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Vitruvius and Frontinus - Hydraulics in the Roman period

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1. INTRODUCTION

The names of Vitruvius and Frontinus do not represent great persons who succeeded in the scientific development of hydraulics. Here they are dealt with, because they are authors of books by which we get knowledge of principles of planning, construction, operation and management of Roman hydraulic structures. The most famous of these structures are the water bridges. Some of them are even several kilometers long. They represent the peak standard in technology, which we can still admire today. In comparison to the Greeks, the great achievement of the Romans is the improvement of technology not in the field of science. Therefore it is logical that the great scientists of the renaissance reactivated the ideas from the Greek while the Roman heritage of technology was handed via Byzantium and the Osmanic world to modern times, as it is stated by van Buren (1955) when commenting on the water supply system of Constantinople.

2. VITRUVIUS

2.1 *Life*

The architect and author Vitruvius described the principles of planning of hydraulic structures in his ten books *De Architectura.* Not very much is known of the author Vitruvius himself. He seems to be born about 84 B.C. If the thesis of Thielscher (1961) is right, then Vitruvius is identical with Lucius Vitruvius Mamurra. Catull gives more information about this person. Following this idea, Vitruvius was praefectus fabrum in Caesar's army and was thus responsible for all tasks of the pioneers. He had seen much of the Roman Empire during the wars under Caesar's and later Augustus's reign. In this time he had to carry out various tasks with regionally different materials. He also had the opportunity of studying various technologies and structures even in distant provinces. Obviously Vitruvius decided to write down all his knowledge and experience when he resigned from the army as an old man. His intention was certainly supported by the fact that he was sponsored at the personal request of Augustus's sister. It is still undecided when he finished his books. It is also not known when he died. But it is unlikely that he lived longer than the end of the first decade B.C.

2.2 *The treatise in general*

At the beginning of his script Vitruvius ponders on the self- esteem of an architect — the term engineer as distinguished from that of an architect did not exist at that time. The main part of the book reflects the various stages of planning for a new settlement, beginning with the selection of the area, continuing with the infrastructure, the big monuments and public buildings. He also describes the construction of private houses. In this context, he also considers the different materials found locally. At the end of his books, he deals with the construction of clockworks and machines.

With respect to hydraulics, his remarks on water-lifting devices and water-mills in his last book are of special interest to us. He describes the shaduf which is still used today, for example in Egypt, the Archimedic screw, a bucket chain and the water-wheel as devices for water lifting as well as water power. The following section will particularly concentrate on book VIII concerning the different elements of water supply.

2.3 *Construction of aqueducts*

After an introduction about the importance of water for every creature in general, Vitruvius reflects on water quality. In this respect he mainly refers to other reports by mostly Greek authors. Besides correct observations concerning judgements of water quality (purity, coolness), properties are associated with the liquid which might be understandable in the light of the ancient ideas of mythology but which are naturally wrong. Today we may smile about thoughts that, for example, illness of the feet are caused by drinking bad water.

Vitruvius continues by describing methods of determining the location of springs. He recommends correctly the observation of intensive evaporation at flora and fauna.

In the next chapter he tells us the method of levelling

Fig.1. Schematic sketch of a Roman aqueduct

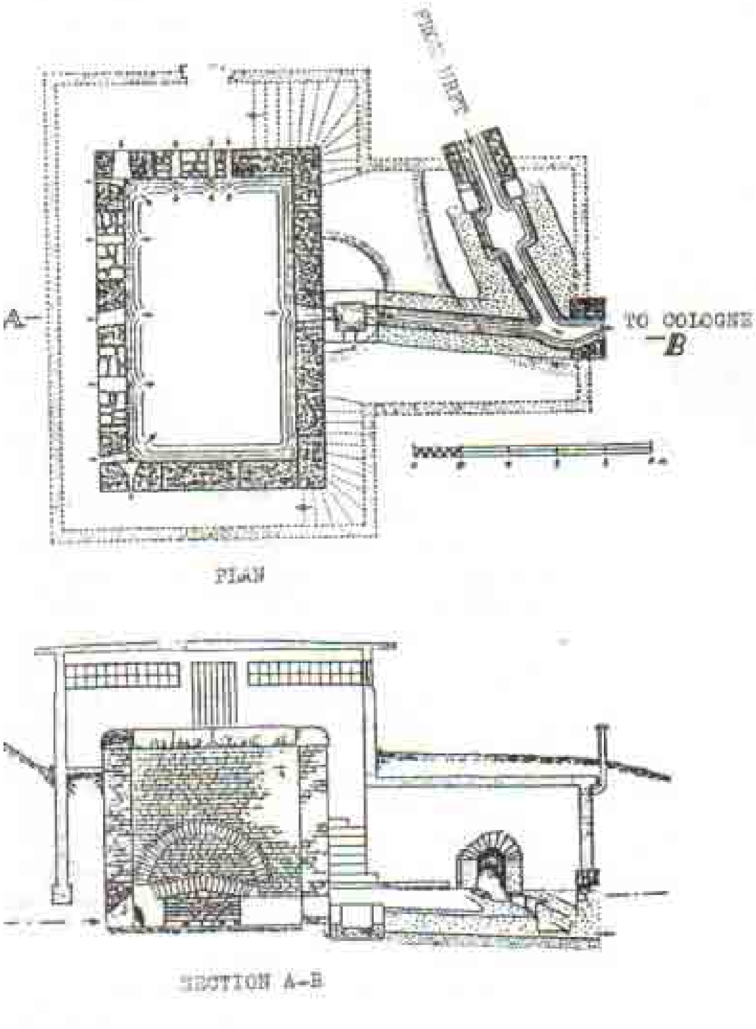

Fig.2. The Klausbrunnen - reconstruction (Haberey 1972)

for an aqueduct by means of a chorobates, which is comparable with a water balance. Then he writes of the construction of an aqueduct. As he does not follow a clear pattern, certain parts of his text are open to different interpretations.

The single elements are shown in the systematical sketch (Fig.1). Every aqueduct will start at its adit or spring. The essential construction details are not reported upon by the author but rather the respective items for percolation wells, which have to be constructed alternatively in case no water can be conducted from springs. A typical example for such a percolation well was found and reconstructed in the course of the aqueduct for Cologne from the Eifel mountains, the so-called Klausbrunnen (Fig.2).

According to Vitruvius the collected water is conducted in the aqueduct, mostly a vaulted channel (Fig.3) with a slope of 'not less than 1:200'. This recommendation would have caused high velocities in the carefully polished cross-section. But only in very mountainous

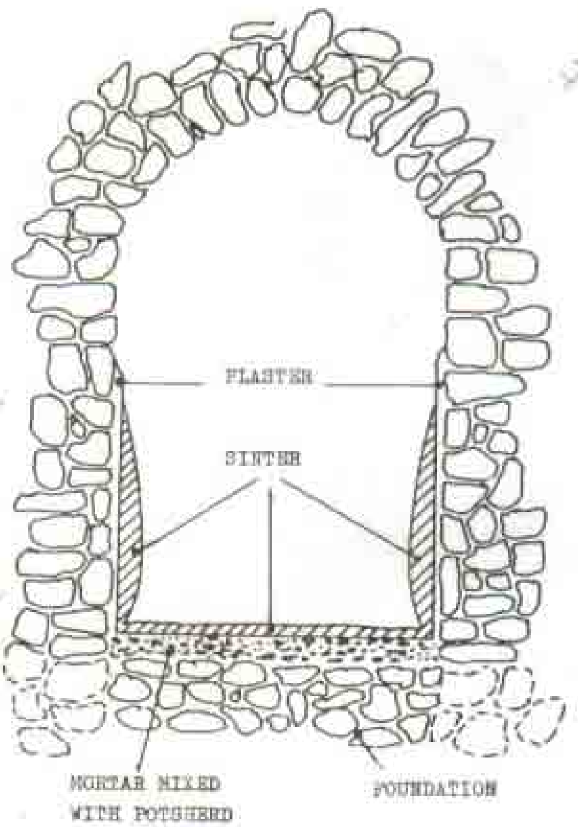

Fig.3. Typical cross-section of a vaulted Roman water supply channel

areas channels with a slope higher or equal to 1:200 can partly be confirmed for Roman aqueducts. Often the slope was much smaller. As an example of this the aqueduct of the ancient city of Nimes in France may be mentioned. Its slope is mostly about 1:5000, by far less than the recommendation of Vitruvius. Fensterbusch (1964) thus corrected and supplemented the respective part in Vitruvius's script according to a comparison with Pliny's *History of Nature* to 'the slope should not be more than 1:200 and not less than 1:4800' (sicilicus = 1:48). This supplement seems to fit in much better with the archaeological evidence.

Hills and mountains as hindrances along the course of aqueducts are to be crossed by tunnels, according to Vitruvius' remarks. The construction of tunnels was not new in Roman times. For instance, the famous tunnel of Eupalinos on Samos existed already for nearly 500 years when the Roman author lived. But his recommendation to cross soil by a tunnel and to strengthen its cross-section was new. An excellent example for this method is proved along the course of Pergamon's Aksu-channel (Garbrecht & Fahlbusch 1978).

The opposite kind of obstacles along aqueducts naturally are valleys. To overcome these Vitruvius suggests three alternatives:

1. Diversion around the valley in case the extension of the course is not too long
2. Construction of bridges
3. Construction of pressure conduits.

The first alternative means no special effort. The bridges of the second alternative are the monumental evidences of the high standard of Roman hydraulic structures. An example is the most famous bridge, the Pond du Gard with its three stories in the course of the aqueduct of ancient Nimes (Fig.4). The third alternative again implied no new development. A pressure conduit was already constructed in Pergamon in hellenistic times which had to bear a pressure of nearly 20 bar. But Vitruvius' description gives us an idea of how people tried to explain the phenomena of communicating tubes in Roman times. And this was partly very mysterious. According to the translation of Fensterbusch he writes (Fig.5):

'In case the valleys are wide, the conduit will be lead down hill. When it reaches the bottom of the valley a substructure is to be constructed on a level that the conduit can be kept on this level as long as possible. This will be the belly, which is called koilia by the Greek. When the conduit comes to the other, inclining part, the water will swell due to the long distance and will thus be pressed uphill to the top. In case there is no belly in the bottom of the valleys and no horizontal substructure but a knee, then the water will break through and destroy the connecting joints of the tubes. Furthermore colliquiaria have to be applied in the belly in order to release the air pressure. ...'

This text indicates that Vitruvius knew the effect of the principle of communicating tubes but not its reason. Obviously he was aware that sharp bends in the course of pressure conduits are especially endangered. But again in this case he didn't recognize the reason, i.e. the deviation of the resultant from the axial direction.

The unknown word colluvaria in the Latin text, which was modified by Fensterbusch to colliquiaria, in the last quoted sentence has been widely speculated upon. By another comparison with the respective text in Pliny's *History of Nature* it seems correct to identify towers with this device, which bore an open tank on its top. The pressure conduit emptied on one side into this tank and on the opposite side the water flowed into the following conduit. These towers have been constructed at horizontal or vertical bends in the course of the conduit. They served for the ventilation as well as to avoid the above-mentioned forces which threatened to destroy the pipes in these bends. Two examples of these towers are still to be seen in Aspendos at the southern coast of Turkey (Fig.6).

Vitruvius recommends the application of clay — as well as leaden pipes for pressure conduits. The first

Fig.4. The Pont du Gard

Fig.5. Schematic sketch of Roman pressure pipes

Fig.6. Tower in the pressure conduit near Aspendos/Turkey

Fig.7. Roman pipe made of lead

Table 1. Standardized measures of Roman pipes acc. to Vitruvius

Name of pipe	Inner diameter (digiti)	(cm)	Circumference (digiti)*	(cm)	Area of cross-section (digiti)²	(cm²)	quinariae
5 quinaria	1.59	2.94	5	9.25	1.99	6.81	1.62
8 octonaria	2.55	4.71	8	14.8	5.09	17.43	4.15
10 denaria	3.18	5.89	10	18.5	7.96	27.24	6.48
15 quinum denum	4.78	8.83	15	27.75	17.91	61.28	14.59
20 vicenaria	6.37	11.78	20	37.0	31.83	108.93	25.94
30 tricenaria	9.55	17.67	30	55.5	71.62	245.11	58.35
40 quadragenaria	12.73	23.55	40	74.0	127.32	435.75	103.75
50 quinquagenaria	15.92	29.44	50	92.5	198.94	680.86	162.11
80 octogenaria	25.47	47.11	80	148.0	509.30	1743.08	415.02
100 centenaria	31.83	58.89	100	185.0	795.78	2723.45	648.44

*Source of name

had to be sealed in the joints by a lime-oil mortar. For the other pipes plates of lead had been bent around a cylinder and soldered at the joints. This method resulted in the typical drop-like shape (Fig.7). The author seems to be the first person who reports about a system of nine different standardized types of pipes (Table 1). The name of the single pipe derived from the width of its unbended plate, i.e. from the circumference of the tube. As the standard length and the respective minimum weight is also mentioned, the thickness of the tube-wall could be determined to be about 6 mm.

Aqueducts terminated in the cities in a distribution structure, a so-called castel. According to Vitruvius the water was distributed from here to the public pools and fountains, in order to supply the population. Furthermore the conduits to the baths and for private persons were connected with the castle. In order to ensure the supply for the population, private persons should only get water if the demand of firstly the population and secondly of the baths was covered. This arrangement was obviously invented by Vitruvius, since the construction of such a castel could not be confirmed by archaeological findings up to date.

2.4 *Water purification*

From the hydraulic point of view another aspect in Vitruvius' book VIII seems to be of special interest. In case neither spring nor wellwater is available for the supply of the population, the author recommends the construction of cisterns. Again this was no news. Cisterns have been used in the mediterranean area centuries before the Romans. But Vitruvius extraordinarily suggests a combined system of two or three cisterns which are only separated by walls made of opus signinum, i.e. a porous mixture of limestone and

Fig.8. Cisterns at Ampurias/Spain (Photo: Lamprecht 1984)

gravel. The author reports that water will be purified by infiltration from one cistern through such a wall into the next one. Without exaggeration these suggestions are nothing else but a description of water purification by means of filters. It seems that the cistern of Ampurias in Spain had been constructed in this way (Fig.8, Lamprecht 1984).

2.5 *Importance of Vitruvius*

It is an open question whether Vitruvius' recommendations have been used in practice. An answer cannot be given. Channels, bridges, pressure conduits have been constructed all over the Roman Empire. We do not know whether the discussed text has been used as a guideline at these works. But it is a fact that later on, authors who dealt with the water supply of Rome like Pliny or S.J.Frontinus quoted or at least mentioned Vitruvius. This may indicate that his books were well known among people who were interested in technical subjects.

Undoubtedly the *10 books on Architecture* are of great importance for the research on history of civil design as authentic evidence of the art of contruction in antiquity.

3. FRONTINUS

3.1 *Life*

The second author to be dealt with is Sextus Julius Frontinus. He became important for the development of the art of hydraulic construction because of his two books *De aqueductu urbis Romae*. Again only a little is known about this Roman author. He was born presumably about 35 A.D. He probably originated from the class of knights (Eck 1982). Obviously he was very successful in his public career. Tacitus mentioned him first, when he opened the session of the city council as prätor. He became consul, governor of the province of Britannia and later on of Asia. He must have had an excellent relationship with the emperors Nerva and his successor Trajan, because he was extraordinarily honoured by not only a second but even a third consulate, the last one together with the emperor himself. Frontinus died 103 or 104 A.D.

Frontinus wrote several treatises, i.e. two on surveying which are partly passed on to us, one on craftiness in wars, the *strategemata*, another one on the art of war, which is lost, and at least the two mentioned books on the water supply of Rome. Especially with this treatise he won great fame. The following remarks are based on the translation of the books by Kühne (1982).

3.2 *The treatise De aqueductu urbis Romae*

Frontinus introduces himself in the first book about the aqueducts of Rome as a thorough and careful head of an office. After he was appointed curator aquarum in 97 A.D. by emperor Nerva he first of all wrote down all information available on the water supply system of Rome in order to become acquainted with his new task and also to inform his successors. Thus even plans and maps were drawn from the existing system.

Then he describes the nine different aqueducts which were in operation when he got his official position. He reports the origin and destination, the elevation there, and the length above and below surface of the course of every channel. Thus the reader is informed about all the aqueducts, which are listed in Table 2. After Frontinus' death the Traiana and Alexandrina have been constructed. Their data are added in Table 2. The whole system is shown in the map (Fig.21 in paper 'Hydraulic and hydrological concepts in antiquity').

Frontinus continues with the description of the system of standardized pipes, which was used for the distribution of water (Table 3). This system was more detailed than its predecessor. It was also the basis for the determination of the discharge. He explains the system hitherto used, and the manipulations he discovered.

Table 2. Rome's aqueducts according to N.Smith

Name	Date	Length (km) Total	Below surface	Above surface	Bridge	Cross-section (m^2)	Height (mMSL)	Origin
Appia	312 BC	17.6	16.8	0.8	0.09	0.69 × 1.68	20	Springs in Anio Valley
Anio Vetus	272	64	63.6	0.4	–	0.91 × 2.29	48	Anio River
Marcia	144-140	91.2	80	0.8	10.4	1.52 × 2.59	59	Springs in Anio Valley
Tepula	126	18.4	8.4	0.8	9.2	0.76 × 1.07	61	Springs near Alban Mountains
Iulia	33	22.8	12.4	0.8	9.6	0.61 × 1.52	65	Springs near Alban Mountains
Virgo	19-21	20.8	19.2	0.4	1.2	0.61 × 1.75	20	Springs in Anio Valley
Alsietina	10-2	32.8	32.4	–	0.4	1.75 × 2.59	17	Lake Alsietinus
Claudia	38-52 AD	68.8	53.6	1.2	14	0.91 × 1.98	67	Springs in Anio Valley
Anio Novus	38-52	86.4	72.8	2.4	11.2	1.22 × 2.74	70	Anio River
Traiana	109-117	59.2	59.2	–	–	1.30 × 2.29	73	Springs near Lake Sabatina
Alexandrina	226	22.4	12.8	7.2	2.4	–	–	Springs at Sasso Bello

Table 3. Standardized measures of Roman pipes according to Frontinus

Name of pipe	Inner diameter digiti	Inner diameter (cm)	Circumference digiti	Circumference (cm)	Area of cross-section digiti	Area of cross-section quinariae	Area of cross-section (cm^2)
5 quinaria	5/4*	2.31	3.93	7.27	1.23	1.00	4.20
6 senaria	6/4*	2.78	4.72	8.72	1.77	1.44	6.05
7 septenaria	7/4*	3.24	5.50	10.18	2.41	1.96	8.22
8 octonaria	8/4*	3.70	6.29	11.63	3.14	2.56	10.75
10 denaria	10/4*	4.63	7.86	14.54	4.71	4.00	16.80
12 duodenaria	12/4*	5.55	9.43	17.44	7.07	5.76	24.19
15 quinum denum	15/4*	6.94	11.79	21.80	11.04	9.00	37.80
20 vicenaria	20/4*	9.25	15.72	29.07	19.63	16.00	67.20
20 vicenaria	5.05	9.34	15.85	29.32	20*	16.26	68.45
25 vicenum quinum	5.64	10.44	17.73	32.80	25*	20.37	85.56
30 tricenaria	6.18	11.44	19.42	35.92	30*	24.43	102.62
35 tricenum quinum	6.67	12.35	20.98	38.81	35*	28.51	119.74
40 quadragenaria	7.14	13.20	22.42	41.47	40*	32.58	136.85
45 quadragenum quinum	7.57	14.00	23.79	44.00	45*	36.65	153.94
50 quinquagenaria	7.99	14.76	25.07	46.39	50*	40.73	171.05
55 quinquagenum quinum	8.37	15.48	26.29	48.64	55*	44.80	188.16
60 sexagenaria	8.74	16.17	27.46	50.80	60*	48.87	205.26
65 sexagenum quinum	9.09	16.82	28.58	52.88	65*	52.94	222.37
70 septuagenaria	9.44	17.46	29.67	54.88	70*	57.02	239.47
75 septuagenum quinum	9.77	18.08	30.71	56.81	75*	61.09	256.58
80 octogenaria	10.09	18.67	31.71	58.65	80*	65.17	273.70
85 octogenum quinum	10.40	19.24	32.69	60.47	85*	69.24	290.79
90 nonagenaria	10.70	19.80	33.64	62.23	90*	73.31	307.90
95 nonagenum quinum	11.00	20.34	34.56	63.93	95*	77.38	325.01
100 centenaria	11.28	20.87	35.46	65.60	100*	81.45	342.10
120 centenum vicenum	12.36	22.86	38.83	71.84	120*	97.75	410.55

*Source of name

Frontinus' second book reports on the results of discharge measurements in the single aqueducts and the comparison with former records. He lists the quantities, which have been distributed to the different types of structures such as basins, fountains, pools, baths, etc. and furthermore the classification of the water for public use and for licensed private consumption. Especially this part gives us detailed information on the hydraulic infrastructure of the ancient capital. The treatise terminates with remarks on legal obligations for the construction, maintenance, and protection of the aqueducts as well as penal codes in case of disrespect against emperor's orders.

3.3 *Discharge measurements*

Those parts in Frontinus' books dealing with hydraulics are to be examined here in detail, i.e. especially his statements on discharge measurements. In Roman times, the discharge obviously was equated with the discharged cross-section. The dimension was the quinaria. This expression signified the smallest pipe which was used (see Table 1 and Table 3). According to Vitruvius a quinaria was a pipe of a circumference of five digits, or more exactly of a leaden plate having a width of five digits. This plate was bent around a cylinder and soldered at the joint. Thus the circumference determined the name of the single pipes in Vitruvius' system. According to Frontinus' system a pipe with a diameter of five quarters of a digit was called quinaria. Its cross-section was nearly 40 % smaller than the corresponding one of Vitruvius. The new, more detailed system described by Frontinus consisted of in total 25 standardized pipes. Herein the name signified the diameter in quarters of a digit up to the vicenaria. That is a tube with a diameter of 20 quarters of a digit. For bigger pipes the name represented the cross-section in square digits. The particulars of the whole system with respect to diameter, circumference and cross-section in Roman as well as in metric measures are listed in Table 3.

In principle, Vitruvius' and Frontinus' discharge measurement systems do not differ. Both aim at the determination of cross-sections. But it has to be emphasized that Frontinus' measurements have been much more accurate. He determines the cross-sections of the circular pipes by taking into account a fractional number of 22/7 for π. Vitruvius used in his treatise the less accurate value of 25/8 which is easier to use for calculations. Frontinus criticizes Vitruvius' system, because of the lack of exactness, when he states, that bended plates will be compressed on their inner surfaces while their outer ones are stretched. But the reported deviations between both systems are so small that they can be neglected. On the other hand the observation of them by Frontinus emphasizes the particular accuracy of the curator which he mentioned at the beginning of his treatise as typical for his character.

As already stated both authors discussed here determined the discharge by measuring cross-sections. In modern dimensions square meters have been measured instead of cubic meters per second. This fact is really astonishing. Liquid measures had been known for a long time. In Rome the amphora as gauge was standardized. The determination of time, even in small periods, was in common use for centuries. Thus it seems to be curious that the dimension of the discharge, i.e. the volume per time unit, was not detected. This dimension can be considered as product of the parameters cross-section and velocity. These single parameters were also well known in Roman times. But the product obviously not. For discharge measurements the cross-sections were determined, not the elapsed time. Thus also the product could not be calculated.

On the other hand Frontinus was aware of the fact that the discharge depends on the velocity, at least qualitatively. He reports this verbatim. He also states absolutely correctly, that the velocity depends on the slope in a channel, since higher pressures cause higher

Fig.9. Calix (Photo: Petrolieri d'Italia 1972)

discharge rates in pressure conduits. He even recognized when investigating the manipulations of the water distribution devices that an enlargement of their cross-sections inreased the outflow from a tank. In order to prevent such nuisance in future, firm, unbendable standardized outflow-pipes, made of bronze, so-called calices, had been invented (Fig.9). Frontinus also observed that the direction of the current to the outflow opening influences the discharge through the calix.

It can be concluded that the curator had intensive knowledge of hydraulic relationships. In this context it really seems to be curious that he made — compared with our knowledge — the error of not taking the velocity into account when determining the discharge.

It has been attempted to calculate the velocities and the discharge rates of the different aqueducts in the vicinity of Rome according to the knowledge of hydraulics of today (Fahlbusch, 1982). This calculation was based on Ashby's (1935) measurements of the rectangular channels (width and slope) and Frontinus's records of the discharged areas. The results are listed in Table 4. The following aqueducts were running in the vicinity of the city partly above each other or respectively parallel:

1. Anio vetus
2. Marcia, Tepula, Julia above each other
3. Anio Novus, and Claudia above each other

(Fig.10 shows an artist's view of the intersection of (2) and (3).)

When comparing the results of the velocity calculation the minimum data differ by nearly 22 %, i.e. v = 0,72 m/s at the Tepula to v = 0,92 m/s at the Claudia. It hardly seems to be understandable that such a careful person as Frontinus denounced an inaccuracy of less than 1 % when determining cross-

Table 4. Estimation of discharge in Rome and determination of discharge per quinaria

	A		b	hi	b^1	A^1	J	R		k	v	Q	EQ
Aqueduct	Area according to Frontinus		Width according to Ashby	Depth	Width	Area	Slope	Hydr. radius		Friction co-efficient	Velocity min.-max.*	Discharge min.-max.*	Quinaria min.-max.*
					Channel with calc. crust				with crust				
	(Quinaria)	(m^2)	(m)	(m)	(m)	(m^2)	(%)	(m)	(m)		(m/s)	(m^3/s)	(l/s)
Aqua Appia	1825	0.77	1.67	0.46			0.05	0.30		70-75	0.70-0.74	0.53-0.57	0.29-0.31
Aqua Anio Vetus	2362	0.99	0.86	1.15	0.76	0.88	0.15	0.31	0.29	50-55	0.84-0.98	0.74-0.99	0.31-0.41
Aqua Marcia	2944	1.24	0.75	1.65	0.65	1.07	0.13	0.31	0.27	50-55	0.76-0.90	0.81-1.11	0.28-0.38
Aqua Tepula	445	0.19	0.63	0.30			0.13	0.15		70-75	0.72-0.77	0.13-0.14	0.30-0.32
Aqua Iulia	1206	0.51	0.50	1.01			0.13	0.20		70-75	0.86-0.92	0.44-0.47	0.36-0.39
Aqua Virgo	2504	1.05	1.33	0.79			0.025	0.36		70-75	0.56-0.60	0.59-0.63	0.24-0.25
Aqua Claudia	3312	1.39	1.14	1.22	1.04	1.27	0.13	0.39	0.37	50-55	0.92-1.06	1.17-1.47	0.35-0.44

* The differences are caused by taking into account calcareous crusts and different friction coefficients

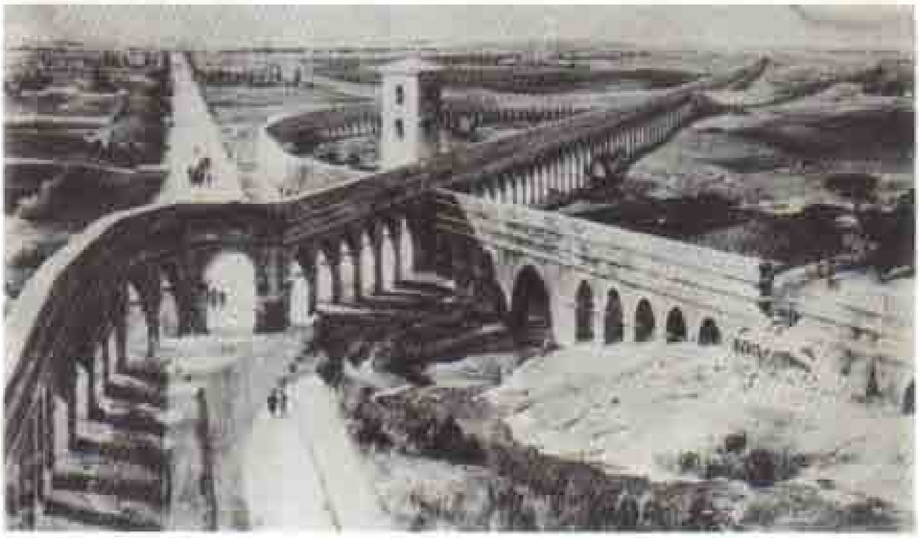

Fig.10. Intersection of the course of five aqueducts near Rome (painting by Zeno Diemer, Deutsches Museum, München)

sections, but omitted a deviation of the velocity of about 20 % although he knew its influence at least qualitatively.

We do not know what the measuring devices, the so-called mensura, looked like. According to a note in Frontinus's text on the discharge determination at the Appia, the width and depth was measured in the rectangular channel. The spot where these measurements have been carried out, was selected according to the author with view to a certain necessary velocity of the water. Thus it seems possible that he had tried to install equal flow conditions at the respective measuring spots, e.g. by an equal slope. Thus he could have tried to eliminate the measuring mistakes due to different velocities he knew about. But as long as there is no archaeological evidence in this respect this idea is pure speculation.

According to Hodge's (1984) opinion, this mensura might have been constructed as a sluice gate in order to force supercritical flow when being underflown. This would have only been possible within certain limits if a constant difference was kept between the upstream and the downstream water level at the gate with a submerged hydraulic jump. The diffeence in head was to be fixed in the different channels and their changing discharge rates. In order to guarantee this the gate must have been adjustable. But such a procedure would have been far too complicated in view of the knowledge about hydraulics in Roman times. For sure Frontinus would have reported such measurement methods if they would have been applied.

3.4 *Relationship between Frontinus and Heron of Alexandria*

The real correlation, that the discharge is the product between cross-section and velocity, has been described for the first time nearly unequivocally correctly by Heron of Alexandria in his *Dioptra* (translation by Schöne 1909). It is not known when Heron lived. Assumptions stretch from the second century B.C. to the second century A.D. Heron wrote, like Frontinus, a treatise on surveying. Single parts of both authors are really similar (Cantor 1890). Apparently the successor knew the text of his predecessor. In case this statement is true and refers not only to the books on surveying, it may be concluded from the above arguments that Heron did not live before Frontinus. Otherwise the extremely thorough and careful curator aquarum would certainly have used Heron's knowledge when determining the discharge in the aqueducts of Rome. His influence in the capital would have enabled him to be informed relatively quickly on request with the scientific understanding available.

Heron's discoveries led to theoretical questions in mathematics, but it does not seem clear whether they were applied in measuring practice in Roman times. If the Osmanic water supply system of the former Constantinople represents the direct heritage of Rome via Byzantium then this measuring method was not used in practice. There the water had been distributed according to the discharged cross-sections until the last century (Cecen 1975).

3.5 *Importance of Frontinus*

'The expenditure for a grave monument is unnecessary. The remembrance for us will continue, if we earned it by our life.' Thus Eck (1982) quotes from the testament of S.J.Frontinus.

We got from this great Roman the most detailed written information about water supply in antiquity. Obviously this was the peak of knowledge in water supply technology for many centuries. The reference in Leupold's (1724) treatise 'Schauplatz der Wasserbaukunst' can hardly be interpreted differently.

The importance of Frontinus's books for the historical research in the different fields — from engineering to law — need not be emphasized. These books seem to be the best evidence for the statement of the curator in his testament. He is still remembered after nearly 2000 years and will also be in future.

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