CHAPTER V

MEASURING WATER, A. D. 97

Mensor bonus vir et justus.
FRONTINUS, *Agrimensores*
(ed. Lachmann), p. 55.
The engineer, a good man and true.

IN Chapter 23 Frontinus takes up the distribution system, as we should now call it, of the water supply of the City of Rome, and as a preliminary and explanatory study he first considers the methods according to which water was then measured and allotted; a train of thought that carries him to Chapter 63, the end of Book I.

Let us see what ideas were extant on hydraulics, in Frontinus' time. The most troublesome point of ignorance he had to contend with was a total inability to measure the velocity of water, or even to rightly and fully grasp the idea of such velocity, whether as flowing in an open channel or in closed pipes. He accordingly compares streams of water merely by the areas of their cross-sections. A square foot of water is all one to him, whether it be one of the eight square feet of cross-sectional area of a stream in a conduit, or whether it be composed of the sum of two hundred or more cross-sectional areas of lead pipes leading out of delivery tanks to fountains, or to water basins, or to private consumers, and ending and discharging at as many different elevations. To the expert of to-day this seems excessively silly; and yet the same thing is constantly being done even now by those who ought to know better. The average man to-day will talk about "a stream of water that will fill a six inch pipe," a perfect parallel to the *quinaria* of Frontinus; and there are hundreds of deeds on record conveying "square feet of water" for power purposes, just as though the law of falling bodies and its application to hydraulics had never been discovered; and unmindful of the fact, as one old Italian writer on

water-rights has expressed it, that to speak of a stream of water by its area of cross-section is like estimating the volume of a cylinder merely from the area of its base.[1]

Chapter 35 gives us some of the ideas Frontinus had on velocity of flow, as follows: "Let us not forget in this connection that every stream of water whenever it comes from a higher point and flows into a delivery tank through a short length of pipe, not only comes up to its measure, but yields, moreover, a surplus; but whenever it comes from a low point, that is, under a less head, and is conducted a tolerably long distance, it will actually shrink in measure by the resistance of its own conduit; so that on these accounts, either an aid or a check is needed for the discharge." That is to say: an aid or a check is needed to make the pipe discharge the *normal* quantity allotted to *that size* of pipe.

He also says, speaking of Virgo, 70: "The gauging could not be made at the intake, because Virgo is made up of several tributaries, and enters its channel with too slow a current. Near the city, however, at the seventh mile-stone, on the field which now belongs to Cejonius Commodus, and where Virgo has a greater velocity, I made the gauging, and it amounted to 2,504 *quinariae*, being 1,752 *quinariae* more than was set down in the records. But proof of the correctness of our gauging is at hand; for Virgo discharges all the *quinariae* we found at the point of gauging; that is, 2,504." Meaning by this, that the sum of the areas of all the pipes leading out of Virgo was equal to the area of the cross-section of the stream at the second mile-stone, as found by him; and flattering himself that such equality of areas was the way to attain equality of volumes of discharge. He had already said, 65, in speaking of the Appia aqueduct: "At the Twins, which is below Spes Vetus, where it joins the branch of the Augusta, I found a depth of the water of five feet, and a width of 1 ft. plus ¾, making 8¾ square feet of area; twenty-two 100-pipes, plus one 40-pipe;" that is: twenty-two pipes each one hundred square digits in area (nominally at least), and one pipe of forty square digits (nominal area); "which makes 1,825 *quinariae*," says Frontinus. In point of fact, 5 ft. × 1.75 = 8.75 sq. ft., as he says. This equals 1,260 square inches (Roman). And as

[1] Romagnosi, German translation by Bunsen, p. 176.

one *quinaria* equals the area of a circle one and one-fourth digits in diameter, it is equal to 0.69026 square inches (Roman); and 1,260 square inches equals 1,825.4 *quinariae*, where Frontinus had 1,825. And then he goes on again, as before quoted, worrying himself into all sorts of explanations why his gaugings by areas, made irrespective of heads and velocities, do not balance. The frauds of the water-men, of the plumbers, and of others who draw water unlawfully, always furnish a handy explanation, however.

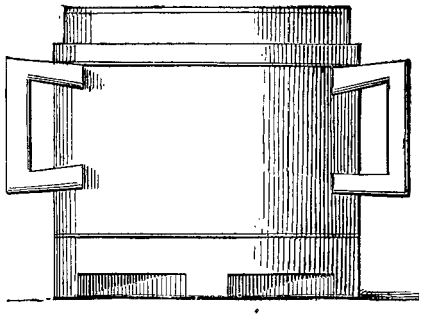
Another passage relating to the velocity of flow is 73: "Whence it appears, that the amount measured by me is none too large; the explanation of this is, that the more impetuous stream of water increases the supply, since it comes from a large and rapidly flowing river." That is to say: the unusual velocity causes that size of pipe to discharge more than it would ordinarily or normally discharge.

Hero of Alexandria, who, by means of his widely circulated writings, and possibly at the school in Alexandria, where Hero had formerly taught, may be considered as the teacher of Frontinus, had already said,[1] "Dioptera," 31: "Observe always that it does not suffice to determine the section of flow, to know the quantity of water furnished by the spring. This we said was twelve square digits. It is necessary to find the velocity of its current, because the more rapid the flow, the more water the spring will furnish, and the slower it is, the less it will produce. For this reason, after having dug a reservoir under the stream, examine by means of a sun-dial how much water flows into it in an hour, and from that deduce the quantity of water furnished in a day. Thus one has no need to measure the section of the stream. The measure alone of the time suffices to make evident the flow of the spring." This exhibits a clearer understanding of the beginnings of the art of measuring flowing water, and better practice than is anywhere shown in "De Aquis," or in Roman water-law, so far as I have seen it.

But some control of the amount drawn had to exist, and we accordingly find that the measure of a grant in the City of Rome, A. D. 97, was the right to insert, at a designated place in the public delivery tanks, which received their supply, either directly or through lead pipes,

[1] J. Assoc. Engineering Societies, July, 1897.

from the public aqueducts, a circular, bronze ajutage, or short piece of pipe, stamped by the public authority, not less than about nine inches long and of a designated diameter; some fifteen such diameters being in ordinary use; and to allow water naturally to flow through this ajutage; it being the law, moreover, to ensure a natural flow through the stamped bronze ajutage, that the lead or other pipe immediately down-stream from it should have the same diameter as the ajutage, on a length of not less than fifty feet, measuring from the down-stream end of the ajutage.



MODIUS.[1]

This is a long definition of a grant; but, nevertheless, it did not ensure the draft of a definitely limited quantity of water, as Frontinus himself was well aware. He makes note, for example, that the direction of insertion of the ajutage, relatively to the direction of the current in the cistern, is of great moment. This is what he says on this point, 36: (An ajutage) "placed at right angles and level, it maintains its proper measure; set against the current of the water and sloping down, it will consume more; set sloping to one side, so that the water flows by, and inclined with the current, that is, placed less favorably for swallowing water, it will receive the water slowly, and in a scant quantity."

A mis-quotation, and a mis-translation of the mis-quotation, of a part of this sentence,[2] has been read to mean that a flaring ajutage will increase the discharge; thus attributing a knowledge of the properties of a Venturi tube to the ancients. The word and context prove the falsity of this translation, however.

Bearing on this same matter, and more nearly referring to the properties of a Venturi tube, is the following, 105: "It must also not be left optional to attach any kind of lead pipe to the ajutages; but there must rather be attached for a length of fifty feet one of the same

[1] From a terra-cotta lamp. The modius, the largest dry measure of the Romans, was a third of an amphora and a sixth of the Greek medimnus; it held nearly two gallons.

[2] "Calix devexus amplius rapit."

interior area as that which the ajutage has been certified to have, as has been ordained by a vote of the Senate, which follows:

"The consuls, Q. Aelius Tubero and Paulus Fabius Maximus, having made a report that some private parties take water directly from the public conduits, have inquired of the Senate what it would please to order upon the subject; upon which it has been ordered: It shall not be permitted to any private party to draw water from the public conduits; and all those to whom the right to draw water shall have been granted shall draw it from the delivery tanks, the water commissioners to direct at what points, within and without the city, private parties may erect suitable delivery tanks, for the purpose of drawing water from them, under grants which, in common with others, the water commissioners have located; and no one to whom a right to draw water from the public conduits has been granted shall have the right to use a larger pipe than a *quinaria* for a space of fifty feet from the delivery tank out of which he is to draw the water."[1]

Also, 112: "In some of the tanks, though their ajutages were stamped in conformity to their lawful admeasurements, it was found that pipes of a greater diameter were attached to them. As a consequence, the water, not being held together for the lawful distance, and being, on the contrary, forced through the short restricted distance, easily filled the adjoining larger pipe. Care should therefore be taken, as often as an ajutage is stamped, to stamp also the adjoining pipe over the length prescribed by the vote of the Senate which we have quoted. For thus only is the overseer relieved of every excuse he could make, when he knows that none but stamped pipes are allowed to be set in place." Now, the only way to have made a Venturi tube out of such a lawful arrangement of pipes would have been to expand the lead pipe fifty feet from the cistern *very gradually and uniformly* into a larger pipe.

Eytelwein made some experiments to test the point whether a Venturi tube would increase the discharge of a long pipe when placed at the outer end of it (Gilbert's "Annalen," Vol. VII., p. 295). He experimented with a one-inch pipe twenty feet long, and found that

[1] See also Venafrum aqueduct laws, *Zeitschr. f. gesch. Rechtsw.*, xv. 317; Venafrum, 44. Or see Brun's *Fontes*, sixth edition, p. 239.

when discharging freely *into the air* under a three-foot head it made no apparent difference in the discharge whether the Venturi tube was on or off. This, however, leaves the main question still undetermined; and it remains to be seen whether the same apparatus discharging *under water*, — that is, submerged, — or a Venturi mouth-piece discharging through a long pipe of the diameter of the larger end of the ajutage, will or will not discharge more than the small pipe alone. Venturi thought that it would; and I should not be surprised if it did, to put it no stronger.

Here is another correct conception of the matter of head acting on orifices entertained by Frontinus, though he spoke without knowledge of the laws of hydraulics as they have been developed in the eighteen hundred years following his time: 113. "In setting ajutages, care must be taken to set them on a level, and not place the one higher and the other lower down. The lower one will take in more, the higher one will suck in less, because the current of water is drawn in by the lower one."[1]

But the proper placing of the ajutages was evidently kept in the hands of the authorities; and Frontinus had clear ideas of the value of those lead pipes not less than fifty feet long, as we have seen, and that they should be stamped by the public authorities, as well as the bronze ajutage, as a safeguard against fraud.[2]

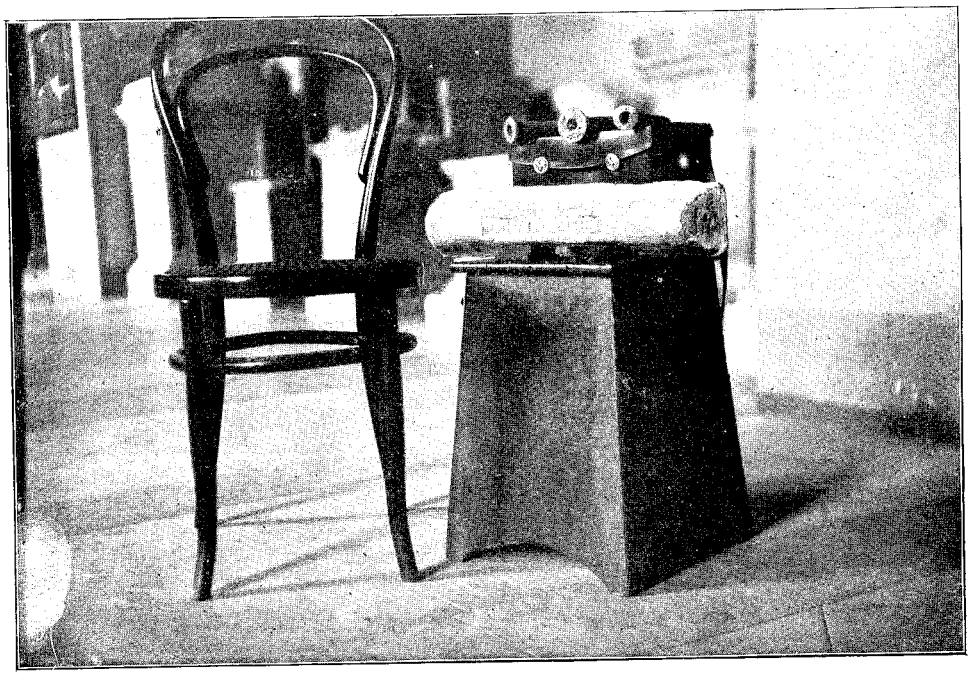
Lanciani (in his commentary on Frontinus, p. 575), and, presumably following him, Middleton (ii. 320) speak of two of these ancient Roman bronze ajutages (*calices*) as having been preserved, and being

[1] In *Zeitschr. f. gesch. Rechtsw.*, xv. 309, note 22, an emendation to an inscription found at Tivoli, namely, "Supra foramen in libram est," supplies so and so many inches. This would no doubt be good for modern times; but, considering the knowledge possessed by the Romans of practical hydraulics, its correctness must seem doubtful. We must note that it was not until 1764, in Modena, and for irrigation purposes, that we have any record, so far as I have been able to find, of anybody prescribing a definite head on an orifice as a *measure* of water granted. I get this from Romagnosi, *Irrigation Laws in Italy*, German translation by Bunsen.

Belidor, who wrote in 1737, says (*Archit. Hydr.*, ii. 366) that the "fontaniers" of Paris were not particular what head was acting on the orifice of the water-inch so long as it was a moderate one. Marchetti, p. 221, quotes Fea as saying that the water-inch was invented at Rome by Biscia, in 1585–90. These data give some idea of the beginnings of the art. I suggest, therefore, a less rigid emendation, to the effect, possibly, that the space between the water-level and the several orifices set at that *castellum* must always be the same, which would correspond to *De Aquis*, 113.

[2] *De Aquis*, 105.

now kept, the one in the Kircher Museum, the other at the Vatican. I could not find the one said to be at the Vatican; neither in the library nor among the small bronzes; but the designated little tube of the Kircher Museum is positively not an ajutage for measuring water. Instead, it is probably the top of a drain-pipe from a sink or some



CALICES AND PIG OF LEAD IN THE NAPLES MUSEUM.[1]

such vessel, for it has two small pins crossing each other put through it, just as drain-pipes for kitchen sinks would have nowadays.

On the other hand, there are three little bronze pipes in the Museum of Naples, — in a glass case near the Farnese Bull (1897), Nos. 111,954, 111,955, and 111,956, — which the distinguished superintendent of this museum, M. Jules de Petra, was kind enough to let me measure and photograph, and also to write to me about. They are supposed to have been found at Pompeii. One of them is marked, with a prick-punch, "L ∴ MARI SOPATRI"; the other two are marked, in the same way, "A ∴ SEI ∴ GNOSTI". These I believe to be genuine ancient ajutages for defining the measure of a grant of

[1] From a photograph taken by the author.

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