

UNITED STATES DEPARTMENT OF AGRICULTURE

WEATHER BUREAU

WILLIS R. GREGG, CHIEF

MEASUREMENT OF PRECIPITATION

**INSTRUCTIONS FOR THE MEASUREMENT AND
REGISTRATION OF PRECIPITATION BY MEANS
OF THE STANDARD INSTRUMENTS OF THE
UNITED STATES WEATHER BUREAU**

CIRCULAR E, INSTRUMENT DIVISION
FOURTH EDITION

REVISED, 1936

By BENJAMIN C. KADEL
Meteorologist



UNITED STATES DEPARTMENT OF AGRICULTURE

WEATHER BUREAU

CIRCULAR E, INSTRUMENT DIVISION

(FOURTH EDITION)

Washington, D. C.

MEASUREMENT OF PRECIPITATION

INSTRUCTIONS FOR THE MEASUREMENT AND
REGISTRATION OF PRECIPITATION BY MEANS
OF THE STANDARD INSTRUMENTS OF THE
UNITED STATES WEATHER BUREAU

REVISED 1936

By BENJAMIN C. KADEL

Meteorologist



UNITED STATES
GOVERNMENT PRINTING OFFICE
WASHINGTON : 1936

MEASUREMENT OF PRECIPITATION

CONTENTS

	Page		Page
Rain-gage exposure and installation-----	1, 2	Snow mat-----	17
Standard 8-inch gage-----	2-7	Snow in remote regions-----	18-24
Tipping-bucket gage-----	8-13	Snow stakes-----	18-20
Fergusson weighing gage-----	13-16	Snow samplers-----	20-24
Snow measurements-----	16-25	Snow surveys-----	24-25

1. *Definition.*—The word “precipitation,” as used in meteorology, is understood to include moisture that reaches the earth’s surface in whatever form, as rain, snow, hail, dew, frost, etc., although in practice dew and frost are seldom measured.

2. *Units.*—All forms of precipitation are measured on the basis of the vertical depth of water, or water equivalent, which would accumulate on a level surface if all of it remained as it fell and none flowed or soaked away or was lost by evaporation. Snow, hail, etc., are also measured on the basis of actual depth. The unit for all United States Weather Bureau measurements of precipitation in whatever form is the inch.

3. *Exposure of gages.*—The literature of rainfall measurements abounds with experiments which prove that the most disturbing agency to a proper collection of rainfall is the wind. Even the light wind that prevails 2 or 3 feet above the ground may cause a deficiency of 10 percent in the catch. Records of wind velocity made at Indio, Calif., show two to three times as much wind at 12 feet above the ground as at 1½ feet above the ground in an alfalfa field. This example shows the advantage of a ground exposure for a rain gage. It is therefore important to select for the exposure of the gage a position in some open lot, unobstructed by large trees or buildings. Low bushes, shrubbery, fences, or walls that break the force of the wind are beneficial; but in order that these protecting objects may not themselves intercept rain that would otherwise fall into the gage, they should be no nearer to the gage than their own height. Unfortunately the necessity of locating Weather Bureau offices in large cities renders it in some cases impracticable to find a ground exposure, and then the gage must be exposed on a roof. In such case the middle of a large, flat, or nearly flat, roof should be selected, and all possible advantage should be taken of parapets, penthouses, etc., that will break the force of the wind. In some instances, fences 6 or 8 feet square have been built upon the roof to protect the gage. There is no satisfactory exposure possible on a pyramidal roof exposed to the wind, or near the edge of any roof exposed to the wind. A description of the site and surroundings should be made a matter of record.

4. *Installation.*—In general, at regular Weather Bureau stations the rain and snow gages will be installed side by side, not nearer to each other than $3\frac{1}{2}$ feet, center to center. At stations where a recording gage is in operation, a standard 8-inch gage should also be exposed for use as a snow gage in the winter and as a check on rainfall in cases of emergency.

5. *Leveling.*—Rain and snow gages are always installed with their receivers level, no matter what the slope of the ground in the vicinity may be.

6. *Description of standard 8-inch gage.*—The gage consists of the following parts: The receiver *A*, figure 1; the overflow attachment *B*; the measuring tube *C*; the measuring stick.

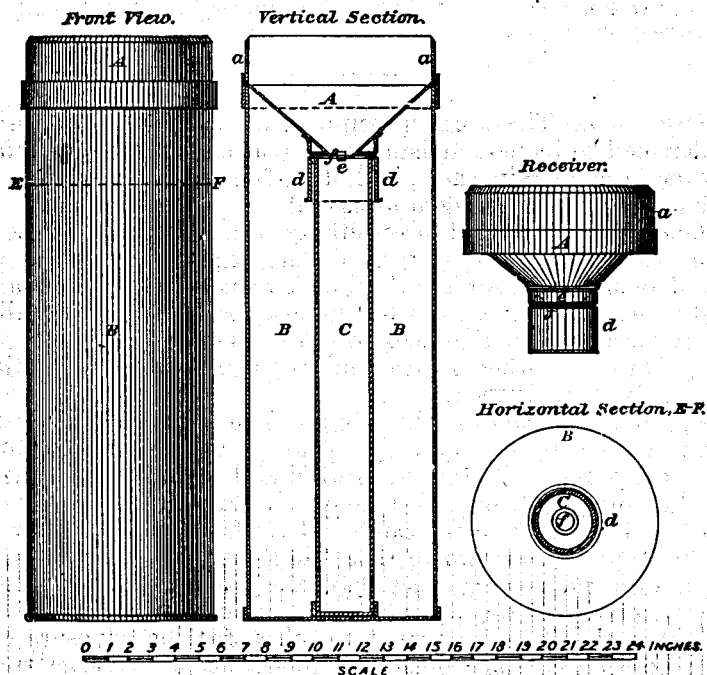


FIGURE 1.—Rain gage, 8-inch, line drawing.

The top cylindrical portion of the receiver, marked *a* in figure 1, is exactly 8 inches in diameter inside, and is provided with a funnel-shaped bottom, which conducts rain falling into the receiver into the tall cylindrical measuring tube *C*, the total height of which, inside, is exactly 20 inches. The diameter of this tube is much smaller than the large receiving tube *a*, being only 2.53 inches. In consequence of this a small amount of rain falling into the receiver and flowing into *C* fills the latter to a depth greater than the actual rainfall in proportion as the area of the receiver is greater than the area of the measuring tube. In the standard gages of the Weather Bureau the depth of the rainfall in accordance with this principle, is magnified just 10 times. The receiver *A* has a sleeve *d*, figure 1, which slips over the tube *C*. When the rainfall is very heavy the tube *C* may be filled to

overflowing. In this case the excess of rainfall escapes between the sleeve *d* and the tube *C* and is retained in the large overflow attachment *B*. The overflow has the same diameter as the collector *B*, namely, 8 inches, and is used separately as a snow gage in the manner explained in paragraph 4. The several portions of the gage are also illustrated in figure 4.

7. *Measuring stick*.—The measuring stick is best made of a strip of straight-grained cedar, nine-sixteenths of an inch wide, seven sixty-fourths of an inch thick, and 24 inches long, and graduated into inches and tenths of inches. Remembering that the actual depth of the rainfall is magnified 10 times, as explained above, it is plain that if the water be 10 inches deep in the measuring tube the actual rainfall must have been only 1 inch, or if the water in the tube be only one-tenth of an inch (or written as a decimal, 0.1 inch) deep, then the rainfall must have been only one one-hundredth of an inch (or written as a decimal, 0.01 inch).

8. *Rain-gage box support*.—The box in which the gage is shipped serves well as a stand or support for the instrument and is in some respects superior to the iron tripod for the purpose (see par. 48), although not as lasting. The wooden head may be removed by withdrawing the four screws that hold it in place, after which it is to be lowered to the level of the four screw holes in the sides of the box about 10 inches from the bottom. The same four screws then serve to hold it in the new position. Four flat stakes driven down, to which the box support is attached by nails or screws, serve to anchor it to the ground. Provision for air circulation underneath the bottom board decreases the liability to decay.

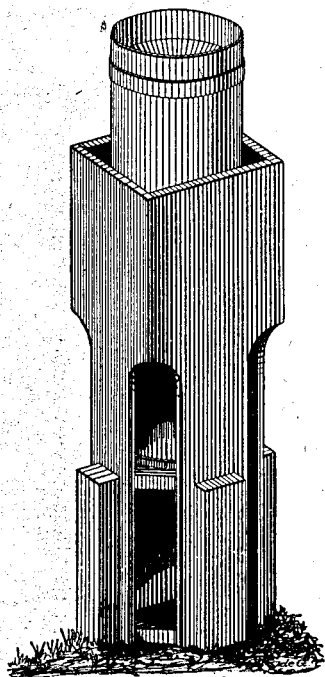


FIGURE 2.—Rain gage, 8-inch, in box support.

9. *Iron-tripod support*.—Figure 3 illustrates the gage mounted in the standard iron-tripod support, which, when erected upon a roof platform, is easily secured with screws through the feet. When a ground exposure is selected for the gage, it will be sufficient to drive down three substantial wooden stakes until about flush with the surface and screw the feet of the tripod to them. If the ground is so hard that the top of the stakes are bruised in pounding, it will be best to stop driving a few inches short of the surface and saw off the projecting stakes to the proper level, then secure the screws firmly in the stakes. A better method is to fasten the feet to a concrete walk with lead-sheathed anchor screws.

10. *To measure rainfall and snowfall: Rainfall*.—The depth of the water in the 8-inch gage is measured by inserting the measuring stick into the gage through the small hole in the funnel. When the stick reaches the bottom of the measuring tube, it should be held for

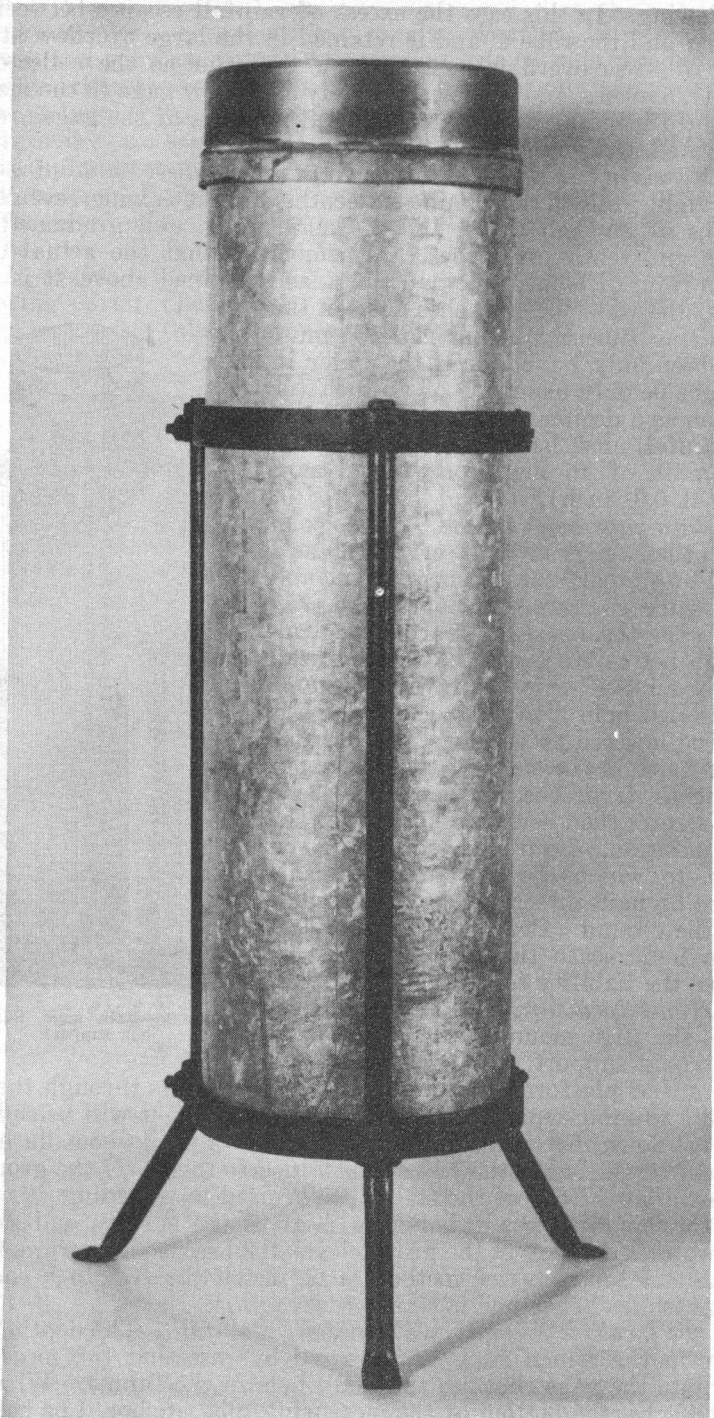


FIGURE 3.—Rain gage, 8-inch, in iron-tripod support.

1 or 2 seconds and then withdrawn and examined to see at which division of the graduation the top of the wet portion comes. The numbering of this division, as stamped on the stick, gives the actual depth of rainfall. In making out records and reports observers should always use the decimal expressions.

11. After measuring and recording the precipitation, the receiver of the gage should be removed, the measuring tube emptied and drained, and the parts placed in position again. Observers should

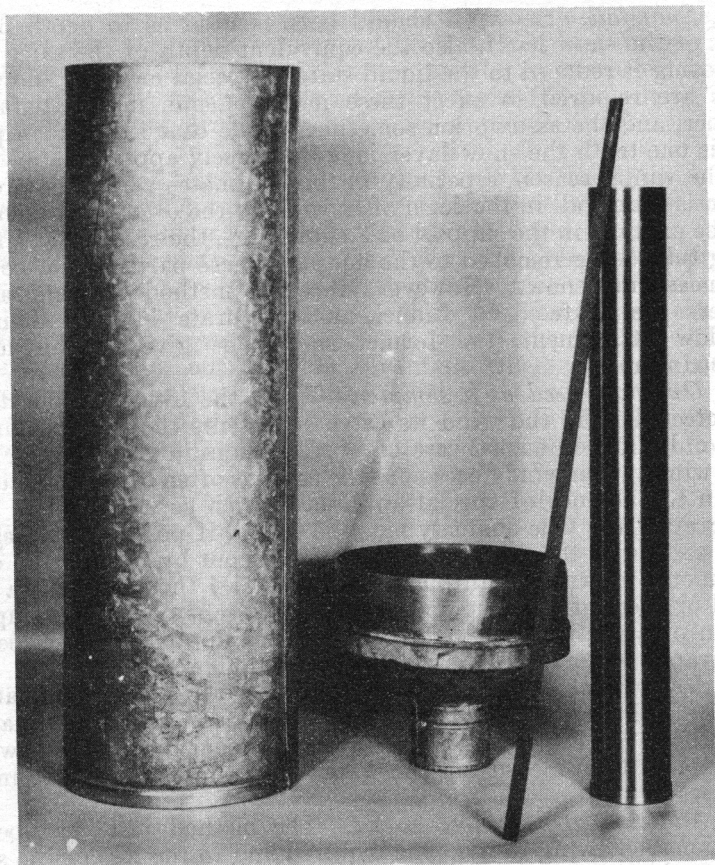


FIGURE 4.—Rain-gage parts.

be careful to replace the measuring tube so that the bottom stands within the ring or bead in the middle of the bottom of the overflow, and in putting on the receiver to see that it passes over the measuring tube and rests squarely upon the overflow.

12. *Measuring tube overflowed.*—When the amount of rain that has fallen more than fills the measuring tube, first carefully remove the receiver, so as not to spill any of the water in the measuring tube, which should be exactly full. If some of the water has been spilled into the overflow, a proper allowance for the amount shall be made, or that remaining accurately measured with the stick, as

already described. The tube is carefully lifted out, so as not to spill any of the water into the overflow, then emptied and drained. The water remaining in the overflow is now poured into the measuring tube, and the depth obtained in the usual way. Suppose this is found to be 0.47-inch rainfall; then, remembering that the measuring tube contains 2 inches, the total amount is 2 inches plus 0.47 inch = 2.47 inches. Or, in case some water was spilled from the measuring tube, the 0.47 inch should be added to the first-measured amount to give the total rainfall.

13. *Snowfall*.—Snowfall should be measured as to depth of the layer of the snow itself, also the equivalent depth of the same layer supposing it reduced to the liquid state. Special methods and apparatus are required to effect these measurements in a satisfactory manner, and the assumption sometimes made that the water equivalent is one-tenth the snow layer is only coarsely approximate. During the winter season, especially in those climates where the precipitation is nearly all in the form of snow, only the overflow attachment will be exposed in the support as a snow gage, the receiver and measuring tube being removed to the house. These parts cannot be used for measuring snow. However, since the method of manufacture renders the knife-edged funnel more accurate in area than the overflow attachment, the former should be given preference in measuring rain.

14. *Overflow used as a sampler*.—When the overflow collector is unprotected from the wind its catch represents the true amount of snow only in the unusual case of precipitation during calms or very light winds. On windy occasions the catch is often highly inaccurate, and in the absence of special appliances, such as described in later paragraphs, the true quantity must be found, if possible, by measuring a section of the freshly fallen snow cut out by forcing the overflow mouth downward through the layer and then slipping a thin board or sheet of metal underneath so as to separate and lift up the section of snow thus cut out. The special appliances described in paragraphs 65 to 70 will be used when available.

15. *Melting the sample*.—Assuming that a representative quantity of snow has been obtained in the overflow, a measurement may be secured by placing the vessel in a warm room until the snow has melted, and then measuring the water in the measuring tube in the usual way.

16. *Addition of measured water*.—The method just described is objectionable, owing to the time required and to the loss of the snow or water by evaporation. The following plan is much better: Take the overflow into the room and pour into it one measuring tube full of water to the brim, preferably warm. In cases of deep snowfall more water will be required. This will melt, or at least reduce to a fluid slush, a considerable amount of snow. The measuring tube should then be filled to the brim from the melted contents of the overflow and emptied, thereby discarding a quantity of water equal to that added. The remaining water in the overflow when measured in the tube then gives the actual depth of melted snow.

17. *The one-tenth rule*.—In addition to this measurement by the gage, a measurement will be made of the actual depth in inches of the snow on the ground. Select a level place of some extent where

the drifting is least pronounced, and measure the snow in at least three places. The mean of these measurements will give the snowfall, which is to be entered in the column of the report headed "Depth of snowfall in inches." Whenever it is impracticable to melt the snow as described in the preceding paragraph, one-tenth of this mean will give an approximate value, in water, for the snow which could not be melted. This value must be set down in the proper column of the report in precisely the same manner as rainfall or snow melted in the gage, but with an appropriate explanatory note on the margin of the sheet. After snowfall has once been measured the same snow should not be measured at subsequent observations. Any fresh snow, however, should be measured and recorded as it falls. For additional instructions for measuring snow see detailed description of methods and apparatus beginning with paragraph 46.

18. *To determine amount by weighing.*—When there is at hand a trustworthy spring balance or other form of weighing device, the contents of the gage may be weighed, and the corresponding depth of water determined from the table below. It is best to empty the water or snow into a lightweight container such as a pail made of thin sheet metal or aluminum in order that the tare may not be too great. It is, however, possible to weigh the entire gage and contents, a plan of considerable advantage when rain is frozen in the gage and the observer is limited for time.

19. *Conversion table.*—Depth of water corresponding to the weight of snow (or rain) collected in an 8-inch gage is given in the following table:

[1 pound equals 0.55 inch]

Weight (pounds)	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
	<i>Inch</i>	<i>Inch</i>	<i>Inch</i>	<i>Inch</i>	<i>Inch</i>	<i>Inch</i>	<i>Inch</i>	<i>Inch</i>	<i>Inch</i>	<i>Inch</i>
0.0-----	0.00	0.01	0.01	0.02	0.02	0.03	0.03	0.04	0.04	0.05
0.1-----	.06	.06	.07	.07	.08	.08	.09	.09	.10	.10
0.2-----	.11	.12	.12	.13	.13	.14	.14	.15	.15	.16
0.3-----	.17	.17	.18	.18	.19	.19	.20	.20	.21	.22
0.4-----	.22	.23	.23	.24	.24	.25	.25	.26	.26	.27
0.5-----	.28	.28	.29	.29	.30	.30	.31	.31	.32	.33
0.6-----	.33	.34	.34	.35	.35	.36	.36	.37	.38	.38
0.7-----	.39	.39	.40	.40	.41	.41	.42	.43	.43	.44
0.8-----	.44	.45	.45	.46	.46	.47	.47	.48	.49	.49
0.9-----	.50	.50	.51	.51	.52	.52	.53	.54	.54	.55

20. *Description of the tipping-bucket gage.*—The gage comprises five principal parts, figures 5 and 6, namely:

- (1) The tripod support.
- (2) The collector and enclosing case, which are in three pieces.
- (3) The bucket frame.
- (4) The tipping bucket.
- (5) The measuring tube (not shown).

The collector is detachable from the remaining portions of the enclosing case, in order to facilitate access to all parts. This is also true of the middle section of some gages.

21. *The collector.*—The top section, called the receiver or collector, is made of a sharp-edged brass rim, 12 inches in diameter inside, and provided with a funnel-shaped bottom and a small tubulure at the

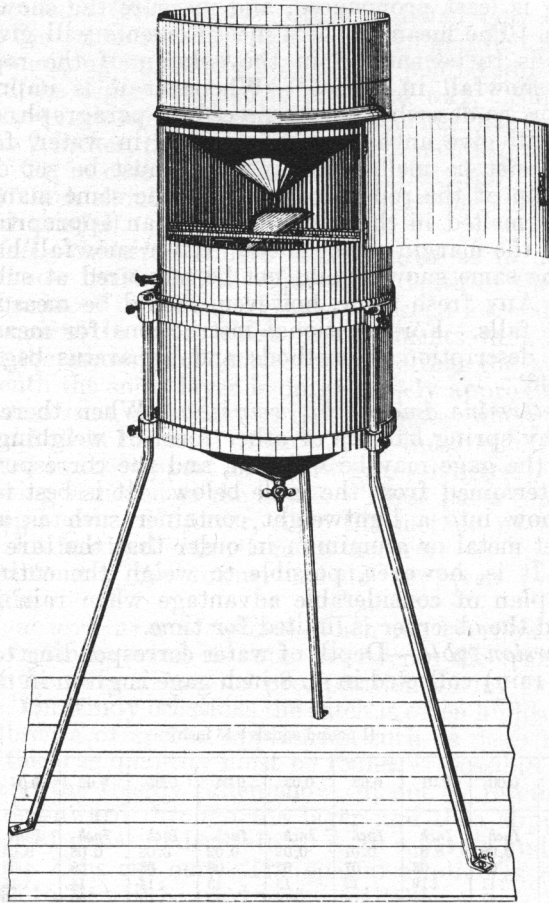


FIGURE 5.—Tipping-bucket gage.

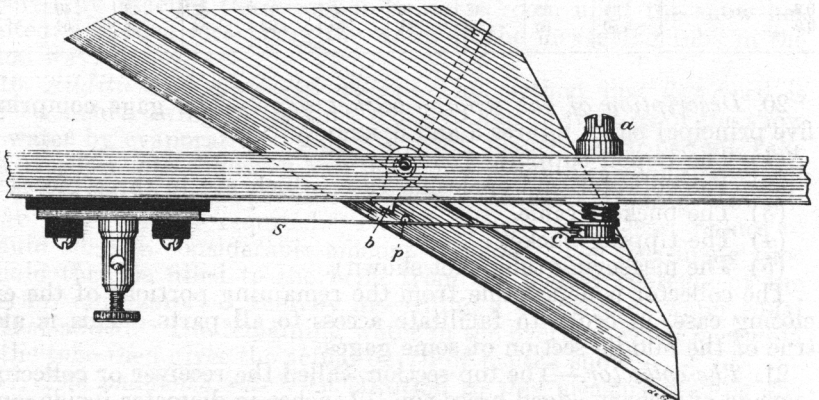


FIGURE 6.—Tipping bucket and frame.

center so that the water falling within the collector is conducted to a point directly over the center of the tipping-bucket bearings. The middle section is made of copper, with a hinged door. The lower section, or reservoir, is also of copper, and is provided with a brass stopcock at the bottom for emptying the gage of water.

22. *Tipping bucket and frame.*—The tipping bucket and a portion of the frame are shown in figure 6. The bucket is mounted on a detachable brass frame carried on insulated brackets within the enclosing case. A central partition, indicated by dotted lines in figure 6, divides the bucket into two equal compartments. The trunnions forming the axis upon which the bucket tips are placed below its center of gravity, and the bucket is further supported in one or the other of two limiting positions by either of two blunt knife-edgewise stop pins located on the side of the bucket opposite that shown in the picture. In either position of the bucket one or the other of the compartments will receive and retain the water delivered through the funnel of the collector. The weight of the bucket and the position of its center of gravity have been so adjusted in relation to its supports that when one of the compartments has been charged with the quantity of water representing one one-hundredth of an inch of rain in the 12-inch gage, the bucket tips upon its bearings, emptying the water from the one compartment, and at the same moment presenting the other compartment to receive the incoming water. The water thus delivered from the buckets is retained in the reservoir section for subsequent measurement in bulk.

23. *Automatic registration.*—The automatic registration of each hundredth of an inch of rainfall, that is, each tip of the bucket, is effected by aid of the electrical circuit closer shown in figure 6. Short sectors *b* are attached to each trunnion of the tipping bucket. When the bucket is at rest in either of its limiting positions, the sectors stand near to, but not in contact with a pair of circuit-closing springs of which the insulated one is shown at *S*.

24. *Electric contact.*—In the act of tipping, after the bucket has moved a little, the sectors *b* make contact with the springs and rub over them during the greater part of the subsequent motion. This closes the electric circuit which is formed between the whole metallic framework, including the bucket, and the insulated spring *S*. During the last portion of the tip of the bucket the sector *b* slips off and moves a small distance away from the springs, thus opening the electric circuit, and also leaving the bucket perfectly free to tip with the next hundredth of an inch of rain.

25. *Contact insurer.*—The contact of the sectors *b* with the springs will generally close the electric circuit; nevertheless, when the contact spring *S* is deflected by the passage of the sector *b* the platinum-tipped end at *c* makes contact with the platinum point attached to the adjustable post *a*, thus providing a second simultaneous independent closure of the electric circuit.

26. *Adjustment of contact spring.*—The contact spring is in proper adjustment when the end *c* rests against the insulated point on the adjusting screw *a* and when, upon tipping the bucket, the sectors *b* rub rather easily over the springs; at the same time the platinum tip at *c* must make contact with the platinum point on the adjustable

screw *a*. If *p* is but slightly touched by the sector *b*, or is missed entirely, or if *p* must be pushed aside considerably and presses hard against the sector while passing, these defects may, in general, be remedied by properly turning the screw *a*. In some cases it may be necessary to bend the spring slightly as well as to adjust the screw *a*. Observers are particularly cautioned to remedy faulty adjustments of the contact springs. All instruments are in perfect adjustment when sent out, and little or no occasion should arise for readjustment if the mechanisms are properly cared for. The holes in which the axis of the bucket rests are intentionally about twice the diameter of the pinions in order to diminish the friction to the minimum. One of the holes is slotted on top to permit the removal of the bucket for cleaning or other purpose.

27. *Double-contact springs*.—To insure electrical connection during tipping, buckets are provided with two spring contacts similar to the one described above, except that the end and the contact at *c* are omitted in some cases. The second spring, with its corresponding sector, is placed on the opposite side of the bucket from that shown in figure 6.

28. *Back-tipping, or rebounding, of bucket*.—If the bucket is placed in the frame with the stop pins on the front side, that is, so as to strike on the side of the supporting frame having the slotted opening and binding posts, it will be found that during rainfall the recoil of the bucket, on tipping, will frequently cause it to rebound and produce two steps of the recording pen in quick succession. These are apparent on the record and are due to the faulty position of the bucket which must be placed with the stop pins on the rear side of the frame, in which position there is scarcely any rebound.

29. *Instructions for mounting*.—When shipped, the brass frame carrying the tipping bucket is generally separate from the gage, and the tripod support is in parts. The manner of putting the latter together will be easily understood from a view of the completed tripod in figure 5. The bucket frame is readily placed in position within the enclosing case and secured to the brackets. The binding posts on the frame should come on the side nearest the door in the middle section.

30. *Accuracy of measurement*.—The accuracy with which any given bucket will deliver a certain quantity of water at each tip has been experimentally investigated. Although every precaution has been taken to secure the greatest accuracy in the adjustment of the buckets, yet, owing to unavoidable irregularities in the action of the water in the buckets, and to the fact that a very small discrepancy in the volume of a single tip may become important in the total volume of 100 or 200 tips, it will often be found that the total volume shown by the automatic record fails to agree with the actual volume of water retained in the reservoir.

31. This may result from one or more of several unavoidable causes. The buckets have been adjusted to deliver the proper volume of water for slow and moderate rates of rainfall, such as most frequently prevail. During heavy showers, when, for example, rain is falling at the rate of 5 or 6 inches per hour, each bucket will be filled to the tipping point in from 6 to 7 seconds, or thereabouts. Inasmuch as a very small but nevertheless perceptible amount

of time is required for the bucket to tip far enough to cut off the inflow of water, it is obvious that during such rapid rainfall an appreciable quantity of water will flow into the bucket after it has begun to tip. Accurate measurements made at this office have shown that the time required by the standard buckets to tip from the starting point to a point where the inflow of water is cut off is about three-tenths of a second. It therefore follows that when the water is flowing into the bucket at a rapid rate—such, for example, as will fill the bucket to the tipping point in 6 seconds—then during the three-tenths of a second occupied in tipping water will continue to flow into the bucket, and the excess thus delivered will be about one-twentieth of the whole amount; that is, an inch of rainfall will cause the bucket to tip only about 95 times, whereas the same amount of rain at a slow rate would cause the bucket to tip 100 times. The discrepancy from this cause has been reduced as much as possible, but it cannot be entirely eliminated in the case of small buckets—such, for example, as will make 100 tips per inch of rainfall.

32. *Effects of dirt.*—It will be found also that the different hygroscopic conditions of the metal surfaces cause the water to wet the buckets in a different manner on different occasions. This will lead to a slight difference in the volume of water delivered per tip of the bucket.

After being thoroughly wetted with more or less dirty rain water, which afterward dries away, a sediment is left upon the metal surfaces; as this alters their hygroscopic character, it is desirable that at least the inside surface of the bucket be kept as clean as possible. The bucket should be removed from the supporting frame from time to time as may be required by the atmospheric conditions at the several stations, and the compartments thoroughly cleaned. The use of a mild scouring agent is recommended. No deposits of dirt should be allowed to accumulate in the bearings of the axis or about the small pinions of the bucket. Special pains must be taken to avoid bending trunnions, as slight changes here will have an important effect in changing the volume of water delivered per tip.

33. *Corrosion.*—The most serious cause of error in the amount of water delivered per tip has been found to be due to the effects of dust and corrosion on the frame and stop pins of the bucket. It is absolutely necessary that the stop pins and points on the frame where the pins strike be frequently cleaned. Of course the bucket and frame should be kept clean elsewhere also, but as soon as the pins and points of contact on the frame become dirty a slight adhesion is established between the two then in contact. When the dirt at these points becomes wet or damp, as it does during long rains, the adhesion becomes aggravated, and more water must enter the bucket in order to overcome the sticking at the stop pins, thus causing a more or less serious deficiency of record.

34. *Effect of faulty leveling.*—If the brass frame which carries the bucket is not properly leveled, one of the compartments will deliver a greater and the other compartment a less volume of water, per tip than the normal amount, although the average of the two will still remain very nearly the normal volume. While the errors resulting from small defects of level are not serious, it is desirable

that some pains be taken when installing the gage to make the frame upon which the bucket is mounted as nearly level as practicable.

35. *Recording mechanism.*—The apparatus designed to record the tips of the bucket is attached to the so-called triple register. The record sheet upon this instrument moves at a relatively rapid rate. Nevertheless, in order to render the registration of the most rapid rates of rainfall legible, the recording pen traces its record in a zigzag line of steps, each step represents a hundredth of an inch of rain, and one complete zigzag comprises 10 steps. In the majority of cases the individual steps are perfectly legible, but in records of very rapid rates each individual step cannot always be discerned. The points of the zigzag, however, are separated by 10 tips or steps and are distinguishable under even the most rapid rates. The recording mechanism is described in detail in Circular D, Instrument Division.

36. The recording pen on the zigzag trace should be adjusted to fall within the available space on the record sheet so as not to encroach upon the anemometer record.

37. When a record sheet is to be changed, the whole pen arm is lifted a short distance upon the staff supporting it, and turned to one side, thus providing free access to the cylinder. In replacing the pen, care must be exercised to place the steel pin within the groove of the cam wheel, which produces the zigzag motion.

38. When the pen of the rainfall magnet has been lifted from the sheet temporarily, care should be exercised not to disturb or move the armature of the magnet or to make any change in the position of the ratchet cam, except such as results from the closure of the electric circuit. If these parts are not disturbed, the pen, when replaced, will continue its trace of steps in proper sequence relative to the original trace. By this precaution the pen may be lifted from the sheet for a short time while record is being made, and although a few steps of the cam may be taken during the interruption of the record and of which no corresponding trace is made, yet an examination of the record with respect to the complete zigzag will show the number of steps less than 10 that may have been lost.

39. *Check readings.*—Owing to unavoidable sources of errors in the volume of water delivered per tip of the bucket under various circumstances already explained, it is necessary that when rain has been recorded the total volume of water in the gage shall be checked with the automatic record, and for this purpose the observer will enter upon the record sheet, when changed, the stick measurement of the gage.

40. *Check readings, how made.*—To ascertain the total volume of water in the gage the water retained in the reservoir will be drawn off into the brass measuring tube, with which each gage is provided, and the amount measured in hundredths of an inch by stick in the usual way.

41. Observers are cautioned against using the small brass measuring tube belonging to the ordinary (8-inch) gage for measuring the rainfall collected in the tipping-bucket (12-inch) gage. If, from necessity, the small tube is used, the apparent depth of rainfall measured in the smaller tube must be divided by 2.25, in order to ascertain the true depth of rainfall in the 12-inch gage.

42. *Precautions against freezing.*—As the tipping-bucket gage does not record snow or similar precipitation in the solid form, observers will use all necessary precaution to prevent the collection of partly melted precipitation which may subsequently freeze and injure buckets, or otherwise make the gage unserviceable. When such injuries are probable, the cylindrical portions of the gage should be removed to the office, or covered.

43. The Marvin float rain gage, described in the fourth revised edition 1932 of this publication, is no longer issued to Weather Bureau stations; hence, description of it is omitted.

44. *The Fergusson weighing rain and snow gage.*—This gage is used but little in the Weather Bureau because it does not meet public demands for immediate information about rainfall as well as does the tipping bucket gage. Its purpose is to record at the particular spot chosen for its exposure the amount and time of occurrence of precipitation in any form, such as rain, snow, hail, sleet, etc. The action of the gage is best explained by reference to figure 7, in which its several parts are shown. By means of a suitable collector *C* the precipitation is directed into the receiver *R*, which is a well-made cylindrical copper vessel resting upon the scale platform *J*. This platform is rigidly connected to a yoke *Y*, whose lower cross member is attached to a strong coiled spring. The upper end of this same spring is attached to a bracket *E*, the purpose of which is to provide a rigid point of suspension. This point of suspension may, however, be adjusted up or down to a slight degree by turning the screw *O* to permit setting the recording pen to the zero of the sheet when the gage is empty. The movement of the receiver-platform-yoke assembly produced by the added weight of the precipitation in the receiver is transmitted through a series of multiplying levers to the recording pen. Ordinarily a system of this kind would provide for only one traverse of the pen across the record sheet; but in this instrument there has been introduced an ingenious balanced linkage by means of which continuous downward movement of the receiver-platform-yoke assembly causes the pen to make three traverses of the sheet; that is, from its zero position to the top of the sheet, back again to zero, and again to the top. Each traverse of the sheet represents 3 inches of precipitation, and the total capacity of the instrument is therefore 9 inches.

The clock cylinder is of the same size and style as the well-known thermograph clock, but its rate of speed is such as to provide a complete revolution in 24 hours. The right-hand margin of the record sheet is trimmed close to make the scale continuous when the sheet is on the cylinder, to which it is secured by means of rubber bands. The record may thus be repeated on the same time scale day after day, using the same record sheet until rain has fallen, when the sheet is removed for preservation. When abrasion and consequent spreading of the ink indicate that the pen has been running on the same line for too long a time, the pen can be raised a little, say one-tenth of an inch, so that a record of precipitation will leave a clear, sharp line. The total in such case is to be measured from this new zero. The funnel *F* is designed to be attached to the lower portion of the collector *C* to prevent evaporation, and also to minimize the effects of gusts of wind, which by their impact may cause momentary oscillations of the pen. This funnel must be removed when snow is expected.

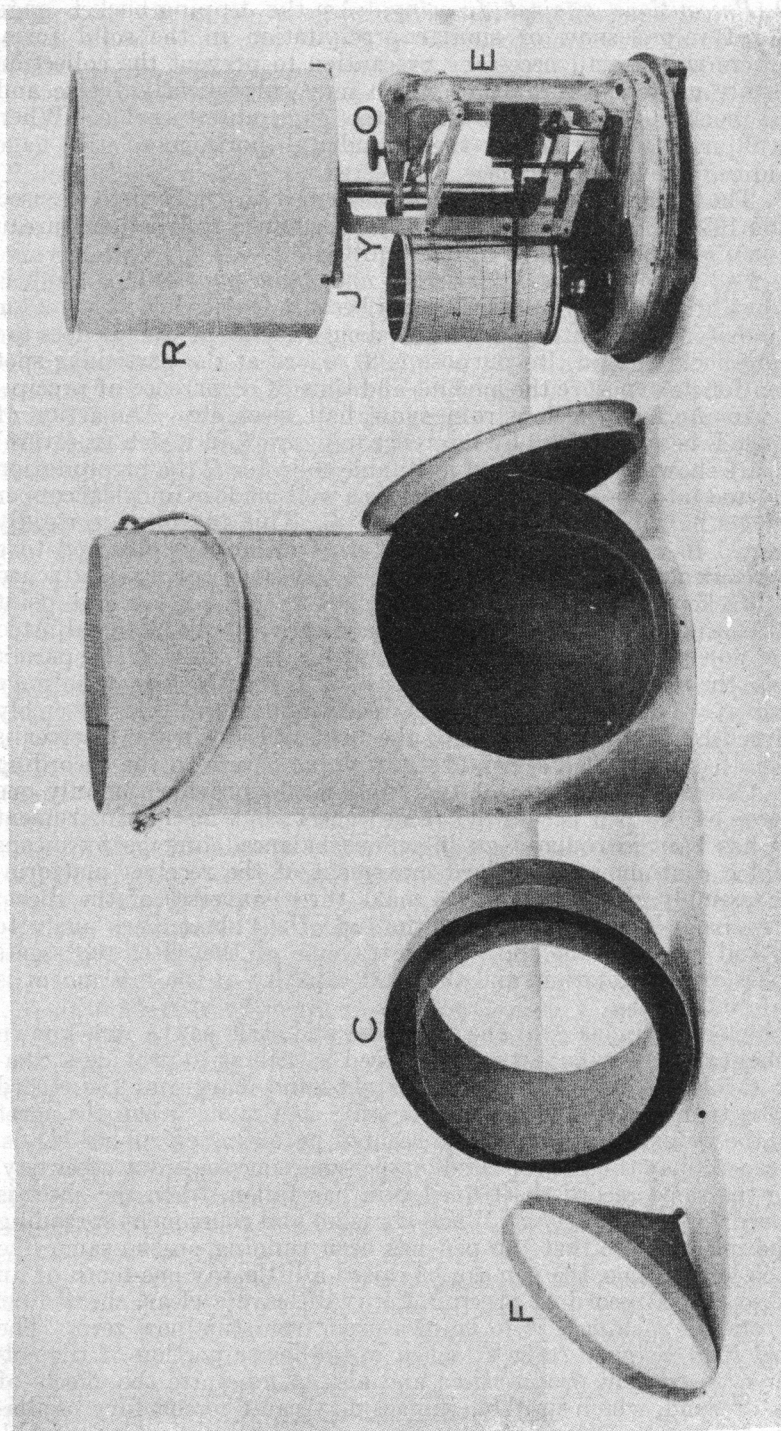


FIGURE 7.—Fergusson weighing gage, parts.

Its removal is a simple process that will be readily apparent upon inspection of the bayonet joints that serve to hold it to the collector.

The effects of wind pressure are further minimized by the use of a dash pot or stilling device. This dash pot should be filled with

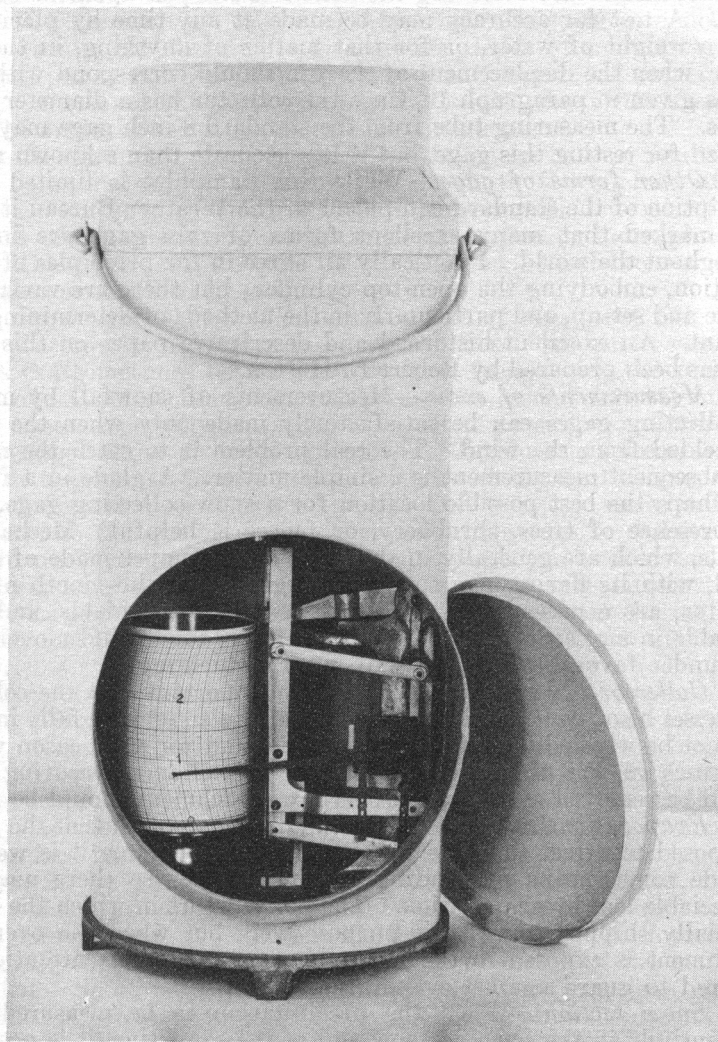


FIGURE 8.—Fergusson weighing gage, complete.

A more detailed description of the gage may be found in the *Monthly Weather Review*, July 1921, 49: 379-384.

glycerin just sufficient in amount to cover the bottom of the movable cup when the receiver is empty. When the glycerin is in place, kerosene should be added until there is a layer about one-half inch deep floating on top of the glycerin.

The enclosing case has been somewhat altered in form in the gages recently purchased, but the purpose is the same, namely, to permit

access to the instrument for changing sheets, inking pens, etc., and at the same time to keep out rain and snow.

Upon starting a new instrument it is well for the observer to familiarize himself with its operation by gradually pouring water into the receiver, meanwhile observing the action of the pen upon the record sheet. A test for accuracy may be made at any time by placing a known weight of water, or for that matter of anything, in the receiver, when the displacement of the pen should correspond with the values given in paragraph 19, since the collector has a diameter of 8 inches. The measuring tube from the standard 8-inch gage may also be used for testing this gage, but is less accurate than a known mass.

45. *Other forms of gage.*—While this pamphlet is limited to a description of the standard equipment of the Weather Bureau it may be remarked that many excellent forms of rain gage are in use throughout the world. Practically all agree in the principles of construction, embodying the open-top cylinder; but there are variations in size and set-up, and particularly in the methods of determining the amount. An excellent historical and descriptive paper on this subject has been prepared by Robert E. Horton.¹

46. *Measurements of snow.*—Measurements of snowfall by means of collecting gages can be satisfactorily made only when the gage is shielded from the wind. The real problem is to catch the snow. Its subsequent measurement is a simple matter. A glade in a forest is perhaps the best possible location for a snow-collecting gage, and the presence of trees, shrubbery, or fences is helpful. Mechanical shields, which are generally in the form of a trumpet made of sheet metal, with its flaring rim somewhat higher than the mouth of the collector, are a necessity in the absence of natural shields, and are desirable in any event, because there is always some wind movement, even under favorable conditions of natural shielding.

47. *Collector to be removed.*—It is also important that the collecting vessel be of considerable depth so that the snow that falls into it may not be whirled out again by the wind, and for this reason when the 8-inch gage is used to catch snow the funnel and measuring tube should be removed and only the overflow attachment should be used.

48. *Evaporation lessened.*—When conditions are such that the gage is exposed to direct sunshine for any considerable time it is well to provide some means of shading it, since otherwise there may be appreciable loss by evaporation. The box support in which the gage is usually shipped serves this purpose well, but when the overflow attachment is exposed in the iron-tripod support some attention is required to guard against evaporation loss.

49. *Snow section.*—When the precipitation to be measured has been entirely in the form of snow and at the same time it is possible to identify the layer, then the determination of the water content of the snow as it lies is the best method known, particularly since an opportunity is afforded to select sheltered spots and to make a number of independent measurements the mean of which is of acceptable accuracy. This method may be used to demonstrate the degree of accuracy of the catch made in the gage. Almost any tube with rigid walls and of known cross section may be used to obtain the sample,

¹ HORTON, ROBERT E.: THE MEASUREMENT OF RAINFALL AND SNOW: Jour. of the New England Water Works Assoc., vol. XXXIII, no. 1.

provided proper allowance be made for its area, although at the majority of Weather Bureau stations it is most convenient to use the 8-inch overflow attachment. Recent improvements in special snow-sampling devices simplify the work greatly, and it is hoped to supply samplers of suitable length to all first- and second-order stations that need them when facilities permit.

50. *Measurement of depth of snowfall.*—Existing instructions, which require the observer to measure the depth of snowfall at one or more points representative of the normal depth, will continue in force. There are two general conditions under which measurements must be made, however, which call for consideration.

The measurement of snow which has fallen on bare ground—here it is necessary only to measure the depth to the surface of the ground. Under such circumstances observers will determine, with the aid of the measuring stick, the depth at one or more places in open fields or on level surfaces where the layer has not been seriously disturbed or modified by drifting.

51. *Snow upon snow.*—The measurement of snow that has fallen on a previous layer—under these more difficult conditions measurements can sometimes be made on surfaces from which the previous layer of snow had been removed before the second fall began. In other cases, especially in cities, it is often possible to distinguish the surface of the previous layer by its discoloration from soot or dirt, or the formation of a crust through sleeting or freezing. The line of demarkation between the old and the new snow is often apparent to the eye by slight differences of texture or density, and which are revealed by cutting down through the bed of snow so as to expose a definite vertical section. Under such circumstances measurements of the depth of newly fallen snow may be made by ordinary methods that will readily suggest themselves to the observer.

Efforts to provide a floor or platform that shall be swept clear before a new fall of snow occurs cannot be generally successful because of drifting, and its weight precludes supporting such a floor upon the snow itself. Further complications arise in the matter of temperature differences between the floor and snow in the sunshine.

52. *The snow mat.*—This simple device will often aid in marking the surface between the old and new snow. It consists of a small square, 28 by 28 inches, of white duck, medium weight, neatly hemmed, and provided with a small triangular pocket at each corner. Two slats of wood, $2\frac{1}{4}$ inches wide by one-fourth thick, forced into diagonally opposite corner pockets, serve to maintain the mat taut and flat. Short pegs, projecting downward from the slats, may be provided if necessary to better secure the mat against displacement by the wind. When snow is already on the ground, the mat is simply laid upon the surface in some favorable location. A few yards of small cord tied to the mat and to some slender stake nearby prevent the possible loss of the mat, and serve to indicate its location when covered with snow. Snow mats are not supplied from the Central Office but are easily prepared locally.

The lightness of such a mat permits the soft snow to support it, so as to remain even with the surface of the old snow. Its color and material favor equality of snow and mat temperatures under condi-

tions of sunshine, and thus lessen the chances of partial melting. Since the surfaces of the mat and snow so nearly coincide, drifting is of slight consequence, except in very light snowfalls.

53. When a measurement is to be made, the position of the mat must first be located by the cord, and a little of the snow cleared so as to expose a small portion of the mat. The depth of the snow over the mat can then be accurately measured.

54. *Snow in remote regions.*—The collection of snow by means of gages in remote regions seldom visited by observers has not thus far been satisfactorily accomplished. Need for such collection no doubt exists where the precipitation is partly in the form of rain, or where melting temperatures are experienced; but where the precipitation is in the form of snow throughout the winter, and particularly where cool northerly slopes retain it, the ground itself is a collector, and save for small evaporation losses, the seasonal fall may be determined when desired by the methods set forth in paragraphs 65-75.

55. The actual depth of the snow layer, in inches, is measured and recorded daily, generally about sunset, at regular observing stations. The rain-gage measuring stick, or for that matter any rule graduated in inches and tenths, is inserted in the snow layer at several selected spots where experienced judgment indicates that a normal and representative depth is to be found, and the mean of such measurements is taken as the depth of the snow layer.

56. Measurements of the depth of snow in regions visited only occasionally, particularly those regions in which the layer of snow has an important bearing on power and irrigation projects require special preparation and devices in addition to those mentioned in the preceding paragraph.

57. *Snow stakes.*—These are upright sticks of wood either driven into the ground to hold them vertical, or held in a vertical position by guy wires, used in regions of deep snow, particularly in the Rockies and the Sierras, the depth being read directly from the stakes. They are graduated in inches, black triangles on a white background serving to increase visibility, and are permitted to remain in the same spot year after year. The length is varied according to the depth of snow expected. Earlier models were made of a board about 1 inch by 6 inches, but on account of the effects of reflected heat and wind eddies in creating spurious depths in the immediate vicinity of the stake, this board form has been replaced by stakes $1\frac{3}{4}$ inches square, one face of which bears the graduations, while the adjacent face bears a number for each 10 inches or multiple thereof; that is, "1" means 10 inches, "2" means 20 inches, "3" means 30 inches, etc. (*Caution: These numbers have been mistakenly read as feet by persons unfamiliar with the scheme.*) The standard type of snow stake is shown in figure 9.

The stake is painted *white*, to minimize radiation effects. These scales have graduation marks to *inches*. The 10-inch marks are largest, while opposite each 10-inch mark on the adjacent face of the stake is a large figure: "1" for 10 inches; "2" for 20 inches, etc., while the graduation marks at 5, 15, 25, etc., inches are of an intermediate and readily distinguishable size. The stake, with its scales and numbers, is securely bolted to a piece of galvanized-steel angle, after the latter, which is sharpened at the lower end for that purpose,

is driven into the ground to a proper depth, about 26 inches; all substantially as indicated in figure 9. Snow stakes are not stocked in the Instrument Division, but are readily constructed locally.

58. *Installation of scales and stakes.*—Upon reaching the site selected for the scale, drive the anchor post into the ground as nearly vertical as possible, using a heavy mallet or equivalent means that will not batter or damage the iron at the top edge. The anchor post should project so that when the stick is bolted in place its lower end will just touch the surface of the ground. A small-diameter post is sometimes employed in lieu of the angle iron, the post being notched to receive the stake.

59. *Guy.*—Under ordinary conditions of exposure it is not believed that any wire guys are required. Wherever needed, however, it will be necessary to procure a small quantity of annealed, galvanized-iron wire (about no. 14, B. & S. gage); also a few galvanized-iron nails about $2\frac{1}{2}$ inches long (eight-penny); and, where guys are needed, attach three under the head of a nail driven part way down into the center of the top of the stake, the head of the nail projecting sufficiently to permit securing the three guy wires thereunder, the outer ends of the guys being secured by any form of anchorage that may be most permanent and suitable. With the stake as a center, the wire guys should spread about 120° apart to afford the best stability.

60. *Method of reading snow depths.*—The depth of snow around the snow scales will be recorded to the nearest whole inch. The reading of the scale should not necessarily be the reading at the level of the snow immediately adjacent thereto, but a reading probably greater than the latter and one that represents the *level of the snow within a few feet of the stick*. Notwithstanding the small dimensions of the stick, it will probably often occur that, on account of wind eddies around it, and more particularly because of the melting and sinking of the snow close to the stick, due to the heating action of the sun thereon, a hollow will be made in the snow; and for a true reading of the depth, due allowance must be made for the presence of any

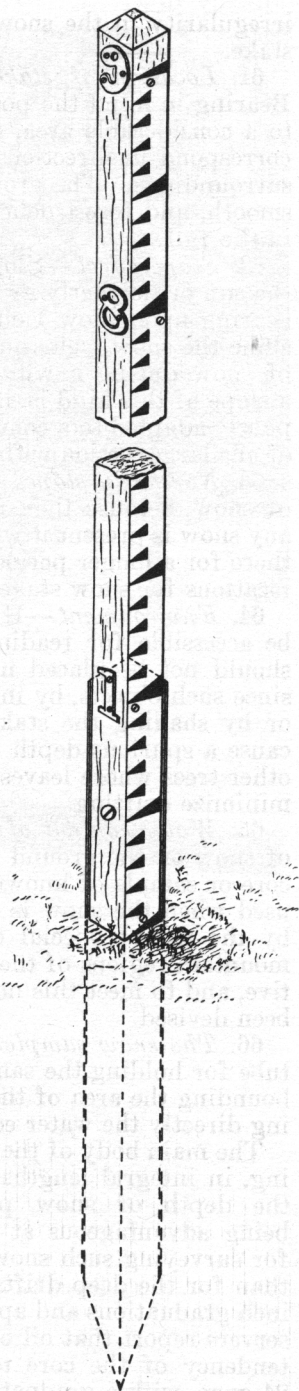


FIGURE 9.—Snow stake (Weather Bureau pattern), 1913.

irregularity in the snow surface in the immediate proximity of the stake.

61. *Location of stakes.*—Location of snow stakes is important. Bearing in mind the possible application of the reading at the stake to a considerable area, the ground in the immediate vicinity should correspond in direction and steepness of slope with the neighboring surroundings. The ground at the foot of the stake should be fairly smooth, and forest debris, sticks, brush, etc., should be cleared away in the fall.

62. *Slope effect.*—Slope of the ground, whether southerly toward the sun or northerly away from the sun, has an extremely important bearing upon snow melting. On steep south slopes exposed to sunshine the snow melts quickly so that such slopes are frequently bare of snow during a winter. Hence the depth of snow measured on a slope of this kind is, in a sense, a result of fortuitous causes, and is poorly adapted to a comparison of one winter with another, or indeed of one large section with another.

63. *Northerly slopes preferable.*—Northerly slopes are conservers of snow, because they receive relatively little sunshine. Hence, if any snow is present it will be found on such slopes, and it will remain there for a longer period in the spring. Such slopes afford excellent locations for snow stakes and should be preferred.

64. *Environment.*—It is of course important that the snow stake be accessible for readings. As to immediate surroundings, stakes should not be placed near to large trees, bluffs, or buildings, etc., since such objects, by intercepting falling snow or by reflecting heat, or by shading the stake, or by causing wind swirls, are likely to cause a spurious depth at the stake. Low shrubs, bushes, aspen, or other trees whose leaves drop before winter are beneficial, since they minimize drifting.

65. *Water content of snow layer.*—The water content of the layer of snow on the ground is determined by taking out and weighing a core or sample of known area. Almost any cylindrical tube may be used when the snow is not deep, but the work is greatly simplified by the use of special equipment, while in the deep snows of the mountain regions of the Western States special apparatus is imperative, and to meet this need the following-described snow sampler has been devised.

66. *The snow sampler.*—There are three parts to the device: The tube for holding the sample while it is being weighed, the cutter for bounding the area of the sample, and the spring balance for indicating directly the water equivalent of the snow layer.

The main body of the sampler (fig. 10) is of 3-inch duralumin tubing, in integral lengths varying from 2 feet to 6 feet, according to the depth of snow prevailing in the vicinity, several lengths being advantageous at some stations. The instrument is intended for surveying such snow layers as are found over wide areas, rather than for the deep drifts of the timber-line region. The tubes have inch graduations and appropriate numbers to show snow depth. Observers report that oil or lacquer applied to the inner surface lessens tendency of the core to stick. Tinnern's downspouting, 3-inch by 24-gage, with a graduated metal tape riveted in place longitudinally, is sometimes used in place of the special tubing.



FIGURE 10.—Snow sampler, with balance and alpenstock.

The cutter (figs. 11 and 12), with its special shape, constitutes an extremely important part of the device. The inside diameter is turned true to 2.655 inches, which makes one-fifth of a pound of snow equal to 1 inch water equivalent. The diameter selected is the result of a number of carefully made experiments in the field, which showed that cutters of too small diameter take up a sample that is too small to be representative of the layer from which it is cut, while samplers of larger diameter are too large and clumsy for use, particularly when they must be transported on snowshoes, although they possess the advantage of giving precise results. An examination of the illustrations will show that the cutter is sharply shouldered off at a point one-half inch above its cutting edge. This shoulder is found in practice to wedge the snow so that in the great majority of cases the entire core can be withdrawn without losing the sample, although in some instances of extremely light dry snow it is necessary to tamp the snow into the bottom of the tube by means of a long slender stick in order that it may be somewhat packed before the tube is withdrawn. The cutters have smooth edges and are made interchangeable, so that in case of damage a new one can be easily attached.

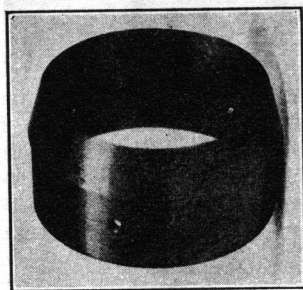


FIGURE 11.—Snow cutter.

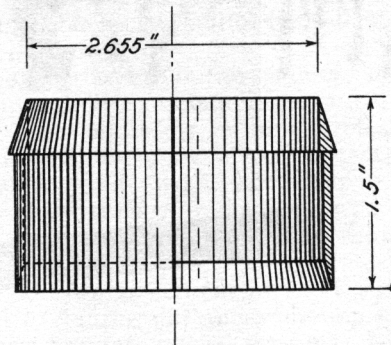


FIGURE 12.—Snow cutter, line drawing.

67. *Weighing device.*—The spring balance (fig. 13) as shown in the illustration has grown out of experience. The graduations, which are engraved directly on the case of the spring balance, give inches and tenths of water equivalent direct. The indicating hand is rigidly pinned to its arbor, thus eliminating the chance of accidental displacement. The bent aluminum wires are intended to hold the filled tube in a horizontal position for weighing, while the hook at the top is intended to be placed across a limb of a tree or other means of support. The entire balance is built largely of aluminum for lightness. In using the sampler, it is necessary to weigh the empty tube, then the snow-filled tube, the difference between the two giving the water content of the snow in inches and tenths.

68. *Alpenstocks.*—Alpenstocks are helpful in furnishing a steady support on which to hang the balance, although they are not required when other forms of support, such as limbs of trees, are at hand. They are not stocked in the Instrument Division of the Weather Bureau.

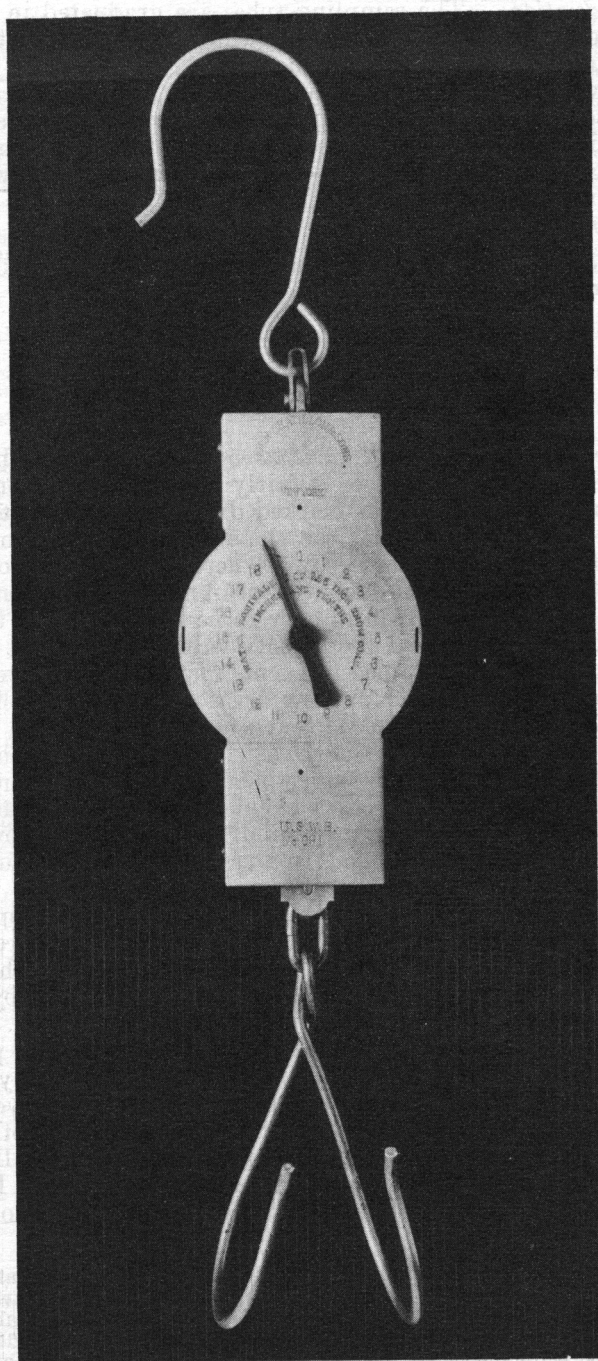


FIGURE 13.—Weighing balance for snow sampler.

69. *Graduations.*—The sampling tubes are graduated in inches, so that the depth of the snow layer from which the sample is taken may be read directly from the side of the tube. Now, since we can determine the water content by the weight of the sample, and the depth from the scale on the tube, we may easily determine the density of the snow by dividing the water content by the depth. The quotient thus obtained gives the density or specific gravity of the snow as compared with water.

70. *Example.*—

Scale reading, with snow sample included.....	Inches 7.6
Scale reading, with tube empty.....	4.3
Water equivalent of snow.....	3.3
Depth of snow.....	22
Density of snow = $\frac{3.30}{22}$ = 15 percent.	

71. *Extended application of measurements.*—Experience has shown that the density of a snow layer is fairly uniform over a considerable area of similar slope, but that marked differences in density may be expected according to whether the slope is toward the sun or away from it. Therefore if we have, say 100 acres of fairly uniform slope, we may determine the depth from the mean readings of a considerable number of stakes, which require only to be read, while to the depth so obtained may be applied the density values determined at only a few points. Hence a few measurements may suffice to give a working value of the snow cover over an area of considerable size. Due regard must be had for marked differences in altitude.

72. *Sample normal to slope.*—Density measurements on a steep slope generally require the sample to be taken normal (at a right angle) to the slope, since an effort to take out a vertical sample on a hillside will often fail to take up a small portion of the snow next to the ground. The depth normal to the slope should be used only for the purpose of obtaining density.

73. *Depth measured vertically.*—Depth of snow on a slope should always be measured vertically. The reason will be apparent when it is remembered that land surveys are made on the basis of horizontal distances. Hence we have the relation: Depth multiplied by density multiplied by area equals water content.

74. *Large drifts.*—Deep drifts of the timber-line region present a special problem whose solution has been accomplished only in part. Such drifts are, however, fairly constant from year to year as to locality, and their extent depends upon the general depth of the snowfall. Furthermore their total area is relatively small so that their real importance to the flow of streams is not great. In Bulletin 55 of the Agricultural Experiment Station of Colorado, page 9, L. G. Carpenter says:

As snow is most evident on high peaks, undue importance is attached to high elevations. I have had occasion to examine the watershed tributary to the Rio Grande. While this has an area of 4,611 square miles above 8,000 feet elevation, there is less than 200 square miles of it above 12,000 feet, although this watershed has a large number of the highest peaks in the State. In this case over 90 percent of the watershed is below timber line and above 8,000 feet.

75. *Survey method.*—The testimony of those who have actually engaged upon snow surveys agrees as to the uniform fall^{2 3} over large areas, while agreement in depth and density under similar conditions of slope and elevation has been established by a number of years survey at Wagon Wheel Gap, Colo. Therefore we have at hand a method that with discretion may be applied to an entire drainage area.

² CHURCH, J. E., JR. SNOW SURVEYING FOR THE FORECASTING OF STREAM FLOW. Engineering News-Record, Feb. 10 and 17, 1921, vol. 86, nos. 6 and 7.

³ COLE, HARVEY S. SNOW SURVEY IN THE WALKER DRAINAGE BASIN, NEVADA. Monthly Weather Review, March 1913, 41: 448-9.

INDEX

	Paragraph		Paragraph
Automatic records	20-29	Roof exposures	3
Accuracy of tipping bucket	30, 31, 32	Recording mechanism	35, 36, 37, 38
Alpenstocks	68	Sampler, snow	49, 65-70
Balance, spring	67	Slope as affecting snow	62-63
Check readings	39	Slope, how considered	2
Definition of precipitation	1	Snow collecting in remote sections	54
Density of snow	71-75	Snow, depth on the ground	17, 56, 67
Drifts	75	Snowfall	10, 46
Evaporation losses	48	Snow mat	52, 53
Exposure of gages	2, 3, 46	Snow measured with inverted gages	14
Exposure of snow stakes	61-64	Snow, melted	15
Fences as windbreaks	3	Snow platform	51
Freezing temperatures	4, 42	Snow samplers	49
Gages, rain, exposure	3	Snow, section of	49
Gages, rain, 8-inch	6	Snow stakes	57
Gages, rain, tipping bucket	20	Snow, units of measurement	2
Gages, rain, Marvin float	43	Snow, weight of, in 8-inch gage	18-19
Gages, weighing rain and snow, Fergusonson	44	Springs, contact	26, 27, 28
Gages, rain, reference to other forms of	45	Sticks, measuring	7
Ground as a snow gage	54	Supports, box type	8
Leveling	34	Supports, iron-tripod type	8
Marvin float-gage	43	Tipping-bucket gage	20-24
Measuring tubes	41	Tripod, iron	9, 20
Overflow attachment	6, 13	Tipping buckets, how positioned	22
Overflowing tube	12	Units of measurement	1
		Wind, effects of, on catch	3, 46
		Weighing method of measurement	18, 19

