers; Readout Devices

Contacting anemometers consist of four major parts: (1) a three- or four-cup rotor assembly, (2) a main vertical shaft or spindle, (3) a gear mechanism, and (4) an electrical contact. In addition, some contain a built-in dial or counter that records and accumulates total wind movement between settings.

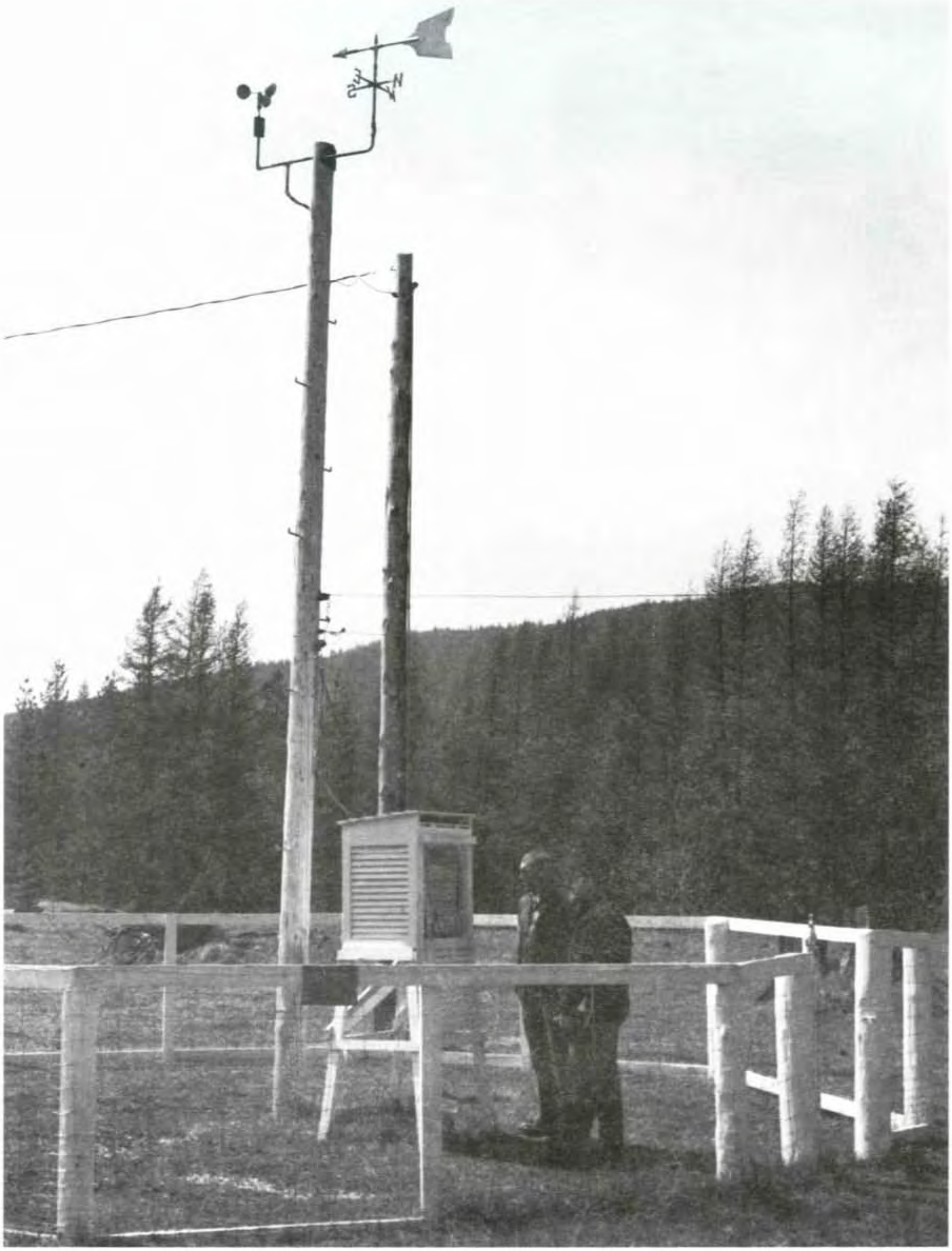


Figure 8.1—Anemometer and wind vane exposed at standard 20-ft height at a fire-weather station.

Figure 8.2—Small Airways anemometer with 1/60-mile contacts, used at many fire-weather stations.

ANEMOMETERS EQUIPPED WITH 1/60-MILE CONTACTS

The most widely used contacting anemometers are geared to close a contact after each 1/60-mile of wind has passed the cups (fig. 8.2). The number of contacts per minute, therefore, represents the windspeed in miles per hour.

Readout is obtained from a buzzer, flasher, or, more commonly, a mechanical counter. These devices are wired to the binding posts located on the anemometer housing. Each buzz, flash, or advance of the counter indicates a closure of the anemometer contact. Thus, the count per minute can be read directly as windspeed in miles per hour.

MECHANICAL COUNTERS

The mechanical counter is recommended over the buzzer or flasher because the chance of miscounting is greatly reduced, particularly when windspeed is averaged over a number of minutes. Mechanical counters are of three general types: nonreset, reset (fig. 8.3), and reset with 10-minute timer (fig. 8.4). The reset type can be zeroed at the beginning of each wind observation and, thus, can be read directly at the end of the prescribed averaging period. The reset type equipped with a timer further simplifies the observer's task because it records for only the period of time desired.

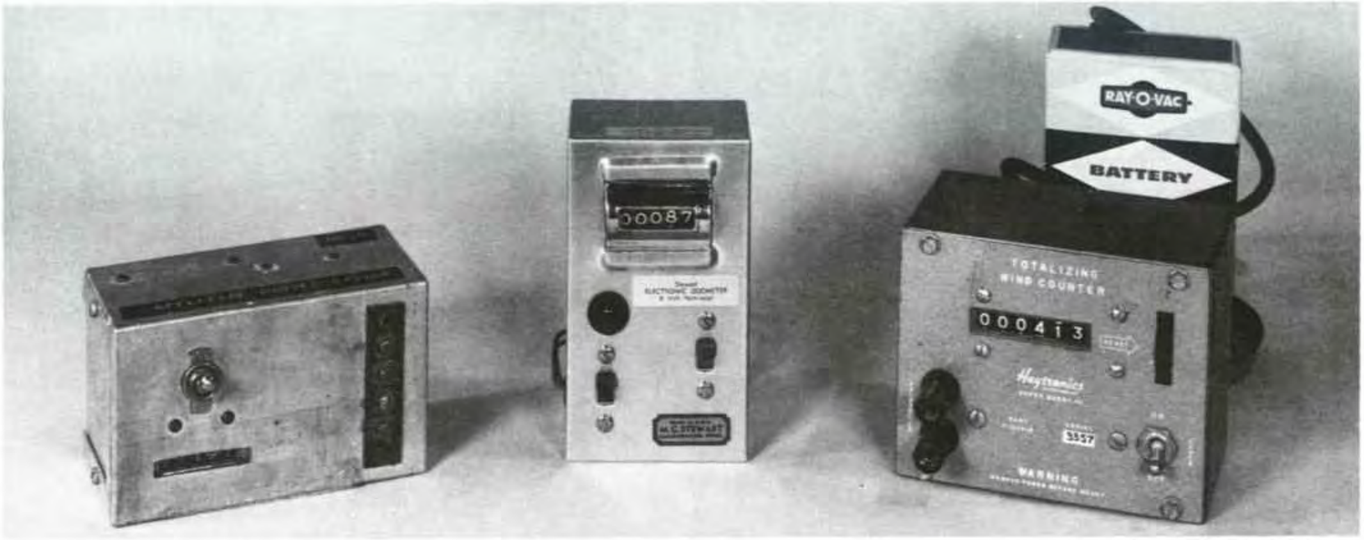


Figure 8.3—Mechanical counters in use at fire-weather stations: left and center, nonreset types; right, reset type.

Figure 8.4—Reset type mechanical counter with timer; simplifies determination of 10-minute average windspeed.

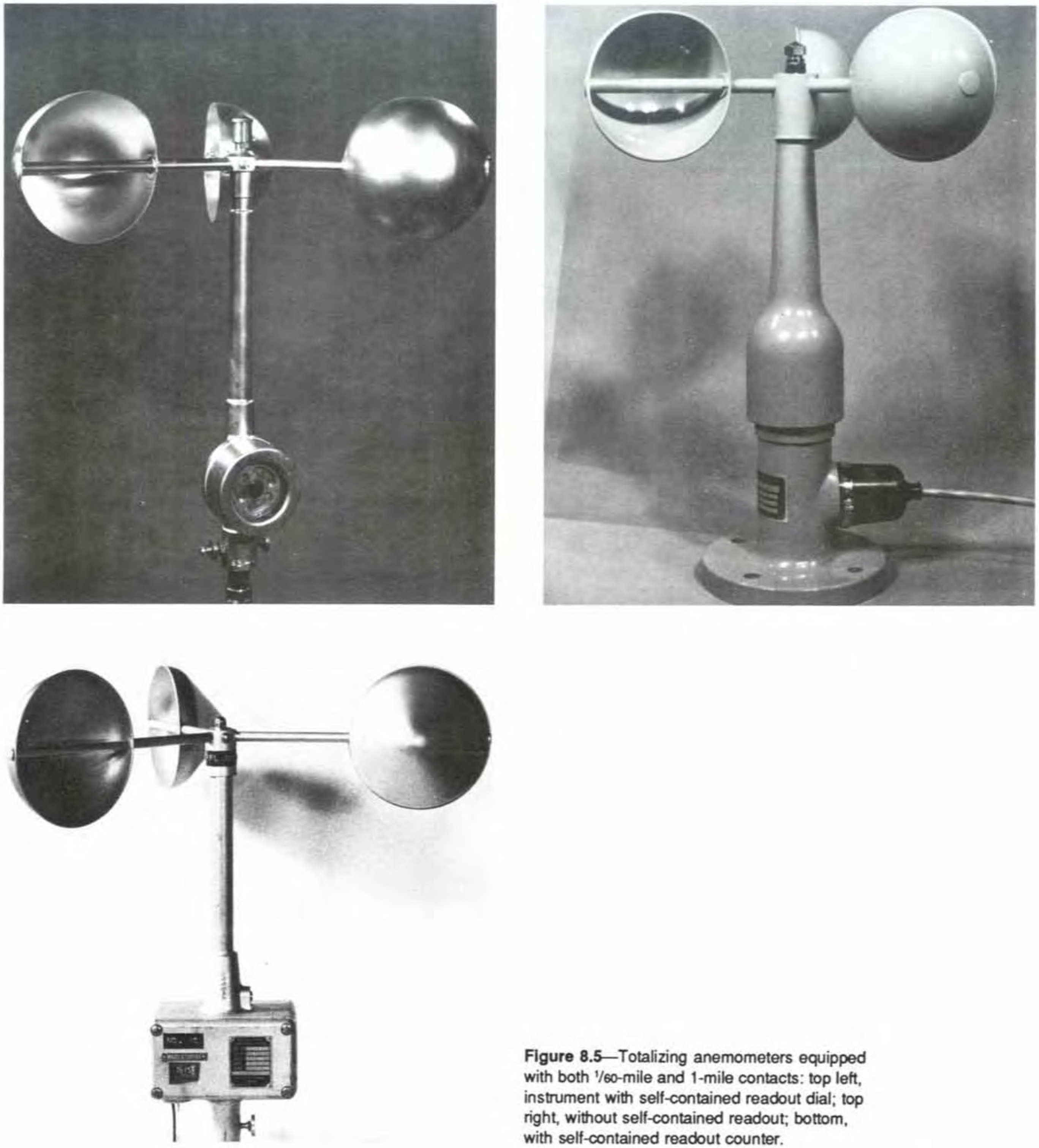


Figure 8.5—Totalizing anemometers equipped with both 1/60-mile and 1-mile contacts: top left, instrument with self-contained readout dial; top right, without self-contained readout; bottom, with self-contained readout counter.

ANEMOMETERS EQUIPPED WITH 1-MILE CONTACTS

Some anemometers have 1-mile contacts instead of, or in addition to, 1/60-mile contacts (fig. 8.5). Operation is similar to that for the 1/60-mile contacting anemometers, except that one contact is made for each 1 mile of wind passing the cups. The number of contacts per hour, therefore, gives the windspeed in miles per hour. Special totalizing counters are available for readout from these anemometers.

Usually, the ninth and tenth pins of the contact wheel are bridged to give a longer contact for each 10 miles of wind passage. One-mile contacts are often used to obtain daily or longer chart records of wind movement, in 1-mile steps accentuated every 10 miles.

THE HYGROTHERMOAEROGRAPH

Anemometers with 1-mile contacts can be used in conjunction with a hygrothermoaerograph (HTAG) to obtain a chart record of wind movement. The HTAG (fig. 8.6) is simply a conventional hygrothermograph that has been modified by the addition of a third pen arm to record each mile of wind movement (Fischer and others 1969). Tick-marks produced by each contact closure are recorded along the top portion of the chart, above the temperature trace. See appendix 5 for construction and wiring details.

ANEMOMETERS WITH SELF-CONTAINED READOUT

Some anemometers are constructed with a self-contained readout device that is driven directly, through gears, by the anemometer spindle (fig. 8.5). The readout device, indicating total wind movement (statute miles) is a four- or five-digit counter in present models; a former model uses dials. Known as totalizing anemometers, these instruments are more commonly used for obtaining 24-hour average windspeed than for 10-minute average speeds. They are standard accessory equipment, mounted near pan level, at evaporation stations.

Reading of the four- or five-digit counter is straightforward. The old dial readout device consists of two thin, concentric wheels that mesh with the same pinion gear. The inner dial is graduated in tens and hundreds of miles. The outer dial is graduated in miles and tenths of a mile (fig. 8.7).

Because the counter or dial operates accumulatively (until it reaches its limit and begins another cycle at zero), the observer must take a reading at the beginning and end of any period for which data are required. To calculate the average windspeed, the change in counter or dial reading is divided by the elapsed time (in equivalent hours).

8.3 Generator Anemometers

Generator anemometers consist of a rotor or cup assembly, a vertical shaft, a generator, and usually a windspeed-indicating device showing instantaneous values. The shaft connects the cups to a small permanent magnet generator. As the cups rotate, the voltage is generated in proportion to the windspeed. The windspeed indication is obtained from a connected voltmeter calibrated in miles per hour or other units (figs. 8.8 and 8.9). Also available are devices that electronically accumulate the total wind movement during an averaging period.

It is somewhat difficult to obtain average windspeed values from generator anemometers that give only instantaneous dial readings. Approximations may be made by observing a series of these readings, at fixed intervals

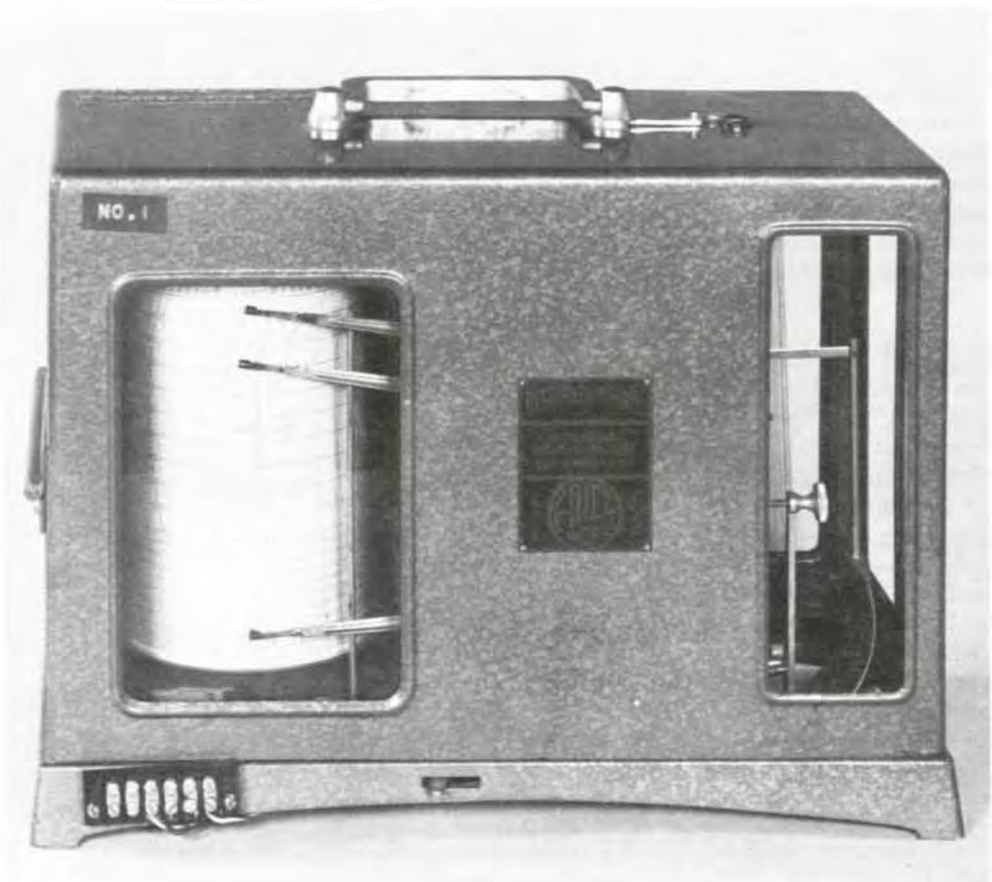


Figure 8.6—A hygrothermoaerograph. Uppermost pen arm has been installed to record each mile of wind movement.

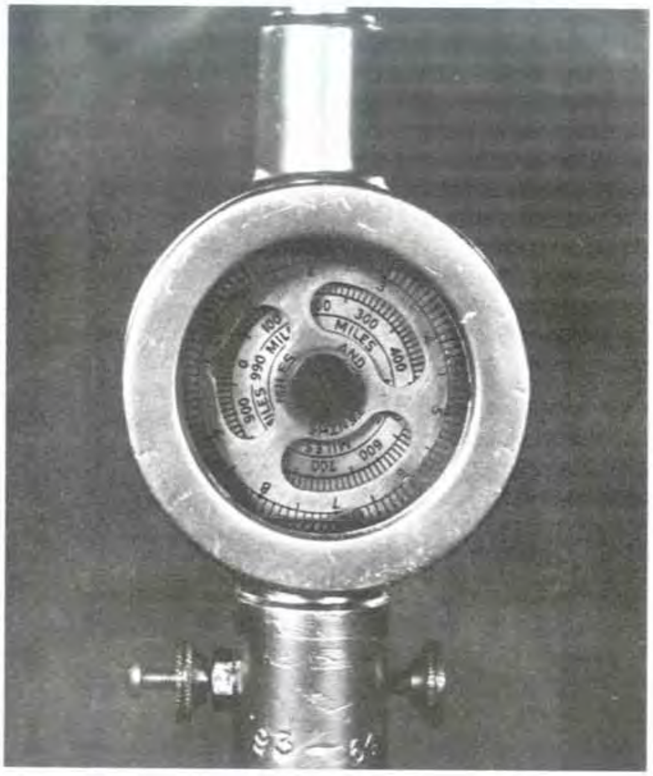


Figure 8.7—Closeup of self-contained readout dial, which accumulates total wind movement past anemometer cups.

Figure 8.8—Generator anemometer with remote readout dial is particularly useful for instantaneous windspeed measurements.

over a number of minutes, and taking an arithmetic average. Averages with greater accuracy can be obtained from traces produced on a chart recorder.

Generator anemometers are available in a design that uses a propeller, rather than cups, as the wind sensor—part of a relatively expensive system that also indicates wind direction. These are described further in Part 3 (section 44.2).

ACCUMULATING GENERATOR ANEMOMETERS

These anemometers, which electronically indicate the accumulated wind movement, have found increasing use in the northeastern United States—particularly the Natural Power Anemometer (fig. 8.10). The anemometer head sends windspeed information as a variable-frequency AC signal to the "accumulator" (a calculating and readout unit), which can be located several thousand feet away. The signal is translated into distance units equaling 1/60 mile. Upon command (in Natural Power models A21 and A22) the accumulator displays, in LED digital readout, the accumulated number of 1/60-mile units since the previous setting. Dividing that number by the elapsed number of minutes yields the average windspeed (mi/h). A newer model (A19-S6A) automatically computes a 10-minute average windspeed.

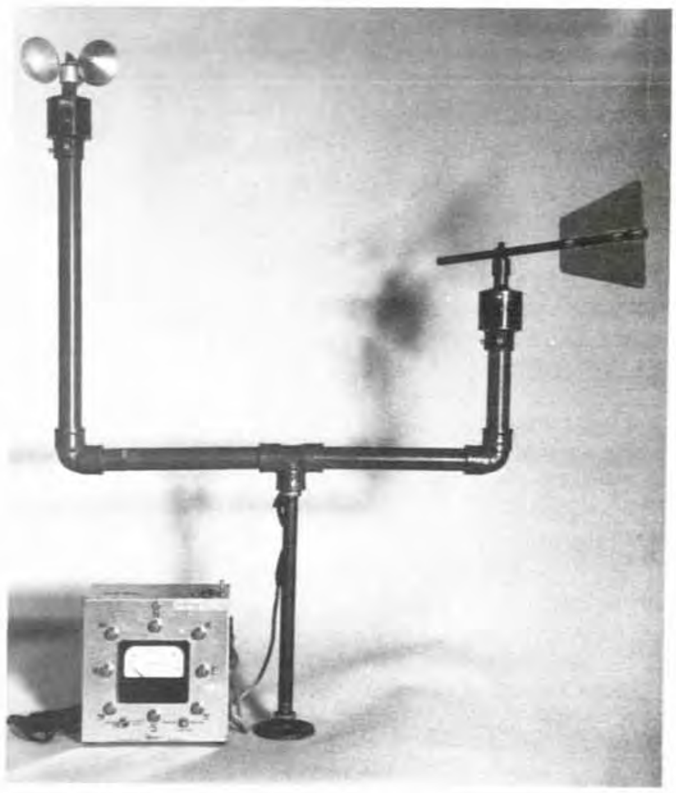


Figure 8.9—Windspeed system, with wind vane and generator anemometer. Remote readout device shows windspeed (dial) and wind direction (lights).

Figure 8.10—Accumulating-type generator anemometer, Natural Power model A19-S6A; digital readout gives 10-minute average windspeed. (Photo courtesy of Controlex, Inc.)

8.4 Hand-Held Anemometers

Hand-held anemometers indicate windspeed directly on the instrument body, typically by means of a pointer on a dial or by a digital readout (figs. 8.11 and 8.12). Some of these are three-cup generator-type anemometers, but others operate on different principles. Anemometers with a rotating dial (and fixed pointer) employ a magnet on the rotating shaft, which sets up eddy currents that rotate a spring-loaded drum assembly in proportion to the windspeed. Lower priced generator anemometers may have somewhat high threshold windspeeds (the speed required to start the cups rotating)—as high as 5 mi/h.

Both indoor and outdoor accumulator units are available. The outdoor unit, housed in a weatherproof enclosure, operates on alkaline or lithium "C"-size batteries; the indoor unit has an internal nickel-cadmium battery for backup in cases of AC power failure.

A similar device is the NRG Systems Model 2800-10M wind odometer, which displays the 10-minute average windspeed in LCD readout. The odometer interfaces with a Maximum #40 generator anemometer and counts the number of revolutions of the cups for 10 minutes. Then it displays the average speed for 10 minutes, after which the process begins again. The unit is powered by an internal, 10-year lithium battery.

Figure 8.11—Hand-held anemometer, with scale on rotating drum. (Photo courtesy of Qualimetrics, Inc.)

Figure 8.12—Hand-held anemometer with digital readout showing 2-minute or 5-minute average windspeed; Sims model DIC-3. (Photo courtesy of Simerl Instruments.)

A hand-held instrument from Sierra-Misco, Model 1039, has both a wind vane and anemometer (with dial readout); specified threshold speed of the generator anemometer is only 1 mi/h. The digital-reading "Turbo-Meter" (fig. 8.13) manufactured by Davis employs turbine blades suspended on jewel bearings and protected by the case cowling; in operation, the blades must correctly face into the wind.

To obtain average windspeed values, averaging of instantaneous readings is generally required. A digital model from Sims, however, displays the instantaneous, peak, and 2- or 5-minute average windspeeds. This instrument, Model DIC-3, employs a solid-state "Hall Effect" device.

Windspeeds obtained with hand-held instruments, at 5 to 6 ft above ground, will generally be lower than those at the standard 20-ft anemometer height, but they may be more representative for certain needs. These include actual windspeeds near flame height in ground fires.

DWYER HAND-HELD WIND METER

The Dwyer wind meter (fig. 8.14), based on pressure effects, is an inexpensive, highly portable means of obtaining approximate windspeed at observer's level. Again, averaging of instantaneous readings is necessary. The meter's slightly tapered plastic shell encloses a tube containing a small, white pith ball. Wind entering two small holes ("dynamic" ports) near the base of the shell causes a pressure difference between these ports and a "static" port at the top of the tube. This generates an air flow up the tube, varying with the windspeed, and the freely moving white ball rises and falls accordingly. Its position is read on an adjacent windspeed scale.

The meter indicates windspeeds up to 10 mi/h on its low scale and up to 60 mi/h on its high scale. When properly maintained and held (facing the wind), the meter is accurate within 1 or 2 mi/h at low speeds, but errors may exceed 5 mi/h at higher speeds (Snow and others 1989).

Belt Weather Kit—The Dwyer wind meter is a component of the belt weather kit (fig. 8.15), which also contains a small sling psychrometer (section 7.6) and accessory items fitted into a canvas carrying case. This kit is the simplest, least expensive, and most widely used portable "station" unit.

Figure 8.13—Hand-held anemometer with digital readout, employing turbine blades. (Photo courtesy of Davis Instruments.)

Figure 8.14—Dwyer hand-held wind meter, based on pressure effects; windspeed indicated by white ball rising and falling within tube.

8.5 Wind Direction Indicators

Wind direction can be obtained quite simply by facing into the wind or by observing the movement of smoke columns, blowing dust, leaves, and other vegetation. Flags make good wind direction indicators; colored plastic flagging or a wind sock fastened to an anemometer pole is also satisfactory. As closely as possible, the observer should be directly underneath the indicator; this will minimize errors due to perspective. Accuracy with any of these methods depends on correct knowledge of the cardinal directions or use of a compass. It may be helpful to establish a true-north reference at each station.

WIND VANES

The wind vane usually consists of an arrow assembly mounted on a vertical shaft or spindle that rotates freely on bearings (figs. 8.1 and 8.9). The arrowhead, pointing into the wind, is weighted sufficiently to counterbalance the larger tail section of the arrow. The tail, offering the greater air resistence, turns to the leeward. In another, generally higher priced design, a propeller serves as both anemometer and wind direction pointer.

Wind vanes at some manual weather stations are read directly through visual observation of the arrow. Other vanes transmit their indications by electrical contacts or resistance circuits to a readout device. The readout may employ a series of eight lamps (fig. 8.16), each representing a point of the compass (N, NE, E, SE, etc.), or a dial indicator (figs. 8.8 and 8.9). More-expensive chart recorders can also be used, for a continuous record of wind direction. The readout devices are usually part of a system that also shows windspeed.

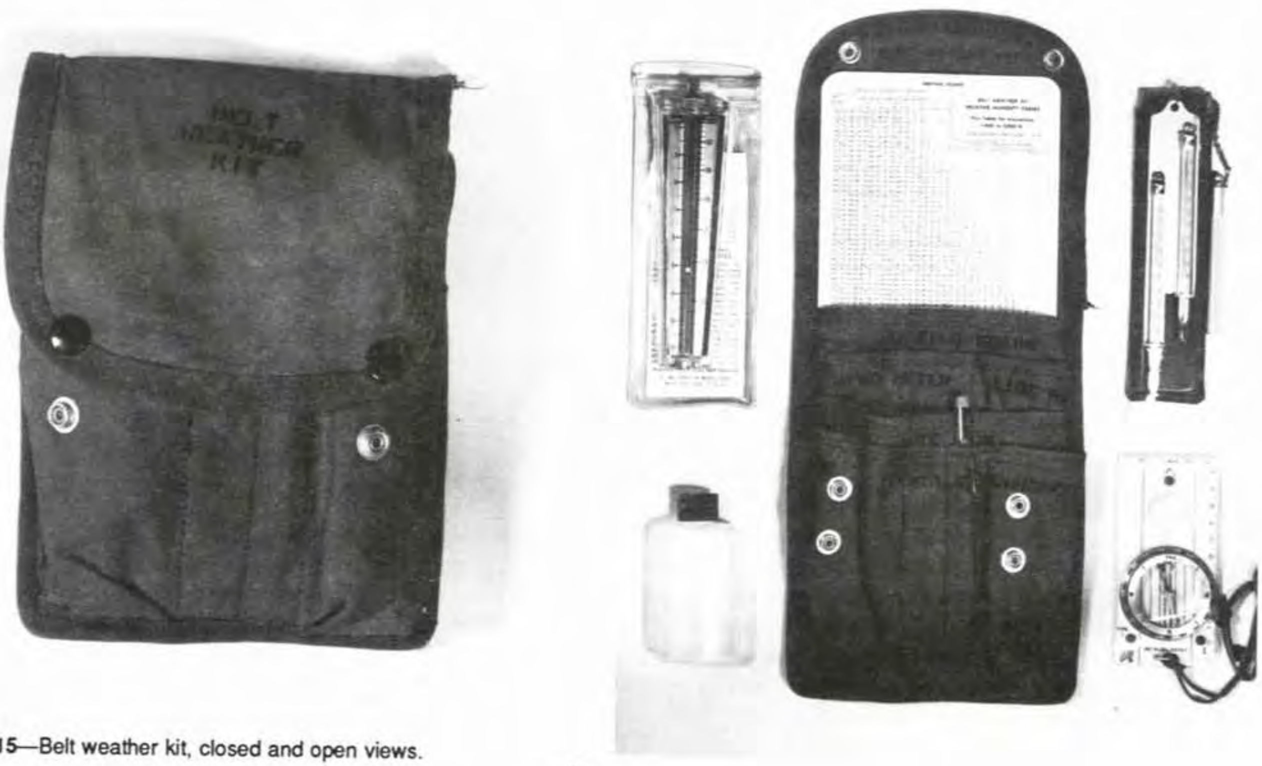


Figure 8.15—Belt weather kit, closed and open views.

Figure 8.16—Wind direction indicator; direction shown by lighted lamps.

CHAPTER 9. PRECIPITATION

Precipitation is the amount of water falling upon the earth as rain or in frozen forms such as snow, sleet, and hail. It is expressed as the depth of water that would cover a flat surface and is measured with a suitable receptacle termed a gauge. Measurement units, for fire-weather and standard climatological observations in this country, are in inches. Amounts are recorded to the nearest hundredth of an inch (for example, 0.47 inch).

There are three general categories of precipitation gauges (also called rain gauges, for brevity): (1) ordinary (nonrecording) gauges, such as dipstick (or "stick") gauges, (2) recording gauges, and (3) storage gauges. These gauges are available in various designs and sizes; standard designs have a circular cross section. The standard nonrecording gauge has an 8-inch diameter.

9.1 Nonrecording Gauges

STANDARD 8-INCH RAIN GAUGE

Components of the standard 8-inch "stick" gauge are shown in figure 9.1. Precipitation is caught within the collector (the funnel), or top section; this has a knife-edge rim with an 8-inch inside diameter. The water is funneled into the measuring tube set within the outer cylinder, which is also termed the overflow can. The top section, seated on the overflow can, also acts as a shield in curtailing evaporation of the collected water.

The cross-sectional area of the measuring tube is one-tenth that of the collector. Therefore, the depth of water standing in the tube is ten times the depth that has actually fallen. This magnification enables easy measurement of precipitation to the nearest hundredth of an inch.

The measuring stick is graduated at one-tenth inch (0.10-inch) linear intervals, each representing 0.01 inch of precipitation. An actual length of 1.00 inch on the stick represents 0.10 inch precipitation.

Large and Lower Capacity Gauges—The standard 8-inch gauge is available in two types: the traditional, large-capacity rain and snow gauge (fig. 9.2) and the less expensive but lower capacity Forest Service gauge (fig. 9.1). The traditional type, used by the National Weather Service (NWS) at year-round climatological stations, can hold 2.00 inches precipitation in its measuring tube and a total of 20 inches in the overflow can. The Forest Service type holds only 0.50 inch in its measuring tube and a total of 7 inches in the overflow can. This gauge was designed to provide an economical instrument for use in areas where 24-hour precipitation rarely exceeds a few inches.

For collecting snowfall, which is later melted to obtain its water content, these gauges are exposed with only the outer can in place (the top section would block the downward passage of snow). The shallow Forest Service gauge is, of course, limited in its snowfall capacity, particularly under windy conditions when snow may be swirled out of the can.

Measuring Sticks—Measuring sticks of laminated plastic are now widely used for both types of standard gauges, replacing wooden (cedar) sticks. The plastic stick has several advantages over the wooden stick: (1) water will not creep up the stick, (2) the plastic stick and its white, easy-to-read markings are more durable, and (3) the plastic stick can be easily washed clean of oil, dirt, or grease. On the other hand, the waterline is often much easier to see on the wooden stick than on the plastic stick.

The waterline, also, may be displaced slightly upward on the nonabsorbant plastic stick, but this error can be considered negligible, considering possible errors in gauge catch of precipitation. Also, close to 0.005 inch precipitation—one-half the increment between stick markings—

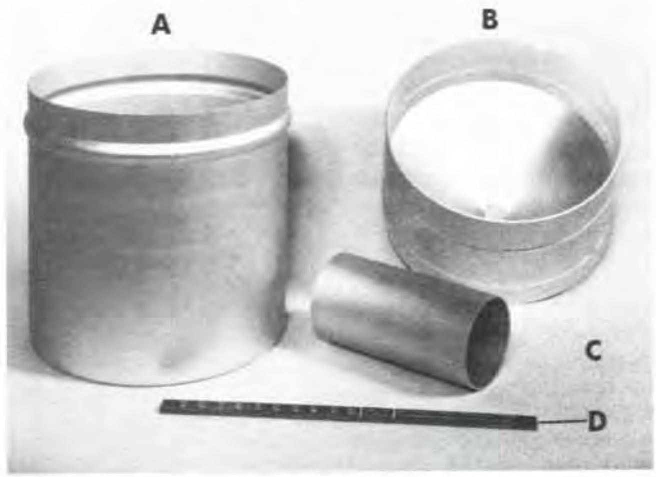


Figure 9.1—Components of small-capacity standard 8-inch rain gauge, Forest Service type: A, overflow can; B, collector; C, measuring tube; D, measuring stick.

Figure 9.2—Large-capacity standard 8-inch rain gauge, National Weather Service type.

may be required to wet a previously dry funnel before water will flow into the measuring tube.

Gauge Mounts—The large-capacity 8-inch gauges are mounted in either a steel or aluminum tripod stand or in a wooden stand. The wooden stand, less common in newer installations, was in the past constructed from a box in which the gauge was shipped (fig. 9.2). The shorter, Forest Service rain gauge is usually mounted in a specially-constructed wooden stand (section 18.2).

Weighing Scales—Spring-type weighing scales (fig. 9.3) provide a convenient means of measuring the water content of snowfall collected in the standard, large-capacity 8-inch gauge overflow can—an alternative to the method described in section 25.1. The scale is particularly suited where the 8-inch can, charged with antifreeze solution (section 9.3), is used as a storage precipitation gauge. The can and scales are also used for determining the total water content of snow on the ground, from snow cores (section 25.1), at locations with snow depths less than 2 ft. A small hole is usually drilled near the rim of the overflow can for suspending it from a hook on the scale. The scale in figure 9.3, with graduations in 0.05-inch increments, can measure 11 inches water (or water plus antifreeze) content in one revolution of the pointer; 22 inches in two revolutions.

SMALL-ORIFICE RAIN GAUGES

Rain gauges designed with small collection areas (orifices) and reduced capacities are often used to obtain supplemental rainfall data at locations away from the main or permanent weather station. Most of these gauges are constructed of durable plastic and have the advantage of lower cost and easy portability. A survey of literature

Figure 9.3—Weighing scales, used with overflow can of large-capacitiy 8-inch rain gauge; a convenient means of measuring water content of snow. (Photo from U.S. Department of Commerce 1972.)

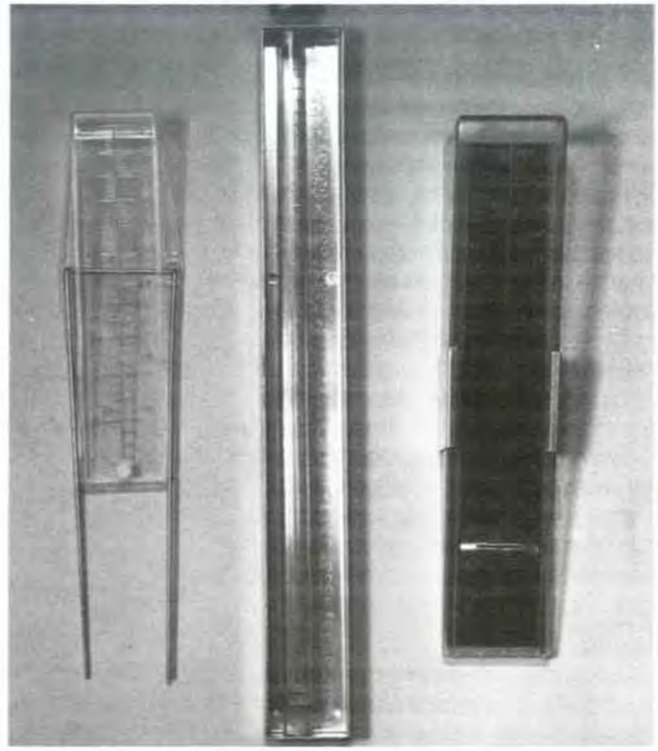


Figure 9.4—Several types of direct-reading, small-orifice rain gauges.

examining small-orifice gauges (Corbett 1967) showed them to have the following characteristics:

1. Accuracy of some gauges compares favorably with the standard 8-inch gauge.
2. Under certain conditions, a more accurate catch of rainfall can be obtained because these gauges do not obstruct the airflow (and thus create eddies) as greatly as a large gauge.
3. Most are unsuitable for snowfall collection.
4. Use is not recommended during freezing weather.
5. Evaporation loss is relatively high; hence, these gauges should be read as soon as possible after precipitation has ended.

Most small-orifice rain gauges are designed as direct reading instruments and do not require a measuring stick. Several of the more common types are shown in figures 9.4 and 9.5. Two models considered suitable for supplementary or temporary field use are described below.

Four-Inch Clear Plastic Gauge—This gauge (fig. 9.5) is modeled after the traditional 8-inch-diameter gauge; all parts are durable plastic. It consists of a 4-inch-diameter knife-edge collector with funnel, an outer (overflow) cylinder, and a direct-reading measuring tube. The measuring tube has 0.01-inch graduations and holds 1.00 inch

Figure 9.5—Four-inch clear plastic direct-reading rain gauge.

of rain; the overflow cylinder holds an additional 10 inches. The gauge is supplied with a stainless steel bracket for mounting on a post or other suitable support that does not block precipitation.

Wedge-Shaped (Fencepost) Gauge—This flat-sided, one-piece plastic gauge consists of a wedge-shaped well on which a scale is embossed (fig. 9.4). Rectangular in cross section, its knife-edge orifice measures 2.5 by 2.3 inches. The gauge has a capacity of 7.00 inches, with the scale graduated in units of 0.01 inch for rainfall up to 0.30 inch; 0.02 inch for rainfall between 0.30 inch and 1.00 inch; 0.05 inch for rainfall above 1.00 inch. Measurement is by direct observation of the water level. The gauge is supplied with a mounting bracket.

Evaporation loss can be quite high in this gauge. Contributing to this loss is the open top and also the tendency for small amounts of water to cling to the sides; the small gauge and its contents can also heat up rapidly in the sun, providing energy for the evaporation process. The gauge must be read very soon after rainfall has ended.

9.2 Recording Precipitation Gauges

Recording gauges provide a chart record or other readout that can be used to determine the time, duration, intensity, and amount of precipitation for each occurrence. They also show the accumulation during a specified time period.

Two basic types of recording gauges are in common use: the weighing type and the tipping bucket type. The traditional ("Universal" type) weighing gauge uses an ink trace on a rotating chart. A newer, digital type weighing gauge employs punched tape.

Recording gauges consist of four basic parts: a collector, measuring mechanism, recording mechanism (or transmitting device), and housing.

UNIVERSAL WEIGHING GAUGE

The Universal weighing gauge (fig. 9.6), also known as the Fergusson weighing gauge, continues as the standard recording gauge in use at manual fire-weather stations and at the NWS primary (airport) stations. But the punched-tape gauge, described below, has replaced the Universal gauge in the NWS cooperative recording-gauge network.

The Universal gauge's operating principle is relatively simple. In the standard model, the collector has an 8-inch (inside diameter) orifice and "chimney," together with a removable funnel. As precipitation enters the chimney, it is funneled or directly deposited into a 12-quart bucket resting on a spring-scale weighing platform. The funnel is removed during the snow season, when, also, a charge of antifreeze is added to the bucket. A high-capacity model is also available. To inhibit snow bridging across the orifice, its collector measures 11.3 inches in diameter and is coated with teflon.

The weight of precipitation in the bucket, converted to inches, is transmitted through a linkage system to the pen arm and onto the rotating chart (fig. 9.7). A dashpot is provided in the linkage system to dampen pen arm oscillations caused by wind or other sources of vibration.

The standard model can be supplied calibrated to record, on appropriate charts, a total of either 2.4 inches, 4.8 inches, 6 inches, 12 inches, or 20 inches precipitation. Some of these ranges include dual traverses of the pen arm. The high-capacity model will record 30 inches, dual-traverse (including antifreeze charge). Standard range is 12 inches. In this case, a 1-inch vertical spacing on the chart equals 1 inch of precipitation. The first 6 inches are recorded on the ordinary upward traverse of the pen; the second 6 inches, on a downward traverse.

The chart drives are similar to those available for the Belfort-type hygrothermograph—spring-wound or battery-operated (sections 3.1 and 7.7). Likewise, the chart rotation period can be varied by gear selection. Daily, weekly, and monthly charts are available.

The housing encloses the entire operating mechanism and the collector-funnel assembly serves as the top. A vertically sliding door is provided at the bottom of the housing for access to the chart, chart drive, and pen arm assembly.

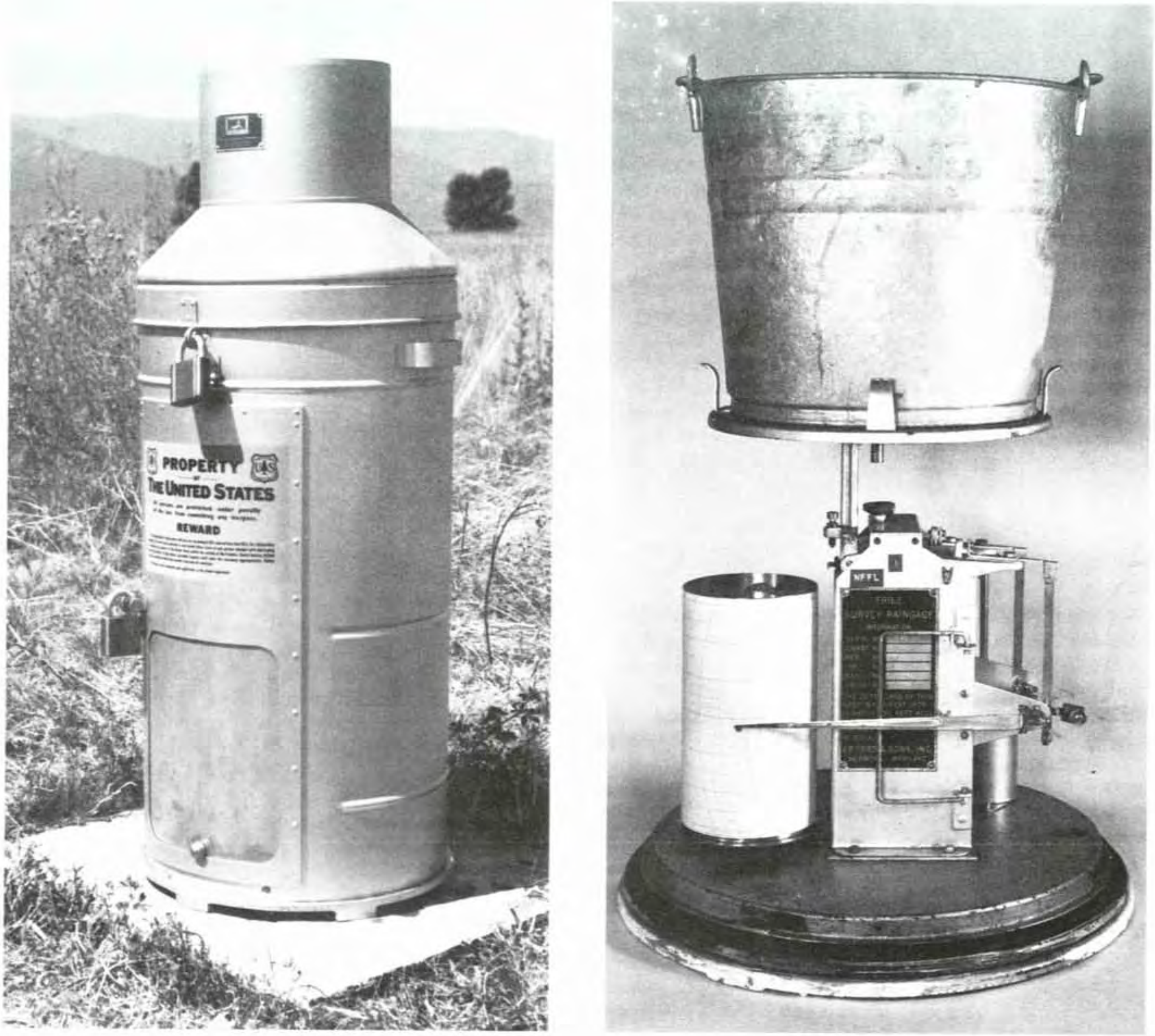


Figure 9.6—Universal weighing-type precipitation gauge: left, assembled gauge; right, weighing and recording mechanisms.

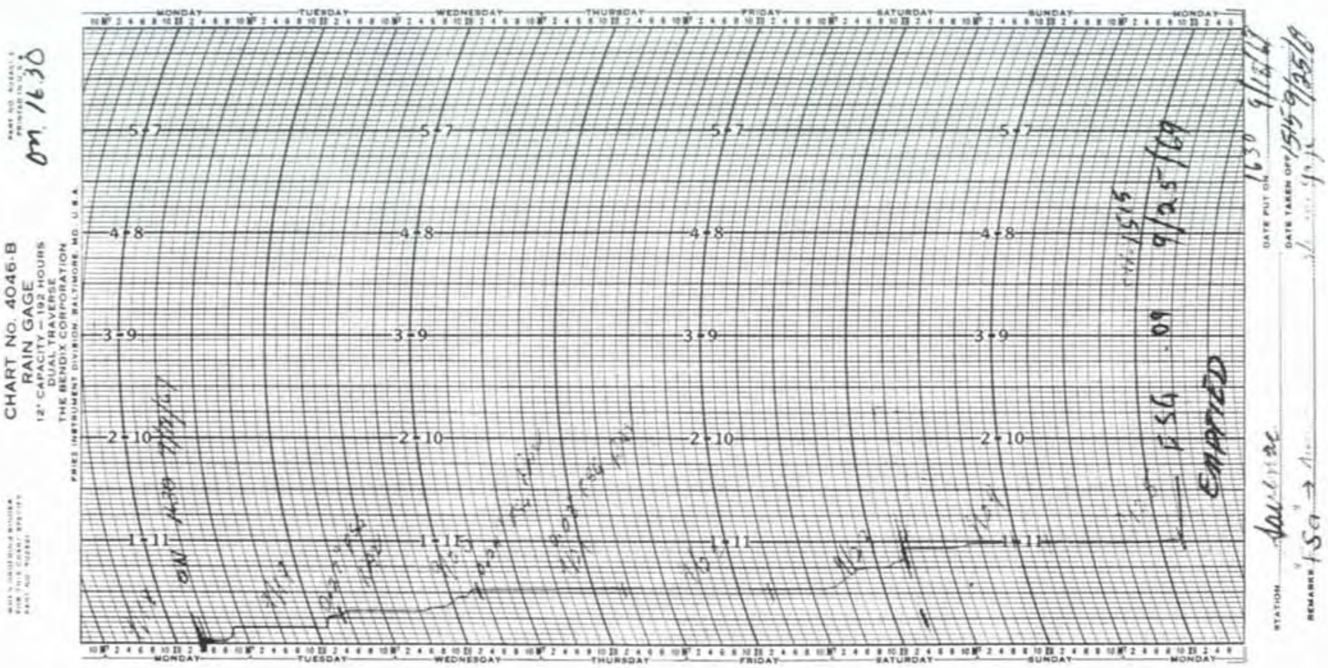


Figure 9.7—Weighing gauge chart record. The first 6 inches of precipitation are recorded on the upper traverse of pen.

PUNCHED-TAPE RECORDER

This type of weighing gauge (fig. 9.8), also known as the Fischer & Porter gauge, has replaced the Universal gauge in the NWS cooperative recording-gauge network. It operates on the same principle as the Universal gauge, though the recording mechanism is quite different. The instrument is electrically powered, usually with a 7½-volt VDC battery. Recording capacity is 20 inches.

The weight of precipitation entering the collector and deposited in a bucket is translated into a binary-decimal code and punched on paper tape. Precipitation is recorded only in 0.1-inch increments, compared with the 0.01-inch resolution that is possible from the Universal weighing gauge.

The punched-tape record can be read visually, translated manually by using a desk reader, or converted to computer inputs. An interval timer controls the frequency of data collection. By changing a cam, the punch or printout interval can be varied between 5 and 60 minutes. At the 5-minute interval, 3 months of record can be obtained from a roll of tape.

With added antenna equipment, data from this gauge can be transmitted via satellite to distant offices requiring real-time information. The NWS, for example, receives such data for hydrological forecasting.

Figure 9.8—Punched-tape recording precipitation gauge, a digitally recording type of weighing gauge.

TIPPING BUCKET GAUGE

Tipping bucket rain gauges are used for remote recording or readout of precipitation amounts, as in an office at manual stations. Such gauges are also widely used in automatic weather station systems. Both 8- and 12-inch-diameter models are available (figs. 9.9 and 9.10).

In these gauges, precipitation is funneled from the collector through a small spout to a tipping-bucket mechanism. This mechanism consists of a pivoted container, or bucket, divided into two compartments, each having a capacity of 0.01 inch precipitation. The compartment under the spout fills to capacity, overbalances the other compartment, and tips the bucket. The tipping action closes a mercury or reed switch, sending an electrical impulse representing 0.01 inch precipitation to the recording unit. As the bucket tips, the second compartment is positioned under the spout, ready to fill and repeat the cycle.

In some models, water from the tipping bucket is emptied into a reservoir for later drainage and stick measurement. In other models, the water drains immediately, giving unlimited recording capacity. As usually supplied, the tipping bucket gauge will not function in the case of snowfall and freezing temperatures. But heated, insulated models (fig. 9.11), with either electric or propane heaters, may be operated down to about –10 to –20 °F.

Several types of recorders can be used with tipping bucket gauges. The most commonly used is the spring-wound or battery-operated, clock-driven event recorder. The chart record shows precipitation by a stepped trace, each step representing 0.01 inch (one tip of the bucket). After 1.00 inch of precipitation has been recorded, the pen returns to the bottom of the chart and starts a new upward cycle. Some event recorders are equipped with a digital counter, which shows total accumulated precipitation at a glance.

Figure 9.9—Tipping bucket rain gauge containing reservoir, with tube for stick measurements; standard NWS design with 12-inch-diameter orifice. (Photo courtesy of Belfort Instrument Company.)

Figure 9.10—Self-draining tipping bucket rain gauge; model with 8-inch-diameter orifice. (Photo courtesy of Sierra-Misco, Inc.)

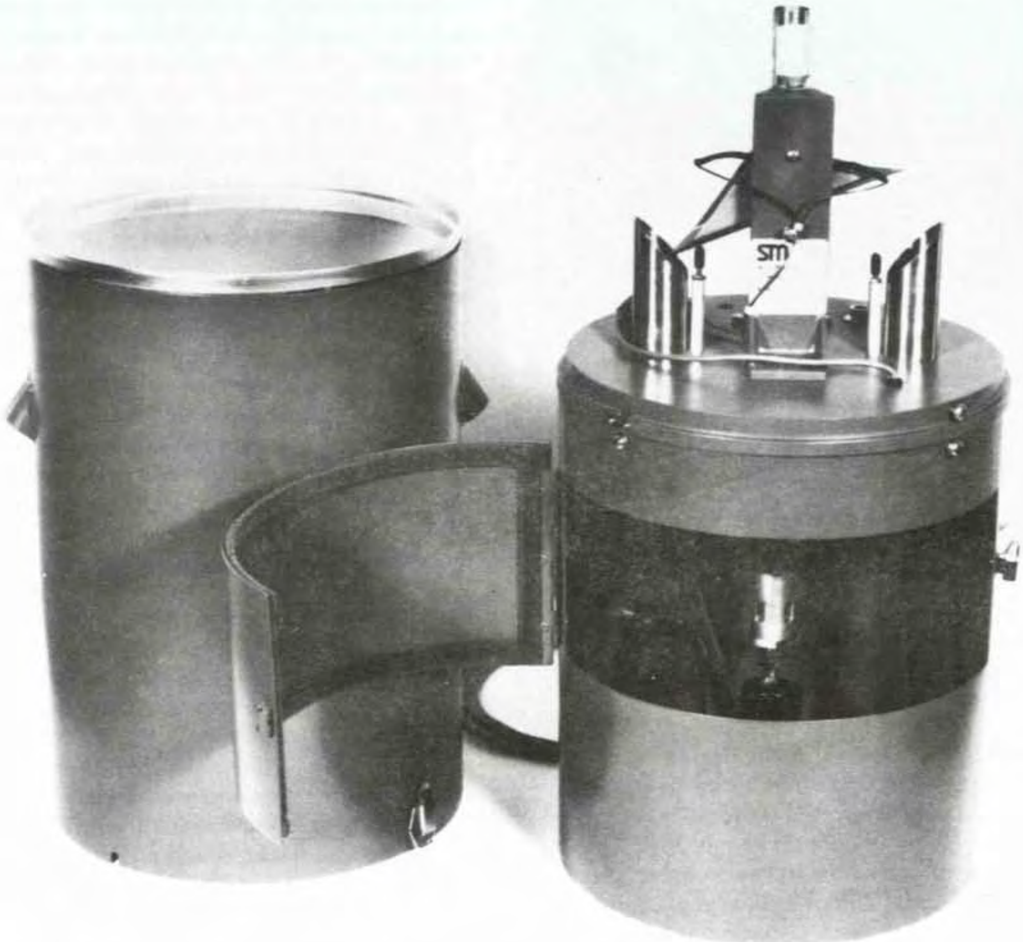


Figure 9.11—Tipping bucket gauge, as in figure 9.10, with propane heater for measurement of both rain and snow (water content). (Photo courtesy of Sierra-Misco, Inc.)

Figure 9.12—Electronic rain gauge, self-draining tipping-bucket type, with digital counter. (Photo courtesty of RainWise Inc.)

Remote-Reading Electronic Rain Gauge—An inexpensive tipping-bucket gauge manufactured by RainWise (fig. 9.12) provides a digital readout on a battery-operated indicator. The gauge, usable only for rain or melting snow, has a standard 8-inch-diameter collector and is self-emptying. The indicator will accumulate rainfall up to 99.99 inches or can be reset for daily readings.

RELIABILITY OF RECORDING RAIN GAUGES

Observers may often encounter differences in catch between a recording rain gauge and a nearby nonrecording gauge. Such differences are, in fact, typical.

Studies by Jones (1969) showed that recording gauges with sloping shoulders below the orifice—such as the Universal gauge—collected 2 to 6 percent less rain than standard nonrecording gauges, which have a straight profile. The slope can induce upward wind currents that carry away some of the raindrops. Larger errors typically occur with snowfall.

In addition, the tipping bucket gauge has characteristics that can produce errors in recorded precipitation. During light rains in warm weather, water can accumulate in the bucket slowly enough to allow losses from evaporation before the bucket is tipped. During intense rainfall, some error will result as water continues to pour into the already filled compartments during the tipping motion. With an actual rainfall rate of 5 in/h, the recorded rate in gauges with a mercury switch may be 5 percent too low (Parsons 1941). The error should be about one-half this in models employing a magnetic reed switch.

9.3 Storage Precipitation Gauges

Storage precipitation gauges are employed in remote, usually mountainous areas, where frequent attendance by an observer is impractical; access is commonly limited by deep snow cover. Many such gauges are read only once or twice per year. Storage gauges at Soil Conservation Service (USDA SCS) snow survey courses, however, are now part of a SNOTEL (snow telemetry) system that provides data on a daily basis, via radio transmissions bounced off ionized trails of meteors (Barton 1977).

Storage gauges are usually mounted on a platform or tower, or are in the form of a standpipe, at a height that maintains the gauge orifice above the location's maximum expected snowpack depth. Clearance of at least 2 ft above the snow surface is advisable. Except at well-sheltered sites, wind shields (section 9.4) are usually installed. Many gauges employ a collector that is tapered toward the top to prevent wet snow from adhering to the inside walls and clogging the orifice. The recommended storage-gauge type and capacity (or dimensions) depend largely on the depth of snow that may accumulate between visits—not on the equivalent water depth—and on the characteristic type of snow that falls (dry snow versus heavy wet snow) (USDA SCS 1972).

Storage gauges are charged with an antifreeze solution. Glycometh—a solution of 40 percent ethylene glycol and 60 percent methyl alcohol—is now preferred over ethylene glycol or calcium chloride (USDA SCS 1972); ethylene glycol has been recommended over calcium chloride (Kidd 1960). Only glycometh, with a specific gravity between that of ice and water, is self-mixing, preventing an ice layer from forming at the top of the solution (diluted by melted snow). When such a layer forms, in other solutions, snow builds up on the ice and, if the gauge has inadequate capacity, the gauge caps over; excess snow may blow away. Particular caution is required, however, in preparing glycometh, as methyl alcohol (methanol) is toxic and flammable; avoid skin contact and inhalation, taking care to protect the eyes with goggles.

The antifreeze charge is covered with a film of light oil such as transformer oil, mineral oil, or refrigerant oil, at least 0.3 inch thick, to prevent loss of water by evaporation. Light motor oil such as SAE 10 has been found unsatisfactory at low temperatures (Farnes 1988).

Gauges with an orifice 12 inches in diameter are recommended over those with an 8-inch orifice in areas where heavy wet snow is likely to bridge the smaller orifice. Heat absorption for melting snow buildups can be increased by painting the outside of the gauge with flat black or brown paint.

TYPES OF STORAGE GAUGES

Storage gauges most commonly used in the United States fall into two general categories, having either constant diameter or variable diameter, and these comprise four basic designs: the Sacramento gauge (which has a truncated cone shape), the straight-sided can, the can-cone (straight-sided can with truncated cone top), and the standpipe. The first three gauges are mounted on towers (USDA SCS 1972), while the standpipe gauge rises from its base at the ground. Most of the gauges are equipped

Figure 9.13—Sacramento storage precipitation gauge.

with a drain cock to release their contents for weighout measurement of the seasonal precipitation. Interim measurements of the precipitation catch are made by stick or tape readings inside the gauge.

The Sacramento gauge (fig. 9.13) usually has an 8-inch orifice. Its conical shape increases the gauge's capacity to well above that of a straight-sided gauge of equal height. Capacity is typically 100 or 200 inches liquid (water plus antifreeze charge).

Straight-sided cans are usually 8 inches in diameter and either 24 or 42 inches in length. Their relatively low capacity makes them suited mainly for drier locations or for locations that can be visited often (for example, at monthly intervals). The shorter can is not equipped with a drain.

The can-cone gauge (fig. 9.14) usually has a 12-inch-diameter can, with the cone on top reducing the orifice to a diameter of 8 inches. Capacity is thus somewhat greater than that of a straight-sided can of equal height.

The standpipe gauge (fig. 9.15) has in the past been constructed from 5-ft sections of 12-inch-diameter thin-walled pipe, commonly 10-gauge steel. A one-piece aluminum standpipe gauge is now favored by the Soil Conservation Service at its SNOTEL stations. A truncated cone 18 inches long, forming the top of the traditional standpipe gauge, reduces the orifice to a diameter of 8 inches. The SNOTEL standpipe gauges have a 12-inch diameter throughout, including the orifice.

A modified standpipe gauge described by DeByle and Haupt (1965) consisted of a 40-inch-tall, 12-inch-diameter tank of 12-gauge or heavier steel, together with a truncated cone top section, mounted on a single 3½-inch support pipe. This gauge was recommended as a rugged, vandalproof gauge suitable for sites receiving 60 inches or less precipitation during the storage season. Standpipe gauges may also be fashioned from PVC pipe used in sewer lines (Farnes 1988).

9.4 Wind Shields

Precipitation gauges are sometimes installed in locations where wind effects, reducing the gauge catch, cannot be minimized by site-selection efforts (section 18.1). In such cases, use of a wind shield may be advisable, particularly at stations subject to much snowfall.

Two types of shield have had wide use in the United States: (1) the Nipher shield, a flared metal device that attaches to the precipitation gauge, and (2) the Alter type

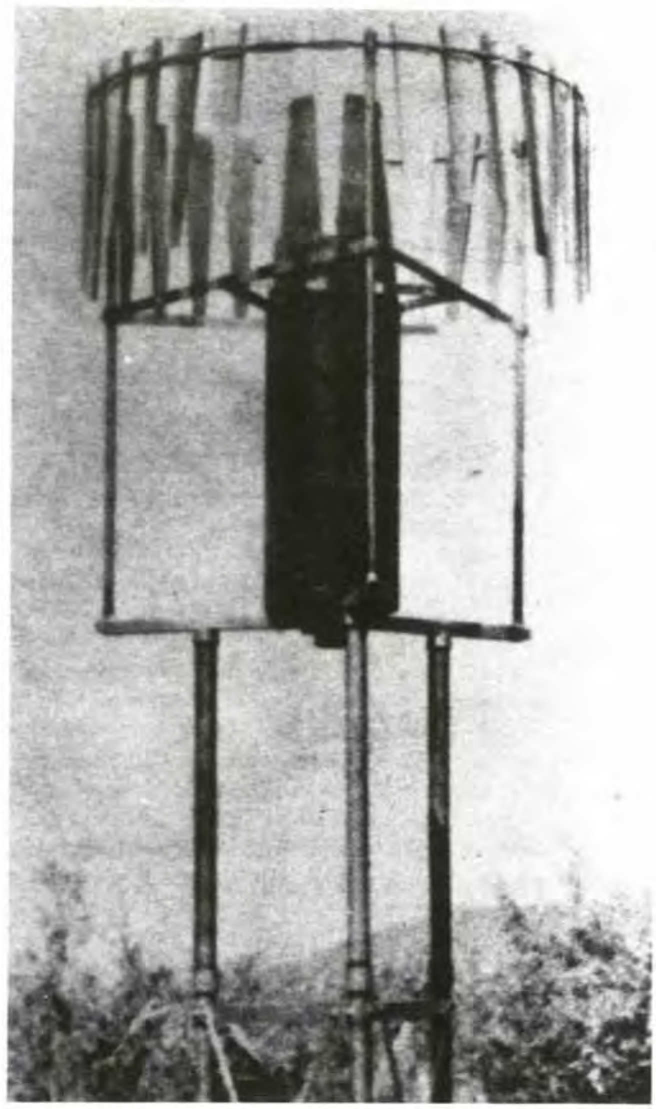


Figure 9.14—Can-cone storage precipitation gauge, with Alter wind shield. (Photo from USDA SCS 1972.)

Figure 9.15—Standpipe storage precipitation gauge, with Alter shield. (Photo from National Weather Service.)

(figs. 9.15 and 9.16), which consists of 32 free-swinging galvanized metal leaves, or baffles, attached to a steel ring 4 ft in diameter. At ground level, the Alter shield is supported on three or four galvanized pipe legs installed around the precipitation gauge. In the standard design, with four support pipes, one of the shield quadrants is hinged and swings outward for easy access to the gauge.

Although deficiencies in precipitation catch may still be large at very windy sites, overall both types of shield can greatly improve the catch. At gauges that are not frequently attended, however, snow can often build up on the Nipher shield and bridge the gauge orifice. The Alter shield has thus become the standard shield in the United States for storage and other gauges. Nevertheless, heavy wet snow can also cause buildup problems with the Alter shield, particularly when the shield is used with the sloping-walled Sacramento storage gauge (Garstka and

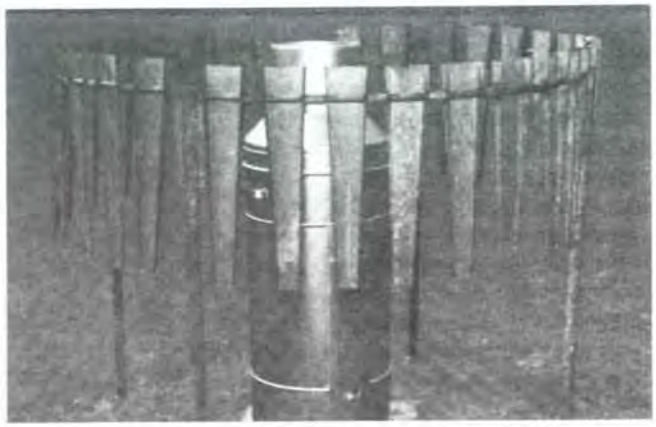


Figure 9.16—Alter wind shield, installed around weighing gauge.

others 1958). In this regard, the present Alter shield configuration (figs. 9.15 and 9.16) is an improvement over the previous configuration, which had angled, constrained baffles (fig. 9.17).

The use of wind shields at fire-weather stations would improve the accuracy of precipitation data, particularly at openly exposed, windy locations. As indicated earlier, however, their main benefit occurs during the snow season (Brown and Peck 1962).

9.5 Snowfall and Snow Depth Indicators

SNOWFALL

Snowfall is the depth of new snow that has fallen and accumulated during the measurement period (usually 24 hours); it is recorded in inches and tenths. The snowfall water content is also measured, as described later. Although snowfall is collected in the standard 8-inch precipitation gauge (with only the open, outer can exposed), its depth is ordinarily measured outside the gauge on nearby ground—on a short grassy surface away from pavements, buildings, and trees. The rain gauge measuring stick is commonly used for this purpose, but sturdier sticks are advised where the snow has become deep or crusty.

Snow Boards—Snow boards provide a cleared surface for determining new snow accumulation (and its water content). They can be particularly convenient where snow often falls on previous snow cover that has not formed a distinguishable, harder surface (or crust). A snow board is made of thin, white-painted wood or plastic. It should be about 2 ft square, with the surface somewhat rough or covered with a layer of white cotton flannel. In use, the board is set flush with the existing snow surface; a stick with red-painted top is inserted nearby to mark the board location.

The board should be set in a location that usually has representative snowfall accumulation and is also sheltered from the wind. Otherwise, snow could blow off or drift onto the board, making it unreliable for measurements.

Figure 9.17—Snow buildup that may occur between Alter shield and sloping wall of Sacramento storage gauge, particularly with shield of previously used configuration (see text). (Photo from National Weather Service.)

SNOW DEPTH

Snow depth, as distinguished from snowfall, is the total snow (and ice) cover on the ground. This may include the contribution of many individual snowfalls, or it may be derived entirely from a single snowfall, past or present. The depth is recorded to the nearest whole inch; its water content may also be measured, as described later.

Snow depth measurements should be made over a representative grass surface. The rain gauge measuring stick will often be adequate if handled carefully, but deeper and coarser snow will require a longer and stronger stick. A stick with a sharp metal end may be necessary to break through ice layers near the snow-ground interface. The snow depth is read in several sampling spots to obtain an average value.

Snow Stakes—Snow stakes provide the simplest means of measuring snow depth in areas of deep snow accumulation. Recommended stakes (U.S. Department of Commerce 1972) are made from wood $1^3/_4$ inches square, of appropriate length, and painted white to minimize undue melting of the immediately surrounding snow. The entire length is graduated at 1-inch intervals, using small black edge markings and numerals. Stakes are usually anchored against the ground surface with angle iron supports. Location should be at a carefully selected, representative site that allows easy reading from a distance if necessary. Where a single snow stake is not consistently representative, several stakes should be installed and an average depth taken.

Snow Sampling Tubes—Snowpack depth and water content may also be measured with sampling tubes and a spring scale. The federal snow sampler, widely used in the Western United States, consists of 30-inch sections of duraluminum tube with an inside diameter of $1^{11}/_{16}$ inches. A steel cutter bit is fitted to the bottom section. Measurements, usually taken monthly or semimonthly along marked snow courses for water supply forecasts, are outside the scope of this handbook. These measurements are described in detail by the USDA Soil Conservation Service (1972). Snow pillows, which automatically record the snowpack water content, are also described.

9.6 Supplemental Information

In addition to the amount of precipitation that is measured, the following supplemental information is part of a complete precipitation record, such as that required for fire-weather observations (Deeming and others 1977):

1. Kind of precipitation.
2. Time precipitation began.
3. Time precipitation ended.
4. Duration of precipitation.

KIND OF PRECIPITATION

The kind of precipitation specifies whether it was rain, drizzle, snow, ice pellets (sleet), or hail. Further distinctions include freezing rain and drizzle (glaze), and also snow pellets and snow grains (U.S. Department of Commerce 1972). This information is often entered in coded form.

TIME PRECIPITATION BEGAN AND ENDED

The beginning and ending times of each continuous precipitation occurrence should be noted, to the nearest half hour if possible. A recording rain gauge, either the Universal or tipping bucket type, is a ready source for this information (except when amounts are less than 0.01 inch).

DURATION

The duration of precipitation is the elapsed time from beginning to ending of each occurrence. Usually, the sum of the elapsed times for all occurrences during the reporting period is entered. Just 1-hour total duration, however, is recorded in fire-weather observations when only trace amounts of precipitation (amounts less than 0.01 inch) have occurred.

CHAPTER 10. FUEL MOISTURE

10.1 Fuel Moisture Sticks

Since Gisborne (1933) first developed the idea in 1924, fuel moisture indicator sticks have been widely used to estimate the moisture content of small-diameter (10-hour timelag) forest fuels. A fuel moisture indicator stick is ". . . a specially prepared stick or set of sticks of known dry weight continuously exposed to the weather and periodically weighed to determine changes in moisture content as an indication of moisture changes in forest fuels" (Society of American Foresters 1958).

Unlike conventional weather instruments, indicator sticks do not measure any single weather variable but, rather, they ". . . measure the net effect of climatic factors affecting flammability in terms of the most significant item, the fuel itself" (Davis 1959). For this reason, the practice of using fuel moisture indicator sticks is common at fire-weather stations, both in conjunction with fire-danger rating systems and prescribed burning operations. Also, in some areas the fuel moisture stick readings during critically dry periods serve as a basis for initiating fire protection measures, such as restrictions on logging operations, camping, and open burning.

STANDARD FUEL MOISTURE STICK

A standard fuel moisture indicator stick consists of four 1/2-inch ponderosa pine sapwood dowels space one-fourth inch apart on two 3/16-inch-diameter hardwood pins. The dowels are held in place on the pins by wire brads at each intersection. The resulting stick (fig. 10.1) is 2 3/4 inches wide, about 20 inches long, and has an ovendry weight of 100 grams. A screw hook is inserted in the end of one of the dowels, and the notation, "This end NORTH, this side up," is stamped on the dowel surface just below the screw hook (Hardy 1953).

The wooden fuel moisture stick has several shortcomings as a fuel moisture analog (Fosberg 1971). Specifically:

1. The response characteristics of wood are highly variable. Dowels cut from the same board will sometimes give different fuel moisture values when exposed side by side in the same environment.
2. Exposure and aging will change both the response characteristics and the calibration of a wooden stick. Discoloration with age changes the radiation characteristics of the stick. If the dowels check and split, as they often will, more surface area is exposed to the air and the calibration of the stick is changed. The actual weight or mass of the stick can be reduced if splitting and checking are severe.

Efforts to develop an improved, more consistent analog for indicating fuel moisture, utilizing inorganic material, have, at present, been unsuccessful. Thus, the NFDRS 10-hour fuel moisture continues to be estimated with the wooden sticks at manual fire-weather stations. Corrections for aging changes in these sticks (Haines and Frost 1978) are, however, incorporated in the NFDRS (Deeming and others 1977). As a further step, these corrections are now adjusted, based on NFDRS climate class. For example (Harrington 1983), the weathering rate (average monthly weight loss) of fuel moisture sticks in a dry Southwest climate is about one-half that in a wet climate.

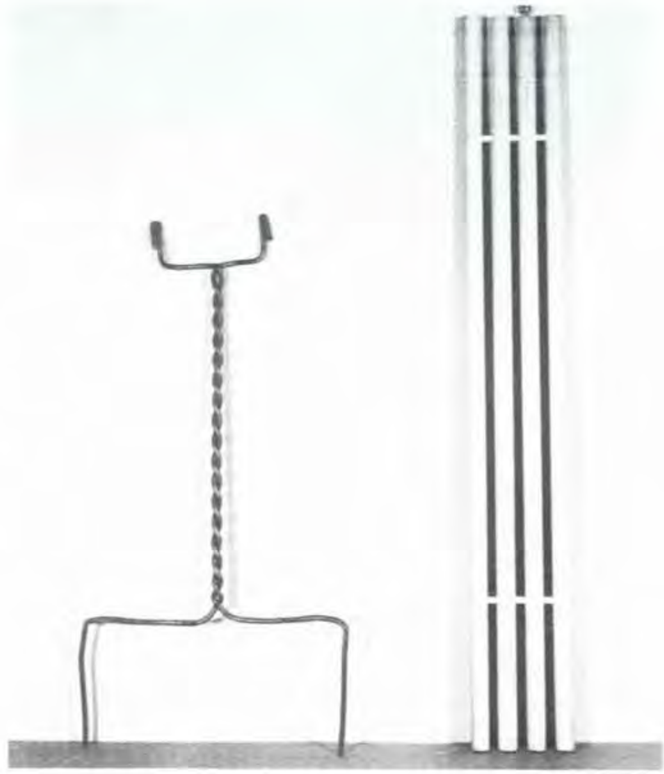


Figure 10.1—Standard fuel moisture stick, consisting of 1/2-inch ponderosa pine dowels, and wire mounting rack (two rack sections are required for installation).

10.2 Fuel Moisture Scales

Using a properly exposed stick, analog fuel moisture is measured by weighing the stick on a suitable scale. The fuel moisture is represented by the stick weight in excess of ovendry weight (100 grams for a set of 1/2-inch ponderosa pine dowels). Several scales in common use at fire-weather stations are described below. These include scales designed specifically to weigh fuel moisture sticks, either at permanent stations or in the field. Such scales are recommended over the laboratory balances.

THE FORESTER FUEL MOISTURE SCALE

This scale (fig. 10.2), traditionally known as the Appalachian Fuel Moisture Scale, is recommended as the standard scale at permanent stations. It was designed by Byram (1940)—originally for weighing basswood slats, which were similar in purpose to the present fuel moisture stick but had variable ovendry weights. The scale consists of a pivoted balance arm mounted on a 10- by 10-inch metal back. A sliding weight on the arm is used to adjust the scale for the ovendry weight of the stick. When weighed, the stick is hung on a small hook

Figure 10.2—Forester (Appalachian) fuel moisture scale mounted in Appalachian scale shelter.

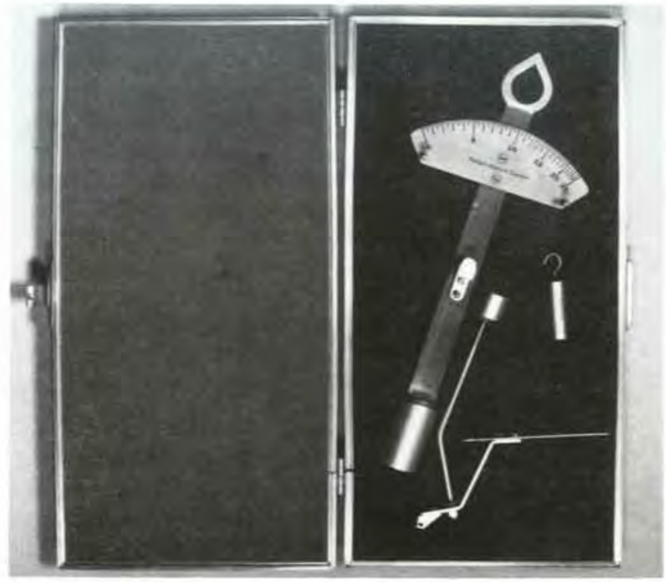


Figure 10.3—Forester (Chisholm) portable fuel moisture scale.

at the left end of the balance arm. The pointed right end of the balance arm indicates the analog moisture content on a curved scale graduated from 0 to 50 percent. A standard 100-gram weight is provided to level and zero the scale.

Appalachian Shelter—The Forester scale should be mounted in a specially designed shelter known as the Appalachian shelter. This shelter (Barney 1962) facilitates correct leveling of the scale and also the weighing process (affording protection from moisture and wind). It provides leveling adjustment in two planes, adequate space, and ample viewing through a large window in the door (fig. 10.2). Construction details are shown in appendix 5.

FORESTER PORTABLE FUEL MOISTURE SCALE

The Forester portable scale (fig. 10.3), also known as the Chisholm Portable Fuel Moisture Scale, operates in the same manner as the previously described Forester (Appalachian) scale, except that it has no adjustment for a range of ovendry weights. It is calibrated for weighing the standard 100-gram ponderosa pine stick. Although the Forester portable scale can be hand held, it is much easier to use when hung on a post, tree, truck, or similar support. A 100-gram test weight is provided with the scale.

WILLIAMS POCKET FIRESTICK MOISTURE SCALE

The Williams scale (fig. 10.4) is a portable, accurate, and durable scale. Measuring 1½ inches in diameter and less than 5 inches long, it weighs only 14 ounces. Its case weighs 100 grams and doubles as a calibration weight. Micrometer graduations are read as direct percentages of the amount of moisture in 100 grams of wood; the upper limit is 25 percent. Scale sensitivity is one-fourth gram.

TRIPLE BEAM AND HARVARD BALANCES

These are standard laboratory balances. The triple beam balance (fig. 10.5) has a single pan; the Harvard balance (fig. 10.6), a double pan. Fuel stick weight is read from the scales after balance has been achieved.

When used at fire-weather stations, triple beam and Harvard balances are installed in a scale shelter similar to that shown in figure 10.7. It is important that the shelter is watertight, firmly mounted, and exactly level and plumb.

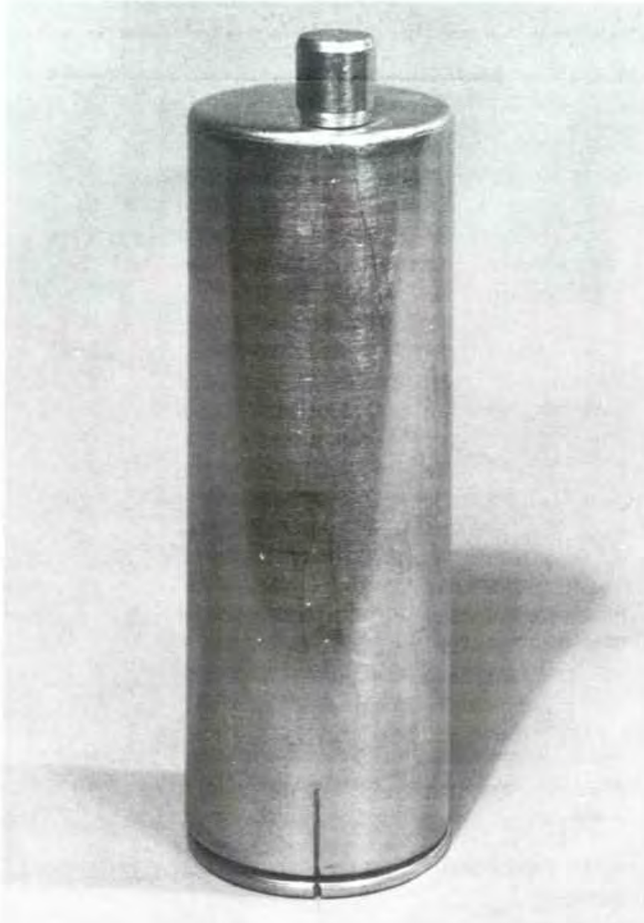


Figure 10.4—Williams pocket scale: left, assembled for storage; right, assembled for use.

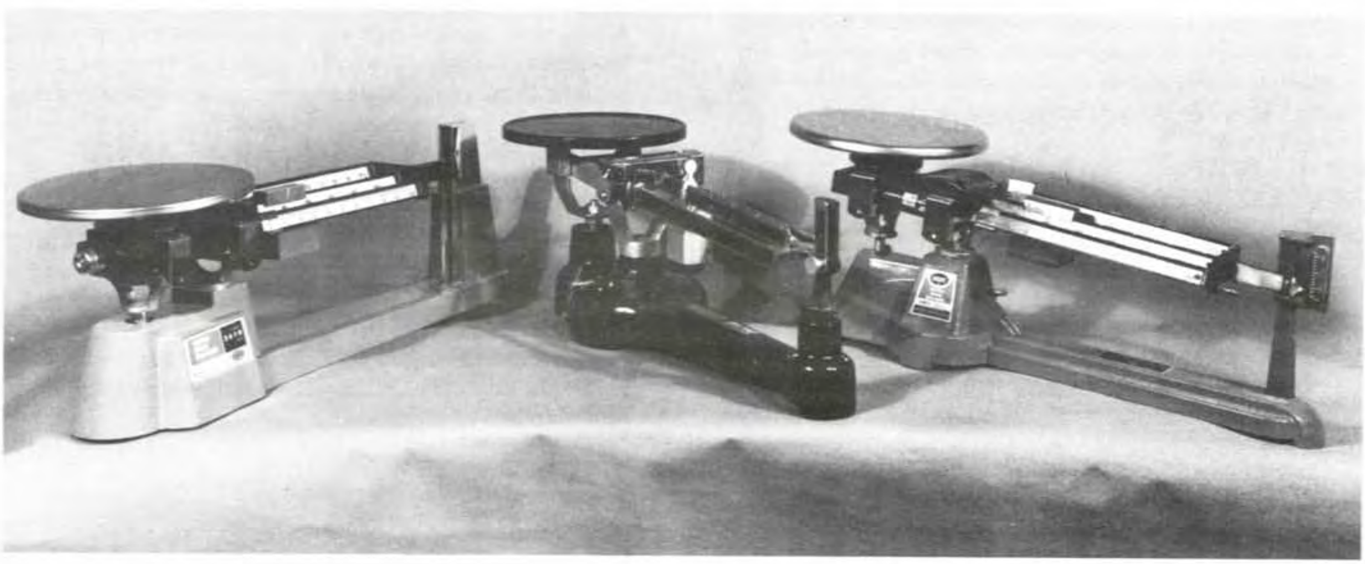


Figure 10.5—Triple beam balance, three models.

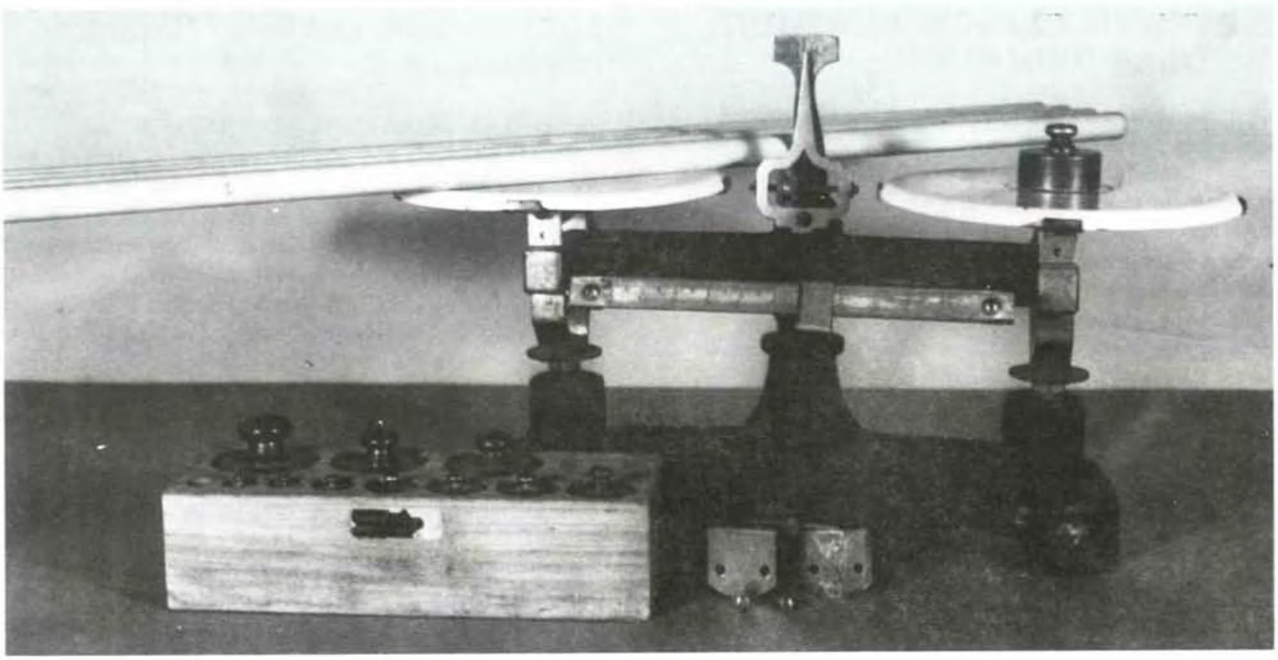


Figure 10.6—Harvard balance.

Figure 10.7—Scale shelter for triple beam balance or Harvard balance.

CHAPTER 11. CLOUDS, SUNSHINE, AND SOLAR RADIATION

The amounts of solar radiation reaching the ground or vegetative cover have an important influence on fuel moisture. Depending on the time of season and available moisture, solar energy can promote both growth and drying. The amount of cloud cover (or state of weather), as routinely observed at fire-weather stations, serves largely as an indicator of solar radiation and related changes in fuel moisture.

Relatively few weather stations in the United States routinely measure incoming solar radiation (or other radiation parameters). Only a few hundred, mostly National Weather Service airport stations, measure sunshine duration, which is a better indicator of the radiation received than is the amount of cloud cover. Observations at fire-weather stations do not distinguish between low, opaque clouds and the higher, thin types through which greater solar radiation can pass.

11.1 Clouds

Unlike the other weather and environmental measurements covered in this handbook, the cloud observations are visual, employing no instruments.

CLOUD FORMS

Details concerning cloud types, or forms, are helpful for various purposes. This is particularly true with clouds that have vertical development, because of their importance as potential lightning producers. These clouds, and "stratiform" types, also serve as indicators of atmospheric stability or instability.

A cloud is a visible aggregate of water or ice particles, or both, that is based above the ground surface (such an aggregate lying on the surface is known as fog). Clouds, varying greatly in their origin and appearance, have been classified into certain basic, characteristic forms. The "International System" for cloud classification lists 10 major cloud forms (genera) within three height classes (families), together with recognized species and subspecies.

A simplified cloud classification is presented in figure A3.1, appendix 3. Some clouds forms are illustrated in figures A3.2 through A3.10, appendix 3.

CLOUD COVER

Cloud cover refers to the fraction of the sky (in tenths) that is covered by clouds or obscured by phenomena such as fog or smoke. The following cloud cover classification, together with code numbers, is used in fire-weather observations (Deeming and others 1977):

Clear (code 0)—Cloud cover less than $^1/_{10}$.
Scattered clouds (code 1)—Cloud cover $^1/_{10}$ to $^5/_{10}$.
Broken clouds (code 2)—Cloud cover $^6/_{10}$ to $^9/_{10}$.
Overcast (code 3)—Cloud cover more than $^9/_{10}$ (completely overcast or overcast with small breaks).
Obscured by fog (code 4).

11.2 Sunshine and Solar Radiation Instruments

SUNSHINE DURATION RECORDERS

Two main types of sunshine duration recorders are in use in the United States: (1) the Campbell-Stokes recorder, which focuses radiation from the sun to burn a trace in a card, and (2) the Foster photoelectric sunshine switch, a remote recording instrument used at primary (airport) stations of the National Weather Service. The Foster sunshine switch (Foster and Foskett 1953) is a successor to the Marvin electrical sunshine recorder (Middleton and Spilhaus 1953; World Meteorological Organization 1971). The Foster instrument consists of a pair of electrically connected selenium photocells, one exposed to direct sunshine and the other shielded; direct radiation produces a signal that activates a recorder or counter.

Sensitivity differs between these two instruments and thus their recorded sunshine durations are not comparable. Only the Foster switch allows reliable measurements when the sun is near the horizon (near sunrise and sunset). The Campbell-Stokes recorder, however, may more closely measure the duration of "bright" sunshine. It is more commercially available and is relatively simple in operation, acting as a sundial. A disadvantage of the Campbell-Stokes recorder is the variation of its sensitivity threshold (Mazzarella 1985). Sunshine recorders require very careful installation and adjustment to minimize errors (chapter 20).

Campbell-Stokes Sunshine Recorder—The Campbell-Stokes sunshine recorder (fig. 11.1) consists basically of a "glass sphere about 4 inches in diameter mounted concentrically in a section of a spherical bowl, the diameter of which is such that the sun's rays are focused sharply on a card held in grooves in the bowl" (World Meteorological Organization 1983). Three different cards are used during the year—for defined summer, winter, and equinoctial periods. The radiant heat of the sun, concentrated by the sphere, burns a track in the card; the cards are graduated in $^1/_2$-hour increments. The width and depth of the burn depend on the sun's brightness. Specific rules are provided for evaluating the traces (above reference). Precautions must be taken in cold weather to keep the sphere free of frost or snow. This can be accomplished by use of a heating element and fan or the application of deicing fluid.

PYRANOMETERS

There are various types of instruments available for measuring solar radiation (Fritschen and Gay 1979; Szeicz 1975). The type most often employed for general climatological and weather monitoring purposes is termed a pyranometer. Such an instrument measures the total, or global, radiation (both the direct beam radiation and the diffuse, or sky radiation) received on a horizontal surface. The sensor usually employs a thermopile (a series of very closely spaced differential thermocouples) or, in less expensive and less precise models, a silicon photovoltaic cell.

Figure 11.1—Campbell-Stokes sunshine recorder. (Photo courtesy of Qualimetrics, Inc.)

Eppley Pyranometer—One of the most precise pyranometers, adopted as a standard reference instrument in the United States, is the Eppley black and white pyranometer (fig. 11.2, top). (A similar instrument is shown in figure 11.2, bottom.) Its glass cover, or dome, is transparent to most of the solar radiation spectrum. The black and white areas, differing greatly in their absorption or reflection of radiation, develop a temperature difference that increases with radiation intensity. This difference, sensed by the thermopile, produces an output voltage proportional to the radiation. Instrument response time for a 66 percent change in radiation is 3 to 4 seconds. The output, converted to radiation units, can be read either from a strip chart recorder or an electronic integrator that displays or prints the cumulative count between settings.

Bimetallic Pyranograph—The bimellatic recording pyranometer, or pyranograph (fig. 11.3), is a relatively simple, self-contained and mechanically operated instrument. Also termed an actinograph, it is slower responding and less precise than either the thermopile or silicon-cell pyranometer. Its dome transmits about 90 percent of the solar radiation within a somewhat restricted spectrum. Radiation intensity is measured by the temperature difference between black and white bimetallic strips. The recording chart is fastened to a rotating drum, as in a hygrothermograph (section 7.7). Overall accuracy is within 5 to 10 percent.

Figure 11.2—Black and white pyranometers: Eppley model (top, photo courtesy of Sierra-Misco, Inc.); star pyranometer (bottom, photo courtesy of Qualimetrics, Inc.).

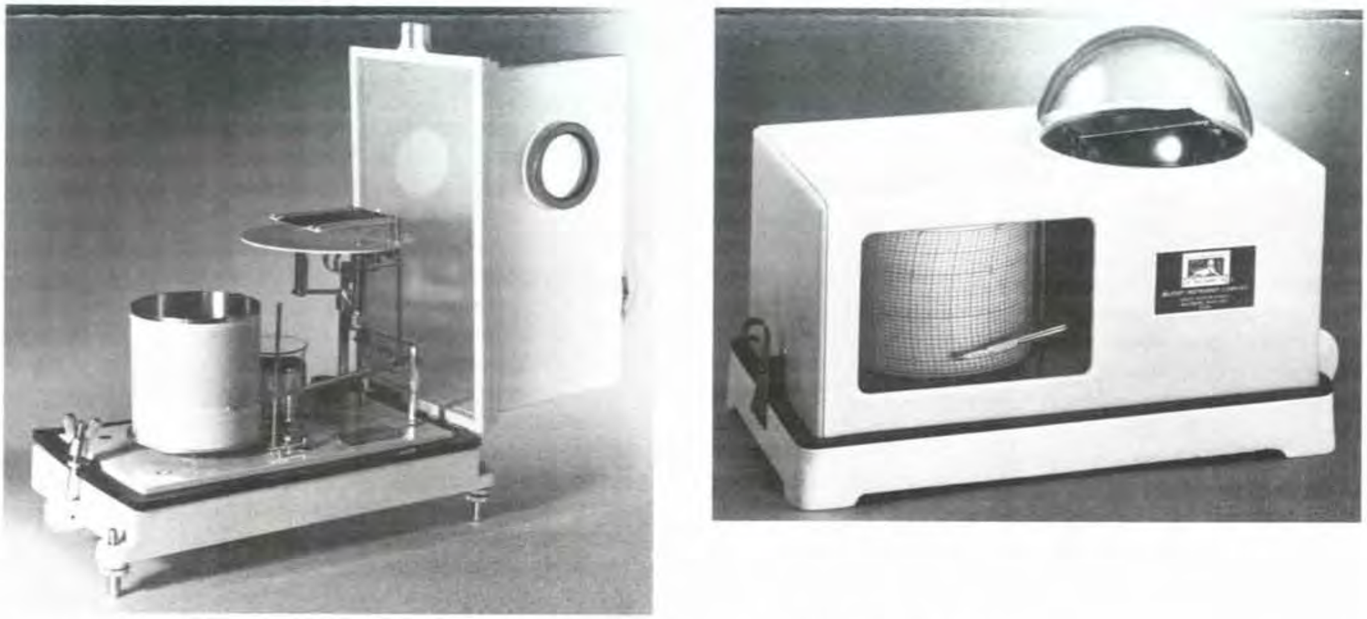


Figure 11.3—Bimetallic pyranograph, two models. (Photos courtesy of Qualimetrics, Inc., left, and Belfort Instrument Company, right.)

CHAPTER 12. EVAPORATION

Measurements of evaporation provide an estimate or index of the actual evaporation from free water surfaces and the soil. The measurements may also indicate the potential water use (transpiration) by vegetation. The amount of evaporation, given the available water, integrates the effects of variables such as solar radiation, air and water surface temperatures, relative humidity, and windspeed.

12.1 Evaporation Pans

The most widely used evaporation indicator in the United States is a large pan filled with water. Observations measure the change in water-surface level, correcting for precipitation. Some pans are sunken (installed below ground level) or mounted on anchored floating platforms on lakes, but the most practical exposure is at a small height above ground (World Meteorological Organization 1983). The aboveground exposure allows some objectionable boundary effects, however, such as radiation on the side walls and heat exchanges with the pan material. These effects tend to increase the evaporation. The measured amounts are thus multiplied by a coefficent, such as 0.70 or 0.80, to more closely estimate the evaporation from naturally existing surfaces. The standard pan in the United States, mounted aboveground, is termed the "Class A" evaporation pan.

12.2 Evaporation Station Equipment

Standard, daily measurements at evaporation stations in the United States include (1) the 24-hour evaporation from a Class A evaporation pan, (2) precipitation (for which the pan water level reading is adjusted to obtain the actual evaporation), (3) wind movement near the rim of the pan, and (4) maximum and minimum water temperatures in the pan. Soil temperatures may also be measured (chapter 13).

CLASS A EVAPORATION PAN AND ACCESSORIES

The standard Class A evaporation pan (fig. 12.1) is constructed of noncorrosive metal—galvanized iron,

Figure 12.1—Class A evaporation pan on wooden support, with installed accessory equipment: stilling well (containing fixed-point gauge), submerged-mount Six's thermometer, and totalizing anemometer. (Photo from National Weather Service.)

Figure 12.2—Stilling well with hook gauge installed; leveling screws in base plate. (Photo from U.S. Department of Commerce 1972.)

stainless steel, copper, or Monel—and normally left unpainted. It is cylindrical, with an inside depth of 10 inches and diameter of 47½ inches. It is supported on an open wooden frame, constructed of 2- by 4-inch or heavier lumber that is either rot resistant or treated with a wood preservative. The pan is filled with water to a depth of 8 inches (2 inches below the rim). The water-surface level is measured by either a hook gauge or fixed-point gauge supported or mounted in a stilling well. The well provides a water surface that is undisturbed by possible ripples. Changes in water level between observations, adjusted for precipitation, represent the evaporation.

Stilling Well for Hook Gauge—The stilling well used with the hook gauge (fig. 12.2) consists of a cylinder made of brass, Monel, or other noncorrosive metal. To minimize electrolytic action, the metal should be the same as that used in the pan. The cylinder is about 9 inches high and 3½ inches in outside diameter. It is mounted on a triangular or three-legged base plate of the same material, resting on the bottom of the evaporation pan. The top of the stilling well is leveled by three screws provided in the base plate. A small tube or pipe through the center of the base plate allows only slow movement of water to and from the well, thus preventing possible rippling of the water surface within the well.

Hook Gauge—The hook gauge (fig. 12.3), also termed a micrometer hook gauge, can measure changes in the pan water level to the nearest thousandth of an inch, but actual observations are recorded to the nearest hundredth of an inch. The gauge consists of a hook in the end of a stem that is graduated to tenths of inches over a range of several inches. A three-legged "spider" and adjusting-nut assembly supports the hook inside the stilling well and provides for height adjustment of the hook to measure the water level (U.S. Department of Commerce 1972). A circular hundredths scale is situated within the spider.

Fixed-Point Gauge—The fixed-point gauge (fig. 12.4) consists of a pointed ⅛-inch rod affixed within a stilling well to the center of the base. The tip is located 7½ inches above the bottom of the pan (2½ inches below the rim). Two small openings in opposite sides of the well, near the base, allow movement of water to or from the well while preventing possible rippling of the surface.

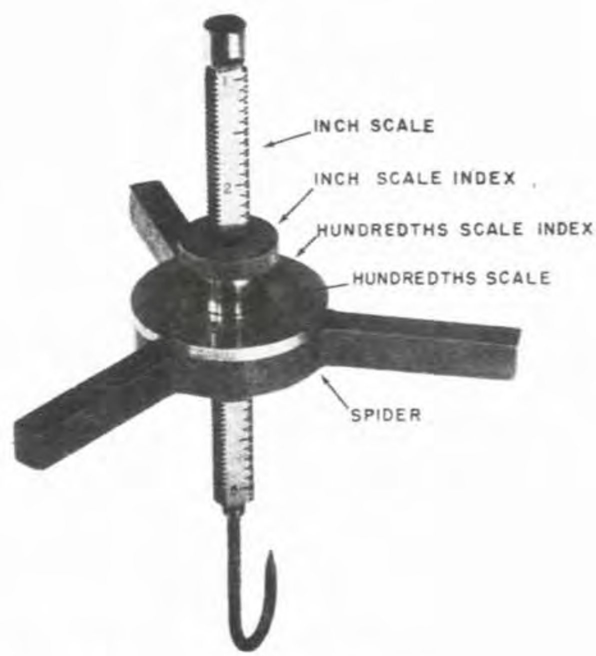
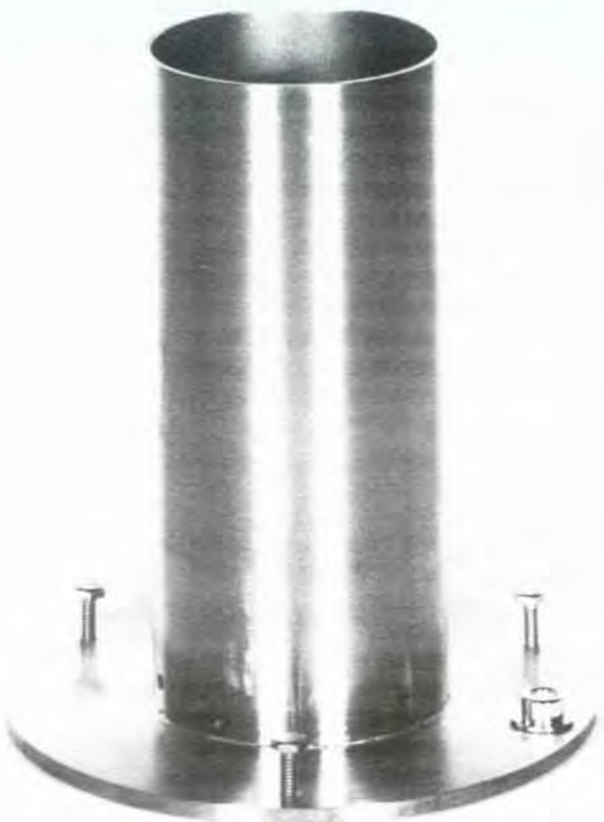


Figure 12.3—Detailed view of hook gauge, showing a reading of 2.53 inches. (Photo from U.S. Department of Commerce 1972.)



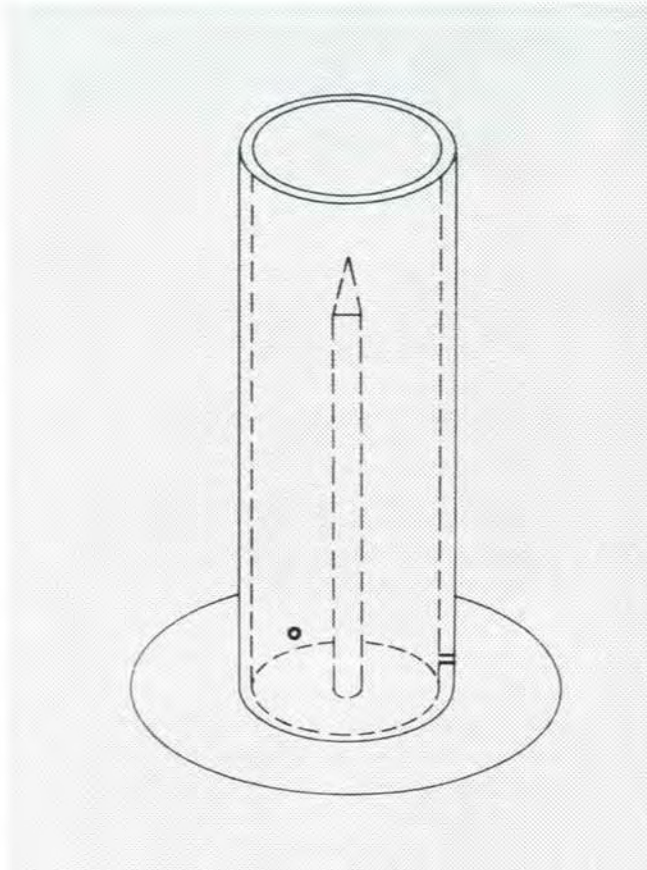


Figure 12.4—Stilling well for fixed-point gauge (photo courtesy of Sierra-Misco, Inc.); the gauge is affixed inside, as shown in drawing at right (from U.S. Department of Commerce 1972).

A transparent plastic measuring tube (fig. 12.5) is used to add or remove water at each observation until the water surface coincides with the tip of the fixed point. The tube is 15 inches deep and has a cross sectional area one hundredth that of the evaporation pan; the inside diameter, thus, will be 4.75 inches for a 47.5-inch pan. Graduations on the tube are at 1-inch intervals, corresponding to 0.01-inch increments of water level in the pan.

Water Storage Tank—At stations some distance from a water source, a water storage tank at the site will provide a convenient supply of water for refilling the evaporation pan. Tank capacity should be at least 30 gallons. In the absence of rainfall, this amount will last only 2 weeks during a month with 8 inches evaporation. The water placed in the tank should be free of oil.

SUPPLEMENTAL INSTRUMENTS

Precipitation Gauge—The basic precipitation gauge used at an evaporation station is the standard, large-capacity, 8-inch nonrecording gauge. A Universal recording (weighing) gauge may be added. These two gauges have been described in sections 9.1 and 9.2.

Pan-Level Totalizing Anemometer—The anemometer for measuring wind movement over the evaporation pan is mounted on the wooden pan support, with the center of the cups about 6 to 8 inches above the rim of the pan. A 3-cup contacting anemometer is usually employed; it has both 1-mile and 1/10- or 1/60-mile contacts and self-contained readout, as previously described in section 8.2 (fig. 8.5). Most widely used among these anemometers is the 5-digit odometer type, which is replacing the older, circular-dial type.

Water Temperature Thermometer—Maximum and minimum pan-water temperatures are usually measured with a Six's thermometer (section 7.4); however, a recording thermometer (such as an electrical resistance or mercury-in-steel type) having a sensing element suitable for immersion in water may also be used (U.S. Department of Commerce 1972). The recommended Six's model has its scale markings on the glass tube; the range is from +20 to 110 °F, in 1-°F divisions. The thermometer is provided with a white, reflective shield over its bulb for protection and shading. Two types of mount have been employed—a float mount and a submerged mount (fig. 12.6), with the submerged mount now favored by the National Weather Service.

In the float mount, the thermometer is mounted horizontally on a plastic (acrylic) frame supported by a float at each end. The thermometer rides about one-fourth inch

Figure 12.5—Plastic measuring tube used with fixed-point gauge. (Photo courtesy of Sierra-Misco, Inc.)

below the water surface. Flexible lines of proper length are attached between the two floats and an anchor to keep the thermometer in place, 1 ft from the edge of the pan and the stilling well.

In the submerged mount, the thermometer is mounted horizontally on a plastic frame that rests on the bottom of the pan. A nonmagnetic metal handle is fastened to the bulb end of the frame and hooked over the south rim of the pan.

CHAPTER 13. SOIL TEMPERATURE

Soil temperatures are measured at one or more standard depths (section 13.2) in nonirrigated, representative plots (section 22.1). Depending on location, the plot may have sod cover, natural cover, or only bare soil.

13.1 Instruments

Soil temperatures at manual stations are generally measured by either mercury-in-glass thermometers or dial-type thermometers. The dial type preferred by the National Weather Service (U.S. Department of Commerce 1972) is actuated by a mercury-in-steel sensing element, rather than a bimetallic element (section 7.5). Sensors employing thermistors or thermocouples may also be used (Fritschen and Gay 1979; Mazzarella 1985).

MERCURY-IN-STEEL THERMOMETERS

The thermometer shown in figure 13.1, similar to that in figure 7.10, will indicate maximum and minimum soil temperatures. Its mercury-in-steel sensor is connected to a Bourdon-spring drive by flexible, 5-ft stainless steel capillary tubing.

LIQUID-IN-GLASS THERMOMETERS

The most convenient liquid-in-glass (usually mercury) soil thermometers are made with stems bent at approximately right angles; these are suitable for soil depths down to about 8 inches. The scales thus face upward, enabling easy reading without disturbance of the instrument. Such thermometers might not be readable, however, when there is snow cover, which should not be disturbed.

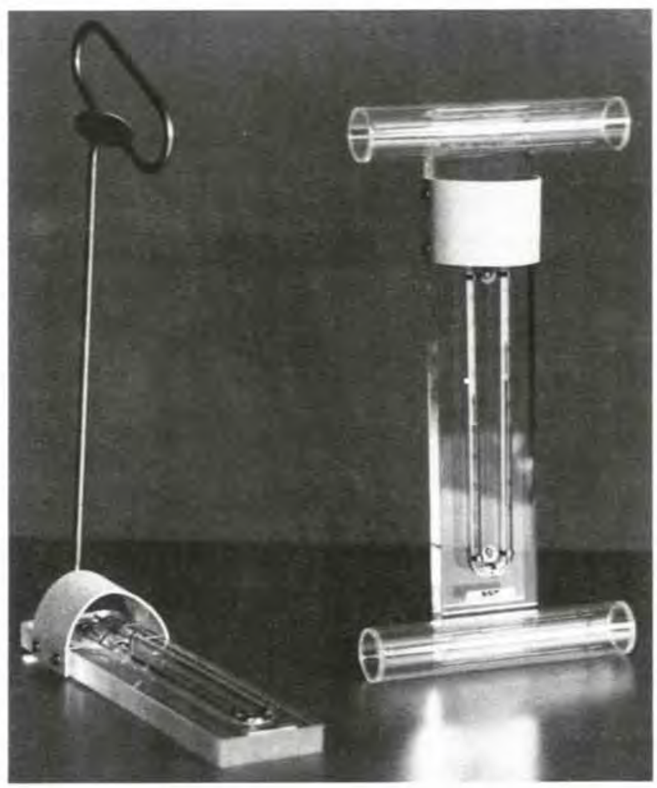


Figure 12.6—Six's water-temperature thermometers, with shields: left, thermometer in submerged mount; right, in float mount. (Photo courtesty of Qualimetrics, Inc.)

Figure 13.1—Soil maximum-minimum thermometer, similar to thermometer in figure 7.10 but with 5-ft flexible armor capillary tubing connected to mercury-in-steel sensing probe. (Photo courtesy of Palmer Instruments, Inc.)

For greater soil depths, mercury-in-glass thermometers should be suspended in thin metal or plastic tubes (World Meteorological Organization 1983); the tops of these tubes should extend above the expected depth of snow cover. The thermometers, themselves, should be mounted in wooden, glass, or plastic tubes, with their bulbs embedded in wax to provide sufficient temperature lag when they are raised for reading.

Special liquid-in-glass, bent-stem thermometers are available for measuring maximum and minimum soil temperatures. These are either of the U-tube (Six's) type or pairs of individual thermometers. The separate maximum thermometer uses a steel index set by a magnet; the minimum thermometer uses a glass index.

THERMOMETER HEAD SHELTER

Thermometer dials (or "heads") must be protected from rain and other elements by a shelter. Several shelter designs, for either mercury-in-steel or electrical instruments, are illustrated by the U.S. Department of Commerce (1972); the dimensions will depend on the number of thermometers installed.

13.2 Measurement Depths

Standard, recommended soil temperature measurement depths (U.S. Department of Commerce 1972) are 4, 8, and 20 inches, in that order of priority. Where the equipment is available, additional depths, in recommended order of priority, are 40, 2, 60, and 120 inches.

CHAPTER 14. SOIL MOISTURE

14.1 Measurement Methods

The accurate measurement of soil moisture has been a difficult instrumentation and sampling problem (World Meteorological Organization 1983). Of the presently available measurement techniques, the direct gravimetric method appears to be one of the most accurate and is commonly used as a calibration control for other methods (though laboratory calibration is preferred where feasible). The gravimetric method, however, wherein a soil sample is weighed before and after drying in an oven, is cumbersome and precludes repeated monitoring of a fixed soil mass. The direct but nondestructive lysimeter method, in which a container is filled with soil and weighed, is very costly; it cannot be used for obtaining soil moisture profiles.

The neutron method (World Meteorological Organization 1983) is considered to be the most accurate and efficient of the indirect methods. The USDA Soil Conservation Service (1972) indicates that both the electrical resistance method and neutron method can give reasonably satisfactory results. These methods, however, may be best suited for determining soil-moisture profiles or changes rather than the actual soil moisture (World Meteorological Organization 1983); careful calibration is necessary (Mazzarella 1985). The tensiometer method, used to indicate soil moisture suction, has limited application because of the instrument's small range of sensitivity. Its main use is in agriculture, for irrigation control.

ELECTRICAL RESISTANCE METHOD

In the electrical resistance method, two electrodes carefully spaced in a block of water-absorbant material are buried in the soil. The block comes into equilibrium with the soil, responding to moisture changes. The electrical resistance of the block, varying with the amount of moisture, is measured by means of a meter connected to the electrodes. The moisture blocks are usually composed of gypsum (plaster of Paris), nylon, or fiberglass, or combinations of these materials. Nylon and fiberglass units (World Meteorological Organization 1983) are more suitable than gypsum for higher soil moisture contents and have greater durability, but they exhibit greater calibration shifts. Gypsum blocks have been combined with fiberglass or nylon, and further modified, to give improved performance.

The resistance method's main advantages are its relatively low cost and the fast speed at which readings can be made. The method is particularly suited for automated, remote recording. For manual type readings, the Bouyoucos and Colman soil moisture meters have had field use by the USDA Soil Conservation Service (1972), which presents operational details. These two instruments employ nylon-reinforced gypsum blocks and fiberglass-mesh blocks, respectively.

NEUTRON METHOD

The neutron method, also termed neutron scattering, employs a fast neutron source and detector combined in an instrument called a neutron probe. The neutrons are slowed down in the presence of hydrogen atoms. Because water is the most significant source of hydrogen in soil, a count of the slowed neutrons as provided by the detector is proportional to the nearby soil water content per unit volume. Although portable, the neutron probe is heavy because of the need for radiation shielding, and it is relatively expensive. Improved, more compact, and automated neutron equipment is being developed. The neutron method is not reliable at shallow soil depths (about 10 inches or less) because some of the neutrons will pass into the air instead of the soil.

In use, the neutron probe is lowered into a noncorrosive access tube that has been installed in the soil (section 22.1); further operational details are given in the preceding two references. It is necessary to follow all instructions for protection against possible radiation hazards.