Cura Aquarum in Israel II

Water in Antiquity

In Memory of
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Prof. Ehud Netzer
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Front cover: The six shafts tunnel at Sepphoris (photo: Alon Levite)

Dynamic Control Elements in Roman Aqueducts - A Reconnaissance Study*

Wilke D. Schram

1. Introduction: dynamics in Roman aqueducts?

Many aqueduct studies present a static view: the water source, the main conduit with tunnels, bridges, and sometimes siphons, with at the end the water distribution in the town.
In ancient times one may suppose a more dynamic environment: seasonal fluctuations in the supply (up to 1 to 10 for the present source of the Metz aqueduct, Chanson 2002, pag. 2), day and night rhythm on the demand side, temporarily closing of a section for maintenance and major interventions e.g. extra supply or users.
In response to these external stimuli one would expect a need for control.

The main question in this study is: was there any control in Roman aqueducts from the source to the main distribution point near the city? Modern authors hint on the need for control in Roman aqueducts (Hodge 1992 pag. 293-4, Aicher 1995, pag. 136 & 139, Ellis 1996, pag. 179, Wilson 1997, Bossey 2000, pag. 771, Blackstone & Hodge 2001, pag. 132, Chanson 2002, pag. 4).
Based on a sample of 26 basins with control elements, we try to throw some light on this interesting subject.

2. Dynamic control

Several control elements were found in aqueducts which raises many questions: which functions did they execute and which mechanisms were used, was there any systematic approach in Roman times, is there any literary or epigraphic evidence about these actions. Basically: how did the Romans control an aqueduct?

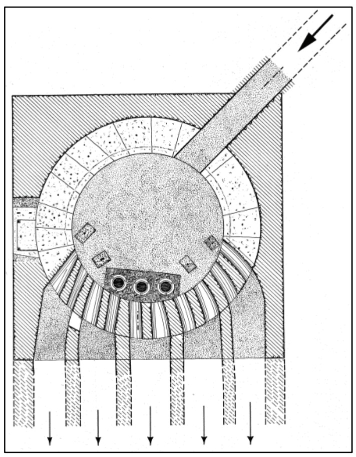
The common factor of the dynamic control elements is the *time dependency*. So we are in search for elements – often enclosed in basins – which position can change over time, in order to control the water flow.

On the other hand, there were fixed elements found in aqueducts like overflows: when the water reached a certain level the overflow led the excess water to a drain or brook nearby. These we call *static* control elements because they are not time-dependant and so are not a part of our study.

3. Examples of control elements

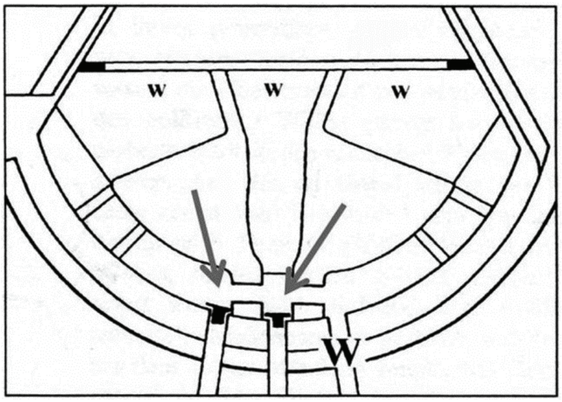
To illustrate our subject, we will point at some examples of control elements present in Roman aqueducts:

- Of course the distribution basins in *Nîmes* and *Pompeii*: how long and how much water was made available to which groups of users, given the fact that the supply was not constant over the year and the demand was dependant from the time of the day?



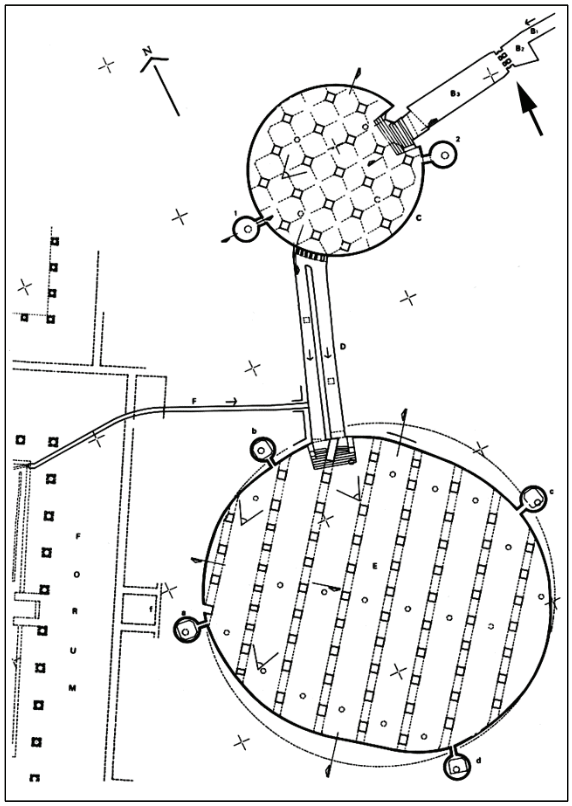
Water distribution basin (*Castellum divisorium*) in Nîmes. How did the Romans close the apertures? (Neyses (n. d.) pag. 14, based on Stübinger 1909, fig. 38).

* Dedicated to Sirp J. de Boer. The author wants to thank H.P.M. (Paul) Kessener for his advice.

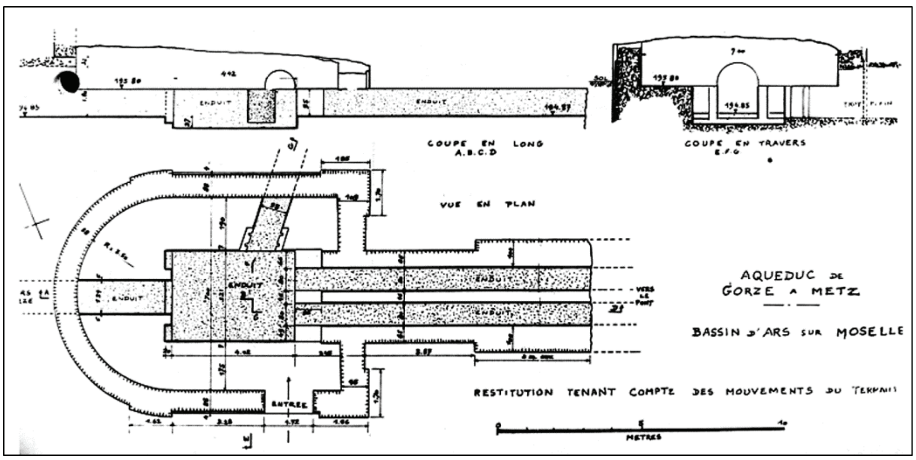


Water distribution basin (*Castellum divisorium*) in Pompeii. Did the Romans use plugs? (Ohlig 2001, fig. 149).

- The regulation basin of the *Metz* aqueduct at Ars-sur-Moselle, just before the water crossed the Moselle river by means of the well known twin aqueduct bridge. How and when was the extra outlet used?



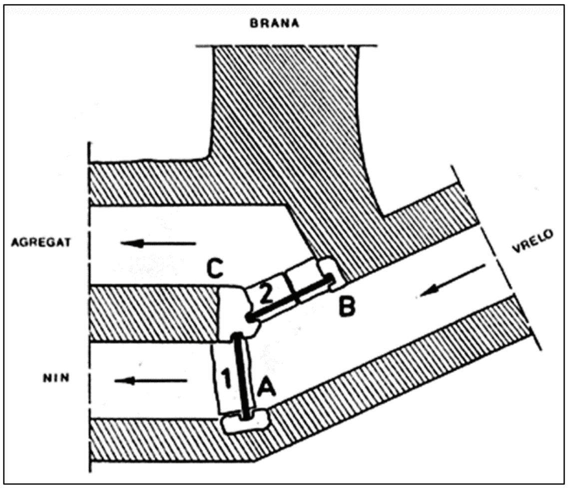
Three sluice gates in the channel between the inlet and the two cisterns in Bararus (Tunisia) (Hallier 1987, pag. 1).



Splitting and regulation basin in Ars-sur-Moselle, part of the aqueduct of Metz (France). Note the double set of grooves in the side branch (Jolin1981, pag. 72).

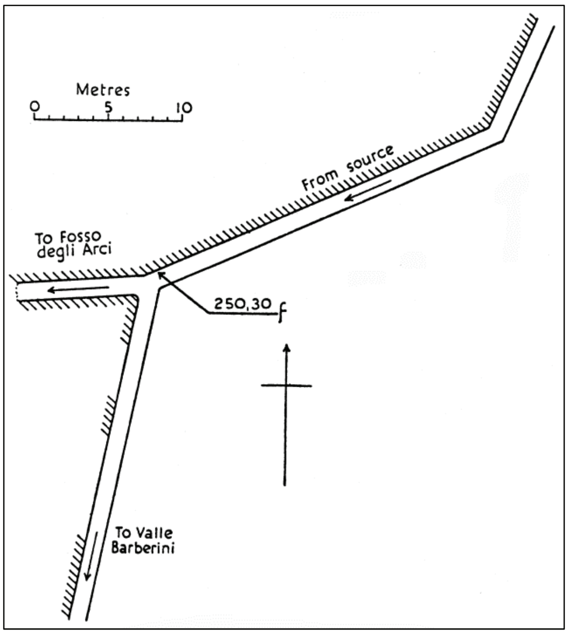
- At *Bararus* (Tunisia) the inlet of a combination of a settling and a storage basin (7600 m^3) was equipped with three sluice gates. Why?

- The splitting basin for a water mill of the Roman aqueduct of *Nin* (Croatia) was equipped with two sets of single sluice gates, so clear decisions could be made how to distribute the water over both users: the mill and the people in Nin. Who made the decisions?



Branch in the aqueduct of Aeona (present Nin, Croatia) to a mill complex (Ilakovac 1982, fig. 36).

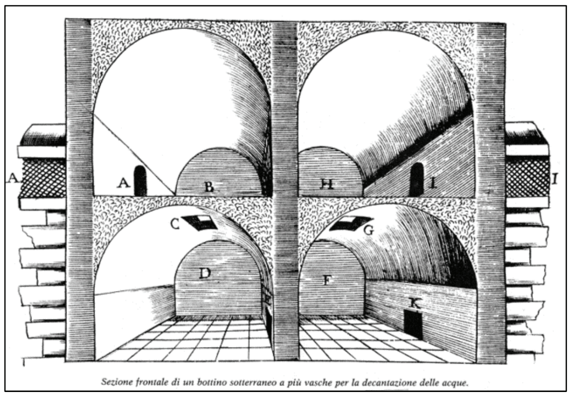
A remarkable example of a seemingly *missing* control element is at *Osteriola*: the start of the Tivoli loop were the water flow of the *Anio Novus* – one of Rome's main aqueducts – was divided (Ashby 1935, pag. 267/268, fig. 27).



A splitting near Osteriola in the Anio Novus aqueduct of Rome, without any regulating mechanism? (Ashby 1935, fig. 27).

There are many more examples where *one would expect* dynamic control elements:

- Where a side channel splits from the main: for example at Porta Maggiore in Rome where the Arcus Neroniana branches off from the Aqua Claudia;
- At the inlets and outlets of storage basins;
- At double bridges like the one of the Aqua Anio Novus in the Valle Barberini and the five double bridges of the aqueduct of Fréjus. We have to realize that it is not always sure that these double systems were in use at the same time;
- In many cases settling and storage basins were equipped with an extra outlet close to the bottom for cleaning purposes, which had to be closed for proper functioning. See for example the settling basin in the Virgo aqueduct as drawn by Fabretti (Evans 2002, pag. 151 at K) and the main storage basin at the La Fourvière hill in Lyon. How were theses orifices opened and closed?



Settling basin in the Aqua Virgo aqueduct of Rome with an outlet at K. (Fabretti 1680, pag. 228).

- At the header basins of siphons: apart from filtering and overflow devices, one would expect one or more stops to close selectively the available pipe(s) in time of maintenance or repair.

4. Ancient sources

There are quite a few echoes of dynamic control in ancient literature.

4.1. Ancient writers

4.1.1. Vitruvius

Vitruvius, who lived in the first century BC, was an architect who wrote the treatise '*De architectura libri decem*' of which the 8th book focuses on water supply.
In 8.6.7 he recommends: "*…to build reservoirs* [castellae] *at intervals of 24,000 feet, so that if a break occurs anywhere, it will not completely ruin the whole work, and the place where it has occurred can easily be found.*[1] Distribution, storage nor settling is plausible here. Vitruvius hints on regulation devices of a *dynamic* nature (in case of a break = time-dependency) where the water upstream of the 'place of trouble' might have been diverted into an other aqueduct or a brook nearby.

We may conclude from Vitruvius 8.6.7 that he recognized, of course unaware of notions of dynamic control, the need for time-dependant regulation elements by means of control devices.

4.1.2. Pliny the Elder

Pliny the Elder (23 – 79 AD) seems to be well informed about time-dependant devices when he noticed the use of water power for 'hushing' in gold mines in Spain (NH 33.75) and time-dependant water apportionment in N. Africa (NH 18.51).

In NH 33.67-78 Pliny gives an account of gold mining with emphasis on mining techniques and the role of waterpower. In open cast mining, to crush and wash away the overburden, reservoirs were made used for 'hushing': "*Five sluices about a yard across occur in the walls. When the reservoir is full, the sluices are knocked open so that the violent down rush is sufficient to sweep away rock debris*" (NH 33.75, Lewis and Jones 1970).
This type of reservoirs has been attested in ancient mines in Spain and Wales.
Apart from these sluices for hushing, the remains of many sluices have been found in regulation basins in gold mining areas in Spain (Jones and Bird 1972).

The method of division by time was not uncommon in N-Africa. Pliny the Elder reports in *NH 18.51* a system, based on the principle of time-division of waters from a constant source in the oases of Tacape (Qabès): *"It is only at certain hours that its waters are distributed among the inhabitants"*. Shaw makes mention of the functioning of this technique at Tolga (SW of Biskra), Ziban (along Wadi Jedi) and Thysdrus (al-Jem) (Shaw 1984).

4.1.3. Frontinus

Frontinus – *curator aquarum* (water manager) of the city of Rome from ca 40 to 103 or 104 AD – is our main ancient source about the – in his time nine – aqueducts of the city of Rome.[2] Rodgers complemented his translation with an exhaustive set of comments (Rodgers 2004).

A. Branches

In his work Frontinus describes many splittings (f. e. Frontinus 19.8, 20.3, 21.2 and 66.2) where decisions had to be made which part of the water flow should be diverted, however without any detail. Not all these branches are attested; on the other hand, from archaeological evidence we know (Van Deman 1934, Ashby 1935) of many more branches.

B. Transfer from one aqueduct into another

Transfer of water from one aqueduct into another was not uncommon, according to Frontinus. At least five links were explicitly cited (Frontinus 67 - 69) through which *fixed*

[1] Translation from M.H. Morgan (1914), see http://www.gutenberg.org/ebooks/20239).

[2] A good translation of his treatise '*De aquaeductu urbis Romae*' is made by R.H. Rodgers and can be found on the internet: http://www.uvm.edu/~rrodgers/Frontinus.html.

quantities of water were diverted, in total 771 quinariae (Frontinus 78.1).
The text suggests (semi-) permanent configurations underlined by Frontinus remarks on the difference between the (static) figures in the imperial records and his own measurements (Frontinus 74).

C. Mixing

Given the fact that there was a great difference in water quality between the aqueducts (Frontinus 90 – 92) the mixing of water from different aqueducts had positive and negative consequences. Frontinus remarks that the Anio Novus was used to remedy shortages in other aqueducts and doing so, contaminated the rest (Frontinus 91.1-2). More than once this was practiced without cause "*because of incompetence on the part of the water-men*" (Frontinus 91.3). Here the text suggests dynamic control, although it remains unclear how and where these replenishments might have taken place. In this context Rodgers points at a construction like Grotte Sconce, just south of Tivoli, in the Anio Novus (Rodgers 2003, note 128).

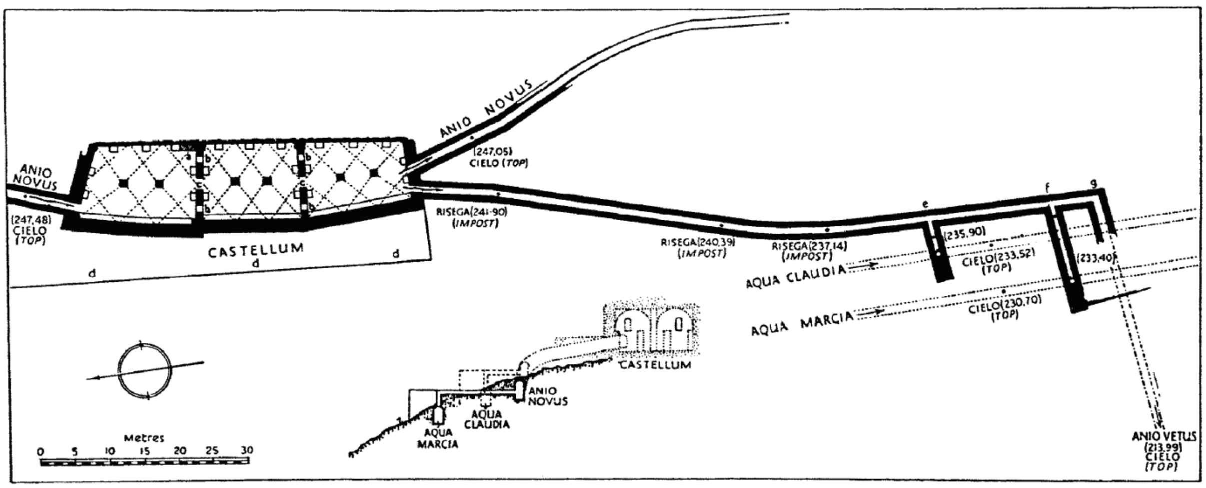
In response to the 'contaminations', the decision was made to abandon the mixing of aqueduct waters (Frontinus 92). Whether this measure was implemented or not, remains unclear. One may realize that the Aqua Claudia and the Anio Novus had a common distribution basin near Spes Vetus (*post hortos Pallantianos*, Frontinus 20.2).

D. Staff

One of the duties of the staff of the cura aquarum inside the city was, in case of sudden emergencies, to divert a part of the water supply "*so that a reserve of plentiful water from several wards may be turned into the ward where difficulty threatens*" (Frontinus 117.3). Rodgers (2004, pag. 301) doubts on uncertain grounds the flexibility in modification of the delivery.

E. Aqua Augusta

A special configuration might have been built by the ancients to support the role of the spring called Augusta in supplementing the Aqua



A storage basin in the Aqua Anio Novus aqueduct called Grotte Sconce, just south of Tivoli (Italy) equipped with a diversion channel with which, according to the circumstances, three aqueducts nearby (Aquae Claudia, Marcia and/or Anio Vetus) could be fed (Ashby 1935, fig. 31).

Marcia and, when this was sufficiently done, to augment the Aqua Claudia if needed (Frontinus 14.3).

Germain de Montauzan points out the work of Rondelet who proposed a static arrangement, see fig. 67, but the former opts for a more easy solution with sluice gates, so pleading for a dynamic arrangement (Germain de Montauzan 1908 pag. 162-3).

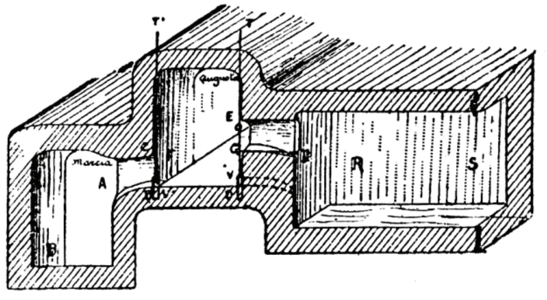


Fig. 67. — Jonction des trois conduites : Marcia, Augusta et Claudia.

The hardware translation of Frontinus 14.3 by Rondelet for the distribution of excess water of the Aqua Augusta water to the Aqua Marcia and the Aqua Claudia, an example of static control (Germain de Montauzan 1908, fig. 67).

F. Aqua Crabra

Frontinus makes mention of a time-dependant arrangement in the area of Tusculum: “For it is the Crabra water [a local brook] which all villa’s in that neighborhood receive in turn, the apportionment made by scheduled days and in fixed quantities” (Frontinus 9.5), but members of the staff of the *cura aquarum* illegally diverted the water into the Aqua Julia.

G. Aqua Alsietina

Frontinus (11) points at the poor quality of the water of the Aqua Alsietina. But he writes that, when necessary – e.g. when the bridges of the Tiber river were under repair and so Transtiberim was cut off from good drinking water – Alsietina water was used to supply the public fountains (Frontinus 11.2).

4.1.4. Conclusions

We may conclude that Vitruvius, Pliny and Frontinus make mention of time-dependant water supply, although in quite different settings: in case of a break, to be able to deactivate only a part of an aqueduct for maintenance or repair, in time-sharing systems like for irrigation, at mining sites for ‘hushing’, and in a multi-aqueduct setting, to augment other aqueducts. Locations and precise nature of the necessary devices remain unclear.

Frontinus provides, where a branch splits off from the main channel of an aqueduct, no information about the character of the used devices.

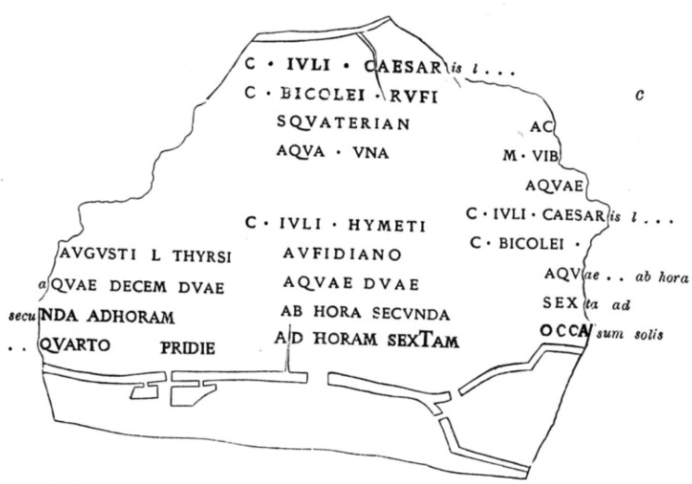
4.2. Epigraphica

4.2.1. Epigraphical material on control devices

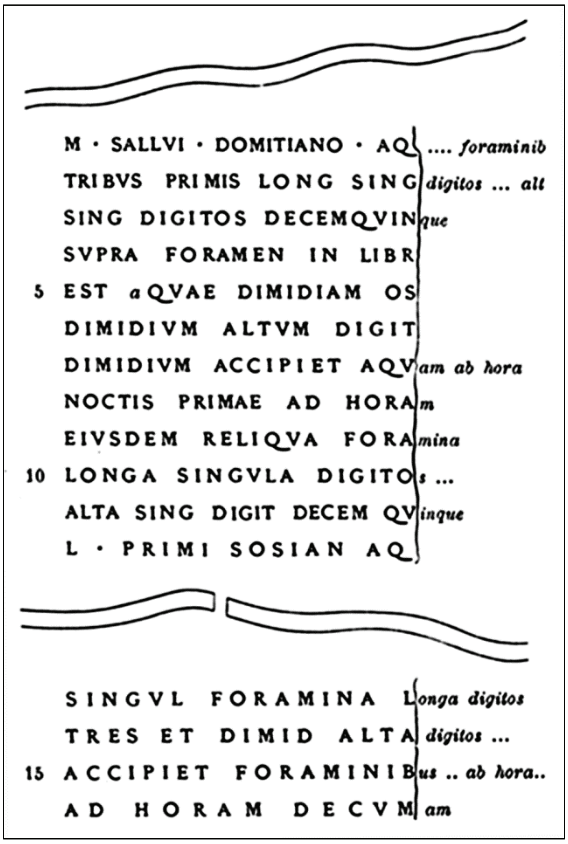
The epigraphical sources below, more or less related to the aqueducts of Rome, present only indirect evidence for control devices.

CIL 6.1261 is the well-known image of a plan plus related text depicting an aqueduct, branches, and on certain places interruptions, which seem to represent sluice gates. The text gives some names and hours owners may count on water, supplied to their properties (Evans 2002, pag. 247-8, Bruun 1991, pag. 87, note 48, Wilson 2008, pag. 310, Liberati Silverio 1986, pag. 174 ff.).

The geographical context seems non-urban (Bruun 1991, pag. 87, note 48).

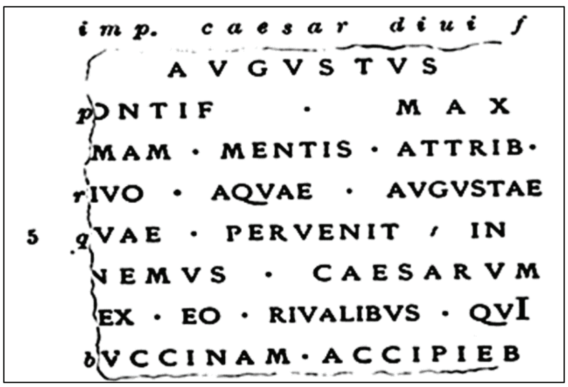


CIL 6.1261: plan of an aqueduct with branches, interruptions (sluices?) and names of water users.



Inscription *CIL 14.3676.*

The inscription *CIL 14.3676* describes regulations for the use of water in the area of Tibur, setting sizes of channels and lengths of time for access (Evans 1993 pag. 448, Liberati Silverio 1986, pag. 174, Wilson2008, pag. 310); it depicts the suggestion of at least one sluice.



Inscription *CIL 6.31566.*

As already cited, on a slab of travertine found in 1887 15 miles outside Rome (Bruun 1991, pag. 149 note 43) used as a cover upon a modern branch of the Acqua Paola, a text was found (*CIL 6.31566*) describing the distribution of Alsietina water by allotment of time: "…so that from it [the Aqua Alsietina] the water might flow continuously to those consumers who once received water at fixed hours only" (Ashby 1935, pag. 183).

So, the three inscriptions above suggest dynamic controlled irrigation schemes in a non-urban context, but close to Rome. Only one inscription can be related directly to one of the 11 aqueducts of the city. Details about nature and location of the applied devices are missing.

A more elaborate time-sharing system is presented in *CIL 8.18587* (=CIL 8.4440 = ILS 5793). It is a decree that records in detail the arrangements for time dependant irrigation of a large number of agricultural plots in the region of the ancient town of Lamasba, present Ain Merwana (Algeria) (Shaw 1982, pag. 76 - 81, Hodge 1992, pag. 447, note 14). However, the source of the water that was distributed did not come from an aqueduct but from a perennial spring nearby.

4.2.2. Workforce

The '*familia aquaria*' in Rome, the *work force* at the disposal of the *curator aquarum* – the head of the water supply of Rome, Frontinus was one of them – comprised of 240 slaves as founded by Agrippa (the '*servi publici*') plus 460 slaves as added later by Claudius, forming the '*familia caesaris*' (Frontinus 116, 3-4). Several functions were discerned (Frontinus 117.1 and 105.4) among which '*castellarii*', men in charge of the *castella* (distribution basins). From four of them we know the names via the inscriptions on funerary monuments, see table below.
Bruun (1991, pag. 191) lists, based on epigraphical sources, the names of 19 workmen from the *familia aquaria* in Rome, of which one may derive that some (if not all) were attached to (only?) one of the aqueducts.

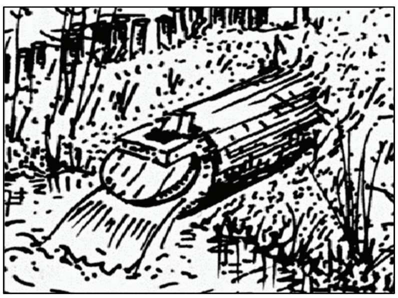
Names on inscriptions	Reference	Literature
Clemens caesarum n(ostrorum) servus castellarius Aquae Claudiae	CIL 6.8494	Ashby 1935, Bruun 1991, Rodgers 2004, Fabretti/Evans 2002
Soter servus publicus castellar(ius) Aquae Annionis Veteris	CIL 6.2344 = CIL 6.8493	Bruun 1991, Rodgers 2004
Naucellius castellarius	CIL 6.8492	Ashby 1935, Bruun 1991
Onesimus castellarius public(us) ser(vus)	CIL 6.2346	Bruun 1991

Table 1: Names of *castellarii* the '*familia aquaria*' on funerary monuments in Rome.

Unfortunately we are ignorant of the exact duties of these *castellarii*: were they watchmen, cleaners, observers, or - when necessary - operators of control devices?
In conclusion: the epigraphical sources do not inform us about nature nor locations of used control elements.

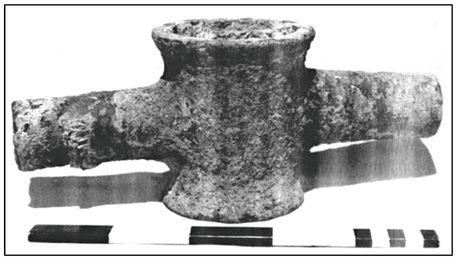
5. Types of control and control elements

Basically there are two types of dynamic control: on/off and adjustable.
The most evident example of *on/off* type of control is a plug in a pipe: the pipe is open or closed.



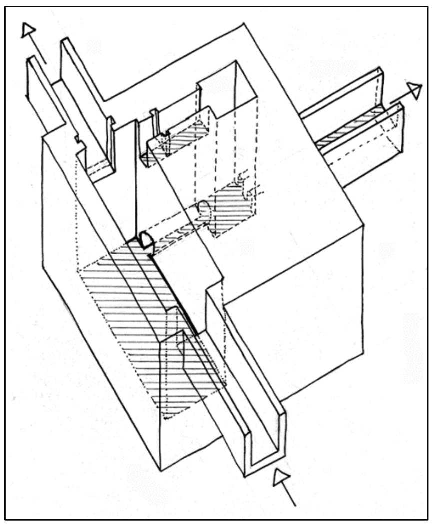
Example of an one way valve (Roman drain pipe in Vlaardingen, Netherlands) (Van de Ven 2003, pag. 12).

A stopcock is an example of an a*djustable* dynamic control element, a sluice gate is another: the opening can be adjusted according the circumstances. In this case one may discern between continuous and discrete control: in the latter case only specific output levels can be reached like with boards in a sluice gate or wedges in a series of slits.



Example of a bronze stopcock at the outlet of the Nabataean reservoir in Auara / Humeima (Jordan) (Oleson 1988, plate 7).

Note that in principle a *sluice gate* is an installation with one door pivoting on a vertical axe as in a sluice lock and sometimes called swing gate (Ellis 1996). A *weir* is a vertical moving board or set of planks contained in two vertical grooves. There are a few Roman examples of the latter and they are generally referred to as sluices or sluice gates.

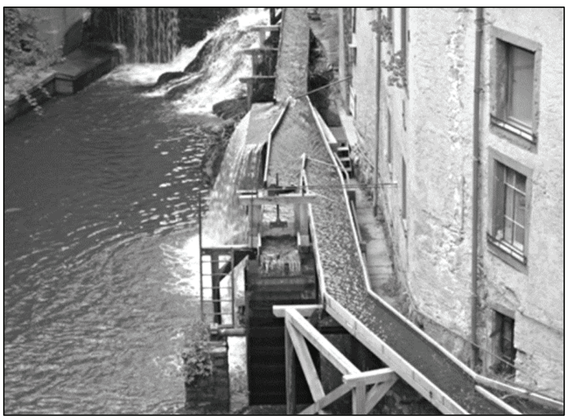


Complex regulation and settling basin with sluice gates, just before the town of Köln / Cologne (Germany) (drawing after Habery 1971 fig. 13 and Grewe 1986, fig. 195).

On this basis different types of *control elements* can be ascertained:

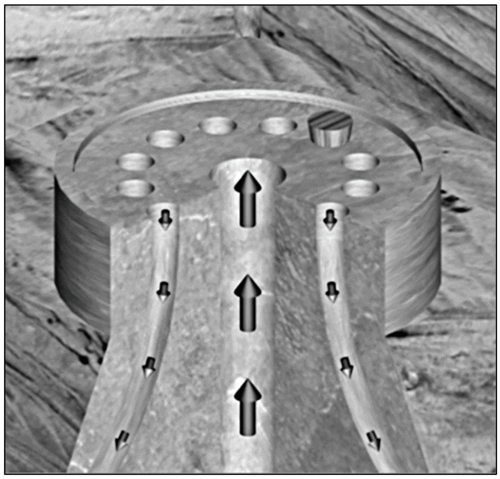
a. On/off-type:
   a. Plug in a pipe)1
   b. Single wedge in a slit)1
   c. Valve in a pipe)2
b. Adjustable-type:
   a. Stopcock and tap
   b. Sluice gate)3
   c. In-stream vertical board pivoting horizontally)4
   d. Multiple plug system)5
   e. Multiple wedge system)6.

)1 Note that the presence of a ancient plug or wedge – often made of wood – in combination with an orifice, is archaeologically difficult to prove;
)2 Mend is a lid plus hinge mounted on a pipe; in principle this one-way device is not a dynamic control element because its function – to shut off the water flow – is not time but pressure dependant;
)3 Sluice gates may have a variety of designs: enclosed by grooves, with or without a threshold, with a (pierced) board and – in a single or double setting – in an overshoot or undershoot arrangement etc.;
)4 To regulate the water flow in an open channel as in modern Saarburg;

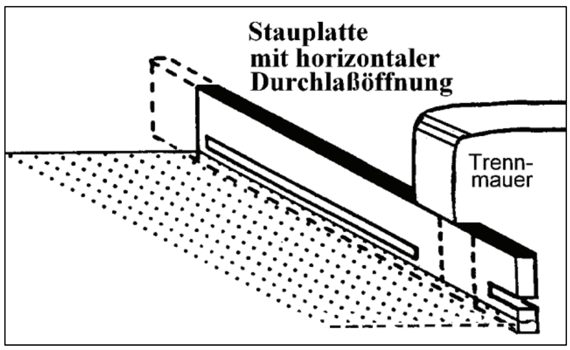


Modern in-stream vertical board pivoting horizontally in Saarburg (Germany) (photo P. Disselhorst).

)5 As in the distribution basin of Apamea;
)6 Wedges in multiple setting as for example supposed by Ohlig in the distribution basin of Pompeii (Ohlig 2004) which lead us to adjustable dynamic control.



Drawing of a (local) basin where plugs may have been used for the water distribution in Apamea (Syria) (drawing C. Romeijn after Lacoste 1940).



Room for wedges in the horizontal apertures in flow control slabs of the distribution basin (*castellum divisorium*) in Pompeii (Italy) (Ohlig 2001, fig. 144a).

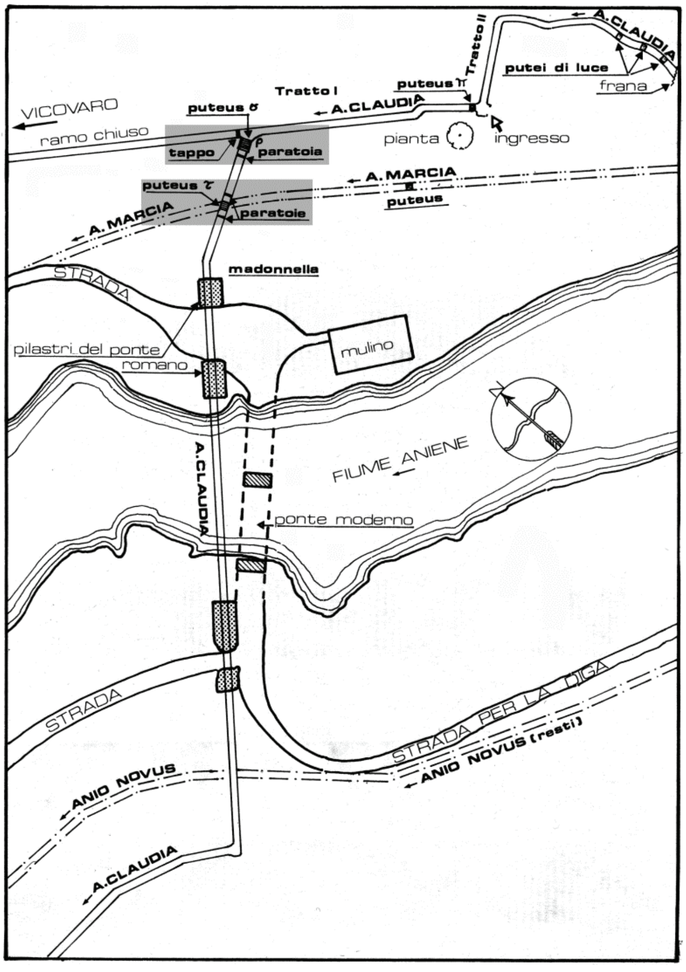
6. Functions and basins

An aqueduct is more than a channel or pipe transporting water from a source to its users. At several places en route specific functions were executed, but not all are time dependant.

Some examples:

Dynamic (time dependent) examples:

- To store water: often in a storage basin (cistern, reservoir);
- To distribute the water among (groups of) users within a city: often in a distribution basin;
- To split the water flow *extra urbem* (for example at an alternative channel like the so-called Hadrians loop in the upper reach of the Aqua Claudia, at 'down channels' in the Anio aqueducts of Rome and possibly at twin channels or at double aqueduct bridges);



Start of the Hadrian's loop near Madonnella in the Aqua Claudia aqueduct of Rome. At "ρ" a splitting with a plug (tappo) in the original channel, and at "τ" sluice gates (paratoie) in the new branch for the 'down channel' to the Aqua Marcia (Roncaioli Lamberti 1986, fig. 7).

- To regulate the flow and to get rid of excess water: often in a regulation basin;
- (sometimes) To settle impurities: in a separate settling basin.

But also other functions were executed in aqueducts, often static ones (not time dependent):

- To settle impurities: often in a (static) settling basin;
- To collect different water streams: often in a collecting or junction basin;
- To fit open channels to pipes or vice versa: often in a transition basin;
- To dissipate water energy: often in a waterfall (with/without a stilling basin);
- To filter the water in a filter device;
- To measure the water flow by means of a weir (Kessener 2005);
- To offer water to the users: often in a street-side basin, nymphaeum, baths etc.

7. Sample of sluice gates as control elements

From the literature we compiled a series of dynamic control elements in aqueducts and sorted them out for functions.

Plugs nor *wedges* were archeologically attested; where surmised they were related to main distribution basins (Nîmes, Pompeii, Apamea).

The number of one way *valves* as described in the literature, was too small to present a reliable statement.

The number of *extra urbem stopcocks* and *taps* were also too few and mostly related to storage basins (Humeima (Oleson 1988), Carthage and other North African cities (Wilson 1997)).

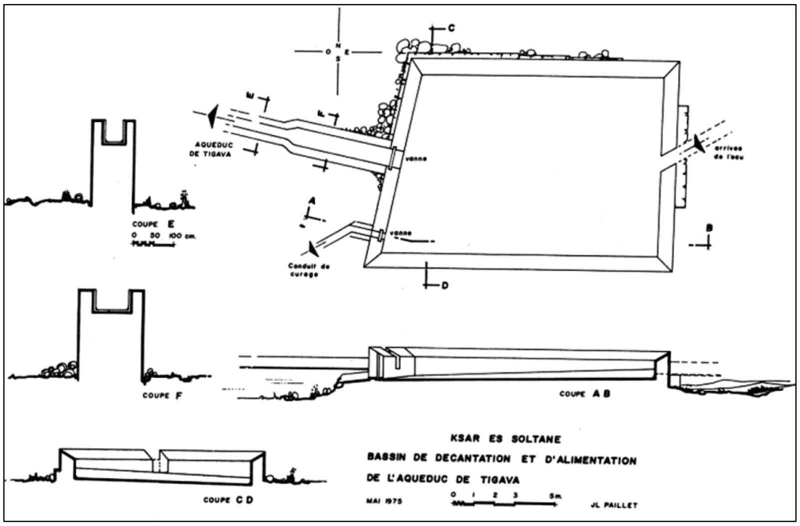
That is why we concentrate here on a sample of 26 *sluice gates* related to one or more of the functions described above. However, this number cannot be a representative sample, given the fact that over 900 Roman and Greek aqueducts are described in the literature.

These sluice gates (see table) differ in function, in location, in the place within the aqueduct system (main course and/or side channel) and in design (single (S) and double (D) sluice gates).

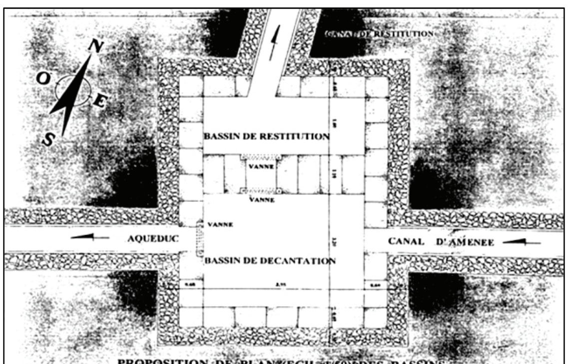
Given the fact that we were confronted with partly inconsistent, incomplete, or sometimes (too) general descriptions, we come to the following *tentative* results:

1. The aqueducts of which the sluice gates were part of, date from the 1st and 2nd century AD. But we have to bear in mind that it is possible that some control elements were later additions;
2. A major part of the described sluice gates (11) were found in France, 3 in Spain and 4 in North Africa;
3. Some 12 were applied in the *main* water course of which 1 in a double setting (Uzès and Pont du Gard); 19 were used in a *side* branch of which 4 with double gates (Ars, Reims, Uzès and Pont du Gard, and Calahorra);

Calahorra (Spain): an aqueduct branch was equipped with three sets of grooves, probably a combination of two sluice gates and a filter screen (Casado 1983, pag. 516).

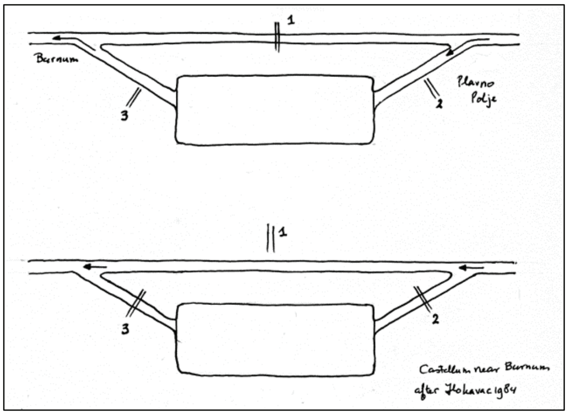


Settling basin in the aqueduct of Tigava (Algeria) with two sluice gates (Leveau 1976, fig. 95).

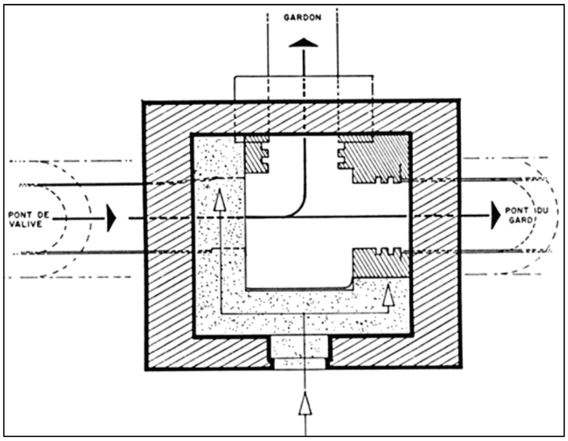


Regulation and settling basin near the source of the aqueduct of Reims (France) (Ardhuin 1997, fig. 3).

4. Of this group of 26 elements 10 were used to *regulate* the water flow and 9 played a role to *split* the watercourse. Only three were related to a storage basin (Tigava, Bararus, and Burnum) and two to a distribution basin (Nîmes and Shivta). As indicated in the table some sluice gates had a double function.



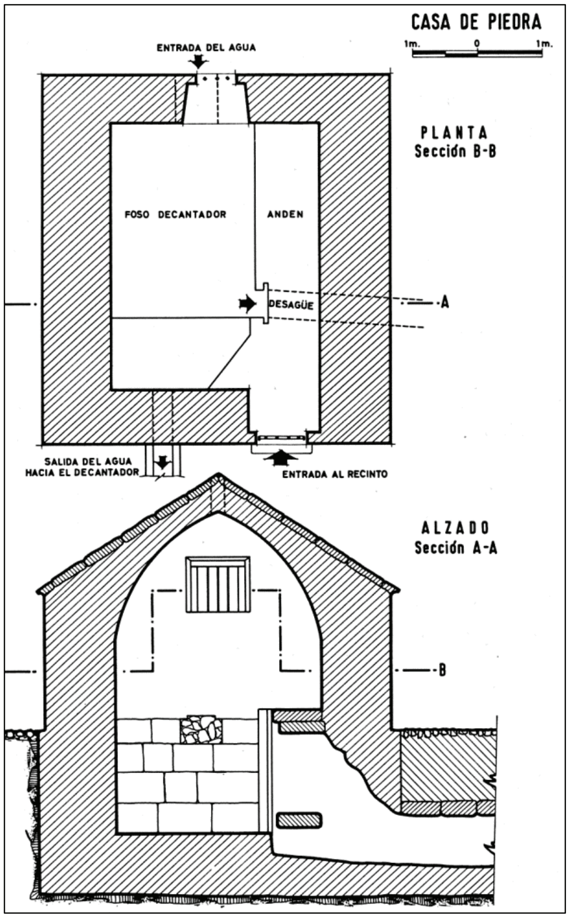
Drawing of a storage and settling basin of the aqueduct of Burnum (Croatia), possibly hypothetical (after Ilakovac 1982, fig. 24).



At several places in the Nîmes aqueduct (France) regulation basins with double sets of sluice gates were present to divert excess water (Fabre 1991, pag. 77).

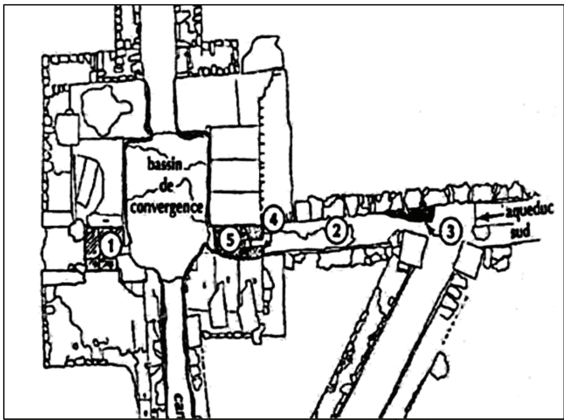
Some of the sluice gates were part of specific settings:

- Köln-Grüngürtel: complex settling and regulation basin with 2 (or 3) sluice gates;
- Reims: regulation and settling basin with one single sluice gate in the main course and a *double* set of sluice gates in the side branch which purpose is unclear;
- Nîmes-Uzès and -Pont du Gard: unique regulation basins with two double sets of sluice gates;
- Bararus: at the supply side of a large double storage basin was a set of three parallel sluice gates;
- Calahorra: a double set of sluice gates in a side branch with probably a filter grating in between;
- Burnum: in total three sluice gates for a storage basin in the main course with a shortcut;
- Segovia 0: sluice gate in combination with a weir to tap aqueduct water from a river;



Settling and regulation basin with a sluice gate in the extra outlet in the aqueduct of Segovia (Spain) (Ramirez Gallardo 1975, fig. 15).

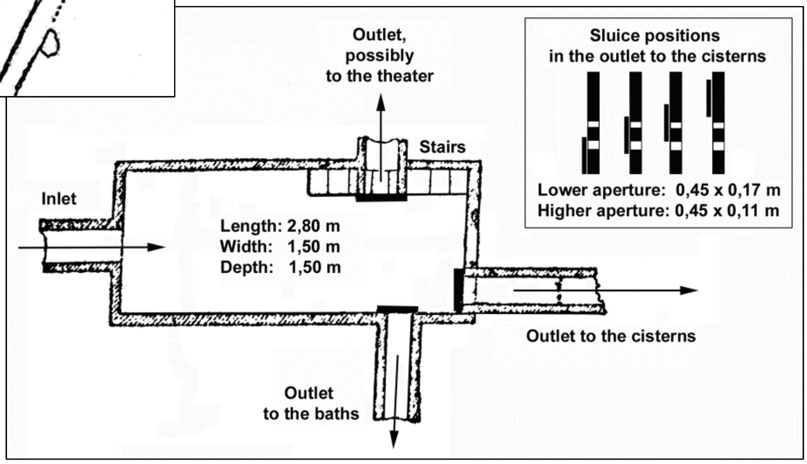
- Nîmes 1: a sluice gate as part of a distribution basin, possibly to measure the water flow;
- Barbegal North: a sluice gate in the main course to Arles as part of a passive (?) regulation basin.



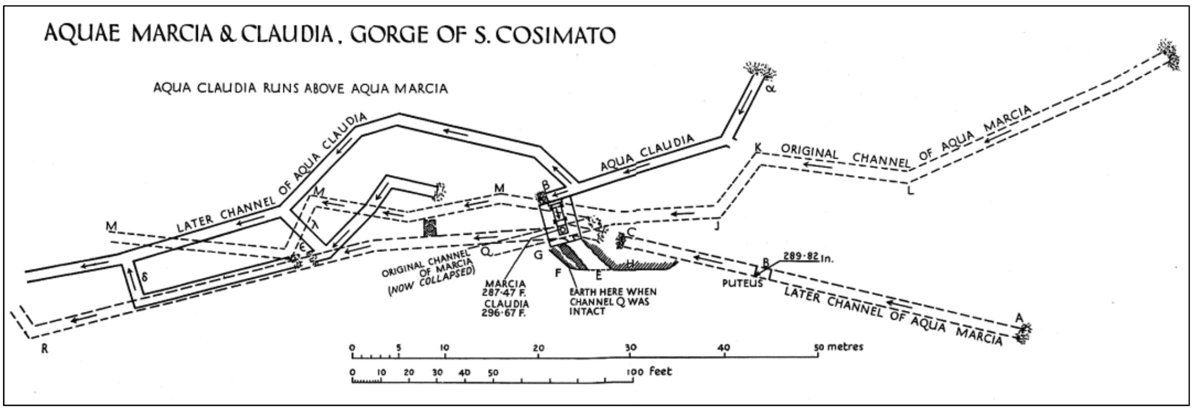
Basin with one inlet and three outlets with a complex history north of Barbegal (France), part of the aqueducts of Arles. At nr 4 “Location of the valve placed at the partial re-opening” (Guendon 2005, pag. 89).

Of special interest are the sluice gates in

- Tebourba: Germain de Montauzan (1908, pag. 316-318) describes this device as a distribution basin with one inlet and three outlets equipped with sluice gates, one of which is pierced and equipped with a vertically moving board in front of it.



Basin in the aqueduct of Tebourba (Tunisia) with one inlet and three outlets equipped with control sluices, two as usual, one more complex (after Germain de Montauzan 1908, pag. 317).



Gorge of San Cosimato: a ‘down-channel’ to divert water of the Aqua Claudia aqueduct into the Aqua Marcia channel (Ashby 1935, fig. 7).

- Rome: in her description of the aqueducts of Rome, Van Deman (1934) makes mention of several ‘down channels’, elements to divert water from one aqueduct to an other. The best known example stems from ‘Grotte Sconce’: a storage basin of the Anio Novus a few kilometers south of Tivoli which was equipped with a diver-

sion channel that descends faster than the channel of the Anio Novus above it. To cite Aicher (1995, pag. 136): "About 75 m from the *castellum* [storage basin] the first of the individual feeder branches diverged, a short stretch of channel perpendicular to the main conduit that transported the water to a vertical shaft dropping water directly into the Claudia channel. A similar method was used for the Marcia 15 m. further on, and again for the Vetus at the end of the side channel".
More common are single diversion channels from the Anio Novus, Claudia and Marcia into the lower lying aqueducts, all equipped with sluice gates.

8. Materials used in sluice gates

In the descriptions of this set of over 26 sluices seldom reference is made to the materials used to close the gates. That is why we have looked into the literature on other applications of sluice gates. The most prominent applications were related to cisterns / reservoirs and fish tanks, but also reference was made to dams, river intakes, water mills, mines, baths, fountains, and even a harbour (silt flushing in Caesarea Maritima).

As is the case with our aqueduct related sluice gates, not in all cases the nature of the applied materials is discussed. Sometimes only general descriptions are available. *Wood* is often surmised but as one can imagine: proof of application is nearly impossible.
In fish tanks often (pierced) *stone* gates were used. On the other hand, Columella (4 – 70 AD) recommended in *De Re Rustica* (8.17.6) the application of *bronze* for gratings.
In certain cases metal, in particular bronze, sluice gates were surmised or found in situ, the latter in the Fountain house of Megara (5^{th} c BC, Gruben 1965 pag. 38), in the Castalia fountain in Delphi (Hellenistic (or Roman), Amandry 1977 pag. 211), and at the Bath Building of Bath (UK) (Roman, Cuncliff 1993).

9. Conclusions

Regarding the main question of this reconnaissance study: "Was there any control in Roman aqueducts", the answer is clear: yes, given the presence of control elements, there must have been dynamic control in over 20 Roman aqueducts.
To execute control, diverse elements were used: plugs, wedges, stopcocks and taps, and sluice gates. But even within the group of sluice gates, locations and design were quite different, so no systematic approach could be deduced.
The only additional conclusion which can be drawn from the sample of 26 sluice gates is, that these elements executed mainly the following functions:

a) To regulate the water flow by diverting excess water;
b) To split the water streams, for example at branches.

But the answer to the additional question "How did the Romans control an aqueduct" remains unclear. In the ancient literature no reference was made to this intriguing question.

So the main conclusion is that the hardware for control was present but diverse. And the software remains an enigma.

Table: Overview over some *dynamic* control elements: sluices

Dynamic CM	Period	Location	Func-tion(s))1	Main course)2	Side course)2	Confi-dence	Remarks	References
Metz Ars (F)	Early 2c	Before bridge	Reg	-	D	High		Jolin 1981
Tigava (Alg)	?	?	Sto + Sett	S	S	Medium	Volume 100 m3	Leveau 1976 p169-70
Segovia 1 (Sp)	1-2 c	Near the town	Reg + Sett	-	S	High	Full height	Ramirez Gallar-do 1975
Saintes (3x) (F)	End of 1 c	Before bridge	Reg	-	S	High	At end of side channels	Bailhache 1983; Triou 1968
Grüngürtel (G)	Late 1 c	Near town	Reg + Sett	S	S	Medium	Diff inter-pretations	Grewe 1983, Schultze1930, Wolf2000
Reims (F)	1 c	Near the source	Reg + Sett	S	D	Medium	? Reliable recon-struction	Ardhuin 1997
St. B-de-C (F)	2nd c	Near the source	Reg	S	S	High		Bailhache 1972 pag. 186
Nîmes Uzès + PdG (F)	2nd half 1c	Near the source	Reg	D	D	High	+ 3rd and more basins?	Fabre 1991
Arles Caparon neuf (F)	2nd half 1c	Half way	Reg	S	?	Medium	only in the main	Own observation
Sens (F)	Early 3rd c	Second source	Reg	-	S	Low)3	Collection basin	Perrugot 2008
Bararus (Tunisia)	1st half 1c	Near the town	Sto	S	-	High	Double basin Vol 7600 m^3	Hallier 1987
Calahorra (Sp)	2nd c ?	Half way	Spl	-	D	High	+ filter	Mezquiriz 1979 / 2004
Nin (Croatia)	2nd half 1c	Half way	Spl	S	S	Medium	Branch to mill	Ilakovac 1982
Rome 7x	2nd half 1c – 1st half 2c	Half way	Spl	-	2 x S	Medium	Down channels (Van Deman)	Van Deman 1934, Ashby 1935
Rome Hadr-loop	Early 2nd c	Half way	Spl	?	S	High	Start Hadrians loop	Roncaioli Lamberti 1986
Burnum (Croatia)	Medio 1c	Half way	Sto + Sett	S	2 x S	Medium	Hypothetical sluices? Vol. 1000 m^3	Ilakovac 1984 pag. 47
Segovia 0 (Sp)	1 – 2c	Source	Spl	Weir	S	High	Difficult classifi-cation	Ramirez Gallar-do 1975
Tebourba (Tunisia)	?	Near town	Spl	S pierce d	2 x S	Medium	Special case	Germain de Montauzan 1908
Nîmes 1 (F)	2nd half 1c	Near town	Distri	S	-	Medium	Combi; Different interpretat	Many
Sebaste (Turkey)	1c	Half way	Spl	-	2 x S	High	Elaiussu	Murphy 2013
Sitifis (Algeria)	?	Start	Sto?	S		Medium	Collecting basin ??	Wilson 1997
Frejus La Foux	Middle 1c	Start	Spl	S?	S?	Low	Only one block	Gebara 2002

Shivta (Israel)	Byzant	Near town Distri (?)			3 x S	High	One block missing	Tsuk 2002
Merida (Sp)	Early 2nd c	Before bridge	Reg (+ Sett)	S	S?	Medium	Incomplete description	Grewe 1993 pag. 253 + Leather 2002
Frejus La Foux junction (F)	Middle 1c	Start	Junction	?	S	Low	Junction without detailed description	Valenti 2002
Barbegal N (F)		Near regulation basin	Reg	S	S?	High	Overflow at the regulation basin?	Guendon 2005
Naumachia Alsietina (Rome, It)		*Naumachia*	*Spl*	*S*	*S*	*Low*	*Hypothetical*	*Taylor 2000*

St-B-de-C = Saint-Bertrand de Comminges (France)
Hadr-loop = Hadrians loop

)1 Function(s):
- Distri — Distribution basin
- Junction — Junction basin
- Reg — Regulation basin
- Sett — Settling basin
- Spl — Splitting basin
- Sto — Storage basin

)2 Main//Side course
- S = Single sluice gate
- D = Double sluice gate

)3 Suggested exit with sluice gate

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