Biswas, A. K. (1970). Rain Gauges in The Seventeenth and Eighteenth Centuries. In A. K. Biswas, *History of Hydrology*, (pp. 180–197). Amsterdam: North-Holland Publishing.

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Rain gauges in the seventeenth and eighteenth centuries

INTRODUCTION

Rain gauges, as already have been shown, were used periodically in various parts of the world at different times, viz., in India around the fourth century B.C., Palestine in the first century A.D., China in the thirteenth century, and Korea in the fifteenth century, but they were not used in Europe till about the seventeenth century.

The first to have done so on that continent was the Italian, Benedetto Castelli, who made some isolated experiments with a non-recording rain gauge around 1639. There too Sir Christopher Wren devised two of the earliest recording instruments,[1] one of which was later modified by Robert Hooke. But it was not until the latter part of the seventeenth century that a widespread interest began to appear in the construction of various types of rain gauges and in obtaining systematic volumetric measurements of precipitation.

CASTELLI'S LETTER TO GALILEO

It seems probable that Castelli's use of such a gauge led to his having sometimes been erroneously,[2, 3] attributed with its invention. The erudite German meteorologist Hellmann[4] had discovered a letter that Castelli had written to Galileo on June 10, 1639, in which he, Castelli, mentioned his use of such a gauge, and Hellmann referred to that discovery in a paper which was published in 1890. In 1891, Symons stated[2] that probably the earliest measurement of rain was made with it. Because many of the present precipitation measurement techniques were developed by Symons, it is reasonable to assume that later engineers were inclined to accept his contention that Castelli had been the first person to have made such quantitative measurement. Symons had spent much of his life, nearly forty years, in systematizing rainfall data in the British Isles, and had performed careful experiments with regard to the construction, exposure, form and operation of rain gauges.[5] Hellmann, however, later published two papers, one in 1901[6] and the other in 1908,[7] in which he attributed the invention of rain gauges to the Jews in Palestine during the first century A.D., and probably in an effort to correct his previous error, he mentioned that he considered the measurements on which *those* gauges were used to be the earliest quantitative measurements of rainfall.[7] He, incidentally, also mentioned therein that Ferdinand II of Tuscany had a rain gauge in operation in Florence early in the seventeenth century. In the letter Castelli had written to Galileo Galilei, Chief Philosopher to the Great Duke of Tuscany, he had stated:

‘Being returned to Perugia, there followed a rain, not very great but constant and even, which lasteth for the space of 8 hours or thereabouts; and it came into my thoughts to examine, being in Perugia, how much the Lake [Thrasimeno] was increased and raised by this Rain, supposing (as it was probable enough) that the Rain had been universal over all the Lake; and like to that which fell, in Perugia, and to this purpose I took a glasse formed like a cylinder, about a palme high, and half a palme broad; and having put it in water sufficient to cover the bottom of the glasse, I noted diligently the mark of the height of the water in the glasse, and afterwards exposed to the open weather, to receive the raine-water, which fell into it; and I let it stand for the space of an hour; and having observed that in that time the water was risen in the vessel the height of the following line [Castelli here draws a line about 0.4 in. long to represent the depth], I considered that if I had exposed the same rain such other vessel equal to that, the water would have risen in them according to that measure.’[8]

Castelli repeated his experiment and showed it to an engineer having a ‘dull brain’ (who was not very enthusiastic about the instrument) while it was ‘out at my chamber-window exposed in a courtyard’. Symons assumed the rain gauge to be a glass cylinder about 5 in. in diameter and 9 in. deep. Frequently it is contended that Castelli made a rain gauge because of an ‘exceptionally heavy downpour,[2] but as can be seen from his letter, the rainfall was actually ‘not very great, but constant and even’.

That measurement of Castelli’s applied only to an isolated rainfall. It does not seem to have occurred to him to use his rain gauge for recording subsequent precipitations. This is borne out by the fact that no references are made to any rain gauges in the Climento manuscripts which date from 1654 to 1664, nor in records of the Monastery of the Angels of Florence of the period 1654 to 1670 where frequent statements can be found concerning the dates on which rain or snow fell. It is reasonable to assume that if a rain gauge had actually been in operation, details thereon as well as the results of any measurements would have appeared in those manuscripts.

SIR CHRISTOPHER WREN’S FIRST RAIN GAUGE

The earliest English rain gauge[9–13] was made by Sir Christopher Wren (1632–1723; figure 1) and, unlike the previous instruments, this one was of a recording type. There is no evidence, however, of it ever having been used for obtaining regular observations of rainfall.

Figure 1. Sir Christopher Wren, from a marble bust by Edward Pierce made about 1673 (by courtesy of the Ashmolean Museum, Oxford).

B. De Monconys, a Frenchman, who visited England in June 1663, described the automatic rain gauge in question. He reported it as having been made by one 'M. Renes'.[14] It is contended here that 'M. Renes' was actually Sir Christopher Wren, and that the poor Frenchman failed to realize that the surname, pronounced 'Ren', was actually spelled Wren. Such a mistake is quite understandable, and is, in fact, believed to have occurred in this instance. The rain gauge which De Monconys described is shown in figure 2. It was, as will be seen, a part of a meteorograph. Below the catch funnel was a three-compartment container mounted on a rack which was moved slowly forward by clockwork in such a manner that one of those compartments would collect any rain which would fall during the first hour; the next compartment would collect any which fell during the second hour, etc.

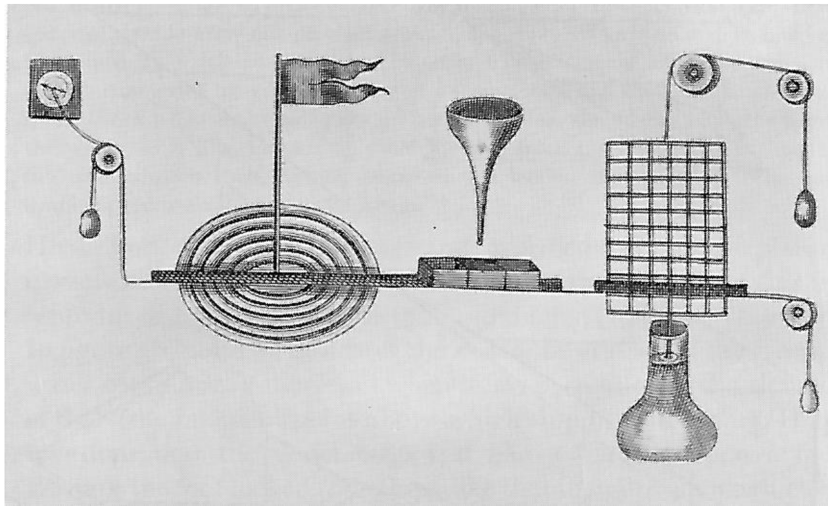

Figure 2. Rain gauge attributed to 'M. Renes' by De Monconys.

Middleton[15] has suggested that assuming De Monconys' diagram has some validity as an elementary sketch, it was probably a rough model constructed by Wren to tidy up his initial ideas. Probably Wren was reluctant to show the weather-clock to the Royal Society in its underdeveloped form. Middleton further suggested that Wren later substituted rack and pinion arrangement for the drum and cord of the first meteorograph.

THE WREN-HOOKE TIPPING-BUCKET RAIN GAUGE

Sir Christopher Wren's second automatic rain gauge was of the tipping-bucket type, provided with recording facilities. It was a part of an all-purposes 'weather-wiser' discussed as follows by Nehemiah Grew (1641–1712), a former secretary of the Royal Society:

'Begun by Sir Christopher Wren, now President of the Royal Society. To which other motions have since been added by *Mr. Robert Hooke* Professor of Geometry in *Gresham-Colledge*. Who purposes to publish a description hereof. I shall therefore only take notice, that it hath six or seven motions; which he supposeth to be here advantageously made altogether. First a *pendulum* clock, which goes with ¾ of a 100 *Lib*. weight, and moves the greatest part of the work. With this, a barometre, a thermometre; a rain-measure, such an one as is next describ'd; a weather-clock, to which subserves a piece of wheel-work analogous to a *way-wiser*; and a hygroscope. Each of which have their register, and the *weather-clock* hath two, one for the *points*, the other for the strength of the wind. All working upon a paper falling off a rowler which the *clock* also turns.
An instrument for MEASURING the quantity of RAINS that fall in any space of time, on any one piece of ground, as suppose upon one acre in one year. Contrived by *Sir Christopher Wren*. In order to the theory of vapours, river, seas, &C. A triangular tin-vessel hanging in a frame, as a bell, with one angle lowermost. From whence one side rises up perpendicular, the other sloaped; whereby he

water, as it fills, spreads only on one side from the centre, till at length it fills and empties itself. Which being one, a leaden poise, on the other side, immediately pulls it back to fill again.'[16]

Hooke both described the gauge and furnished a drawing explaining its construction. Figure 3a shows his original drawing thereof as first reproduced by Derham[17] (in 1726), and later (1930) by Gunther.[18]

In figure 3b, point C indicates the centre of gravity of the prism of water container in the vessel when it has been filled to the elevation of S-T (the incipient point above which tipping will occur). Hooke mentions that the vessel is 'poiz'd like a balance upon a foot'. Perhaps the foot looked something like that in figure 3d, in which the surfaces D and B serve as stops for limiting the number of degrees through which the vessel could tilt. When finished, Hooke's tip- ping-bucket rain gauge may have looked like the assembly illustrated in figure 3e.

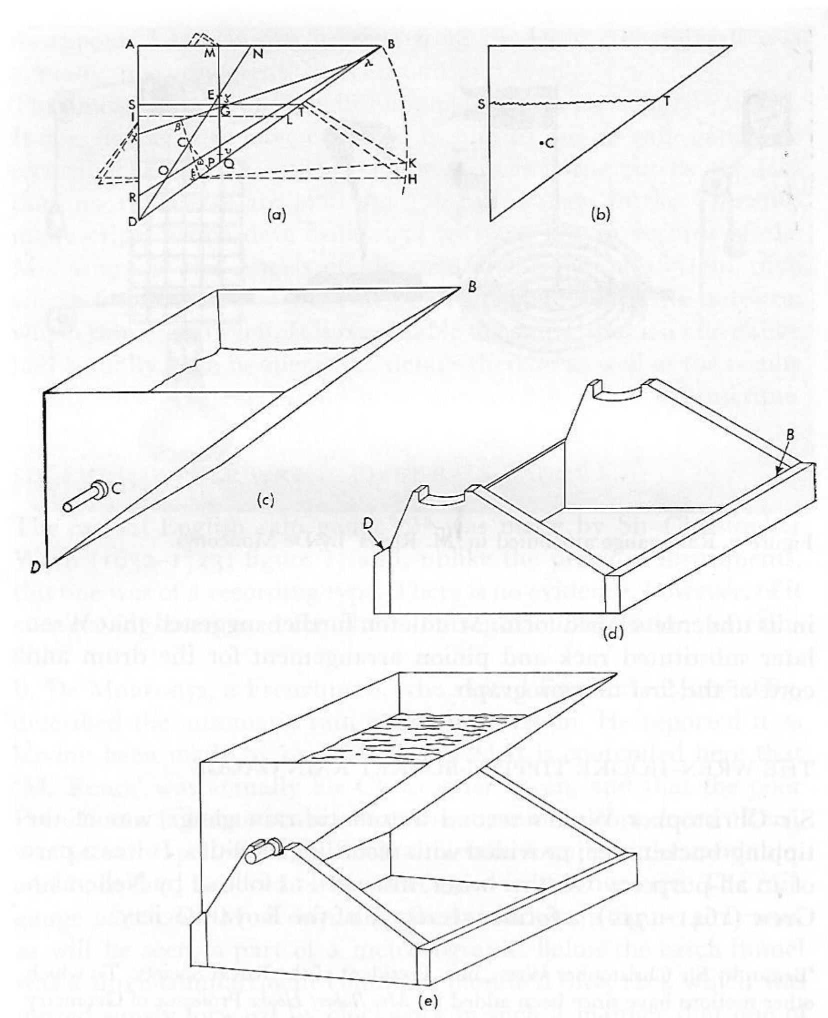

Figure 3. (a) The original sketch of Robert Hooke. (b) All construction lines have been moved. Point C is the centre of gravity of the prism of water contained in the vessel when it has been filled to the elevation of S–T (the incipient point above which tipping will occur). (c) This shows the vessel in three dimensions. (d) Hooke mentions that the vessel is ‘poiz’d like a balance upon a foot’. Maybe the foot looked something like this. Surfaces D and B serve as the stops to limit the travel of the vessel. (e) When assembled, the tipping-bucket rain gauge might have looked like this (by courtesy of Arthur H. Frazier).

Two alternative methods for counterpoising the weight of the bucket were contrived by Hooke. The first used a string of bullets so arranged that when the bucket was empty, all of the bullets would lie on a table. They would be lifted up one after another as more and more water accumulated in the bucket. By the time all of them were lifted from the table, the bucket would empty itself. Hooke rejected that arrangement on the ground that the movement of the bucket would neither be smooth nor continuously equal.

The second method was described as using a

‘counterpoise to the bucket, when empty was a cylinder immersed into water, mercury or any other fluid; which cylindrical counterpoise, according as the bucket received more and more water, was continually lifted higher and higher out of the water by spaces, always proportioned to the quantity of water, that was contained in the bucket. And when the bucket was filled to its designed fullness, it immediately emptied itself of the water, and the cylinder plunged itself into the water, and raised the bucket to the place where it was again to begin its descent.’[7, 19, 20]

The principle of the tipping-bucket rain gauge was certainly known before Wren’s time. For example, Muhammad ibn Ibrāhīm, al-Jazarī, in his treatise on automata (c. 1364) described an automatum in which two figures alternately pour wine for each other (figure 4). It was actuated by wine stored in the dome thereof. Through the action of the tipping-bucket above the- two figures, the wine would flow first to one of them and then to the other. Although the principle was known, up to now there is no evidence to indicate that any tipping-bucket type *rain gauge* had been built before the time of Sir Christopher Wren.[21]

The weather-clock, of which the Wren-Hooke self-measuring rain gauge was a part, consisted of two parts. The first part consisted of a strong and large pendulum-clock designed to measure time as well as to unwind a paper strip into which the records would be punched every 15 minutes. The second part consisted of an arrangement of five meteorological devices: a barometer, thermometer, hygroscope, rain bucket, and finally a revolving type wind vane, all of which provided the data that were punched through the paper strip. A further description of it follows:

‘The stations or places of the first four punches are marked on a scrowl of paper, by the clock-hammer, falling every quarter of an hour. The punches, belonging to the fifth, are marked on the said scrowl, by the revolutions of the vane, which are accounted by a small numerator, standing at the top of the clock-case, which is moved by the vane-mill.' [17, 22]

Figure 4. The principle of 'tipping-bucket' type of rain gauge was known to the Arabs. The illustration (from a manuscript on *Automata* by Muhammad ibn Ibrāhīm, al-Jazari, dated 1364) shows an automatum in which two figures pour wine for each other. The automatum is actuated by wine stored in the dome; through the action of the 'tipping bucket' above the figures, the wine flows first to one man and then to the other (by courtesy of the Museum of Fine Arts, Boston).

The punched records of the observations from the rain-bucket not only showed the number of tippings as they occurred, but also indicated the quantity of water that remained in it.

The meteorograph obviously worked, because Hooke and his assistant were asked by the Royal Society to 'reduce into writing' some of the data from the punched tapes. The fact that the punched tape method of registering data has come into vogue only during the last decade or two, clearly indicates that Hooke, who used it as early as 1678, was well ahead of his tine. To the author's knowledge, no sketch or specimen of the actual punch tape used exists at present, but it may be noted in this connection that Jacob Leupold in his book *Theatri machinerum supplementum*, published in 1739, described with sketches[23] the use of a similar punched tape to record results obtained from way-wisers (pedometers).

The chronology of Wren's recording rain gauge is described[24] by Thomas Birch (1705–1766), the then secretary of the Royal Society, and has been discussed in considerable detail by Biswas.[1]

Hooke also contrived a non-recording type of rain gauge[25] as shown in figure 5. It was used in 1695 at Gresham College where Hooke was a professor of geometry. A large flask capable of holding more than 2 gallons, called a 'large bolt head', was supported by a wooden frame having, presumably, a 11.4-in.- diameter glass catch funnel. The funnel was held steady against the wind by two stays or pack threads strained by two pins. The neck of the container was 20 in. long by 0.2 in. in diameter to minimize evaporation. The rainwater which accumulated in the container was measured every Monday, and the total precipitation over a period of time was expressed as a vertical depth which had fallen during that time interval (see figure 6).

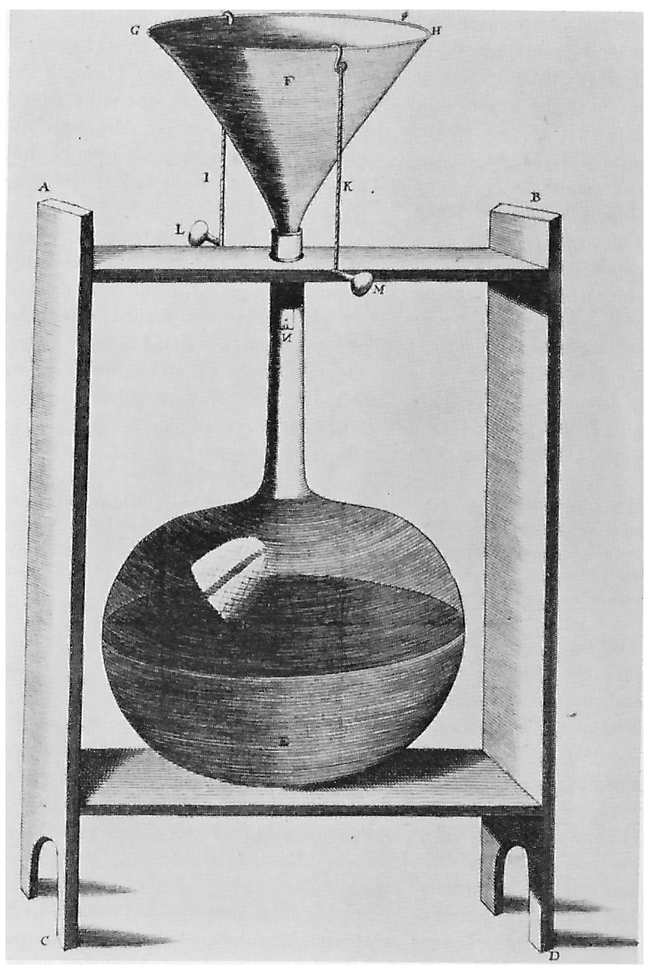

Figure 5. Non-recording rain gauge of Robert Hooke.

Months	Days	℔	℥	Gr.
August	19	2	6	216
	26	4	6	246
September	2	9	4	96
	9	3	10	397
	16	0	1	204
	23	0	6	336
	30	4	1	444
October	7	2	3	95
	14	0	2	60
	21	0	1	234
	28	0	0	45
November	4	0	0	207
	11	1	11	65
	18	1	1	309
	25	0	9	285
December	2	0	8	126
	9	3	7	324
	16	1	3	435
	23	0	1	60
	30	5	8	93
January	6	4	10	105
	13	0	1	12
	20	1	10	450
	27	1	5	82
February	3	6	11	372
	10	4	9	242
	17	0	6	291
	24	0	2	180
March	2	0	9	12
	9	0	2	459
	16	0	0	396
	23	4	4	263
	30	1	5	285
April	6	2	3	375
	13	1	0	294
	20	2	1	000
	27	0	7	390
May	4	4	10	45
	11	7	6	000
	18	6	2	105
	25	1	7	60
June	1	0	0	99
	8	6	6	150
	15	0	2	120
	22	7	5	285
	29	1	5	84
July	6	0	1	120
	13	16	1	000
	20	1	7	240
	27	6	1	256
August	3	1	10	120
	10	1	11	90
	12	0	0	0
The Sum		131	7	113

= to 29 $\frac{1}{10}$ $\frac{1}{2}$ Inches in a Cylinder of the aforesaid Diameter, *viz.* 11 ¾ Inches.

Figure 6. Typical record of observations of Hook’s rain gauge.

OBSERVATIONS BY TOWNLEY

The first continuous observations of rainfall in Britain were made by Richard Townley (1629–1707) of Townley Hall in Lancashire,[26] starting from 1677. For his rain gauge he

‘... fixed a round tunnel of 12 inches diameter to a leaden pipe, which could admit of no water, but what came through the tunnel, by reason of a part soder’d to the tunnel itself, which went over the pipe, and served also to fix it to it, as well as to keep out any wet that in stormy weather might beat against the under part of the tunnel, which was so placed, that there was no building near it that would give occasion to suspect that it did not receive its due proportion of rain that fell through the pipe some nine yards perpendicularly, and then was bent into a window near my chamber, under which convenient vessels were placed to receive what fell into the tunnel, which 1 measured by a cylindrical glass at a certain mark, containing just a pound, or 12 ounces troy, and had smaller parts also.’[27]

The tunnel was fixed on the roof of Townley's house. Symons[2] later conducted some experiments with a similar gauge having 27 ft of pipe, and concluded that its evaporation loss was almost imperceptible.

For the first 6 months of 1699, Derham[28] measured the rainfall at Upminster. No details are available of that rain gauge, but it was probably similar to Townley's.

MEASUREMENTS BY PERRAULT AND MARIOTTE

Very little is known[29, 30] about Pierre Perrault's rain gauge (see chapter 10). His compatriot Edmé Mariotte also conducted[31] a comparison of rainfall and runoff on the river Seine catchment above Paris, and it was an improvement over Perrault's. Rainfall measurements were made at Mariotte's request by 'a very skillful man and very exact in his experiments', probably around 1678.

> 'He placed near the top of the house a square vessel, about two foot diameter, at the bottom of which there was a pipe which conveyed the rain that fell into it into a cylindric vessel, where it was easy to measure it as often it rained; for when the water was in the cylindric vessel, there was very little exhaled during five or six days. The vessel of two foot diameter was sustained by a bar of iron, which advanced about six foot beyond the window, whereon it was placed and fixed that it might receive only rain-water, which fell immediately upon the breadth of its opening, and that there might not enter any but what was to fall according to the proportion of upper surface.'[32]

EARLY EIGHTEENTH CENTURY

The interest in the measurement of precipitation increased considerably during the earlier part of the eighteenth century through-out the world. According to Horton, the physicians Kindmann and Kanold of Breslau, Prussia, invented conical rain gauges[33] around 1717, and they obtained measurements with them throughout the period 1717 to 1727. Probably the earliest approximation of the modern non-recording instruments were made by Horsley in England in 1722. Horsley realized that

> '. . . weighing the water and reducing it from weight to depth seemed pretty troublesome, even when done in the easiest method: to remedy this inconvenience (besides a funnel and proper receptacle for the rain) I use a cylindrical measure exactly 3 inches, the depth of the measure is 10 inches, and the gauge of the same length with each inch divided into 10 equal parts; or, instead of a gauge, the inches and divisions may be marked on the side of the cylindrical measure. The apparatus is simple and plain, and it is easy to apprehend the design and reason for the contrivance; for the diameter of the cylindrical measure being just $1/10$, of that of the funnel, and the measure exactly 10 inches deep, 'tis plain that 10 measures of rain make an inch in depth... By this means the depth of any particular

quantity which falls, may be set down with case and exactness and the whole at the end of each month or year may be summed up without trouble.'[34]

In 1723, James Jurin drew up a set of rules for providing uniformity in meteorological observations.[35]

Many different types of rain gauges were used after 1710. Some important ones – including a few unusual examples – will be briefly described below.

Rain gauges of Leupold

Leutinger[36] described a hyetometer in 1725 which, according to Leupold,[37] was first devised by Leutmann. It had a square funnel leading to two glass tubes (figure 7, Fig. XIV) and measured the total weight rather than the depth of rainfall. The two tubes were calibrated to give the weight of rain water collected. There were two taps in the instrument. No records are available to indicate whether this instrument was actually put into practical use.

Leupold also described various other types of rain gauges, for example, the one (figure 7, Fig. XII) used by the Breslau Natural History Society started in 1717 (the same one mentioned by Horton?) which had a sharp-edged glass funnel of about 4 in. in diameter and a depth of 8 in. As with the Leutmann's gauge, this particular type indicated the total weight of accumulated rainfall rather than its depth.

Leupold's own non-recording type instrument (figure 7, Fig. XIII) had a 9-in. square receiver. The rainfall was collected in a glass tube for determining its quantity. Two automatic gauges of his have also been described. The first had a series of compartments beneath a catch funnel, and the compartments were moved by clockwork so that the funnel remained above each of those receptacles for a measured period of time (figure 7, Fig. XV). If the quantity of water was measured in each compartment, it would represent the total amount of rain that had fallen during the particular time interval involved. The second of those two automatic rain gauges – 'Leupold's hyeto-meter' – was of a tipping-bucket type in which the rainfall collected by a funnel having a square opening was directed into a small bucket at the end of a balance level. Each time the bucket became filled with rainwater it tipped and emptied itself. While so doing, the first wheel of a counting device was advanced by one tooth (figure 8). As there were four wheels, the gauge could automatically indicate as many as 10,000 tips. While tipping occurred, a special device prevented any water from by-passing the measuring bucket. The most striking difference between the English and the continental gauges of this period was in the use made of taps for emptying the measuring flasks. The continentals used them extensively, whereas the English seldom used them because they realized that taps tended to leak after short periods of use.

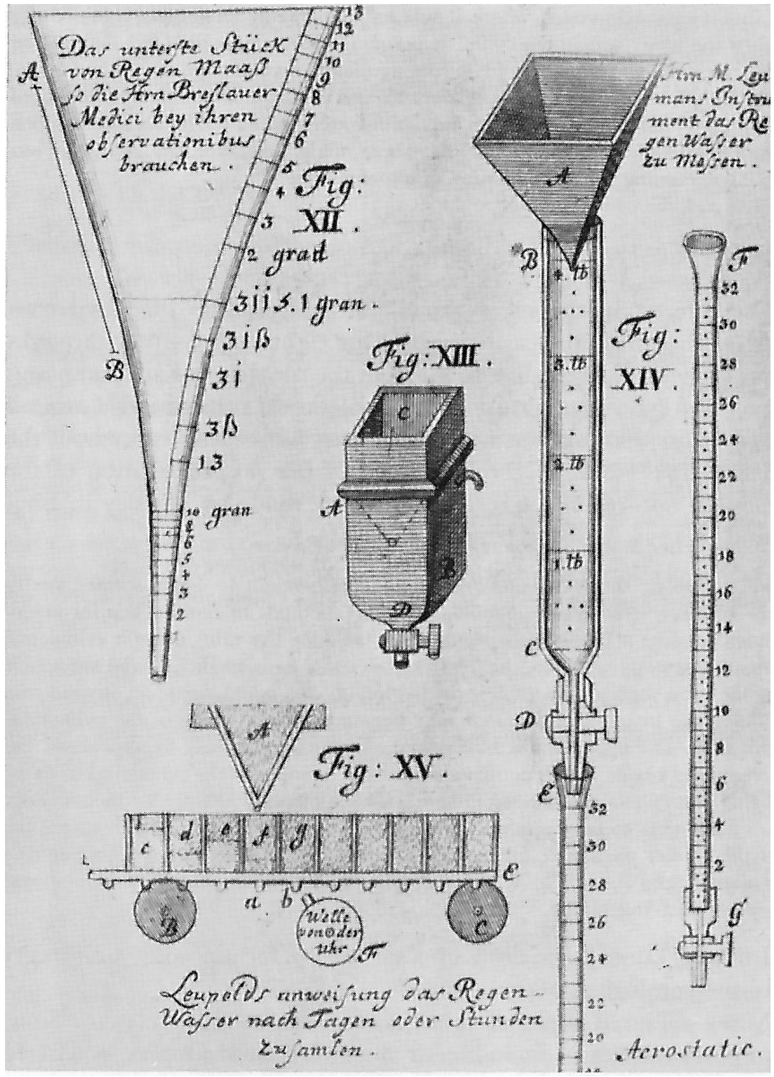

Figure 7. Non-recording rain gauges described by Leupold.

Rain gauges of Pickering, Dobson and Dalton

In 1744, Pickering proposed a rain gauge having a tin funnel of 1 sq. in. area (figure 9) which discharged into a ½ -in.-diameter glass tube that was more than 2 ft long. The entire instrument was mounted on a 3-ft-long board which was hung against the rail at the top of his house.[38] The inch graduations on the tube were divided into 32 parts. He claimed that with a diameter of tube that small, the results would be more accurate than those obtained with instruments using larger tubes. The instrument was very simple and could be repaired easily if the tube became broken.

Dobson was among the first (as of 1777) to measure rainfall in a manner that corresponded with present standards. Most rain gauges used during this period (and even later) were placed on the roofs of houses so that they might 'record free fall of rain'. His rain gauge was a well-varnished 12-in.-diameter tin funnel which was fixed on to the top of a large stone bottle by means of a grooved cork, the use of which was primarily intended to reduce evaporation.

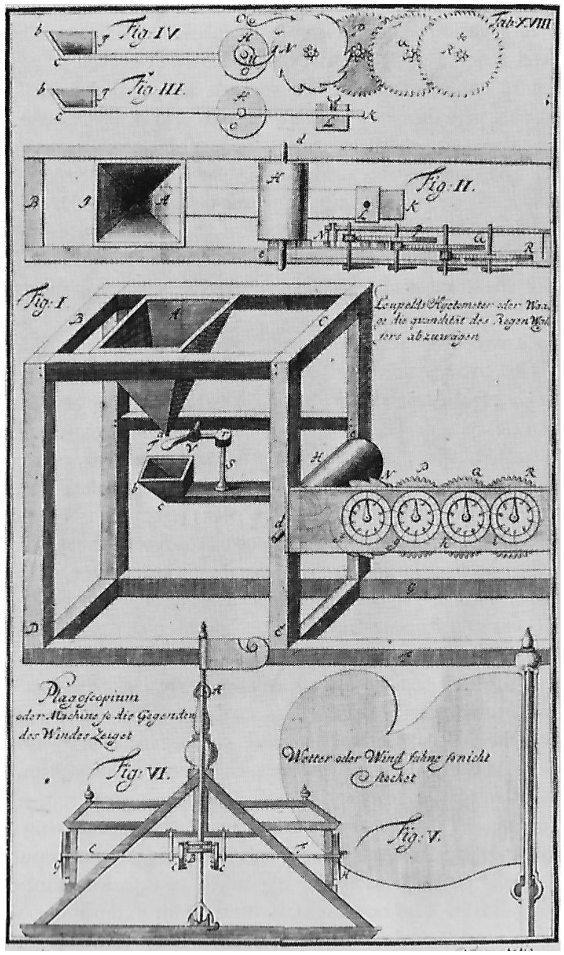

Figure 8. Automatic rain gauge of Leupold.

He chose a site at the middle of a grassy plot overlooking Liverpool, 75 ft above sea level, on rising ground having free exposure to the sun, wind, and rain.[39] His primary interest seems to have been concerned with evaporation.

Dalton's definition of rain gauge and its description was brief and precise:

'The rain gauge is a vessel placed to receive the falling rain, with a view to ascertain the exact quantity that falls upon a given horizontal surface at the place. A strong funnel, made of sheet iron, tinned and painted, with a perpendicular rim two or three inches high, fixed horizontally in a convenient frame with a bottle under it to receive the rain, is all the instrument required.'[40]

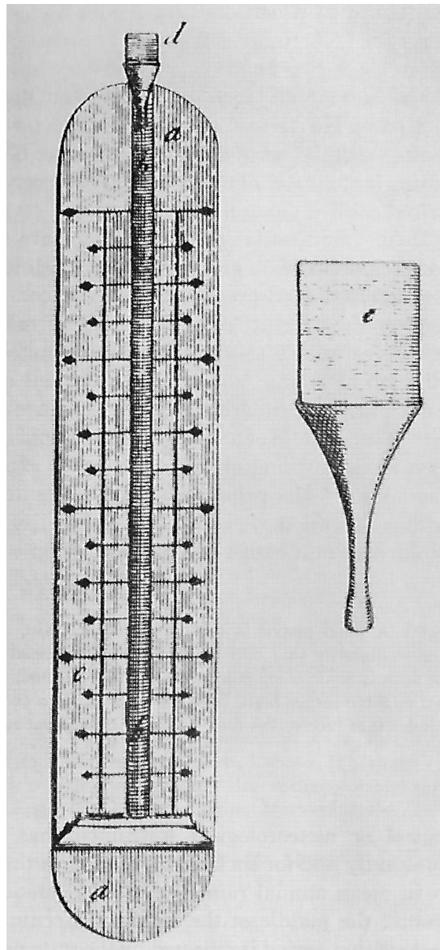

Figure 9. The rain gauge of Pickering.

CONCLUSION

No hydrological or meteorological instrument has received attention so constantly and for such a long period as the rain gauge. The interest in mean annual rainfall, however, made its first appearance around the middle of the eighteenth century. The prevailing attitude of that period is reflected by the statement of Gilbert White[41] who said that his own observations (May, 1779 to December, 1786) were too short to provide a good estimate of the mean rainfall. Credit for keeping the longest rainfall record (by a single person using the same instrument during the seventeenth and eighteenth centuries must go to White's brother-in-law, Thomas Barker of Lyndon in Rutland, England, who did so for a period of 59 years (1736 to 1796).

A major defect appears frequently in one of the average annual rainfall records published for the eighteenth century. Those responsible for it have failed to note that September, 1752, had officially only 19 days.

The present chapter can be best concluded by quoting G. J. Symons, to whom hydrologists and meteorologists all over the world owe their gratitude for his rationalization of rainfall data:

'... I desire to meet at the very outset an objection sometimes raised, viz., that we cannot trust very old observations ... I maintain that we can trust them, ... I think them far more reliable than many modern ones; for in the 17^{th} and early part of the 18^{th} century, to measure the fall of rain was esteemed a serious undertaking, only to he accomplished by first-class men.'[42]

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