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History of Weather Bureau Precipitation Measurements

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PREFACE

This publication presents a history of precipitation measurements in the U. S. Weather Bureau and a description of the gages most used during the life of the Bureau, 1891 to date. It is intended to be useful to the historian as well as the user of weather data.

ACKNOWLEDGMENTS

Thanks for assistance in preparing this bulletin go to my colleagues in the U. S. Weather Bureau for assistance, suggestions, criticism, review and encouragement, and to Mrs. M. Alice Clark for preparation of the copy.

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I. INTRODUCTION

Measurements of rainfall have probably been made, irregularly at least, ever since man first exposed vessels to the elements.

Mention of a rain gage in use as early as 400 B.C. is made in "Arthasastra" by Kautilya, reference [20], on page 64: "In front of the storehouse, a bowl (Kunda) with its mouth as wide as an Aratni (18 inches) shall be set up as a rain gage (Varshanana)." And on page 143: "Hence i.e. according as the rainfall is more or less, the superintendent shall sow the seeds which require either more or less water." Thus weather records were apparently used in agricultural operations many centuries ago.

According to Horton [16] "in the Mashnah, a collection of religious writings of the First Century, there have been found recorded measures of rainfall in Palestine during the First Century of our era. These are probably the first quantitative observations of precipitation now in existence."

In its simplest form a precipitation gage is an open-mouthed can with straight sides, installed with the open end upward and the sides vertical.

A gage of this type, known as the standard 8-inch gage, has been the basic gage in use at substations of the Weather Bureau ever since the Bureau was established in 1891. At present some 9,000 substation observers make daily precipitation observations from a standard gage.

Various types of recording gages have been used in the Weather Bureau in order to obtain precipitation amounts for short periods, as well as rates of fall. In addition to the standard 8-inch non-recording gage described above, the tipping bucket gage, described in Section XIII of this publication, has been in use since the beginning of the twentieth century at first-order Weather Bureau offices. It cannot be used to measure solid precipitation, however, so beginning in the 1930s a network of first order stations likely to experience solid precipitation was equipped with a weighing gage which measured both liquid and solid falls. In addition, approximately 3,000 substations over the country have now been equipped with recording gages.

Obtaining an accurate measurement of snowfall requires careful observational techniques. Instructions for U. S. Signal Service Forms 101 and 113 combined for 1889 state "When snow has partly melted, or rain has fallen since last observation, the amount from the rain-gauge will be the official record. Great care must be exercised in melting snow etc., as overheating will cause very rapid evaporation."

In the 1904 Instructions for Preparing Meteorological Forms detailed instructions are given for the measurement of snowfall. The statement is made there that while one-tenth the depth is arbitrarily adopted as the water equivalent of snow, yet this is only coarsely approximate, and observers should always endeavor to determine the actual equivalent by one of the two methods which are described.

The first method is to cut out a section of new snow with the inverted gage overflow and determine the water equivalent from the weight. The second method is to add a measured quantity of warm water to the snow to melt it, measure the resulting mixture and subtract the amount of water added in order to obtain the water equivalent of snowfall.

These instructions were carried in subsequent issues of Instructions for Preparing Meteorological Forms through the 1938 issue.

In Par. 4050 of Circular N, "WBAN Manual of Surface Observations", Sixth Edition, January 1949, somewhat similar instructions are carried; however, it is not suggested that the water equivalent be determined by weighing. Instead it is suggested that, if representative of the fall, the precipitation in the gage be melted by adding a measured quantity of warm water. If the catch in the gage is not considered representative, the water equivalent should be obtained by cutting a cylindrical sample of snow with the inverted overflow container and melting it as indicated above.

The instructions were continued essentially unchanged in Change No. 10 of the Seventh Edition of Circular N, dated November 1, 1961.

Proper exposure of the rain gage has always been of concern to the Weather Bureau. The following is taken from page 43 of reference [47]:

> "Rain-gauges in slightly different positions differ greatly in the depth of rain indicated. Within a few yards of each other two gauges may show a difference of 20 per cent in the rainfall in a heavy rainstorm. The stronger the wind the greater the difference is apt to be...."

Seventy years later in reference [61] the following statement is made:

> "The exposure of a rain gage is of primary importance in the accuracy of precipitation measurements, especially snowfall measurements. An ideal exposure would eliminate all turbulence and eddy currents near the gage, that tend to carry away the precipitation."

This continued concern over exposure is reflected also in the development of gage wind shields described in section XVI of this paper.

II. EIGHT-INCH STANDARD NON-RECORDING RAIN GAGE

The standard 8-inch non-recording rain gage has been used throughout the life of the Weather Bureau as the official precipitation measuring instrument at climatological substations.

A description and pictures of this gage may be found in "Instructions for Use of the Rain Gauge", 1895, reference [47], and in subsequent editions. See figure 1. It consists of three parts: the 8-inch receiver or funnel, the 8-inch overflow receptacle, and the measuring tube with diameter of 2.53 inches. The measuring tube is so designed that rainfall collected in the receiver is magnified ten times in the tube; thus simplifying its measurement with a stick graduated so as to represent the actual rainfall in inches and hundredths.

The receiver and measuring tube are removed in the snow season. Snowfall is collected in the overflow receptacle, melted, poured into the measuring tube and measured just as if it were rainfall.

In "Instructions for Voluntary Observers", Circular B-C, revised 1892, a gage is described and pictured which has an 8-inch receiver and a 6-inch overflow attachment. See figure 2. This non-standard gage, while satisfactory for measuring rainfall, probably affected the reliability of snowfall measurements. Use of this gage apparently was discontinued by 1895, as no mention is made of it in "Instructions for Use of the Rain Gage", Circular C, 1895, or in later instructions.

Beginning with the 1901 edition (second) of Circular B-C, "Instructions for Voluntary Observers" and continuing through the latest or eleventh edition of Circular B, "Instructions for Climatological Observers", it is suggested that where the solid precipitation caught in the gage is considered deficient (for example, as during snowfall accompanied by high winds) the observer should proceed to discard the snowfall caught in the overflow and obtain a more representative measurement by obtaining a sample where the snowfall represents the precipitation. This may be done by plunging the empty overflow can, mouth downward, in the snow so as to cut out a cylindrical portion the size of the overflow and the depth of the new snow.

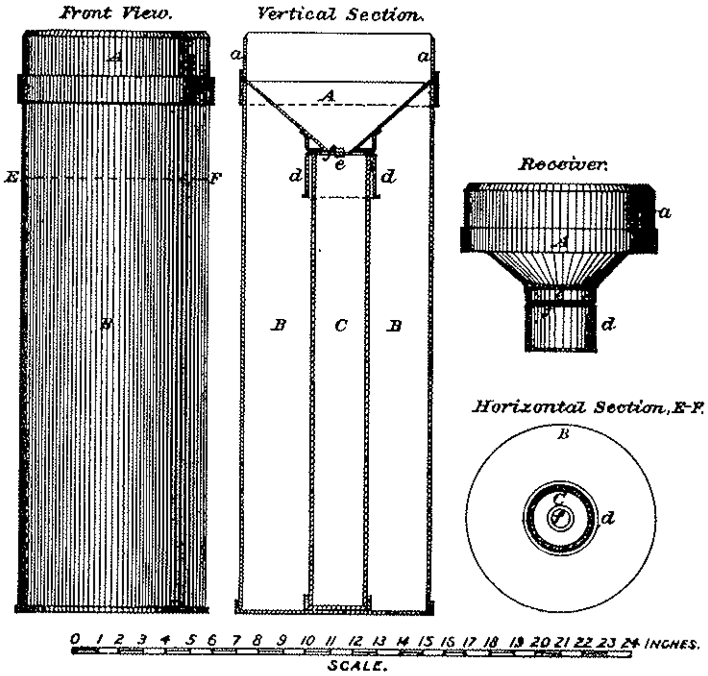


FIGURE 1

Rain Gage

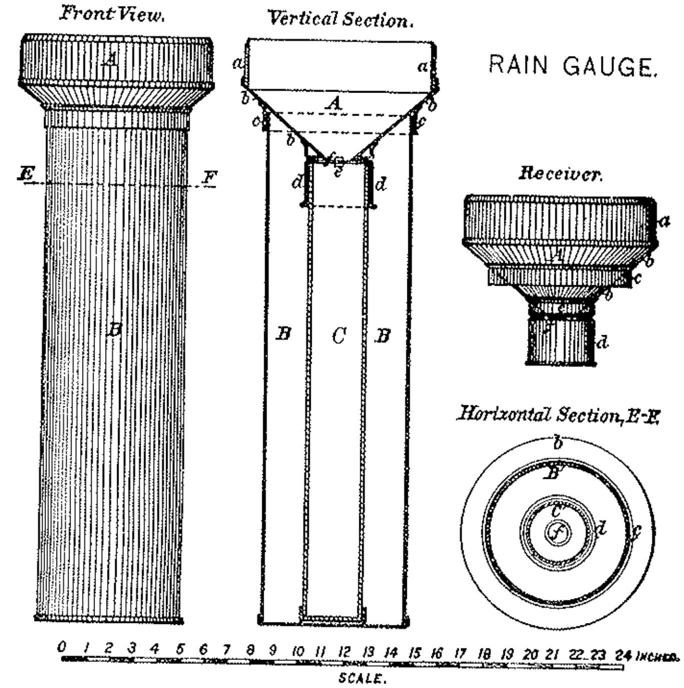


FIGURE 2

8" Gage With Small Overflow

III. FOUR-INCH GAGE

A 4-inch gage was listed as No. 4 in the order of priority of official gages in paragraph 4030, sixth edition of Circular N, "WBAN Manual of Surface Observations", January 1949. In this same issue (par. 4040) it is stated that precipitation collected in the 4-inch gage is measured by lining up the top of the catch with the measuring scale on the wall of the receiver.

The 4-inch gage was mentioned again in Change No. 10 to the 7th Edition of Circular N, effective November 1, 1961, where (paragraph 4030) the 4-inch gage is listed as No. 4 priority in a list of five gages with the statement "When more than one type of gage is in use, the official measurement will be taken from the gage appearing highest on the following list."

Specifications and a detailed description of the 4-inch gage are not available. It appears that this gage has been used very little, if at all, in the U. S. Weather Bureau.

IV. MARVIN DENSITY-OF-SNOW GAGE

This device, reference [42], consisted of a bucket and scale so designed that the scale registered 100% when the bucket was filled with water. To measure the density of snow, the bucket was filled level full with snow without tamping or packing. It was then hung on the hook attached to the scale, and the density of snow read directly from the pointer on the scale.

The water equivalent of snowfall could then be obtained by multiplying the depth of the snow layer by its density. For example, with an 8-inch snow layer with density of .18, the water equivalent would be .18 x 8 or 1.44 inches.

There is no indication that this apparatus, described in detail in the above reference, was ever widely used in the U. S. Weather Bureau. A companion piece of equipment, designed by Professor C. F. Marvin, is a snow tube. This is also described in reference [42].

V. MARVIN FLOAT RAIN GAUGE

According to reference [39], a few Weather Bureau Offices were provided with a weekly gage of the float type designed by Professor C. F. Marvin in 1913. A detailed description and pictures of this gage may be found in reference [39]. Apparently this recording gage was not widely used in the Bureau. The circular receiver was of 8 inches inside diameter, surrounded by a rectangular wind shield. Changes in the level of the float caused a pen to oscillate laterally over an extreme range of one-half inch on a record sheet and this motion, over and back, represented one-half inch of rain. Each sheet provided a record for eight days.

VI. RADAR BEACON PRECIPITATION GAGE SYSTEM

This is a system which employs a tipping-bucket precipitation gage (heated for operation during periods of frozen precipitation) to generate a signal that is telemetered to the master station by means of a radar beam. Since the sensor is located at a considerable distance from the master station and operates without a local observer, correction of the data by reference to stick measurements is not possible. The data are subjected to further error (during periods of frozen precipitation) by evaporation from the heated collector. For these reasons, the data from the Radar Beacon Precipitation Gage systems are not considered acceptable for record purposes, but are used operationally in river forecasting procedures.

VII. RADAR IN THE MEASUREMENT OF RAINFALL

During World War II the advent of radar was a boon for the military but it was quickly discovered that precipitation presented echoes on the radarscope which often prevented its full utilization for military purposes. The meteorologist on the other hand just as quickly recognized the potential of radar for weather detection but it was not until after World War II that the first weather surveillance radar was introduced. This was the CPS-9 radar, developed for the USAF. The primary deficiency of the CPS-9 was that its radiated signal suffered considerably (attenuated) in heavy rain because of its short (3-cm) wavelength. It has been attested to, that for weather surveillance, long (10-cm) wavelength radars must be employed.

Shortly after World War II the Weather Bureau began to acquire surplus 10-cm wavelength, though low powered, military radars and converted them for weather surveillance. Early attempts at determining rainfall by radar were confined to such techniques as correlations with radar echo heights, volume and areal extent. One of the most significant results of these early projects was the realization that radar areally displayed rainfall that would often be missed by the rain gage network.

From 1954-59 the Weather Bureau conducted studies at M.I.T., University of Miami and Texas A&M to learn more about measuring rainfall by radar. See reference [30]. Such procedures evolved as step gain echo contouring, grid tallying and multiple exposure photography. These procedures all had certain advantages and disadvantages depending whether one is interested in the complete areal coverage, just the hard cores, or a composite of these.

It was not until 1959 when the Weather Bureau acquired its first specifically designed weather surveillance radars (10-cm WSR-57) that it was possible for the radar meteorologist, while sitting at the console, to theoretically determine the rate of rainfall within range of the radar. This was possible through special controls in the radar called attenuators. With these devices and a theoretically derived Radar-Rainfall graph it has been possible to determine: rainfall rates for flash flood warnings, isohyetal pattern of rain storms and snowfall in addition to the usual detection and tracking of thunderstorms, tornadoes and hurricanes. See references [15, 17, 18].

Even with this advanced equipment it was realized that, because of the rapid ever changing character of the raindrops, the only way to accurately determine rainfall by radar would have to be done electronically. Such a device has been constructed and its evaluation will be undertaken in 1963 at the Radar Research Laboratory in Norman, Oklahoma.

VIII. RECORDING AND TELEMETERING PRECIPITATION GAGE

A gage is under development by the Fischer and Porter Co. as contracted with the U. S. Weather Bureau. It is to be a weighing-type gage with an 8-inch diameter collector, and with a capacity of not less than 15 inches of liquid precipitation. It will have an accuracy of ± 0.15 inch of precipitation anywhere within the gage range, and a sensitivity such that it will respond to increments of 0.025 inch of precipitation anywhere within the measuring range of the gage. The accumulated precipitation amount will be indicated on a dial for immediate reference, and will be punched on a paper tape in a standard binary-decimal data code in 5-minute intervals. The gage will also have the capability of telemetering the current gage reading when interrogated remotely by radio or telephone. The recorder for the gage will be operated by dry-cell batteries that will be capable of operating for at least one month without attention. The power source for the timing device that controls the punching of the recorder tape will have sufficient capacity to operate the clock for at least six months.

Equipment is available for translating the punched tape record into digital values.

IX. REPORTERS VISUAL RAIN GAGE

This gage was used beginning in 1956 for the purpose of improving the reporting service for river and flood forecasting. See figure 3.

The gage consists of a 3-inch brass collector and funnel to be mounted on the roof of a building. A length of plastic tubing carries the precipitation from the collector to a clear plastic graduated measuring tube installed inside, or just outside, of a window, so that the catch may be observed from indoors.

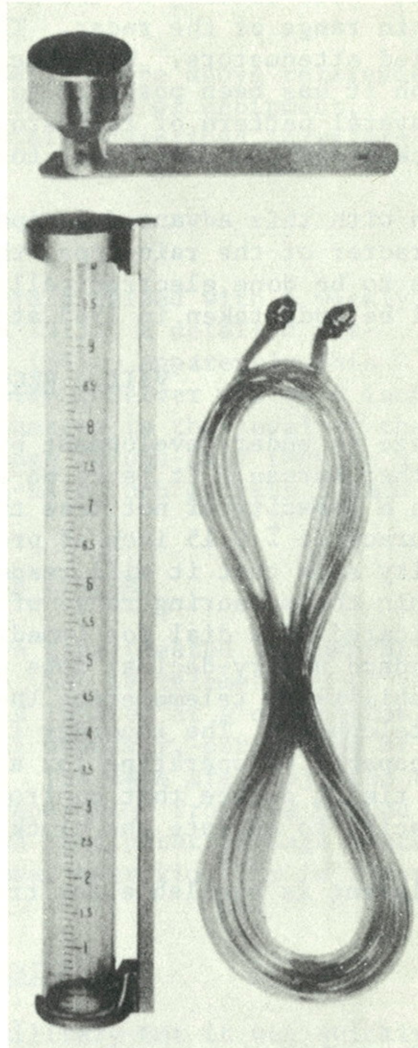
The measuring tube is graduated to indicate up to 10 inches of rain with intermediate graduations of 0.1 inch of rainfall. The visual gage was not intended to be used for official record purposes. It is described in detail in reference [64].

X. SNOW SAMPLER

The snow sampler, reference [44], designed for obtaining water equivalent of deep snows, consists of three parts. These are 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.

XI. SNOW STAKES

Snow stakes, reference [44], are upright sticks of wood either driven directly into the ground to hold them vertical, or held in a vertical position by guy wires. They are used in regions of deep snow, particularly in the Rocky Mountains. The depth is read directly from the stake, whose length is varied according to the depth of the snow expected.



REPORTER'S VISUAL RAIN GAGE

FIGURE 3

XII. STORAGE PRECIPITATION GAGES

Storage precipitation gages have been used in the Weather Bureau since shortly after J. Cecil Alter, then of the Salt Lake City Weather Bureau Office, made a 6-month test in 1907 of an unshielded gage, in which the seasonal total accounted for 97 percent of the sum of the daily measurements from an adjacent official gage.

During the next few years Mr. Alter experimented with various types of shields to overcome the effects of high winds and he also tested various types of anti-freeze agents.

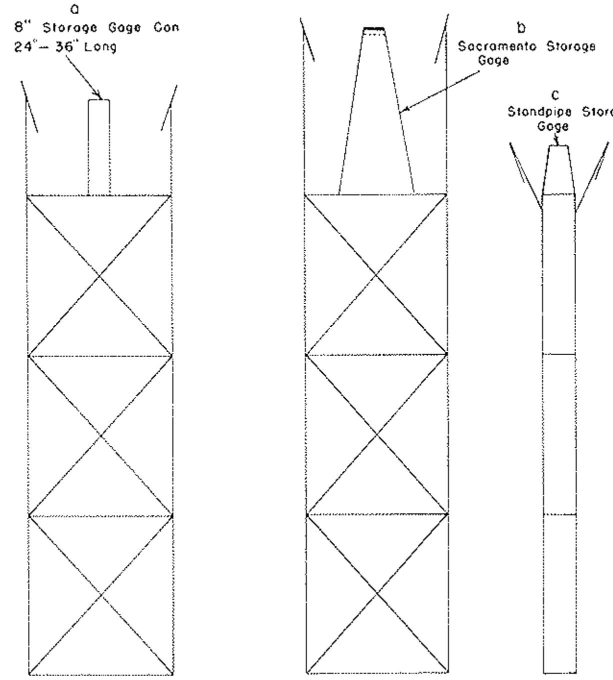
The receiver of the first storage gage was cylindrical, 8 inches in diameter, and either 24 or 36 inches in depth. The can and its contents were weighed by means of a dial-type scale. See reference [63].

Storage precipitation gages are required in order to obtain accurate precipitation measurements in sparsely inhabited areas where extremely heavy snowfall occurs and low temperatures are frequent.

In the design of seasonal gages primary importance is attached to total seasonal weighted catch. Intermediate volume measurements by stick or tape are usually less accurate.

By 1951 three storage precipitation gages (see figure 4) had been developed in the Weather Bureau, as follows:

No. 1 - A small storage can 8 inches in diameter and 24 - 36 inches in height, mounted on a tower above maximum known snow depth, measured periodically at 7 to 30 day intervals by weighing. Due to its small capacity the use of this gage is limited to points where attendance is available at intervals during which precipitation does not exceed the capacity of the gage. This is not a true seasonal gage.



THREE TYPES OF STORAGE GAGES
Scale 1" = 3"

FIGURE 4

No. 2 - The Sacramento type conical seasonal precipitation storage gage made in varying sizes with capacities of 60, 100, 200, and 300 inches. It is mounted on a tower above the level of maximum accumulated snow. The total seasonal catch is determined by weighing once or twice each year. Intermediate stick determinations of volume are made as often as possible.

No. 3 - The standpipe seasonal storage precipitation gage consisting primarily of a vertical 12-inch diameter steel pipe of sufficient length to place its 8-inch diameter catch ring above the maximum accumulated snow, total capacity of 3-section gage 250 inches, 4-section gage 375 inches, etc. The total seasonal catch is determined by weighing once or twice each year. Intermediate stick or tape determinations of volume are made as often as possible. The standpipe gage is the latest development in seasonal storage gages and recent installations by the Weather Bureau have been of this type.

Techniques used in reducing wind effect on the catch are as follows:

1. Alter windshields are installed on all storage gages.
2. Careful choice is made of naturally protected sites, wherever possible.

Other developments are:

1. Use of aqueous solution of calcium chloride to melt snow and hold precipitation in a liquid state.
2. Use of scales calibrated in inches for weighing catch.
3. Use of oil cover to reduce evaporation.

Three independent measurements are made when accumulated precipitation in a storage gage is measured. These are:

1. Measurement with stick or tape of the depth of the liquid in the standpipe storage gage.

2. Measurement of the distance from the catch ring to the liquid surface.
3. Weighing the catch.

Detailed information regarding the publication of storage precipitation data may be found in reference [63].

XIII. TIPPING BUCKET RAIN GAGE

The tipping bucket gage was described in Weather Bureau Instructions No. 7, January 18, 1897, where it is stated "The improved form of tipping bucket rain-gauge shown in the above illustration is the result of a large number of careful experiments and tests." See figures 5 and 6.

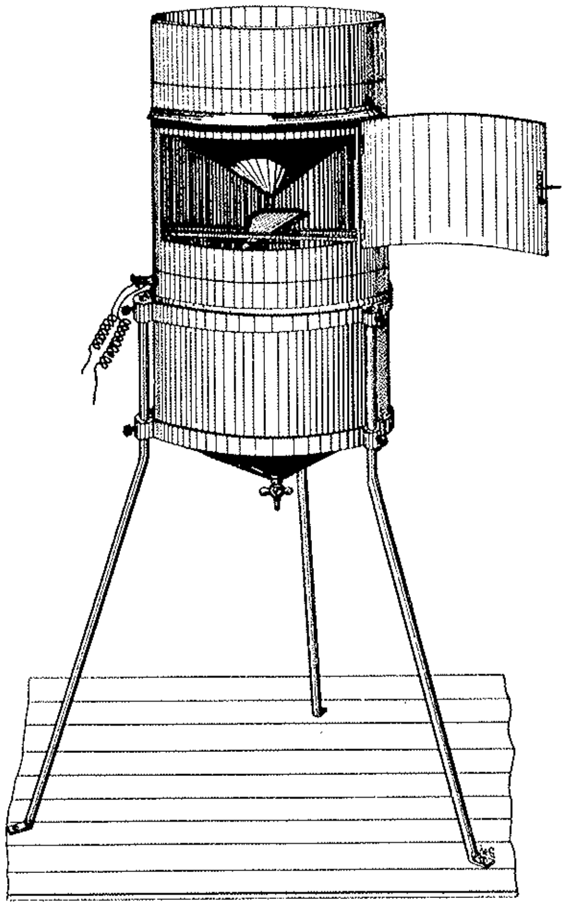


FIGURE 5
Tipping Bucket Rain Gage

Rainfall caught in the receiver (12 inches in diameter) flows through a funnel into a small bucket divided into 2 equal compartments, mounted so that the weight of .01 inch of rainfall causes the bucket to tip. Automatic registration is effected by aid of an electrical circuit closer and a "triple register" or clock-driven drum with a recording pen which traces its record in a zig-zag line of steps. Each step represents one hundredth of an inch of rain. Observers were instructed to draw off the water collected, to measure it in the "brass measuring tube", and to enter this stick measurement on the record at the time that the record sheet was changed. The measuring tube was so designed that the depth was magnified ten times, thus simplifying the stick measurement.

The first mention of a self-recording rain gage in WB Form 1001, Original Monthly Record of Observations, is found in the 1901 issue which states that "the station is supplied with a barograph, thermograph, sunshine recorder and self-recording rain-gauge" with a footnote advising that the words which are not appropriate should be canceled.

The tipping bucket gage was generally discontinued when snow or freezing precipitation was likely, although a few stations did experiment with an electric light bulb to obtain a record of solid precipitation. No mention was made of a heated tipping bucket in the various instructions. A heated gage (not tipping bucket) is described in reference [22].

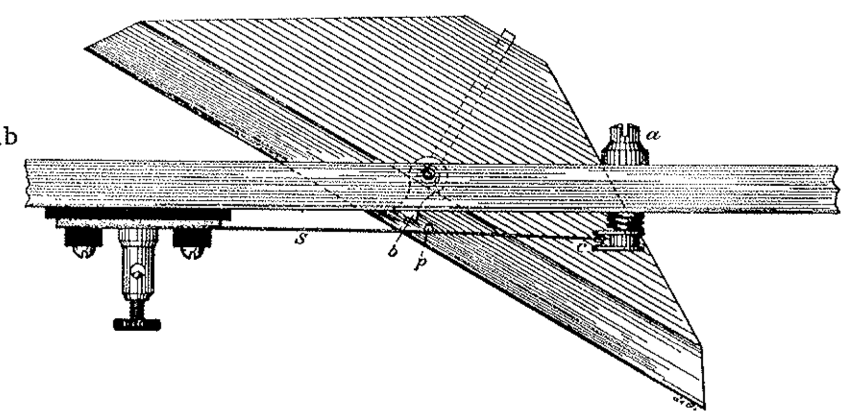


FIGURE 6
Tipping Bucket

The 1904 Instructions for Preparing Meteorological Forms was the first issue to carry the following statement: "Whenever a station is equipped with a recording rain gage, that gage will be regarded as the station gage, and the measurements of the amounts of precipitation it collects will be the official measurement of the precipitation at the station." (Par. 131)

These same instructions (1904) specify how the precipitation collected in the tipping-bucket gage should be drawn off, the contents measured by stick in the measuring tube and this amount recorded. Instructions are also given as to the method of correcting the tipping bucket record to make it agree with the stick measurements by indicating on the record in red ink a small cross (x) where tips are to be stricken out and a caret (∧) where tips are added.

The above instructions were repeated in each issue (usually annually) of Instructions for Preparing Meteorological Forms through the last issue, 1948. They were carried in substance in Par. 5110 of Circular N, "WBAN Manual of Surface Observations", January 1, 1947, as follows:

> "The gages used by the U. S. Weather Bureau are of three types: 8-inch standard gage, 12-inch tipping-bucket gage, 8-inch weighing gage. ...Whenever more than one type of rain gage is in use at a station the stick measurement made from the tipping bucket gage will be regarded as the official measurement to which all other measurements will be corrected. If a tipping bucket gage is not available, or it is inoperative, the measurement from the 8-inch standard gage will be regarded as the official measurement."

Stick measurements from the tipping bucket gage thus were considered as the official measurements from the first use of the tipping bucket rain-gage until the 1949 edition of Circular N was issued.

In par. 4030 of the 1949 edition (sixth) of Circular N, "WBAN Manual of Surface Observations", the following statement was carried:

> "When more than one type of gage is in use, the official measurement will be taken from the gage appearing highest on the following list:
>
> "(1) Shielded gage of any type
> (2) Stick measurements of tipping bucket gage
> (3) 8-inch gage
> (4) 4-inch gage
> (5) Weighing gage
>
> "All other measurements will be corrected to agree with the official measurement."

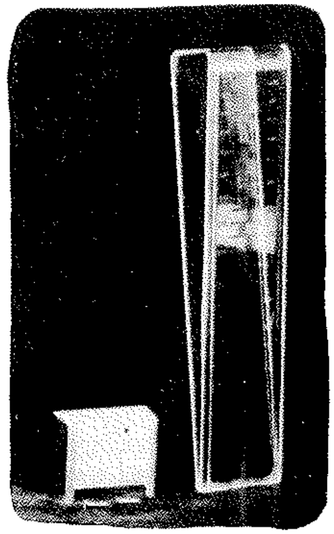
The order of priority of official gages was again changed in November 1961 in Change No. 10, par. 4030 of the seventh edition of Circular N. The order is given as follows:

> "(1) Weighing gage equipped with 24-, 12- or 6-hour gears; with other gears treated as (5) below.
> (2) Stick measurement of tipping-bucket gage.
> (3) Eight inch gage.
> (4) Four inch gage.
> (5) All other types."

This is the present (1963) priority order in use of gages in the Weather Bureau.

XIV. WEDGE SHAPED GAGE

This small, inexpensive, clear plastic wedge-shaped gage (see figure 7) is designed for use in special reporting networks. The over-all length is 13 inches; the opening 1-1/2" x 2-5/16" and the gage is graduated so that precipitation amounts may be read directly from the scale marked on the gage. The first .20 of precipitation may be read to the nearest one hundredth inch (.01); the next .80 to the nearest two hundredth (.02) of an inch and the next 5 inches to the nearest five hundredths (.05) inch. The capacity of this gage is 6 inches. The accuracy of this gage is not acceptable for official record purposes.



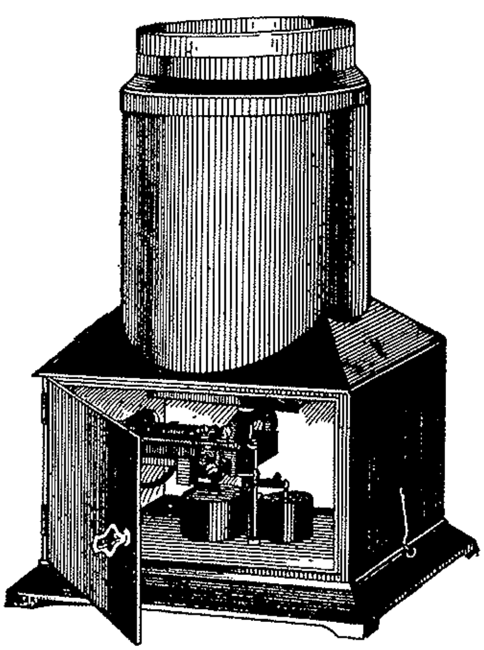
WEDGE SHAPED GAGE

FIGURE 7

XV. WEIGHING GAGES

Although the Fergusson Self Recording Rain or Snow Gage was patented December 17, 1889, the Weather Bureau, during the first few years of its existence, relied upon the standard 8-inch gage for official precipitation measurements at first order stations. However, much thought evidently was given to recording gages in those early days. Circular E, "Instructions for Using Marvin's Weighing Rain and Snow Gage", 1893, reference [40], starts out by saying "It is quite evident that at once the simplest and most accurate method of measuring snow is by weighing the quantity collected within or upon any given receptacle." The 1893 Circular then goes on to explain the mechanism of the gage, which had a receiving vessel 8-1/2 inches in diameter and 11 inches high, and which recorded on a clock-driven register that made one revolution every 12 hours. See figure 8.

The final instruction in Circular E for 1893 states "Stations receiving the new weighing gauge will discontinue the use of the old float recording gauge when the weighing gauge is in successful operation." This implies that a type of float gage was in use at some stations prior to 1893.

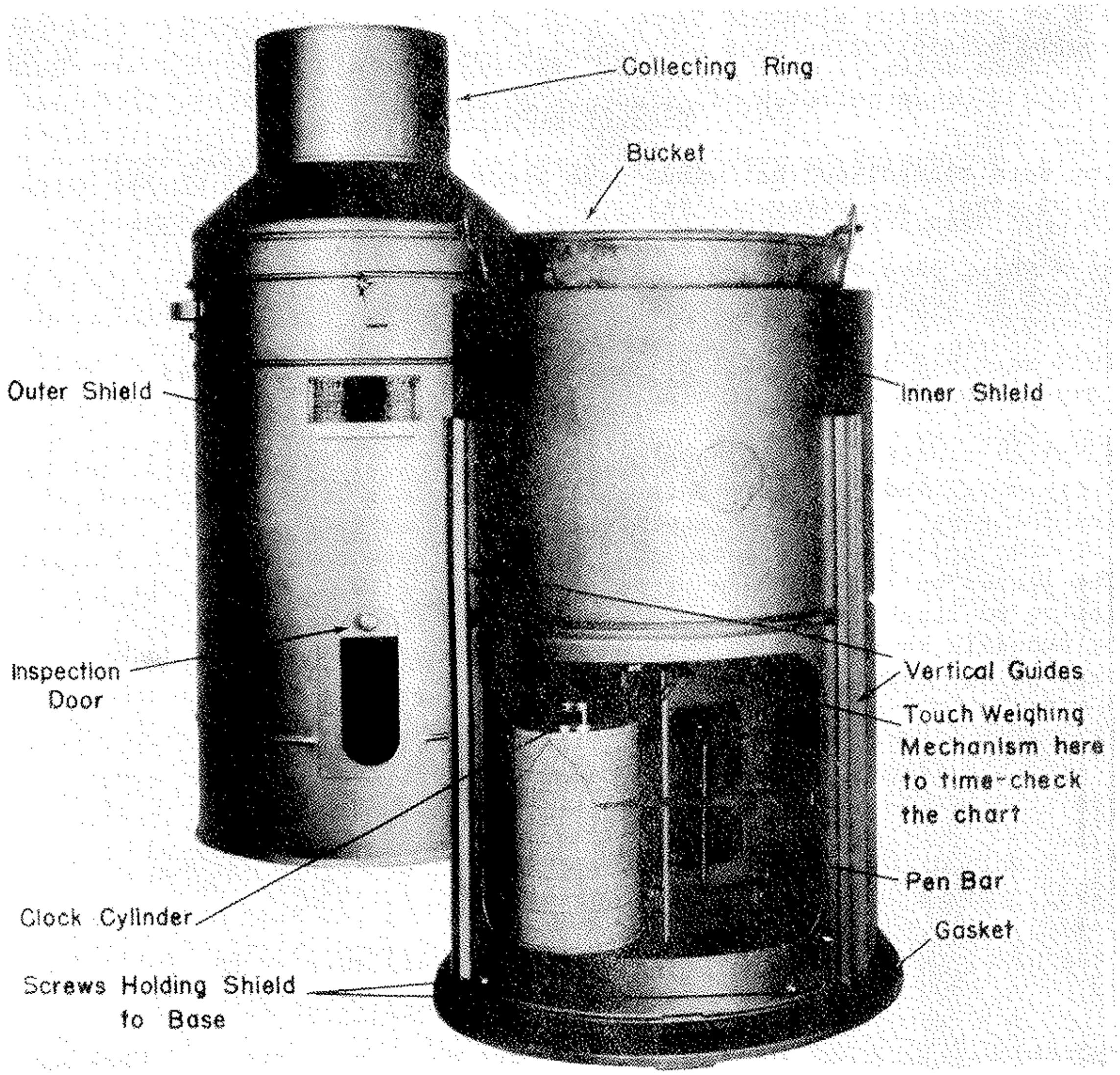


MARVIN WEIGHING RAIN
AND SNOW GAGE

FIGURE 8

Marvin's Rain and Snow Gage was apparently used in 1904 at some stations as shown by Paragraph 137 of Instructions for Preparing Meteorological Forms which read as follows:

> "At stations using the weighing gage, the amount of precipitation at 8 a.m. and 8 p.m. will, in general, be determined from the record sheet; but, in case of failure of the instruments to properly record, the amount of precipitation will be found by adjusting the sliding weight on the gage until equilibrium is established. The amount of precipitation is then shown by the scale reading, which will be taken to the nearest hundredth only. If a satisfactory scale reading can not be made for any reason, the contents of the gage will be emptied into, and measured in, the tube of the standard 8-inch gage. The recording gage should then be set in operation as soon as practicable."



RECORDING, WEIGHING-TYPE PRECIPITATION GAGE,
WITH RECEIVER ASSEMBLY AND OUTER SHIELD REMOVED

FIGURE 9

Apparently use of this early weighing gage did not become widespread, since no more mention is made of it in early instructions.

Beginning in the mid-1930s a number of substations were equipped with a weighing-type recording gage which was designed to record the rate of fall as well as the depth of precipitation. The gage consists of a receiver of exactly 8 inches inside diameter through which precipitation is funneled into a bucket mounted on a weighing mechanism. The weight of the catch is recorded on a clock-driven chart as inches of precipitation. Most recording gages will record up to 12 inches of precipitation. Three designs, Universal, Fergusson, and Leupold-Stevens are in use, with the Universal gage most generally used. See figure 9.

An anti-freeze mixture is used in the winter to melt frozen precipitation falling into the gage and to prevent damage from freezing.

A stick measurement is not made of the precipitation that falls into the recording gage. Charts are to be changed at least once a week; on the first day of each month; and within 24 hours after precipitation has ended.

The network of recording stations (some 3,000 over the country) was established primarily to make hourly precipitation data available to the Corps of Engineers, U. S. Army.

XVI. WIND SHIELDS FOR RAIN GAGES

It has long been recognized that winds have a considerable effect on the catch of a precipitation gage. See reference [67].

Francis E. Nipher, physicist and professor of St. Louis, Missouri, devised a trumpet-like shield in 1878 to counteract the instrument disturbance. Reference [66].

Between 1910 and 1912 J. Cecil Alter, then of the Salt Lake City Weather Bureau Office, did some experimenting with cloth wind shields.

Later the "Alter windshield" was developed as a result of actual field testing of 25 different types of wind shields. This shield had wooden leaves suspended from a ring surrounding the gage. The inward movement of the lower ends of these leaves when the wind was blowing appreciably reduced the up-drafts that would ordinarily disrupt the catch. The leaves were later made of metal for durability. The shield being flexible and responsive to light breezes helped prevent snow from accumulating on it during periods of snowfall in relatively calm weather, a characteristic which was the main disadvantage of the Marvin shield. Reference [63].

The importance of proper exposure of the rain gage was stressed in early "Instructions for the Use of the Rain Gauge" and in "Instructions for Voluntary Observers". A detailed description of a wind shield is given in paragraphs 75 and 76 of reference [44].

No mention of shields was made in the seventh (1924) or eighth edition of Circular B-C (revised 1935) nor in the fourth edition of Circular E, 1936.

However, the ninth edition of Circular B (revised 1941) carries the following discussion in par. 33:

> "Wind Shields. In windy locations, as before mentioned, rain and snow gages give a more or less deficient catch, unless aided by fortuitous features of topography, and gage location, with respect to structures which shield the gage from the wind in varying degrees. Shields for precipitation gages made of metal or cloth have long been known to be effective in securing a reasonably normal catch, and are needed especially for snowfall.
>
> "Shields of various types have been used quite extensively in experiments carried out in the State of Utah and have been found to be distinctly beneficial. ('Shielded Storage Precipitation Gages' by J. Cecil Alter, Monthly Weather Review, July 1937)
>
> "They consist essentially of a circular metal frame from which are suspended wedged-shaped pieces of thin metal, free to be deflected inward by the wind about their suspension. The wind is thereby deflected downward at the windward side of the gage, resulting in a normal instead of an accelerated wind speed over the top of the gage in the absence of shields. When the wind speed over the gage is not accelerated the precipitation enters the receiver instead of being blown past to the lee of the gage where an excess would be deposited."

In the Addendum to Circular N, "Manual of Surface Observations", 6th edition (revised) effective January 1, 1951, shielded gages are discussed in par. A4420 as follows:

"Stations where snowfall and strong wind frequently occur together will be furnished with approved shields. However, where two or more gages are installed, only one will be shielded, preferably the weighing gage."

An explanation of the Alter-type shield is given in the next paragraph.

Circular B, tenth edition (November 1952) says the following in paragraph 3031.1:

"Wind shields, low bushes, shrubbery, fences, and walls that are below a height equal to one-fourth the distance of the object from the gage are beneficial in breaking the force of the wind without setting up eddy currents near the gage that tend to carry away the precipitation."

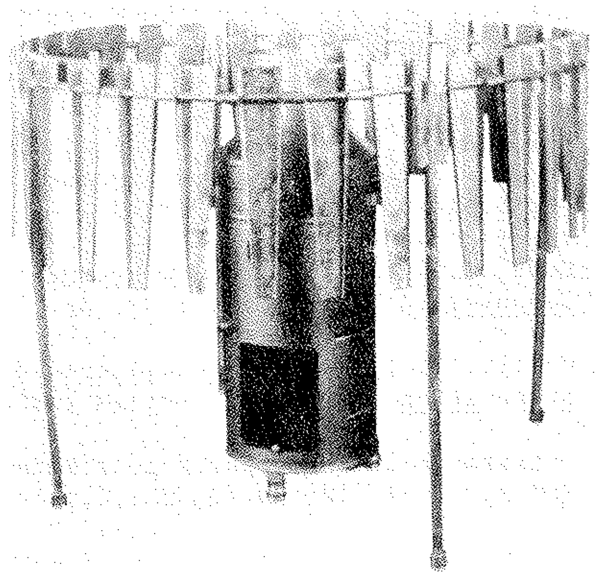
The following is carried in Circular B, tenth edition, (revised October 1955) and repeated in the eleventh edition, revised January 1962:

"Shields of the type shown in Figure 10 help to minimize precipitation loss by deflecting the wind downward. In spite of this defect, open terrain often provides the best exposure available."

Relatively few standard precipitation gages are presently equipped with wind shields. Beginning in various months in the late thirties and early forties (e.g., January 1939 for Utah, February 1941 for California, and May 1941 for Texas) stations with shielded gages are indicated in the Weather Bureau's series of Climatological Data publications by a reference mark in the daily precipitation table and an explanatory note.

The following is taken from reference [63]:

"The currently accepted design of the Alter windshield has thirty tapered, stiffened leaves, 16 inches long and uniformly spaced around the rigidly horizontal ring. This ring is 48 inches in diameter and concentric with the catch ring of the gage. The leaves are hung so that with a breeze their lower ends swing in toward the gage on the upwind side of the gage. In their vertical position the tops of the leaves are one-half inch higher than the level of the gage opening. From the wind-tunnel work of Warnick at the University of Idaho, this distance has been found to give the maximum catch. All shields at Weather Bureau gage installations now conform with this one-half inch specification."



RECORDING WEIGHING TYPE PRECIPITATION GAGE WITH WIND-SHIELD

FIGURE 10

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